UFC 3-230-01
1 September 2018
Change 3, 1 July 2021

UNIFIED FACILITIES CRITERIA (UFC)

WATER STORAGE AND DISTRIBUTION

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WATER STORAGE AND DISTRIBUTION

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING COMMAND (Preparing Activity)

AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

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

Change No.	**Date**	**Location**
1	1 Oct. 2018	1. Updated reference to OEBGD in paragraph 1-3.2. 2. Added the word requirements in paragraph 2.1.1.1. 3. Updated UFC reference in paragraph 4-1.7.3. 4. Updated paragraph numbering in B-3.1.1. 5. Deleted the reference to the 10 State Standards in Appendix B.
2	1 May 2020	1. Updated paragraphs 5-3 and 5-3.6 to coordinate with revision of UFC 3-240-01. 2. Updated reference to UFC 1-200-01, DoD Building Code in paragraph 1-3.1. 3. Revised finished water storage criteria in paragraph 4-1.1 and 4-1.3. Added paragraph 4-1.2 for additional storage volume criteria to address a criteria change request in reference to overseas criteria. 4. Revised criteria for water distribution systems with a separate fire protection system in paragraphs 5-3.2.1, 5-3.5.2, 5-4.1, 5-5, and 5-5.3 to address a criteria change request in reference to water distribution systems without fire demand. 5. Added paragraphs 5-3.5.1.1, 5-3.5.1.2, 5-4.1.1, 5-4.1.2, 5-5.1, 5-5.2, and 5-5.3.1 to address a criteria change request in reference to water distribution systems without fire demand. 6. Revised fire protection criteria in paragraph 5-3.4 and used Designated Fire Protection Engineer. 7. Updated references in Appendix A.
3	1 July 2021	1. Updated CNICINST 5090.1A to CNICINST 5090.1B

		on the revision summary sheet, in paragraph 2-1.1.2 and Appendix A. 2. Revised pump redundancy requirements in paragraphs 3-3.1, 3-3.2 and 3-3.3. 3. Added equivalent in front of host nation standard in paragraphs 4-1.6, 4-1.7, 4-1.8, 4-1.8.1 and 5-2. 4. Revised separation distances in section 5-8. 5. Modified thrust restraint requirement in paragraph 5-7.4.

This UFC supersedes UFC 3-230-01 dated November 2012.

FOREWORD

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

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale should be sent to the respective service proponent office by the following electronic form: Criteria Change Request. The form is also accessible from the Internet sites listed below.

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

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

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

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UNIFIED FACILITIES CRITERIA (UFC)
REVISION SUMMARY SHEET

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

Superseding: UFC 3-230-1, Change 2, *Water Storage, Distribution and Transmission*.

Description: This revision provides updated technical content and includes the adoption of additional industry standards. It also addresses design order of precedence, cybersecurity, advanced metering, direct digital controls, and several criteria change requests.

Reasons for Document:

- This revised UFC provides requirements for the design of water distribution systems. It includes piping, storage and pumping requirements.
- Coordinates fire protection engineering, advanced meeting, direct digital controls and cybersecurity requirements.
- Establishes a design order of precedence for both foreign projects and projects in the United States.

Impact:

- This revision will have minimal impacts on design cost.

Unification Issues: This UFC includes Navy only requirements for overseas drinking water requirements in accordance with \3\ CNICINST 5090.1B /3/. This UFC also includes Navy only requirements for airfield lighting and marking requirements for water towers and other similar structures in NAVAIR 51-50AAA-2.

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CHAPTER 1 INTRODUCTION

1-1 PURPOSE AND SCOPE.

This Unified Facilities Criteria (UFC) provides requirements for typical storage, distribution systems for domestic water, fire protection and non-potable water for the Department of Defense (DoD). These minimum technical requirements are based on UFC 1-200-01. Where other statutory or regulatory requirements are referenced in the contract, the more stringent requirement must be met.

1-2 APPLICABILITY.

This UFC applies to service elements and contractors involved in the planning, design and construction of permanent DoD facilities worldwide. It is applicable to all methods of project delivery and levels of construction.

1-3 OTHER CRITERIA.

1-3.1 General Building Requirements.

Comply with UFC 1-200-01, DoD Building Code \2\ /2/. UFC 1-200-01 provides applicability of model building codes and government-unique criteria for typical design disciplines and building systems, as well as for accessibility, antiterrorism, physical security, cybersecurity, high performance and sustainability requirements, and safety. Use this UFC in addition to UFC 1-200-01 and the UFC and government criteria referenced therein.

1-3.2 Foreign Countries.

DoD 4715.05-G, Overseas Environmental Baseline Guidance Document \1\(OEBGD)/1/ applies when there are no FGSs in place. Therefore, in foreign countries this UFC will be used for DoD projects to the extent that it is allowed by and does not conflict with the applicable international agreements and the applicable FGS or OEBGD.

1-3.3 Safety.

All DoD facilities must comply with DoDI 6055.01 and applicable Occupational Safety and Health Administration (OSHA) safety and health standards.

The Designer of Record (DoR) must follow the concepts from ASSE Z590.3. By applying the concepts in ASSE Z590.3 occupational hazards and risks related to work premises, tools, equipment, machinery, substances, and work processes including their construction, use, maintenance, and ultimate disposal or reuse can be reduced. This standard also provides guidance for a life-cycle assessment and design model that balances environmental and occupational safety and health goals over the life span of a facility, process, or product.

1-3.4 Antiterrorism and Security.

Security must be an integral part of drinking water system design. Facility layout must consider critical system assets and the physical security of these assets. Planners, engineers, security and antiterrorism personnel must determine site specific threats to develop the antiterrorism and security protective measures for water storage and distribution systems. Use UFC 4-020-01 to establish protective measures for water storage and distribution systems. The engineering risk analysis, conducted as part of UFC 4-020-01, should be consistent with the terrorism risk analysis conducted by installation security or antiterrorism staff.

Refer to Best Practice documents, *Policy Statement On Infrastructure Security for Public Water Supplies*, found in the Policy Statements section of *Recommended Standards for Water Works* and ASCE 56-10/57-10, for guidelines on the protection of water utility systems.

1-3.5 Cybersecurity.

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

Cybersecurity is implemented to mitigate vulnerabilities to all DoD real property facility-related control systems to a level that is acceptable to the System Owner and Authorizing Official. UFC 4-010-06 provides requirements for integrating cybersecurity into the design and construction of control systems.

1-3.6 Plumbing.

UFC 3-420-01 is a Core UFC which cites the use of the International Plumbing Code (IPC). Where the requirements in this UFC or UFGS 33 11 00 conflict with exterior plumbing components in the IPC use the requirements in this UFC or UFGS 33 11 00. Where the IPC will be used to provide the minimum requirement, the DoR must submit a list of the conflicts and proposed solutions to the Government Project Manager for review and approval prior to completing design.

1-4 REFERENCES.

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

1-5 BEST PRACTICES.

Appendix B identifies background information and practices for accomplishing certain water supply design and engineering services. The DoR is expected to review and interpret this guidance as it conforms to criteria and contract requirements, and apply the information according to the needs of the project. If a Best Practices document has guidelines or requirements that differ from the Unified Facilities Guide Specifications (UFGS) or UFC, the UFGS and the UFC must prevail. If a Best Practices document has guidelines or requirements that are not discussed in the Unified Facilities Guide specification (UFGS) or UFC, the DoR must submit a list of the guidelines or requirements being used for the project with sufficient documentation to the Government Project Manager for review and approval prior to completing design.

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CHAPTER 2 GENERAL DESIGN REQUIREMENTS

2-1 DESIGN.

Use UFC 3-201-01 for topics such as surveying, site development, grading and storm drainage systems.

2-1.1 Design Criteria.

Design water supply systems to meet the potable water regulations and requirements of applicable federal, state and local government agencies or overseas equivalent.

2-1.1.1 Within The United States.

For projects located in the United States and its territories and possessions design the water supply system in accordance with the following criteria precedence:

1. State waterworks regulations or local regulations for the project location.
2. Utility provider's \1\requirements/1/.
3. *Recommended Standards for Water Works* (also known as the Ten State Standards) as noted herein.
4. Energy and sustainability: Use UFC 1-200-02.
5. Exceptions or additions to the above criteria as indicated in this UFC.
6. Refer to references in Appendix B for design guidance.

2-1.1.2 Foreign Countries.

For projects located outside of the United States and its territories and possessions design the water supply system in accordance with the following criteria precedence:

1. The Forward of this UFC (All construction outside of the United States is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA.)).
2. Final Governing Standards.
3. "DoD 4715.05-G, Overseas Environmental Baseline Guidance Document.
4. Navy Only: \3\ CNICINST 5090.1B /3/.
5. Utility provider's requirements.
6. Recommended Standards for Water Works, (also known as the Ten State Standards) as noted herein.

7. Energy and sustainability: Use UFC 1 200-02.

8. Exceptions or additions to the above criteria as indicated in this UFC.

9. Refer to references in Appendix B for design guidance.

2-1.2 Design Approval.

The DoR must identify, assist, and provide, as applicable, all permits, approvals, and fees required for the design and construction of the new project from Federal, state and local regulatory authorities or overseas equivalent. The Civil Engineering DoR must be a Professional Civil Engineer experienced and licensed. Licensure in the location of the project may be required to obtain permits and approvals. For new potable water supply systems, extensions to new areas, rehabilitation, or replacement of existing potable water supply systems, coordinate with the Safe Drinking Water Act primacy agency, as applicable, to determine primacy agency requirements. In the United States and its territories and possessions the Government will review permits for acceptability. In locations outside of the United States and its territories and possessions with Host nation agreements, follow permit approval procedure as directed in project scope and by the Government Project Manager. In locations outside of the United States and its territories and possessions without Host nation agreements, the Government will review and approve plans for compliance.

Consult with the Government Project Manager to determine the appropriate signatories for permit applications.

2-1.3 Planning for Non-War Emergencies.

Refer to Best Practices document AWWA M19, for non-war emergencies such as earthquakes, hurricanes, tornadoes, floods and vandalism.

2-2 PRELIMINARY SITE ANALYSIS.

Use UFC 3-201-01 for preliminary site analysis.

2-2.1 New Service Areas.

Utilize Installation's existing utility maps and planning documents to develop new service areas for present and future (minimum 5 year) conditions. Where adequate planning documents are not available, estimate future growth as described in UFC 3-230-03, Chapter titled *System Sources and Flows*.

2-2.2 Existing Conditions.

Use UFC 3-201-01 for geotechnical site investigation, surveying, and topographic surveying.

2-2.2.1 Geotechnical Site Investigation –Soil Corrosivity.

Require geotechnical evaluation for soil corrosivity when existing operating records, visual observations, inspections or testing indicate a need for corrosion control. Provide an evaluation of existing soils at the proposed depths and locations of the water piping in accordance with AWWA M27, Chapter titled *Evaluating the Potential for Corrosion* and provide recommendations on materials and positive corrosion protection systems.

2-3 SYSTEM SOURCES AND FLOWS.

Use UFC 3-230-03, Chapter titled *System Sources and Flows*.

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CHAPTER 3 PUMPING FACILITIES

3-1 GENERAL.

Design pumping facilities in accordance with Chapter 2, paragraph titled *Design Criteria* and use *Recommended Standards for Water Works,* Chapter titled *Pumping Facilities*.

3-2 PUMPING STATIONS.

Pumps, piping and equipment must be protected from the weather. In cold climates pumps and piping must be protected from freezing temperatures. The pump station building must comply with 1-200-01, be constructed of noncombustible materials and meet applicable building standoff distances. Building layouts must be designed to accommodate the installation of new equipment, maintenance and future expansion. Equipment layouts must provide vertical and horizontal clearances for the repair or replacement of equipment without interrupting pump station operation. Provide personnel access and equipment access for maintenance and repair operations. Ensure pumping stations and equipment are easily accessible and not located in an OSHA defined permit required confined space. Provide a minimum of one double leaf door with a width of 6 feet (1.8 m) for maintenance and repair operations. Access points must be lockable and meet Installation security requirements. Use Best Practice document, Pumping Station Design for guidance on designing pump stations.

3-3 PUMPS.

Select pumps to supply varying demands and meet pressure requirements based on a hydraulic analysis. Pumps must be capable of providing the varying demands and minimum pressures for the full range of system flows. Investigate surge potential for all pumps. When investigation indicates the potential for flows or velocities that increase surge potential provide a surge analysis. A surge analysis is required for large pump stations (i.e., flows greater than 3,200 gpm (202 L/s).

3-3.1 Redundancy.

Provide a minimum of two pumps at each pump station. \3\ Pumping capacity must be able to discharge the peak flow with the largest pump out of service. /3/

3-3.2 Pumps With Elevated Storage.

Pumps for water storage are selected to meet the average day demand, maximum day demand and maximum day demand plus partial fire flow demand (i.e., fire flow demand not delivered by storage) as need to equalize system pressures. \3\ /3/

3-3.3 Pumps Without Storage.

Pumps are selected to meet flow, pressure, and efficiency requirements. Pumps must accommodate the maximum daily demand, the peak hourly rate plus fire flow demand, and the estimated minimum hourly rate. The location and required capacity of a water pumping system must be determined by a hydraulic analysis of the distribution system. \3\ /3/

3-3.4 Pump Drives.

The factors affecting selection of the type of power used to drive potable water pumps include dependability, availability and economic considerations. Provide emergency power operation, such as a dedicated standby emergency generator or a portable generator, in conformance with applicable regulatory and utility provider requirements.

3-3.5 Motor Capacity.

Motors must be selected with sufficient capacity to drive the pump under service required and to be non-overloading over the entire impeller curve without motor overload or failure. Provide motors in accordance with NEMA MG1 and NEMA MG2.

3-4 APPURTENANCES.

3-4.1 Controls.

Remote monitoring and control systems must meet the Installation's Information Technology security requirements and standards and UFC 4-010-06.

3-5 FIRE PUMPS.

Use UFC 3-600-01 paragraph titled *Fire Pumps*.

CHAPTER 4 FINISHED WATER STORAGE

4-1 GENERAL.

Design finished water storage in accordance with Chapter 2, paragraph titled *Design Criteria* and use *Recommended Standards for Water Works,* Chapter titled *Finished Water Storage*.

4-1.1 \2\ Objectives.

Finished water storage serves the following objectives:

- Supplies water required to meet demands in excess of production or delivery capabilities and equalize flow in water distribution piping;
- Helps maintain the design flow and system pressure in the distribution system;
- Eliminates interruptions caused by power outages; or
- Decreases or eliminates interruptions during water main repairs.

4-1.2 Storage Volume.

Finished water storage is a combination of treatment plant storage, equalization storage, fire demand storage, and emergency storage. Design finished water storage to provide the full range of domestic, industrial, fire, and emergency demands. The design must allow draining the storage facility for cleaning or maintenance without causing a loss of pressure in the system.

In addition to treatment plant storage, provide additional water storage when:

- The water distribution system relies on a single water supply source to maintain design flow and system pressure; or
- The water distribution system cannot maintain the design flow and system pressure.

Use UFC 3-230-03 to determine the minimum *Design Flow.*

Exceptions:

- When the water distribution system is served by more than one finished water storage source and upgrades to the distribution system are capable of providing the design flow and system pressure, additional water storage is not required;
- When design flow and system pressure can be maintained for all demands except fire demand and fire water storage is provided in accordance with UFC 3-600-01; or

- When design flow and system pressure can be maintained for all demands except fire demand and a separate fire water storage and distribution system is provided in accordance with UFC 3-600-01.

4-1.3 Sizing.

Water storage volume must be capable of providing the full range of domestic, industrial, fire, and emergency demands and reduces water usage to maintain drinking water quality. At a minimum, the volume of water storage required is the sum of the average total daily domestic requirements, plus any industrial demand that cannot be reduced during a fire period, and the required fire demand. Use a hydraulic analysis to determine the optimum number and size of finished water storage reservoirs. /2/

Compute fire demand in accordance with UFC 3-600-01.

4-1.4 System Storage.

Calculate water storage capacities based on the full operating levels of the water storage structure as measured to highest design water elevation of the system. The highest design water elevation of the system may not necessarily equal the effective volume available to the water system. Effective storage volume is equal to the total volume less any dead storage built into the system. For example, part of the system's capacity is typically designed as dead storage. Below this water surface elevation, the pressure delivered to the water distribution system falls below minimum pressure requirements. If a water system's source cannot deliver a design flow rate above a certain water surface elevation within the tank, this upper volume of the tank is considered unavailable to the water system and is not a part of the water storage volume.

Additional guidance to water storage may be found in Best Practices documents, AWWA *OPFLOW* and *Hydraulic Design of Water Distribution Storage Tanks*. These alternative approaches may be used if the water storage provided is greater than the minimum storage requirement. The storage required may be adjusted in accordance with UFC 3-600-01, Section titled *Facility On-Site Water Storage*.

4-1.5 Location of Reservoirs.

During the planning and preliminary design process determine the optimum location and type of storage. Use a hydraulic analysis to assist in determining the best type of storage reservoir and location for each system to ensure flow, pressure and water quality. Locate storage tanks to allow space for the types of vehicles and equipment required to operate and maintain the system.

Design of structures must be in accordance with UFC-3-220-01 and UFC 3-301-01.

4-1.5.1 Underground Storage Tanks.

Use elevated or above ground tanks before considering underground storage tanks. Underground storage tanks are the least preferred design option because of the high cost and limited technical advantages. Consider using underground storage tanks when:

- Elevated storage or above ground storage are impracticable.
- Where economy of construction result, such as, when architectural considerations make an aboveground tank very costly.
- Where protection against freezing is required.
- Where the area above the underground tank is to be utilized (e.g., a pedestrian plaza or park area).
- Where the hydraulic grade at a tank site requires the tank to be below grade.
- Where protection against sabotage and destruction warrant concealment.

4-1.6 Construction Materials.

Use materials for water storage structures that protect the quality of the stored water. For potable water storage select materials in accordance with Unified Facilities Guide Specifications, AWWA Standards and NSF 61 or \3\ equivalent /3/ host nation standard.

4-1.6.1 Concrete Tanks.

Provide concrete water tanks in accordance with AWWA D110, or AWWA D115.

4-1.6.2 Steel Tanks.

Provide steel tanks in accordance with AWWA D100 or AWWA D103.

4-1.6.3 Composite Tanks.

Provide elevated composite tanks in accordance with AWWA D107.

4-1.7 Freezing.

Equipment used for freeze protection that will come into contact with the potable water must meet NSF 61 or \3\ equivalent /3/ host nation standard.

4-1.8 Painting and Cathodic Protection.

Use paint systems that meet NSF 61 or \3\ equivalent /3/ host nation standard.

4-1.8.1 Interior Coatings.

Use AWWA D102 and AWWA M42 as applicable. Consult with local and state Health Departments or Host nation for lists of approved interior coating systems. Interior coating systems must comply with NSF 61 or \3\ equivalent /3/ host nation standard.

Use Best Practices document *Coatings for Potable Water Tank Interiors* by the Steel Structures Painting Council for design guidance.

4-1.8.2 Exterior Coatings.

Use AWWA D102, AWWA D103, AWWA M27 Chapter titled *Corrosion Control of Water Storage Tanks* and AWWA M42 as applicable.

4-1.8.3 Cathodic Protection.

Provide cathodic protection for all steel tanks and tanks containing structural steel components. \1\Use UFC 3-570-01 and AWWA D106 for a sacrificial anode cathodic protection systems. Use UFC 3-570-01 and AWWA D104 for an impressed current systems./1/

4-1.9 Disinfection.

Use AWWA C652 for disinfection requirements.

4-2 DISTRIBUTION SYSTEM STORAGE.

Remote monitoring and control systems must meet the Installation’s Information Technology security requirements and standards.

Instrumentation and control in foreign countries may have unique requirements. Coordinate with the Installation’s utility personnel to identify unique Installation practices or control requirements.

4-2.1 Drainage.

Design tank drainage area to minimize soil erosion when draining the tank for operations or maintenance.

4-2.2 Level Controls.

Provide instrumentation to monitor and control water storage volumes in the water system. Sequence pump operation (start and stop) controls to minimize water hammer. Use altitude valves or equivalent level controls to control water levels. Pump controls must be automated and turned on and off in response to signals corresponding to pressure or water levels in storage tanks. Use high and low level sensing switches corresponding to water levels in storage tanks for pump controls and alarm status monitoring. Select a level control system which allows pumps to accomplish the hydraulic requirements of the system but does not include additional control features that are not necessary for operation and monitoring.

Control and monitoring systems must have the capability to provide the range of flow rates, pressures and liquid levels. Select a control and monitoring system that will provide protection from pump and piping system damage and to serve as a tool to find system problems which may need operational adjustment, repair or maintenance.

4-2.2.1 Remote Monitoring.

Provide remote monitoring equipment for pump alarm conditions. Remote monitoring equipment must be able to relay power failure, pump failure (seal failure and start failure), and generator start failure at minimum. Remote monitoring equipment must transmit storage levels and alarms to a location where qualified personnel are available for surveillance on a 24-hour basis. A paging system may be used in locations where no 24-hour manning location exists.

4-2.2.2 Alarms.

Alarms must include high level, low level, and pump malfunctions. Provide for remote monitoring, such as telemetry, in conformance with applicable regulatory and utility provider requirements. If required, provide off site operation capability from a central location.

4-3 AIRFIELD REQUIREMENTS.

Comply with 14 CFR Part 77.

4-3.1 Airfield Notification.

Provide Federal Aviation Administration (FAA) notification in accordance with 14 CFR Part 77.9.

14 CFR Part 77.9 (February 1, 2018) provides the following notification requirements:

> If requested by the FAA, or if you propose any of the following types of construction or alteration, you must file notice with the FAA of:
>
> a) Any construction or alteration exceeding 200 feet above ground level at its site.
>
> b) Any construction or alteration that exceeds an imaginary surface extending outward and upward at any of the following slopes:
>
> (1) 100 to 1 for a horizontal distance of 20,000 ft. from the nearest point of the nearest runway of each airport described in 14 CFR 77.9 paragraph (d) of this section with its longest runway more than 3,200 ft. in actual length, excluding heliports.
>
> (2) 50 to 1 for a horizontal distance of 10,000 ft. from the nearest point of the nearest runway of each airport described in 14 CFR 77.9 paragraph (d) of this section with its longest runway no more than 3,200 ft. in actual length, excluding heliports.
>
> (3) 25 to 1 for a horizontal distance of 5,000 ft. from the nearest point of the nearest landing and takeoff area of each heliport described in paragraph (d) of this section.

c) Any highway, railroad, or other traverse way for mobile objects, of a height which, if adjusted upward 17 feet (5.2 m) for an Interstate Highway that is part of the National System of Military and Interstate Highways where overcrossings are designed for a minimum of 17 feet (5.2 m) vertical distance, 15 feet (4.6 m) for any other public roadway, 10 feet (3.0 m) or the height of the highest mobile object that would normally traverse the road, whichever is greater, for a private road, 23 feet (7.0 m) for a railroad, and for a waterway or any other traverse way not previously mentioned, an amount equal to the height of the highest mobile object that would normally traverse it, would exceed a standard of paragraph (a) or (b) of this section.

d) Any construction or alteration on any of the following airports and heliports:

(1) A public use airport listed in the Airport/Facility Directory, Alaska Supplement, or Pacific Chart Supplement of the U.S. Government Flight Information Publications;

(2) A military airport under construction, or an airport under construction that will be available for public use;

(3) An airport operated by a Federal agency or the DOD.

(4) An airport or heliport with at least one FAA-approved instrument approach procedure.

e) You do not need to file notice for construction or alteration of:

(1) Any object that will be shielded by existing structures of a permanent and substantial nature or by natural terrain or topographic features of equal or greater height, and will be located in the congested area of a city, town, or settlement where the shielded structure will not adversely affect safety in air navigation;

(2) Any air navigation facility, airport visual approach or landing aid, aircraft arresting device, or meteorological device meeting FAA-approved siting criteria or an appropriate military service siting criteria on military airports, the location and height of which are fixed by its functional purpose;

(3) Any construction or alteration for which notice is required by any other FAA regulation.

(4) Any antenna structure of 20 feet (6.1 m) or less in height, except one that would increase the height of another antenna structure.

4-3.2 Airfield Criteria Coordination.

4-3.2.1 Siting Coordination.

Coordinate with UFC 3-260-01.

4-3.2.2 Obstruction Lighting.

Coordinate with UFC 3-535-01.

4-3.2.3 Paint Markings.

Coordinate with UFC 3-260-01 for Army and Air Force and NAVAIR 51-50AAA-2 for Navy.

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CHAPTER 5 DISTRIBUTION SYSTEM PIPING AND APPURTENANCES

5-1 GENERAL.

Design the distribution system in accordance with Chapter 2, paragraph titled *Design Criteria* and use *Recommended Standards for Water Works,* Chapter titled *Distribution System Piping and Appurtenances*.

5-2 MATERIALS.

Provide materials, equipment, components, manufactured units and appurtenances of the potable water system in accordance with Unified Facilities Guide Specifications and NSF 61 or \3\ equivalent /3/ host nation standard. Any part of the water piping system such as, valves, joining materials, gaskets or appurtenances that comes in contact or has the potential to come in contact with potable water is considered part of the potable water system. Provide components of the non-potable water system in accordance with AWWA standards or \3\ equivalent /3/ host nation standards.

5-2.1 Standards and Materials Selection.

Select materials and use of coatings to preserve high hydraulic efficiency to control tuberculation, slime formation and encrustations. During material and coating selection evaluate control potential, structural strength, field conditions, cost and maintenance requirements.

5-2.1.1 Exposed Pipe.

Exposed pipe may be placed on bridges for crossing streams or ravines, piers or pipe supports for crossing fault lines. Exposed nonmetallic pipe may only be used in climates not subject to freezing. Exposed iron or steel pipe subjected to freezing must be insulated or otherwise protected. Any pipe material subject to ultraviolet degradation must be protected.

5-2.1.2 Polyethylene Pressure Pipe.

Use TN-44 2015, and compute service life for potable water systems based on project conditions.

5-2.1.3 Fusible Pipe.

5-2.1.3.1 Fusible Polyethylene Pressure Pipe.

Use AWWA M55 to calculate safe pull and bending forces.

5-2.1.3.2 Fusible Polyvinyl Chloride Pressure Pipe.

Calculate safe pull and bending forces using a minimum factor of safety of 2.5.

5-3 SYSTEM DESIGN.

The distribution system must be designed to provide the design flow, in accordance with UFC 3-230-03 Section titled *Design Flow* and maintain the minimum system pressure. \2\ Use paragraph 2-2.1 to estimate future growth /2/. Use AWWA M31 and AWWA M32 in combination with UFC 3-600-01 for system analysis.

5-3.1 Calculations.

Provide calculations indicating the proposed design provides adequate flow and pressure and reduces or eliminates impacts to water quality. Manual calculations are acceptable for small projects that provide water to a single facility and where compliance with AWWA M32 and this UFC can be demonstrated.

5-3.2 Distribution System Pressure.

This maximum working pressure depends on new and existing piping materials and appurtenances. Specify piping materials and appurtenances with a pressure class that exceeds the maximum working pressure of the water distribution system plus surge pressure. The recommended maximum working pressure is 100 psi (689 kPa).

Higher pressures are required for fire sprinkler systems, ship berthing and drydock facilities in accordance with UFC 3-600-01, UFC 4-150-02 and UFC 4-213-12.

5-3.2.1 Without Fire Demand.

\2\Design /2/ the water distribution system to maintain a minimum pressure of 25 psi (172 kPa) or the minimum pressure required by UFC 3-420-01 for the design flow.

5-3.2.2 With Fire Demand.

Design the water distribution system to maintain a minimum residual pressure of 40 psi (276 kPa) at fire hydrants for the average day demand and 30 psi (207 kPa) during the design flow. Minimum residual pressures at fire hydrants must be at least 20 psi (138 kPa) while supplying fire flow and hose stream demand.

5-3.3 Diameter.

Where water distribution mains provide fire flow, the minimum pipe size is 6 inches (150 mm).

The minimum pipe size for distribution mains is 3 inches (75 mm). A hydraulic analysis and explicit authorization by the Government is required for distribution mains with a pipe size equal to or greater than 3 inches (75 mm) but less than 6 inches (150 mm).

5-3.3.1 Velocity.

Flow velocities should range from 2 to 5 feet per second (0.6 to 1.5 meters per second) in distribution mains for the design flow. The maximum velocity depends on new and existing piping materials and appurtenances. Ensure that the maximum pressure of the piping materials and appurtenances exceeds the maximum pressure of the system, including the potential for surge pressure.

5-3.4 Fire Protection.

Water distribution systems providing water and fire service must be capable of supplying the fire flow specified in UFC 3-600-01 plus any other demand that cannot be reduced during the fire period at the required residual pressure for the required duration. Analysis will determine whether the capacity of the system is fixed by the domestic, industrial, or fire demands, or some combination of the three demands. Compute fire demand in accordance with UFC 3-600-01. \2\ When the water distribution system is not capable of supporting the required fire flow, provide a cost benefit analysis. This analysis must compare design options, such as upgrades to the water distribution system or a separate fire water storage system to supply fire demand, and indicate the most cost effective solution. Consult with the Designated Fire Protection Engineer and consider appropriate design options.

Higher fire flow and pressure demands are required for aircraft hangers, storage facilities, unprotected facilities (buildings without fire sprinkler systems), and other high risk DoD facilities in accordance with UFC 3-600-01. /2/

5-3.5 System Layout.

The configuration of the water system is primarily determined by location of water demands, street patterns, location of water treatment facilities, water storage facilities and topography. Provide a pipe network with flow from two or more water sources and locate distribution piping to minimize connection costs. Reduce head loss and thrust restraint requirements by minimizing changes in direction and the number of bends. Do not connect fire hydrants to water mains not designed to carry fire flows (e.g., mains less than six inches). New underground pipelines must be at least 10 feet (3.0 m) from facility or building foundations, except for building service connections.

When flow demands or pressure requirements require upgrading segments of the distribution system, it is preferable that new pipelines parallel to existing pipelines be sized for the total capacity so that the existing pipeline may be properly abandoned.

5-3.5.1 Branch or Dead End Pattern.

The branch or dead end pattern evolves when distribution mains are extended along streets as the service area expands. Avoid dead ends and stagnant areas in the distribution system to the greatest extent possible.

5-3.5.1.1 \2\ Without Fire Demand.

Where dead ends are unavoidable, provide a flushing hydrant or blow-off assembly for flushing.

5-3.5.1.2 With Fire Demand.

Where dead ends are unavoidable, provide a fire hydrant or blow-off assembly for flushing./2/

5-3.5.2 Grid or Loop Pattern.

The grid or loop pattern has the hydraulic advantage of delivering water to any location from more than one direction, thereby avoiding dead ends. \2\ Provide a grid or loop pattern for water service to mission critical facilities, facilities with high water demands, or where the mission is dependent on potable water service for operation./2/

5-3.6 Capacity.

\2\ Use paragraph 2-2.1 to estimate future growth /2/. Refer to UFC 3-230-03, Chapter titled *System Sources and Flows* for additional criteria.

Evaluate effect of long detention time on decay of chlorine residual in accordance with latest EPA guidance.

5-3.7 Surge Analysis and Control.

Use the rules of thumb in AWWA M32 Chapter titled *Transient Analysis* to identify vulnerable systems and determine when a surge analysis may be required. Once a surge protection device or method is selected, complete an additional analysis to verify the adequacy of the proposed surge protection solution. Surges may be prevented by using water line appurtenances like shutoff valves, pressure relief valves, vacuum relief valves, check valves on pump discharge lines, and surge tanks. Provide appropriate devices to dampen or eliminate surge pressure.

5-3.8 Corrosion.

5-3.8.1 External Corrosion.

For corrosive soils, select materials, coatings, or cathodic protection systems to protect from external corrosion. Use AWWA M27; however, explicit approval by the Government is required prior to providing a cathodic protection system on a buried pipeline.

5-3.8.2 Internal Corrosion.

Use AWWA M58.

5-4 VALVES.

Refer to Appendix B for a general discussion of valves and their uses.

5-4.1 Shutoff Valves.

\2\ The spacing between shutoff valves must not exceed 5,000 feet (1,524 m) on long lines and 1,500 feet (457 m) on loops.

5-4.1.1 Without Fire Demand.

Provide shutoff valves capable of isolating piping sections during a single point failure and maintaining system demands in the distribution system. Locate shutoff valves at reasonable distances and limit the number of facilities without service during repair, maintenance and testing.

5-4.1.2 With Fire Demand.

Provide shutoff valves capable of isolating piping sections during a single point failure and maintaining fire demand and system demands in the distribution system. Use UFC 3-600-01 to locate shutoff valves or sectional valves required for fire protection. Locate additional shutoff valves at reasonable distances and limit the number of facilities without service during repair, maintenance and testing.

5-5 HYDRANTS.

5-5.1 Without Fire Demand.

Provide a minimum of one flushing hydrant or blow-off assembly for each isolated piping section. Use a minimum 2 inch (50 mm) flushing hydrant or blow-off assembly.

5-5.2 With Fire Demand.

Provide a minimum of one fire hydrant or blow-off assembly for each isolated piping section. Use a minimum 4 inch (100 mm) blow-off assembly.

5-5.3 Fire Hydrants.

Comply with the requirements of UFC 3-600-01, Section titled *Hydrants*.

5-5.3.1 Flushing Hydrants and Blow-Off Assemblies.

Locate flushing hydrants and blow-off assemblies in areas accessible to maintenance personnel and adjacent to paved areas. Install a shutoff valve located not more 20 feet (6.1 m) from each flushing hydrant or blow-off assembly. Laterals supplying flushing hydrants or blow-off assemblies must have a minimum diameter of 2 inches (50 mm). Grade to drain away from the flushing hydrants and blow-off assemblies, other facilities, roads, and parking areas. Ensure that the blow-off assembly does not drain into the vault in which it is placed./2/

5-6 AIR RELIEF VALVES.

5-6.1 Air-Valves: Air-Release, Air/Vacuum and Combination.

Use AWWA M51 for the design and selection of air-valves. Provide air-valves as required based on an analysis of the system. For flexible pipe, which might collapse under a vacuum, place vacuum release valves based on the analysis of the system, recommendations of the pipe manufacturer and adjacent to each shutoff valve on the uphill side.

5-7 INSTALLATION OF WATER MAINS.

5-7.1 Minimum Cover.

Minimum cover over pipes must be the most stringent of the following requirements:

a) Minimum required by the applicable AWWA Standard,

b) a minimum of 2.5 feet (750 mm),

c) greater than frost penetration according to UFC 3-301-01,

d) sufficient to support imposed dead and live loads for the pipe materials used.

Evaluate temporary conditions during construction and final conditions. Provide calculations for minimum cover.

5-7.2 Minimum Trench Width.

Provide a minimum trench width of 18 inches (450 mm) or the outside pipe diameter plus 12 inches (300 mm), whichever is greater.

5-7.3 Separation from Other Utilities.

Provide adequate horizontal and vertical separation between water pipelines and other utilities (e.g., electrical, telecommunications, natural gas) for installation, maintenance, and repair or replacement of utilities. The trench width may vary based on the soils encountered and depth. At a minimum, maintain the minimum trench width and bedding depth for the adjacent utilities. Based on site constraints and soil conditions, additional separation may be required to allow the replacement of one utility without impacting the adjacent utility.

5-7.3.1 Separation for Thrust Blocking.

Additional separation is required to ensure thrust blocking is not compromised. Use the following equation to compute length of separation.

$$L = D\tan(45° + \frac{\emptyset}{2})$$

L = separation length

D = depth of cover

∅= Frictional angle of soil

5-7.4 Thrust Restraint.

Use thrust blocks for thrust restraint \3\ in undisturbed, native soils /3/ before considering the use of restrained joints. Use DIPRA for design procedures. Provide calculations for thrust restraint using a minimum safety factor of 1.5. Use the geotechnical investigation report and consult with the Geotechnical Engineer to determine soil bearing capacity.

5-7.4.1 Connections to Existing Pipe.

Use thrust blocks when connecting to existing pipe. Where thrust blocking does not provide the required thrust restraint, require supplemental thrust restraint. Supplemental thrust restraint may include a combination of thrust blocks and restrained joints for the existing pipe. It may be necessary to expose the existing pipe to install the supplemental restrained joints.

5-7.4.2 Fusible Pipe.

Additional restraint may be necessary on fusible pipe at the connection to appurtenances or transitions to different pipe materials. Provide joint restraint as recommended by the fusible pipe manufacturer.

5-7.5 Testing.

Refer to AWWA C600 series for testing requirements for each type of pipe material. Require water mains and water service lines providing fire service or water and fire service to be pressure tested in accordance with NFPA 24.

5-7.6 Disinfection.

For disinfection testing requirements refer to AWWA Standard C651, *Disinfecting Water Mains*.

5-8 SEPARATION DISTANCES FROM CONTAMINATION SOURCES.

\3\Use IPC Section 603 for minimum separation distances for water service lines. Use the paragraphs below for minimum separation distances for water mains.

5-8.1 Parallel Installation.

Measure the separation distance from the closest sides of the two pipes, outside edge to outside edge or outside edge of sanitary sewer manhole, septic tank or subsoil treatment system.

5-8.1.1 Normal Condition.

Provide a minimum horizontal separation of 10 feet (3.0 m) between water mains and any gravity sanitary sewer, sanitary sewer force main, combined sewer overflow, sanitary sewer manhole, septic tank, or subsoil treatment system.

When local conditions prevent a horizontal separation of 10 feet (3.0 m), the water main must have a minimum vertical separation of 18 inches (450 mm) above any gravity sanitary sewer, sanitary sewer force main, or combined sewer overflow and be installed in a separate trench.

5-8.1.2 Unusual Condition.

Realign either the water main or the conflicting source of contamination to meet the required separation unless it is more cost effective to use the following alternative.

When local conditions prevent a horizontal separation of 10 feet (3.0 m) or a vertical separation of 18 inches (450 mm) above any gravity sanitary, or combined sewer overflow, construct the sanitary piping of AWWA approved pressure rated pipe material designed to withstand a minimum static pressure of 150 psi (1,034 kPa) and pressure test in place without leakage prior to backfill.

5-8.2 Crossings.

Measure the separation distance from the bottom of the top pipe to the top of the bottom pipe, outside edge to outside edge.

5-8.2.1 Normal Condition.

Provide a minimum vertical separation of 18 inches above the top (crown) of any gravity sanitary sewer, sanitary sewer force main or combined sewer overflow and the bottom of the water piping.

5-8.2.2 Unusual Condition.

Realign either the water main or the conflicting source of contamination to meet the required separation unless it is more cost effective to use the following alternative.

When local conditions prevent a vertical separation distance of 18 inches (450 mm) above any gravity sanitary sewer, sanitary sewer force main, or combined sewer overflow use the following:

a. Construct the sewer line of AWWA approved pressure rated pipe material designed to withstand a minimum static pressure of 150 psi (1,034 kPa), pressure tested in place without leakage prior to backfill;

b. Center the pressure rated pipe so that joints are 9 feet (2.7 m) to 10 feet (3.0 m) from the water main;

c. For water mains crossing over or under the conflicting source of contamination, maintain a minimum vertical separation of 6 inches (150 mm) between the water main and the sewer line; and

d. Provide adequate structural support to prevent settling and excessive deflection of the joints. /3/

5-9 CROSS-CONNECTIONS AND INTERCONNECTIONS.

5-9.1 Backflow Prevention and Cross Connection Control.

Use AWWA M14 for backflow prevention principles. Comply with the requirements of UFC 3-420-01. Comply with the requirements of UFC 3-600-01 for fire protection systems. Use AWWA C510 for double check valves and AWWA C511 for reduced-pressure principle backflow prevention.

5-10 WATER SERVICES AND PLUMBING.

Use AWWA M22 to size water service lines. Refer to AWWA C800 for underground service connection materials with a diameter of 2 inches (50 mm) or less. Use water distribution materials for services with a diameter greater than 2 inches (50 mm).

5-10.1 Fire Service.

Where the service lateral provides fire service or water and fire service use UFC 3-600-01. UFC 3-600-01 requires flow from two or more directions in the distribution system unless otherwise directed by the Government Civil Engineer or UFC 3-600-01, Chapter titled *Fire Protection Systems*.

5-10.2 Boosters.

Use UFC 3-420-01 for water service boosting systems and pumps.

5-10.3 Water Service Meters.

Use AWWA M6 and AWWA M22 for water meter selection and sizing. Locate meters after the fire service connection so that only non-fire building flows are metered. Meters are typically located near the curb line. Locate meters in grass areas to avoid exposure to vehicular traffic where feasible. In some cases, a meter may be located inside of a building. Locate meters no greater than 4 feet above the floor when inside a building. All meters must be easily accessible for manual reading, maintenance and repair.

5-10.3.1 Advanced Metering Infrastructure.

Comply with UFC 1-200-02 for advanced water meter requirements. Provide water meters compatible with the Installation's advanced metering infrastructure (AMI) systems. Connect the water meter signal to the AMI network. Coordinate advanced metering with UFC 3-520-01.

5-10.3.2 Remote Reading Systems.

Provide metering systems that are compatible with the Installation's remote water meter reading systems.

5-10.4 Sub-meters.

Sub-meters must conform to the same requirements as water service meters when used to comply with UFC 1-200-02.

APPENDIX A REFERENCES

AMERICAN SOCIETY OF SAFETY PROFESSIONALS

http://www.assp.org/

ASSE Z590.3, *Prevention Through Design, Guidelines for Addressing Occupational Hazards and Risks in Design and Redesign Processes*

AMERICAN WATER WORKS ASSOCIATION

http://www.awwa.org

AWWA M6, *Water Meters - Selection, Installation, Testing, and Maintenance*

AWWA M14, *Backflow Prevention and Cross-Connection Control Recommended Practices*

AWWA M19, *Emergency Planning for Water Utilities*

AWWA M22, *Sizing Water Service Lines and Meters*

AWWA M27, *External Corrosion Control for Infrastructure Sustainability*

AWWA M31, *Distribution Systems Requirements for Fire Protection*

AWWA M32, *Computer Modeling of Water Distribution Systems*

AWWA M42, *Steel Water Storage Tanks*

AWWA M51, *Air-Valves: Air-Release, Air/Vacuum and Combination*

AWWA M55, *PE Pipe - Design and Installation*

AWWA M58, *Internal Corrosion Control of Water Distribution Systems*

AWWA C510, *Double Check-Valve Backflow Prevention Assembly*

AWWA C511, *Reduced-Pressure Principle Backflow Prevention Assembly*

AWWA C651, *Disinfecting Water Mains*

AWWA C652, *Disinfection of Water-Storage Facilities*

AWWA C800, *Underground Service Line Valves and Fittings*

AWWA D100, *Welded Carbon Steel Tanks for Water Storage*

AWWA D102, *Coating Steel Water-Storage Tanks*

AWWA D103, *Factory-Coated Bolted Carbon Steel Tanks for Water Storage*

AWWA D104, *Automatically Controlled, Impressed Current Cathodic Protection for the Interior Submerged Surfaces of Steel Water Tanks*

AWWA D106, *Sacrificial Anode Cathodic Protection Systems for the Interior Submerged Surfaces of Steel Water Storage Tanks*

AWWA D107, *Composite Elevated Tanks for Water Storage*

AWWA D110, *Wire- and Strand-Wound, Circular, Prestressed Concrete Water Tanks*

AWWA D115, *Circular Prestressed Concrete Water Tanks*

COMMANDER, NAVY INSTALLATIONS COMMAND (NAVY ONLY)

https://cnic.navy.mil/about/cnic-instructions.html

\3\ CNICINST 5090.1B, CNIC Instruction 5090.1B, Navy Overseas Drinking Water Program Ashore /3/

DEPARTMENT OF DEFENSE (DOD)

DoD 4715.05-G, *Overseas Environmental Baseline Guidance Document, http://www.dtic.mil/whs/directives/corres/pdf/471505g.pdf*

DoDI 6055.01, *DoD Safety and Occupational Health (SOH) Program, http://www.dtic.mil/whs/directives/corres/pdf/605501p.pdf*

DEPARTMENT OF DEFENSE (DOD), UNIFIED FACILITIES CRITERIA (UFC)

http://dod.wbdg.org/

UFC 1-200-01, DoD Building Code \2\ /2/

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

UFC 3-201-01, *Civil Engineering*

UFC 3-230-03, *Water Treatment*

\2\ UFC 3-240-01, *Wastewater Collection and Treatment* /2/

UFC 3-220-01, *Geotechnical Engineering*

UFC 3-260-01, *Airfield and Heliport Planning and Design*

UFC 3-301-01, Structural Engineering

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

UFC 3-420-01, Plumbing Systems

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

UFC 3-535-01, *Visual Air Navigation Facilities*

UFC 3-570-01*, Cathodic Protection*

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

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

UFC 4-150-02, *Dockside Utilities for Ship Service*

UFC 4-213-12, *Drydocking Facilities Characteristics*

DEPARTMENT OF DEFENSE (DOD), UNIFIED FACILITIES GUIDE SPECIFICATIONS (UFGS)

http://dod.wbdg.org/

UFGS 33 11 00, *Water Utility Distribution Piping*

EXECUTIVE ORDER

Executive Order *13693, Planning for Federal Sustainability in the Next Decade, March 19, 2015*

GREAT LAKES – UPPER MISSISSIPPI RIVER BOARD OF STATE AND PROVINCIAL PUBLIC HEALTH AND ENVIRONMENTAL MANAGERS

http://10statesstandards.com/

Recommended Standards for Water Works, Policies for the Review and Approval of Plans and Specifications for Public Water Supplies, A Report of the Water Supply Committee of the Great Lakes--Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers

INTERNATIONAL CODE COUNCIL

http://www.iccsafe.org

IPC, International Plumbing Code \3\ 2018 /3/

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION (NEMA)

http://www.nema.org

NEMA MG1, *Motors and Generators*

NEMA MG2, Safety Standard and Guide for Selection, Installation, and Use of Electric Motors and Generators

NATIONAL FIRE PROTECTION ASSOCIATION

http://www.nfpa.org

\2\ /2/

NFPA 24, Standard for the Installation of Private Fire Service Mains and Their Appurtenances

NAVAL AIR SYSTEMS COMMAND

NAVAIR 51-50AAA-2, *General Requirements for Shorebased Airfield Marking and Lighting*

NSF INTERNATIONAL

http://www.nsf.org

NSF 61, *Drinking Water System Components – Health Effects*

PLASTIC PIPE INSTITUTE

http://plasticpipe.org

TN-44 2015, *Long Term Resistance of AWWA C906 Polyethylene (PE) Pipe to Potable Water Disinfectants*

APPENDIX B BEST PRACTICES

Appendix B identifies background information and practices for accomplishing certain water supply design and engineering services. The Civil Engineering Designer of Record (DoR) is expected to review and interpret this guidance and apply the information according to the needs of the project. If a Best Practices document has guidelines or requirements that differ from the UFGS or Unified Facilities Criteria, the UFGS and the UFC must prevail. If a Best Practices document has guidelines or requirements that are not discussed in the Unified Facilities Guide specification (UFGS) or UFC, the DoR must submit a list of the guidelines or requirements being used for the project with sufficient documentation to the Government Project Manager for review and approval prior to completing design.

B-1 WHOLE BUILDING DESIGN GUIDE.

The Whole Building Design Guide provides additional information and discussion on practice and facility design, including a holistic approach to integrated design of facilities.

The WBDG provides access to all Construction Criteria Base (CCB) criteria, standards and codes for the DoD Military Departments, National Aeronautics and Space Administration (NASA), and others. These include, Unified Facilities Criteria (UFC), Unified Facilities Guide Specifications (UFGS), Performance Technical Specifications (PTS), design manuals, and specifications. For approved Government employees, it also provides access to non-government standards.

B-2 WATER AUDITS AND LEAK LOSS CONTROL.

The loss of treated water can be a substantial economic loss to any water distribution system. Practice water audits and leak loss control following AWWA M36.

B-3 PUMPING FACILITIES.

B-3.1 Planning.

Pumping may be required to move stored water through the piping system to the customers. Planning factors include: availability of electric power, roadway access for maintenance and operation purposes, security and adverse impact to surrounding facilities. Refer to Table B-1 for additional planning factors.

B-3.1.1 Pumps.

The location of a pump station and intake structure, and the anticipated heads and capacities are the major factors in the selection of pumps. The function of a pump station in the overall distribution system operation can also affect the determination of capacities. Consider pump operating costs during pump selection.

Use Hydraulic Institute pump standards for guidelines on pump selection. Basic pump hydraulic terms, formulas, pump fundamentals, applications, instructions for installation, and operation and maintenance are given in the Hydraulic Institute pump standards.

Table B-1 Pumping Installation Planning

Category	Detailed Data and Information
Purpose of Service	Transmission of water from water source. Pumping in the distribution system. Pumping to elevated storage tank. Pumping for fire protection. Booster pumping. Pumping service at treatment plant. Other miscellaneous pumping.
Piping Layout	Length, sizes, fittings.
Demand Requirements	Maximum day demand: mgd or gpm. Average day demand: mgd or gpm. Minimum day demand: mgd or gpm. Peak hourly demand: gpm Variation in demand. Effect of storage on demand rates.
Static Lift Requirements	Static suction head or lift
Liquid Characteristics	Static discharge heads Specific gravity Temperature Vapor pressure Viscosity pH Chemical characteristics Solids content
Power Available	Type Characteristics

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B-3.1.1.1 Pump Drives.

Refer to Table B-2 for preferential choice and applications of various pump drive power systems.

B-3.1.1.2 Valves.

Valves used in pump station systems may include: gate valves, globe and angle valves, cone valves, butterfly valves, ball valves, check valves and relief valves.

B-3.1.2 Pump Station Layout.

Refer to Table B-3 for limitations of pumping arrangements.

Table B-2 Preferential Choice and Application of Pump Drive

Power	Choice	Drive	Application
Electricity	First	AC Motors	Primary power in stationary pumping
Diesel Oil	First	Internal combustion engines	In isolated area for stationary pumping. As emergency standby power source. Portable pumping source.
Natural Gas	Second	Gas turbine or internal combustion engine	In isolated area for stationary pumping. As emergency standby power source.
Air Compressor driven by motors or internal combustion engine	Second	Compressed air	At small installations for airlift pumps and for other pneumatic pumps.

Table B-3 Limitations of Pumping Arrangements

Type of Arrangement	Where to Use	Limitations
Bypassing the discharge (all or part)	Not used for normal operation in a large installation, but during emergency when other arrangements are inoperative	Waste of power
Multiple pumps operating in parallel	Use this arrangement as a normal installation	Requires multiple pumps, and possibly jockey pump to pressurize system at low demands
Intermittent pumping with elevated water storage	Use in areas where water pressure decreases due to either long runs or increases in elevation	May increase water pressure or require different pressure zones in areas with high water pressure or decreases in elevation
Intermittent pumping with ground water storage	Use when additional flow is required	Uses additional energy to run pumps and maintain water pressure
Manual or automatic speed variation to control pump discharge	Use in complex situations where multiple constant speed pumps would be more expensive.	Manual speed control will require personnel to monitor the system and make adjustments.

B-4 FINISHED WATER STORAGE.

B-4.1 Distribution System Storage.

In medium and large distribution systems, water storage is generally located near centers of heavy demand.

B-4.1.1 Ground Storage Tanks.

Ground storage is typically used to reduce treatment plant peak production rates, assist in supplying the design flow during periods of high usage and as a supplemental supply source for pumping to a higher pressure level. Ground storage for pumping is common in distribution systems covering a large area, because the outlying service areas are beyond the reasonable range of the primary pumping facilities.

Ground storage tanks will likely require the installation of variable speed pumps to meet frequent daily fluctuations in demand and eliminate the potential for water hammer.

B-4.1.2 Elevated Storage Tanks.

Elevated storage may be provided to help supply the design flow during periods of high usage and equalize system pressures. In general, elevated storage is more effective and economical than ground storage because of the reduced pumping requirements and the storage can also serve as a source of emergency supply since system pressure requirements can still be met temporarily when pumps are out of service.

B-4.1.2.1 Composite Tanks.

Elevated composite tanks are known to have lower maintenance costs because of the reduction in steel surfaces. In corrosive environments maintenance costs may be reduced by using composite tanks in lieu of steel tanks. Consider the use of composite tanks where corrosive environments are present, including areas like coastlines where saltwater environments increase corrosion potential.

B-4.2 Underground Storage Tanks.

The use of underground storage tanks should be avoided.

B-4.3 Level Controls.

Factors to be considered in selecting a system include cost, efficiency, reliability, structural requirements, ease of operation and degree of maintenance necessary. The ease of operation and degree of maintenance are critical at military installations where adequate personnel cannot always be provided.

B-4.3.1 Variable Speed Control.

In general, variable speed control devices are more expensive, less efficient, and require a higher degree of maintenance than constant speed controls. However, in some instances, variable speed pumping is the best approach. Consider variable speed drives when conditions are too complex for using multiple constant speed pumps and starting scenarios. Prior to installing variable speed pumps, coordinate with and get approval from the Installation’s utility provider.

B-5 DISTRIBUTION SYSTEM PIPING AND APPURTENANCES.

B-5.1 Materials.

B-5.1.1 Polyethylene Pressure Pipe.

Polyethylene (PE) pipe is subject to oxidative degradation by many variables including pH, the concentration and type of disinfectant, water temperature, installation procedure and conditions. Disinfectants like chlorine, chloramines, chlorine dioxide, ozone and others may create an Oxidation Reduction Potential (ORP) in PE Pipe.

B-5.1.2 Fusible Pipe.

Rapid crack propagation (RCP) can occur in many types of materials. Many variables including pipe damage during construction and air in the water line may cause rapid crack propagation (RCP). When RCP occurs in bell & spigot (B&S) pipe, the length of the failure is limited to the length of the pipe. Once pipes are fused together RCP can pass through the fused joints and may result in lengthy pipe failures. RCP has previously occurred in fusible PVC (fPVC) water piping on rare occasions. Ensuring air release valves are used where air may be trapped and pipe is adequately protected from damage during construction are two ways to help avoid RCP.

B-5.2 Distribution System Pressure.

Areas of excessively high or low pressures may be divided into multiple pressure zones. In some cases, the use of pressure reducing valves may be required to protect specific locations.

B-5.3 Valves.

See Tables B-4, B-5 and B-6 for the application of check valves, shutoff valves and gate valves.

B-5.4 Thrust Restraint.

Online thrust restraint calculators can assist in performing thrust restraint calculations. See EBAA IRON Restraint Length Calculator located at http://rcp.ebaa.com/ or the DIPRA Thrust Restraint Design for Ductile Iron Pipe located at https://www.dipra.org/ductile-iron-pipe-resources/calculators/thrust-restraint-of-ductile-iron-pipe. Consider the bearing surface of the fitting when designing thrust blocks. Compact fittings reduce the bearing surface of the thrust block.

B-5.5 Water Services and Plumbing.

Consider using the buildings internal water supply for building additions.

B-5.6 Meters.

Meters may serve multiple purposes. Billing, monitoring and diagnosing the health of the systems are and important operational functions. Metering data provides system operators with important information, such as where additional flow capacity is needed, where water quality may be a concern, and how the distribution system may be impacted from additional population growth. Properly designed meters that are installed using standard industry settings should find rather cost effective solutions exist for accurate metering. Properly sized meters can accurately measure the ranges of expected flows that it provides service to. Sub-metering can increase operational costs without increases in additional income.

Table B-4 Application of Check Valves

Check Valves	Application	Remarks
Swing Checks	All horizontal applications	Refer to AWWA C508
Ball Checks	On reciprocating pumps	Small diameter
Vertical Checks	All vertical applications	Refer to AWWA C507
Cone Checks	Surge relief	Requires automatic operator
Cushioned Checks	Surge relief	Slow closing
Foot Valves	Prevents loss of prime in suction lines	-
Flap Valves	At pipe outlets	-

Table B-5 Application of Shutoff Valves

Shutoff Valves	Application	Remarks
Gate Valves[a]	All applications	Refer to AWWA C500 and AWWA C509
Butterfly Valves	All applications	Largest size 72 in. Refer to AWWA C504
Plug Valves, Eccentric	All applications	Suitable for water containing solids and for three-way valves
Globe Valves	All applications	Small diameter
Needle Valves	All applications	Small diameter
Hydraulic Needle Valves	Reservoir outlets	Very large size requiring hydraulic operators
Mud Valves	Bottom drain opening of basins	-
[a] Except for low pressure, service gate valves 16 in (400 mm) -20 in (500 mm), and larger should be equipped with bypass. Refer to AWWA C500 and AWWA C509.		

Table B-6 Application of Gates

Gates	Application	Remarks
Radial Gates	Channel and reservoir outlets	-
Slide Gates	Channel and reservoir outlets	Low heads
Sluice Gates	Wall openings	Refer to AWWA C560
Shear Gates	Wall openings (low head)	Size up to 24 in. (600 mm)

B-6 BEST PRACTICE REFERENCES.

AMERICAN SOCIETY OF CIVIL ENGINEERS

ASCE 56-10/57-10, Guidelines for the Physical Security of Water Utilities; Guidelines for the Physical Security of Wastewater/Stormwater Utilities

AMERICAN WATER WORKS ASSOCIATION

http://www.awwa.org

AWWA M27, *External Corrosion Control for Infrastructure Sustainability*

AWWA M36, *Water Audits and Loss Control Programs*

AWWA C500, *Metal-Seated Gate Valves for Water Supply Service*

AWWA C504, *Rubber-Seated Butterfly Valves*

AWWA C507, *Ball Valves, 6 in. through 60 in. (150 mm through 1500 mm)*

AWWA C508, *Swing-Check Valves for Waterworks Service, 2-In. through 24-In. (50-mm through 600-mm) NPS*

AWWA C509, *Resilient-Seated Gate Valves for Water Supply Service*

AWWA C560, *Cast-Iron Slide Gates*

AWWA OPFLOW, *Determining Distribution System Storage Needs*

By Murat Ulasir, Robert Czachorski, Vyto Kaunelis, Vol. 31 Issue 9, September 2005

DUCTILE IRON PIPE RESEARCH ASSOCIATION

http://www.dipra.org

DIPRA Thrust Restraint Design for Ductile Iron Pipe

HYDRAULIC INSTITUTE

http://www.pumps.org

Pump Standards

\1\/1/

Pumping Station Design

By Garr M. Jones with Co-Editors Robert L. Sanks, George Tchobanoglous and Bayard Bosserman

STEEL STRUCTURES PAINTING COUNCIL

http://www.sspc.org

Coatings for Potable Water Tank Interiors

Hydraulic Design of Water Distribution Storage Tanks

By Rasheed Ahmad

APPENDIX C GLOSSARY

C-1 ACRONYMS.

AFCEC	Air Force Civil Engineering Center
AT&L	Acquisition, Technology, and Logistics
AWWA	American Water Works Association
B&S	Bell & Spigot
BIA	Bilateral Infrastructure Agreement
CCB	Construction Criteria Base
DDC	Direct Digital Controls
DoD	Department of Defense
DoR	Designer of Record
e.g.	*Exempli Gratia* (one or more possible examples)
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FGS	Final Governing Standards
fPVC	Fusible Polyvinyl Chloride
HQUSACE	Headquarters, U.S. Army Corps of Engineers
HNFA	Host Nation Funded Construction Agreements
i.e.	*Id Est* (clarifies, more precisely)
IPC	International Plumbing Code
NASA	National Aeronautics and Space Administration
NAVAIR	Naval Air Systems Command
NAVFAC	Naval Facilities Engineering Command
NEMA	National Electrical Manufacturers Association
NEPA	National Environmental Policy Act

OEBGD	Overseas Environmental Baseline Guidance Document
ORP	Oxidation Reduction Potential
OSHA	Occupational Safety and Health Administration
PE	Polyethylene
PVC	Polyvinyl Chloride
SOFA	Status of Forces Agreements
UFC	Unified Facilities Criteria
UFGS	Unified Facilities Guide Specifications
U.S.	United States
WBDG	Whole Building Design Guide

C-2 DEFINITION OF TERMS.

Distribution Mains: All pipelines of the potable water distribution system, except the service lines (e.g., water, fire, irrigation).

Pipe Size: The nominal internal diameter of the pipe.

Surge pressure: The maximum hydraulic transient pressure increase (also known as water hammer) above the anticipated operating pressure in the system as the result of sudden changes in velocity of the water column. Two types of surge pressures are recurring (cyclic) surge pressure and occasional (emergency or transient) surge pressure.

Working pressure: The maximum sustained operating pressure applied to the pipe exclusive of surge pressures.

For additional definitions refer to the definitions given in the applicable standard.

UFC 3-230-02
10 December 2019
Change 2, 1 November 2023

UNIFIED FACILITIES CRITERIA (UFC)

OPERATION AND MAINTENANCE: WATER SUPPLY SYSTEMS

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

UNIFIED FACILITIES CRITERIA (UFC)

OPERATION AND MAINTENANCE: WATER SUPPLY SYSTEMS

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

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING **\2** SYSTEMS **/2/** COMMAND (Preparing Activity)

AIR FORCE CIVIL ENGINEER CENTER

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

Change No.	Date	Location
1	1 April 2021	1. Revised paragraph 2-5 to comply with America's Water Infrastructure Act and added a reference to Air Force AWIA ERP Checklist. 2. Revised paragraph 5-4.1.5 and Table 5-8 to clarify recommended maintenance frequencies. 3. Deleted paragraph 7-2.1.2, duplicate paragraph. 4. Revised paragraph 7-2.1.3 to clarify hydrant flushing procedure. 5. Changed AFI 32-1067 to AFMAN 32-1067 throughout UFC.
2	1 Nov. 2023	Modified backflow prevention testing requirements in Chapter 9.

This UFC supersedes UFC 3-230-02, *Operation and Maintenance: Water Supply Systems*, dated 10 July 2001.

FOREWORD

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

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and the Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Defense agencies must contact the preparing Service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale must be sent to the respective service proponent office by the following electronic form: Criteria Change Request. The form is also accessible from the Internet site listed below.

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

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

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

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UNIFIED FACILITIES CRITERIA (UFC)
REVISION SUMMARY SHEET

Document: UFC 3-230-02, *Operation and Maintenance: – Water Supply Systems*

Superseding: UFC 3-230-02, *Operation and Maintenance: Water Supply Systems* dated 10 July 2001.

Description: This document is to serve as a comprehensive operations and maintenance manual that on-site field and operations staff within the tri-service agencies can easily navigate through for operations and maintenance (O&M) of their water supply systems.

Reasons for Document:

- Provide updated O&M guidance that covers water supply systems of varying capacity and capabilities in a clear and concise manner for on-site hands on use by Department of Defense (DoD) field and operations staff.
- Provide relevant O&M features and details that clearly distinguish between “required elements” and “best practices.”
- Provide reference sources from both existing DoD-specific guidance documents as well as accepted industry standard guidelines.

Impact: Standardized guidance will assist operators in obtaining higher availability and design life from their systems.

Unification Issues:

Army:

- Technical Bulletin – Medical (TB MED) 576 to be additional standard for compliance with United Stated Environmental Protection Agency (EPA) Regulations for the Army.
- USA-CERL TR N-86/11 to be additional standard for emergency planning, natural disasters, manmade disasters, and vulnerability assessment for the Army.
- Public Works Technical Bulletin (PWTB) 200-1-46, 200-1-94, and 200-1-104 to be additional standards for water conservation for the Army.
- PWTB 200-1-86 to be additional standard for water availability determination for the Army.
- Preliminary Report: Field Test of Trash Rack Heating to Prevent Frazil Ice Blockage to be additional standard for intake maintenance for the Army.
- TB MED 575 to be additional standards for swimming pool maintenance for the Army.

Air Force:

- Air Force Instruction (AFI) 32-1064 to be additional standard for Safety for the Air Force.
- Air Force Guidance Memorandum (AFGM) 2017-32-01 to be additional standard for cybersecurity for the Air Force.
- AFI 32-2001 to be additional standard for fire protection for the Air Force.
- AF997 to be standard form for recording data for the Air Force.
- **\1** AFMAN 32-1067 **/1/** to be additional standard for administrative issues in cross-connection control for the Air Force.
- AFI 10-246 and QTP 4B071-15 to be additional standards for vulnerability assessment for the Air Force.
- AFI 48-144 to be additional standards for compliance with EPA regulations.
- Air Force Policy Directive (AFPD) 90-8 contains additional requirements for the Air Force for environment, safety, occupational health, and risk management.
- Air Force Water Conservation Guidebook contains additional requirements for water conservation for the Air force.
- **\1** Air Force AWIA ERP Checklist **/1/**

Navy:

- Bureau of Medicine and Surgery, BUMED Instruction, BUMEDINST 6240.10C, provides additional requirements for the Navy.
- Commander Navy Installations Command, CNIC Instruction, CNICINST 5090.1A, provides additional overseas water system requirements for the Navy.
- Office of the Chief of Naval Operations, OPNAV Instruction, OPNAVINST 5090.1E, provides additional environmental compliance requirements for the Navy.
- Headquarters United States Marine Corps, Marine Corps Order, MCO 5090.2, provides additional requirements for Marine Corps personnel and installations.
- Bureau of Medicine and Surgery, BUMED Publication, NAVMED P-5010-5, for additional water quality and operational requirements for the Navy.

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CHAPTER 1 INTRODUCTION

1-1 BACKGROUND.

This Unified Facilities Criteria (UFC) document updates the requirements of and replaces UFC 3-230-02 (10 July 2001).

1-2 PURPOSE AND SCOPE.

This UFC provides general technical guidance for operating and maintaining potable water systems that are fit for human consumption (FFHC), at fixed military installations. Since no two installations are exactly alike, this UFC is supplemental to site-specific operations and maintenance (O&M) manuals provided for each installation. An example of a user-friendly O&M manual template can be found on the State of Colorado's website: https://colorado.gov/pacific/cdphe/drinking-water-operations-and-maintenance-om-manual Use the best practice document *Small Water System Operation and Maintenance Manual,* as referenced in Appendix B for information on a manual template.

1-3 APPLICABILITY.

This UFC applies to fixed-base water systems and in some limited cases swimming pools. To provide military personnel with the most up-to-date information available, the UFC guides the reader to industry standards, manuals of practice, training guides, handbooks, and miscellaneous documents published by the American Water Works Association (AWWA) and other authorities in the water supply and treatment field.

1-4 GENERAL BUILDING REQUIREMENTS.

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

1-4.1 International Plumbing Code (IPC).

IPC regulates the supply of potable water from public and individual sources to fixtures and outlets so that it remains FFHC. IPC also provides regulation on preventing backflow conditions.

1-5 SAFETY.

All DOD facilities must comply with DoDI 6055.01 and the applicable Occupational Safety and Health Administration (OSHA) safety and health standards. The portions that apply directly to O&M of water treatment plants is under Part 1910, Occupational Safety and Health Standards, and its associated subparts. Implementation of these OSHA standards at military installations is by way of specific service regulations. The service regulations are available through the installation's safety, occupational health, and fire department officers. Keep these regulations in the workplace and ensure they are available to all personnel. Use *DoDD 4715.1E* and follow the safety precautions included throughout this UFC and in applicable references. Specific instructions are included in the appropriate service regulations. Instruction manuals and other training aids are available through the library or training office.

General guidelines for safe work practices and techniques for a variety of water utility work situations can be found in the following best practice documents *AWWA M3*; *Water Treatment Plant Operation, Volumes 1 and 2*; *Work Practices for Asbestos-Cement Pipe;* and *ASCE 56-10*.

For the Air Force, see *Air Force Instruction (AFI) 32-1064. Air Force Policy Directive (AFPD) 90-8* contains additional requirements for safety and occupational health.

1-6 REFERENCES.

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

1-7 BEST PRACTICES.

Appendix B identifies supplemental information and practices for completing certain O&M tasks. This includes industry best practices documents and recommendations, and calculation examples. If a best practices document contains content or instructions that differ from UFGS or UFC, then UFGS and UFC shall prevail. An example of a user-friendly O&M manual template can be found on the State of Colorado's website: https://colorado.gov/pacific/cdphe/drinking-water-operations-and-maintenance-om-manual

1-8 GLOSSARY.

Appendix C contains acronyms, abbreviations, and terms.

CHAPTER 2 WATER SUPPLY SYSTEMS AND OPERATION

2-1 ORDER OF PRECEDENCE.

The operation of all fixed military installations' water systems must comply with specific regulatory and environmental requirements.

2-1.1 Foreign Countries.

DoD water supply systems must achieve, maintain, and monitor compliance with applicable environmental requirements and monitor these environmental requirements worldwide. DoD 4715.05-G, Overseas Environmental Baseline Guideline Document (OEBGD), applies when there are no FGS in place. Therefore, in foreign countries this UFC will be used for DoD projects to the extent that it is allowed by and does not conflict with the applicable international agreements and the applicable FGS or OEBGD.

For Army: Army regulations pertaining to the provision of drinking water apply to all Army installations and are found in AR 200-1, AR 420-1, AR 40-5, and TG 179. The Army regulations refer to guidance and procedures outlined in DA PAM 40-11; Technical Bulletin Medical (TB MED 575 and TB MED 576) as appropriate.

2-1.2 Water Quality Standards.

DoD water supply systems must achieve, maintain, and monitor compliance with applicable environmental requirements and monitor these environmental requirements worldwide.

2-1.2.1 Within the United States.

For Installations located in the United States and its territories and possessions the water supply system must comply with the following criteria precedence:

1. All applicable, state, and local drinking water regulations for the project location;

2. DoDI 4715.06, Environmental Compliance in the United States;

3. For Navy: BUMEDINST 6240.10C, OPNAVINST 5090.1E, NAVMED P-5010-5 and MCO 5090.2;

4. For Army: Technical Guide, (TG MED 179), US Army Public Health Command, April 2015; AR 200-1 (Environmental Protection and Enhancement), AR 420-1 (Facilities Management) and AR 40-5 (Preventive Medicine);

5. Utility provider's requirements;

6. Additions to the above criteria as indicated in this UFC; and

7. Refer to references in Appendix A for guidance.

2-1.2.2 Foreign Countries.

For Installations located outside of the United States and its territories and possessions the water supply system must comply with the following criteria precedence:

1. The Forward of this UFC (All construction outside of the United States is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA.));
2. Final Governing Standards (FGS);
3. DoDI 4715.05;
4. DoD 4715.05-G, OEBGD;
5. For Navy: BUMEDINST 6240.10C, OPNAVINST 5090.1E, CNICINST 5090.1A, NAVMED P-5010-5 and MCO 5090.2;
6. Army Only: TG MED 179;
7. Utility provider's requirements;
8. Additions to the above criteria as indicated in this UFC; and
9. Refer to Appendix B for guidance.

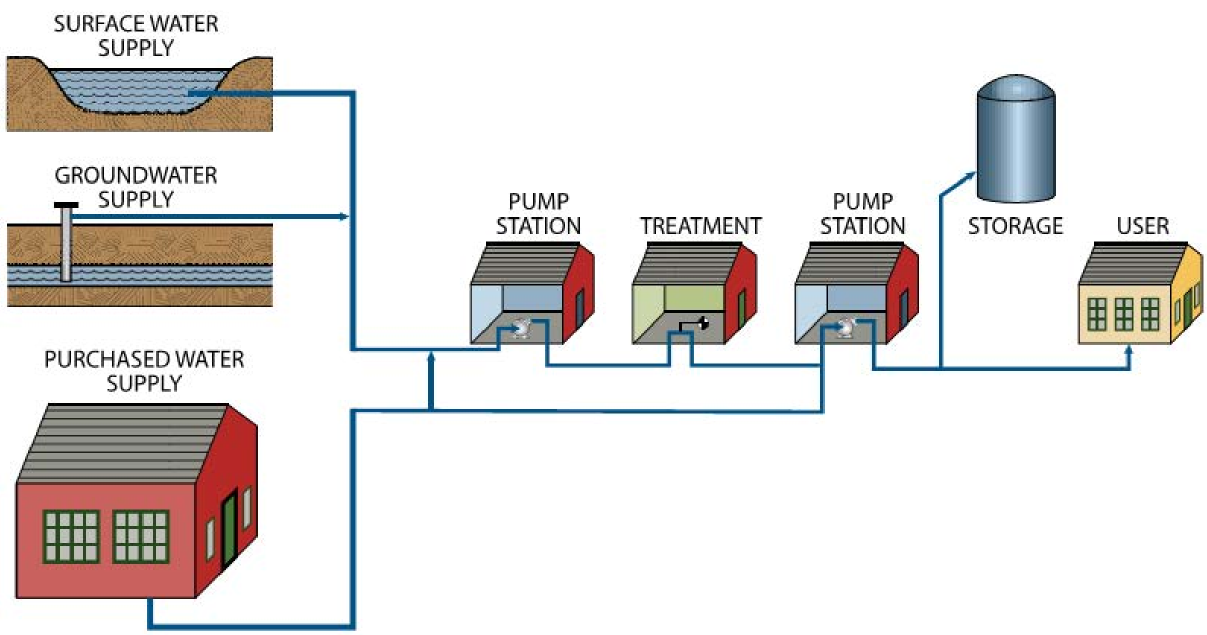
2-2 SYSTEM OVERVIEW.

All fixed military installations' water systems have a water supply source and facilities for distributing water to the point of use. At some installations, treatment and pumping facilities are also required. Figure 2-1 displays a typical water supply system configuration.

Minimum requirements for the operation of drinking water treatment plants and supply systems fall within the following categories:

- Compliance with regulatory requirements
- Operational management practices
- Plant-real property management and maintenance
- Water quality management

Figure 2-1 Water Supply System Configurations



Establish goals within each category, with the primary objective of maintaining the protection of public health. Maintain a consistent operation that satisfies the goals for each system. No changes should be made to the water system without first considering the compliance impacts or need for regulatory consultation and approval of any change. Starting, temporarily stopping, or ending operations of a water treatment plant or supply system must comply with the established goals and meet all regulatory requirements. Treatment plant production capacity should adequately meet system demands at all times. Operation and maintenance functions should be conducted in such a manner that plant site safety and water quality are not compromised.

2-2.1 Water Source.

The most common way to provide potable water at fixed military installations is to buy it from a nearby utility, either a municipality or a private water company. At installations where purchased water is not an option, obtain the water from surface water or groundwater sources such as rivers, lakes, reservoirs, or wells.

More detailed information on water supply is provided in Chapter 3.

2-2.2 Water Treatment.

Water treatment facilities vary from providing basic disinfection of groundwater supplies to sophisticated treatment plants using one or more of the following processes: coagulation, sedimentation, filtration, membrane technologies, carbon treatment, lime-soda softening, fluoridation, disinfection, and desalination. Depending on the quality of the source water and other pertaining factors, some water treatment facilities may only require chlorination.

More detailed information on water treatment is provided in Chapter 4.

2-2.3 Water Distribution.

The primary components of a water distribution system are pumps, pipes, and storage facilities. Well pumps are used to lift water from wells and may discharge directly to a distribution system, storage, or treatment plant. Low-lift pump stations move water from a surface supply to the intake of a non-pressure treatment plant. High-service pump stations transfer potable water from non-pressurized sources, such as storage reservoirs, directly to the distribution system. Pumps are installed in a pipeline or pressure zone of a distribution system to increase the pressure or meet peak demands. Pressure-reducing valves can be used to reduce the pressure for use in a lower pressure zone.

Pumps are included in Chapter 5. Information on water distribution and storage is provided in Chapter 6. Chapter 7 covers valves and hydrants.

2-3 WATER UTILITY STAFFING.

2-3.1 Certification.

Operator certification requirements of water supply facilities vary by regulatory jurisdiction. Just as the number of personnel required is determined by the needs of the facility, determine the numbers and grade levels of certified operators that are required at a given installation by analyzing the size and complexity of the facility installation. Regulatory agencies will also indicate the minimum licensed operator requirements to maintain compliance. For more information on certification, contact the Association of Boards of Certification for Operating Personnel in Water Utilities and Pollution Control Systems (ABC):

Executive Director, ABC
2805 SW Snyder Blvd., Suite 535
Ankeny, IA 50023
Web: http://www.abccert.org/

For more information on service-specific certification, contact the Operator Certification Office of the specific service.

2-3.2 Training.

Obtain operator training by attending technical schools, community colleges, short courses, and workshops and by successfully completing home study courses. Once certification is obtained, have continual training to maintain high standards of service; ensure safe, efficient operation; and stay informed of all current technical developments.

Additional information on training can be obtained either from ABC or *AWWA M52* and from the Operator Certification Office of the specific service.

2-4 INFORMATION MANAGEMENT.

Maintain records as evidence of conformity to requirements and system goals. Records are also necessary for planning purposes. The information management system's needs will vary by installation. The system, at the very least, should contain documented procedures defining the controls needed for identification, storage, protection, retrieval, retention time, and disposition of records. Update records, such as maps, routinely as changes are made to the installation and its surrounding area.

A computerized information management system is recommended for safe file storage. Maintain all records in accordance with service procedures. Example documentation to be maintained in the information management system includes the following compliance requirements:

- Monthly operating reports (MOR)
- Regulatory compliance records
- Monitoring plan and compliance test results
- Sample locations—frequency, low-residual sites, long travel-time sites
- Disinfectant residual results—maximum, minimum, average statistics
- Ammonia and heterotrophic plate count results
- Disinfection goals and residual results
- Disinfection byproduct results—maximum, minimum, averages
- Color, taste, and odor results
- Backflow prevention testing records
- Coliform testing results

Documents that can be considered best practice information that should be maintained in the information management system:

- Flushing program results
- Piping materials used
- Storage tank detention time, cleaning records, treatment evidence
- Leak detection and water loss calculations
- Main repair/replacement information
- Service line repair/replacement information
- Valve exercise goals and numbers

- Valve replacement goals and numbers
- Hydrant exercise goals and numbers
- Hydrant replacement goals and numbers
- Meter testing and replacement records
- Pressure records—maximum, minimum, averages
- Flow records—maximum, minimum, averages
- External corrosion—testing records
- Pump station operation and maintenance records
- Pipeline restoration and replacement records
- Pipeline disinfection records
- Corrosion monitoring results

2-4.1 Operating Records.

Maintain records, if applicable, for the following unit processes as listed below. Additional best practice information on these processes can be found in *Water Treatment Plant Operation, Volumes 1 and 2*:

- Activated carbon
- Aeration
- Chlorination
- Corrosion/scale control
- Filtration
- Fluoridation
- Ion-exchange
- Iron and manganese control
- Pre-sedimentation
- Reverse osmosis
- Screening
- Sedimentation
- Water softening
- Water weed control
- Ultraviolet (UV) disinfection

2-4.2 Logs.

Enter daily operating data in a daily log to provide a record of daily and average monthly operations. Record data from all aspects of treatment and operations, including routine duties, unusual conditions (operational and maintenance), accidents, complaints, and visitors.

Complete monthly and annual operating reports as assigned by site supervisors. Monthly operating reports permit technical review of current performance and comparison of performance over a long period of time. Accumulated monthly reports show variations caused by changes of seasons, methods of operation, and installation population. Annual reports include a description of the facilities, volume of water pumped/treated, quantity of chemicals consumed, capital costs, operating costs, and personnel status. Ensure annual reports are clear, concise, and informative. Keep the format consistent from year to year to facilitate comparison with past performance.

2-4.3 Water Supply System Maps and Records.

Prepare and maintain records of all installations and equipment for the water supply system. These records are to include an inventory listing of all locations and an individual record for each location. Complete or revise records when the components of the system are installed, replaced, repaired, or adjusted. Record locations using Geographic Information System (GIS). Where available, use prescribed forms for recording the data. GIS features include the following:

- GIS can store and display geographically referenced information that is represented through map display. GIS can store information that is useful for system analysis, including pipe assets, customer meter locations, land parcel data, aerial photography, street locations, digital elevation models (DEMs), digital terrain models (DTMs) and more. The usefulness of GIS pipe data is dependent on the way the information is collected and stored in GIS. GIS data may be used to build and, or, update distribution system models to create a detailed representation of the water distribution network.
- Distribution system modeling software data and results can be imported and exported to and from GIS. For utilities that have established a GIS, the added functionality of interfacing with a model can be valuable from enterprise, customer, and operational perspectives. Information in GIS is saved in file formats that most modeling software can access and can be translated into a format that can be imported into a model database. Beneficial data to be transferred between systems may pertain to demand allocation, topography extraction, and results presentation. GIS can be linked to various types of systems, including customer information systems, asset management systems, and common databases. GIS and other applications make building and maintaining models more efficient, valuable, and accurate, and they support various analysis and reporting

functions. Understand how GIS is used and use the system to maintain records for operating manuals, equipment lists, maintenance, repairs, and additional water supply system details, as needed.

For more information on GIS and modeling of water distribution systems, see *AWWA M32.*

2-4.4 Maintenance.

Keep maintenance records, including manufacturers' catalogs, brochures, and instruction manuals for all installed equipment. Use shop drawings and as-built drawings for equipment and facilities along with maintenance manuals to achieve efficient O&M of various systems. At a minimum, document when service was last performed and when it will be required again for each piece of equipment. To the extent possible, include a complete repair and cost history for all installed equipment.

2-4.5 Laboratory Reports.

Follow state and local requirements for reporting the results of water analysis. These requirements are at least as stringent as federal requirements, but specific requirements vary from state to state. Some general information that as a best practice might be recommended for inclusion in every report is covered in *Water Treatment Plant Operation, Volumes 1 and 2*.

2-4.6 Cost Accounting.

The waterworks supervisor should maintain records of operating costs in addition to those that are maintained by accounting personnel. Use these records to provide up-to-the-minute information on expenditures, predict yearly costs, and forecast budgets.

2-4.7 Data Analysis.

Establish an operating and maintenance procedure that documents the functionality of major pieces of mechanical equipment pertaining to water treatment and water supply systems. Record operational conditions and variables via operating logs or industrial control systems, such as supervisory control and data acquisition (SCADA) systems. Use feedback and results from SCADA systems, with additional software programs, to optimize control and operational planning. Develop the necessary graphics to assist in data analysis using Microsoft Excel or other useful software programs. Maintain water sampling details and analysis results and records using programs such as Microsoft Excel. Records should present historical data trends, changes in treatment patterns, or other changes that may affect water quality or plant efficiency. Analyze data trends and develop an action plan to respond to changes.

Maintain an adequate record-keeping system to allow for the continuous assessment of the water treatment and water supply systems. Establish a review cycle of the records to verify that operational control requirements pertaining to water quality, laboratory operations, and mechanical equipment are being satisfied. For more information on record-keeping, data management, and data review, see *AWWA G100 and AWWA G400.*

2-5 EMERGENCY PLANNING.

Develop procedures for water system protection, emergency operation, and ensuring an adequate water supply to protect public health and fire protection. **\1** Section 2013 of America's Water Infrastructure Act requires community drinking water systems serving more than 3,300 people to develop or update risk assessments and emergency response plans. The law specifies the components that the risk assessments and emergency response plans must address, such as:

1. Strategies and resources to improve the resilience of the system, including the physical security and cybersecurity of the system,
2. Plans and procedures that can be implemented, and identification of equipment that can be utilized, in the event of a malevolent act or natural hazard that threatens the ability of the community water system to deliver safe drinking water,
3. Actions, procedures, and equipment which can obviate or significantly lessen the impact of a malevolent act or natural hazard on the public health and the safety and supply of drinking water provided to communities and individuals, including the development of alternative source water options, relocation of water intakes, and construction of flood protection barriers, and
4. Strategies that can be used to aid in the detection of malevolent acts or natural hazards that threaten the security or resilience of the system. **/1/**

See publications *AWWA M5, AWWA M19, AWWA M52,* and AWWA (1994) handbook on Minimizing Earthquake Damage for more information on emergency planning.

For the Army, *USA-CERL TR N-86/11* contains further information on emergency planning.

\1 For the Air Force, AWIA ERP Checklist. **/1/**

2-5.1 Fire Protection.

Provide fire protection for two broad categories: general protection of installation facilities, and protection of the water supply and treatment facilities and equipment. For more best practice information on fire protection planning and procedures, see *AWWA M5* and *AWWA M31*.

For the Air Force, the Civil Engineer Operations Flight Chief is responsible for the inspection, testing, maintenance, and documentation associated with all fire detection, notification, suppression, water distribution systems, including fire pumps. For further information on the Air Force Fire Emergency Services Program, see *AFI 32-2001.*

2-5.2 Natural Disasters.

Address the effects and develop mitigation measures for natural disasters, including earthquakes, hurricanes, tornadoes, and floods. Discussions of the effects of natural disasters, and measures to mitigate them can be found in publications *AWWA M19, AWWA M60,* and AWWA (1994) handbook on Minimizing Earthquake Damage.

For the Army, *USA-CERL TR N-86/11* contains further information on natural disaster response.

2-5.3 Manmade Disasters.

Address the effects and develop mitigation measures for manmade disasters and include accidents, riots, strikes, hazardous material spills, vandalism, terrorism, and bomb blasts. Discussions of the effects of man-made disasters, and measures to mitigate them can be found in *AWWA M19.*

For the Army, *USA-CERL TR N-86/11* contains further information on manmade disaster response.

2-6 SECURITY AND RISK MANAGEMENT.

Each site has an explicit, easily communicated, and readily available security plan. Implement this plan as part of daily operations. Train all employees on the security plan and incorporate their security responsibilities into their job duties.

For the Air Force, *Air Force Guidance Memorandum (AFGM) 2017-32-01* contains further information on cybersecurity. *AFPD 90-8* contains requirements for risk management.

2-6.1 Vulnerability Assessment.

Perform an assessment to identify potential vulnerabilities in the security of the installation. Water system vulnerability assessment is required for compliance with the Bioterrorism Act of 2002. The assessment should include the following steps:

1. Asset characterization
2. Threat characterization
3. Consequence analysis
4. Vulnerability analysis
5. Threat likelihood analysis
6. Risk/Resilience likelihood
7. Risk/Resilience analysis

Identify resources required to maintain the security program and make necessary improvements. Review and update the risk assessment as new hazards and threats emerge. See *AWWA J100* for the full risk analysis and management for critical asset protection (RAMCAP) process. For a list of common water system components and how each component may be vulnerable to typical hazards, as well as an example of a vulnerability assessment, see *AWWA M19.* Do not share weaknesses in system security outside of the site security officer, department heads, and supervisors as determined by the site security plan.

For the Army, required information on vulnerability assessment can be found in *USA-CERL TR N-86/11.*

For the Air Force, required information on vulnerability assessment can be found in *AFI 10-246* and *QTP 4B071-15.*

2-7 REGULATIONS AFFECTING WATER SYSTEMS.

Congress passed the original Safe Drinking Water Act (SDWA) in 1974 (amended and reauthorized in 1986 and 1996) to ensure that the public drinking water system serving the U.S. population would meet established SDWA standards. These standards, known as the Primary Drinking Water Regulations and Secondary Drinking Water Regulations, set the numeric limits for drinking water quality. These regulations apply to all public water systems, defined as an entity that provides FFHC water through a distribution system to a minimum of 15 service connections or an average of 25 people for a minimum of 60 days a year. Most of the military installation water supplies are considered public water systems and are required to comply with local, state, and federal drinking water regulations, including public notification requirements.

Installations within the United States should comply with all state waterworks regulations or local regulations for the project location and the utility providers' requirements as applicable. Installations should check with the bio-environmental engineer and base environmental coordinator to assure compliance with the applicable regulations.

2-7.1 EPA Regulations.

SDWA and the 1986 and 1996 amendments to SDWA direct the United States Environmental Protection Agency (EPA) to promulgate regulations and guidance on maintaining drinking water quality to protect the public health. The 1996 amendments waived the sovereign immunity. All U.S. states have the primacy for the implementation of SDWA provisions, except for Wyoming and District of Columbia for which EPA requirements take precedence.

Individual states can establish additional required compliance requirements. For Installations located in the United States and its territories and possessions the water supply system must comply with the order of precedence criteria as outlined in 2-1.2.1 Within the United States.

For the Air Force, see *AFI 48-144* for guidance on compliance with EPA regulations.

For the Army, see *Technical Bulletin-Medical (TB MED)* 576 for guidance on compliance with EPA regulations.

2-7.2 Government Regulations for Overseas Installations.

For projects outside of the United States and its territories and possessions, the water supply system must follow the order of precedence criteria as outlined in 2-1.2.2 Foreign Countries.

2-8 WATER CONSERVATION.

Water conservation programs emphasize long-term improvements in water use efficiency and to manage drought planning. All U.S. states have the primacy for the implementation of SDWA provisions, except for Wyoming and District of Columbia for which EPA requirements take precedence. Individual states can establish additional required compliance requirements that include conservation, water allocation and unaccounted for water limits. Best practice information can be found in *AWWA M60*.Example water conservation practices can be found below.

- Efficient utilization of sources of supply.
- Leak detection and repair.

For the Army, see *Public Works Technical Bulletin (PWTB) 200-1-46, 200-1-94,* and *200-1-104.*

For the Air Force, see *Air Force Water Conservation Guidebook.*

CHAPTER 3 RAW WATER SUPPLY

3-1 CHAPTER OVERVIEW.

This chapter provides general information pertaining to raw water supply sources. Chapter 3 also presents specific information on the operation and maintenance of water wells, dams and reservoirs, and intake structures.

See publication *AWWA M21 and AWWA M50* for distinctions between source waters and an overview of hydraulic principles. Some best practice information can be found in *Water Treatment Plant Operation, Volumes 1 and 2*.

3-2 WATER USE.

Water use is for residential, commercial, and industrial purposes and for fire protection. The most important reason for maintaining continuity of service is to protect public health. To adequately supply all water requirements, water system operators need to know the magnitude and occurrence of peak flows, anticipated growth, and maximum projected water demand of the service area based on a 50-year drought.

A discussion of water use issues and emergency and alternative water sources can be found in *AWWA M21 and AWWA M50.* Some best practice information can be found in *Water Treatment Plant Operation, Volumes 1 and 2*.

For the Army, *PWTB 200-1-86* provides guidance for water availability determination.

3-3 GROUNDWATER SUPPLIES.

Detailed information on groundwater sources, water well terminology, well location and construction practices, and well types can be found in *AWWA M21,* and *AWWA A100.* Best practice information can be found in *Water Treatment Plant Operation, Volumes 1 and 2.*

3-3.1 Well Operation.

Groundwater sources are normally used to supplement surface-water sources. General engineering support in the form of well drilling by engineers is provided to the water collection and distribution process. Specific considerations necessitating well drilling are:

- When surface sources of water are not available in enough quantity or quality to support the force. This is likely to occur in arid terrain where the quantity of water required is high and surface sources are low. In arid environments, exploring and using groundwater can reduce the need to transport water to a desired location.
- If the distribution system is insufficient to support the force, haul distances may be significantly reduced by a well drilled close to the consumer.

- Chemical, biological, radiological, or nuclear or other type of contamination is expected that would render surface sources unusable.
- The mission is part of a humanitarian and civic assistance and, or, foreign humanitarian assistance mission. A major portion of the world's population lacks a readily available source of potable water. Providing a potable source by conducting well drilling operations may be the decisive operation in stability and, or, reconstruction operations and a critical part of the overall information operations campaign.

Follow all established operating procedures when installing and operating wells. Guidance on installing and operating wells is included in *NTRP 4-04.4.13/FM 3-34.469/AFMAN 32-1072, Water-Well Drilling Operations*.

3-3.1.1 Aquifer Performance.

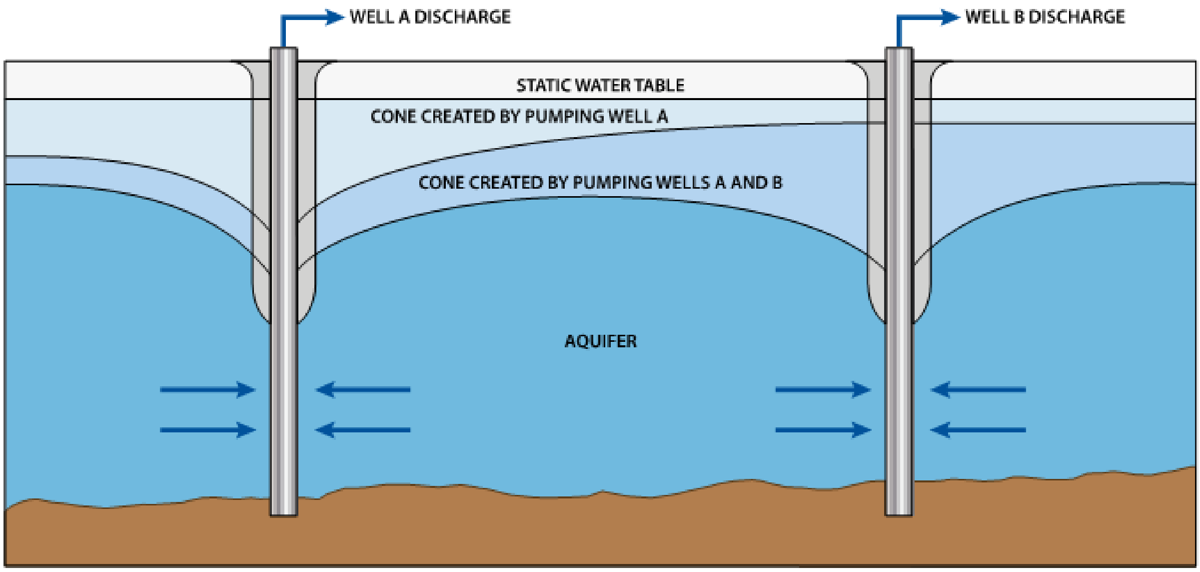
Analyze water well performance by calculating well yield, drawdown, and specific capacity. These calculations provide information for selecting appropriate pumping equipment and identifying any changes in the productive capacity of the well. Examples of such calculations are in Appendix B. Best Practice guidance from *Water Treatment Plant Operation, Volumes 1 and 2* can be used for further parameter definition and additional sample calculations.

3-3.1.2 Pump Schedule.

When water is pumped from a well, a depression is produced in the water table as drawdown occurs. When pumping stops, the water again rises to the static water level. The depth and lateral extent of the cone of depression depends on the pumping rate of the well. If two or more wells are located so closely together that their cones of depression overlap, the wells compete for the groundwater. As a result, each well produces less water than if it operated alone (Figure 3-1).

Place operating wells as far apart as possible to minimize the effect of overlapping cones of depression. Operate wells in rotation to equalize wear on pumping equipment.

Figure 3-1 Effects of Overlapping Field of Influence – Pumped Wells



3-3.1.3 Well Pump Operation.

Follow established operating procedures when pumping wells and keep pumping rates within the specified design range. Continuous operation generally is preferable to frequent starting and stopping, but the varying water demand and storage capacity usually require some combination of on and off time. Both over-pumping and frequent starting and stopping can damage the aquifer, resulting in reduced yield. In coastal areas, over-pumping may also cause saltwater intrusion. Frequent start/stop operations also shorten equipment life and consume more energy. It is usually preferable to limit pump starts to fewer than one per hour.

Follow the recommended operation guidelines below. Well pump information is included in *AWWA M21* and best practice *Small Water System Operation and Maintenance*.

- Always prime the pump with potable water.
- Disinfect the pump and drop pipe before installation and after any repair.
- Disinfect the equipment as it is lowered into the well, with special attention to the disinfection of the pump packing.
- Keep the drain from the pump base open and provide for the drain to be diverted away from the source.

3-3.1.4 Safe Pumping Yield.

Safe pumping yield is the amount of water that can be withdrawn from a well without producing an undesired effect on the well production. It is developed by comparing the measured drawdown to the maximum measured drawdown and how long it takes for the well to recover. This is further defined as the maximum amount of water that the well can produce over a certain period. Operate the well at a pumping rate that achieves 50% of the maximum drawdown to prolong the life of the well and decrease maintenance. Perform maintenance on the well to restore well yield if the desired yield cannot be obtained at this pumping rate.

3-3.1.5 Well Disinfection.

Disinfect wells, springs, infiltration galleries, and radial collectors as a normal maintenance procedure. Disinfect deep wells after original development, each time the pump is removed, each time the screen is cleaned using the surging method, and whenever regular bacteriological analyses indicate contamination is present. Well disinfection is required because well components are susceptible to contamination by pathogens before and during installation. *ANSI/AWWA C654-13* provides steps for the disinfection of wells and can be used as a guide for procedures in chlorination and bacteriological testing. Full disinfection procedures are available in *AWWA A100*, Chapter 11.

The available disinfectants are described below.

- Calcium Hypochlorite. Select a calcium hypochlorite conforming to AWWA B300 in granular or tablet form containing approximately 65% available chlorine by weight. Store the container in a cool, dark, dry environment to prevent deterioration. It is recommended that calcium hypochlorite not be used in water with high calcium hardness (greater than 100 milligrams per liter [mg/L]) unless it is dissolved in solution prior to well application.
- Sodium Hypochlorite. Select a sodium hypochlorite conforming to AWWA B300 that contains approximately 5 to 15% available chlorine. Special attention must be paid to control its length of storage and conditions to minimize deterioration.
- Liquid Chlorine. Liquid chlorine should only be used in combination with appropriate gas-flow chlorinators and injectors and under the direct supervision of an employee trained in its use and emergency procedures. Select chlorine conforming to AWWA B301 that contains 100% available chlorine and packaged in steel containers. See Table 3-1 for proper chlorine volumes. All chemical disinfectants must meet NSF/ANSI 60 certification requirements.

Table 3-1 Liquid Chlorine Volume per Water-Filled Well at 50 mg/L

Well Diameter		Volume per Water Depth	
in.	(mm)	gal/100ft	(L/m)
4	(101.6)	65.28	(8.1)
6	(152.4)	146.9	(18.2)
8	(203.2)	261.1	(32.4)
10	(254.0)	408.0	(50.7)
12	(304.8)	557.5	(73.0)
16	(406.4)	1,044.0	(129.7)
20	(508.0)	1,632.0	(202.7)
24	(609.6)	2,350.0	(291.9)
30	(762.0)	3,672.0	(456.0)
36	(914.4)	5,287.0	(656.7)
48	(1,219.2)	9,400.0	(1,167.5)
60	(1,524.0)	14,690.0	(1,824.1)

in. = inch; L = liter; mm = millimeter; m = meter

3-3.1.5.1 Well Disinfection Procedure.

Follow the below procedures for well disinfection.

a. Divert surface runoff, properly store equipment and components to prevent contamination, use drilling fluid additives that do not promote bacteriological growth, and cover the well between work periods

b. Select a disinfectant that is approved for use in potable water and the desired form: liquid chlorine, sodium hypochlorite solution, or calcium hypochlorite granules or tablets

c. Chlorination of Well after Equipment Installation. Treat water in the well casing to create a chlorine residual greater than or equal to 50 mg/L by using sodium or calcium hypochlorite. See Table 3-2 for proper chlorine application amount by well size. Surge the well three times and verify the chlorine residual of the water surged. Allow chlorinated water to rest in casing for a 12-hour minimum then pump to waste, testing the discharge water periodically for chlorine residual. When no residual is detected, pump the well to waste for 15 minutes and follow with bacteriological testing.

d. Bacteriological Testing. After the well has been chlorinated, 12 hours have passed, and it has pumped to waste for a minimum of 15 minutes with no detectable chlorine residual, at least two water samples shall be taken from the well while it is continuously pumped. Samples must be a minimum of 30 minutes apart. Test the samples for coliform in accordance with Standard Methods for the Examination of Water and Wastewater. If coliform testing is negative, the well may be placed into service. If samples test positive for coliform, perform one or more of the following procedures:

e. Pump the well to waste for a minimum of 15 minutes and repeat the sampling procedure.

f. Repeat well chlorination and testing.

g. Perform corrective action as directed by a qualified groundwater professional or engineer experienced in water well disinfection.

h. Disinfection of Flowing Wells. Perform bacteriological testing. If the samples test positive for coliform, apply chlorine at or below the lowest aquifer formation producing the artesian condition in an amount that will produce a chlorine concentration of a minimum of 25 mg/L in the flowing water. If samples still test positive for coliform, perform corrective action as directed by a qualified groundwater professional or engineer experienced in water well disinfection.

3-3.1.6 Well Records.

Maintain these well records:

- Well boring log
- Well construction record drawings
- Pump design details
- Maintenance records
- Water quality analyses
- Well discharge meter readings
- Schedule of well use (include duration of use)
- Pumping and static levels of well capacity tests
- Discharge pressure at various pumping rates
- Pump curve

Long-term records of rainfall and departures from normal rainfall amounts help show whether changes in the level of the water table and artesian pressure surface are caused by variations in long-term rainfall patterns.

For the Air Force, use form *AF997* to record well information.

3-3.2 Well Maintenance and Rehabilitation.

3-3.2.1 Cleaning Well Screens.

Decreasing yield is often caused by a clogged well screen or a clogged aquifer near the well bore. Clean the well screen to increase the yield if the specific capacity has dropped to 60% of the well's original specific capacity. Redevelop the well if the specific capacity has dropped to 40% of the well's original specific capacity. Basic methods for cleaning deep well screens in-place are described below. Refer to *AWWA M21* for best practice information. All well components need to meet *NSF/ANSI 61* requirements. Shallow well screens can be removed for cleaning.

3-3.2.1.1 Acid Treatment.

Calcium carbonate, calcium sulfate, and iron oxide deposits can cause screen encrustation. Corrosion may also cause encrustation. Screens can be cleaned with properly inhibited muriatic acid or sulfamic acid. Estimate the severity of encrustation from the records of changes in yield, specific capacity, and, or, drawdown. Use an experienced and qualified contractor to perform acid treatment. Unless otherwise directed by the utility manager, base personnel do not typically perform acid treatment operations. Do not pump nearby wells when acid treatment is in progress.

3-3.2.1.2 Chlorine Treatment.

Adding chlorine to a clogged well destroys bacterial slime growths. Follow the steps below for chlorine screen cleaning.

a. Prepare solutions of chlorine that produce 100 to 200 mg/L of chlorine when mixed with the water in the well (Table 3-2). Introduce the solution into the well carefully through a hose placed in the case with its discharge end at the level of the screen.

b. Allow the well to stand for 24 hours. Then pump water to waste until the chlorine residual reaches 0.1 mg/L. Surging during chlorine treatment is helpful (see 3-3.2.1.7).

c. Perform three or four successive treatments with chlorine. Alternating acid treatment with chlorine treatment can be effective. Complete the acid treatment first, followed by chlorine treatment after most of the acid has been pumped to waste. A second series of acid and chlorine treatments can be undertaken after the initial acid and chlorine treatments have been completed.

d. Remove the well pump during chlorine-soaking period. Chlorine and chloride will pit and damage iron and steel pump components as well as some stainless steels at levels of 50 mg/L and less.

Table 3-2 Materials Required for 100 Gallons (400 Liters) of Chlorine Solution

Desired Chlorine Strength	Chlorine		Dry Calcium Hypochlorite 70%		Quarts (L) of Bleach Per 100 Gallons (400 L) of Water		
	lbs	(g)	lbs	(g)	5%	7%	10%
50 ppm	0.05	(23)	0.07	(32)	0.4	0.3	0.2
100 ppm	0.10	(45)	0.14	(65)	0.8	0.6	0.4
150 ppm	0.15	(68)	0.20	(97)	1.2	0.9	0.6
200 ppm	0.20	(91)	0.30	(130)	1.6	1.2	0.8
300 ppm	0.25	(113)	0.40	(162)	2.4	1.7	1.2
400 ppm	0.35	(159)	0.50	(227)	3.2	2.3	1.6

g = gram; L = liter; lbs = pounds; ppm = parts per million

3-3.2.1.3 Phosphate Treatment.

The glassy phosphates (sodium hexametaphosphates) act as dispersing agents on such screen-plugging materials as amorphous silica, hydrated ferric oxide, iron carbonate, and calcium carbonate. Follow these treatment steps:

a. Dissolve 15 to 30 lbs (7 to 14 kilograms [kg]) of glassy phosphate in a minimum amount of water and add 1 lb (450 g) of calcium hypochlorite for each 100 gal (400 L) of water in the well casing (under static conditions). To dissolve the phosphate, suspend the chemical in a wire basket or burlap bag. Do not simply dump the phosphate in the dissolving tank or barrel. Add the solution to the well through a tremie-like pipe placed in the case with its discharge end at the level of the screen.

b. Allow the solution to remain in the well for 24 to 48 hours and surge approximately every 2 hours. If surging is not possible, allow the solution to stand in the well for 1 week.

c. Treatment with glassy phosphate for more than 1 week may cause the well yield to decrease. Phosphorus can be adsorbed to clays and become available to bacteria for metabolism and cell growth and development and subsequently increased clogging.

d. After treatment, pump the well to waste for 8 hours and test the output. Repeat the treatment until the output no longer improves. Analyze the phosphate content of the well water after final treatment and pumping to make sure it has been reduced to normal background levels. All treatment chemicals must meet NSF/ANSI 60 certification requirements.

3-3.2.1.4 Dry Ice Cleaning.

Use compressed carbon dioxide gas, or “dry ice,” to clean deep wells with high static levels. Follow these steps:

a. For wells measuring 6 to 10 in. (150 to 250 mm) in diameter, use 10 to 15 lbs (4.5 to 7 kg) of dry ice for light surging and 25 to 50 lbs (11 to 23 kg) for heavy surging. Drop pieces of broken dry ice of about 2 in. (5 centimeters [cm]) in diameter into the well casing until enough has been added to blow the water through the screen. The water will not freeze if there are 11 lbs (5 kg) or approximately 1.5 gal (5 L) of water in the well casing for each pound (450 g) of dry ice added.

b. Provide a pressure gauge on the well casing and seal the well to prevent loss of carbon dioxide. When the gas is released, it expands and creates a surging action that produces backpressure and backwashing of the screens. The escape of gas through the water-bearing strata will be evident from irregular movement of the pressure gauge needle. The particular conditions involved are different in practically all cases, and the exact procedure depends largely on the operator’s judgment.

Caution: Dry ice may cause “burns” if handled with bare hands. Use heavy gloves or tongs. Also, since high pressure may develop during dry ice treatment, provide for control and release of excessive pressure (150 pounds per square inch [psi] or 1,030 kiloPascals [kPa]). The gas is suffocating. Provide ample ventilation.

3-3.2.1.5 Jet Cleaning.

Clean a well from inside the well screen by horizontal jet cleaning. Figure 3-2 shows the jetting tool. The process requires only a relatively simple jetting tool with an attachment fitted with horizontal nozzle orifices, a high-pressure pump, a hose, a string of 2-in. (50-mm) pipe, and an adequate water supply. Follow these steps to jet clean a well screen:

a. Select a nozzle to match the output of the high-pressure pump used and the well pump (Table 3-3).

b. Attach the string of 2-in. (50-mm) pipe to a hose with a swivel connection at the top.

c. Lower the jetting tool into the screen. Turn on the high- pressure pump and slowly rotate the jetting tool while raising and lowering it. The forceful action of the high-velocity jets, working the water through the screen openings, breaks up the clog.

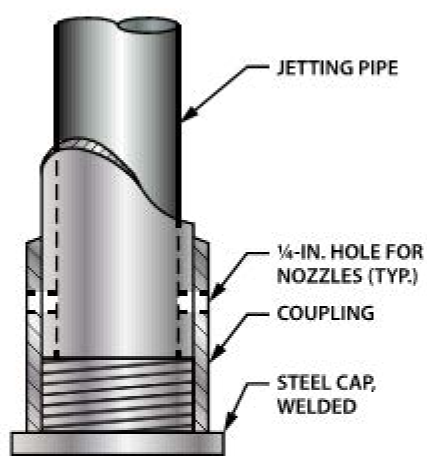
d. Pump the well lightly while the jetting is under way to remove the dislodged material. The well pump should pump out approximately 15% more water than is being added to the well by the jetting tool.

Table 3-3 Jetting Nozzle Discharge

Orifice		150 psi				200 psi				250 psi			
		1 Nozzle		2 Nozzles		1 Nozzle		2 Nozzles		1 Nozzle		2 Nozzles	
in.	(mm)	gpm	(Lps)	gpm	(Lps)	gpm	(Lps)	gpm	(Lps)	gpm	(Lps)	gpm	(Lps)
3/16	(5)	13	(0.8)	25	(1.6)	15	(0.9)	29	(1.8)	17	(1.1)	33	(2.1)
1/4	(6)	23	(1.5)	45	(2.8)	26	(1.6)	52	(3.3)	52	(3.3)	37	(2.3)
3/8	(10)	49	(3.1)	97	(6.1)	56	(3.5)	110	(6.9)	61	(3.8)	120	(7.6)

gpm = gallons per minute; Lps = liters per second. Nozzle discharge rates in Lps are approximate.

Figure 3-2 Jetting Tool for Well Screening



3-3.2.1.6 Sonic Process Cleaning.

Sonic process cleaning is performed by outside contractors by lowering a series of small, explosive charges on a wire into the well and detonating them by means of an electrical charge at the surface. The size of each charge depends on pipe size, thickness, grade, type, and condition. The charges are placed on a connecting wire at calculated distances and detonated in a special time-delay sequence. Each charge, lasting only a fraction of a second, creates an expanded gas bubble that produces a shock wave at its leading edge as it rushes down the well column. As the wave strikes the well casing, it causes strong vibrations that help loosen the clog. The expanding bubble also produces a surging action that helps clean the screen. This action is repeated with the detonation of each charge. Sonic processes are most effective in sandstone aquifers where clogging may only extend 1 to 2 in. into the aquifer. Do not use any other method of blasting for cleaning screens.

3-3.2.1.7 Surging.

Clean a well by surging if it is not desirable to pull the pump. Surging can be done by utility personnel or by seeking expert help. Follow the steps below to clean a well by surging.

a. Disconnect the discharge of the pump and alternately start and stop the pump. This operation raises the water in the pump casing and allows it to fall again. The greater the distance to the static water level, the more effective the operation. If the water level in the well stands at a high elevation, a surge pipe may be attached to the discharge of the pump.

b. Repeat the process of starting and stopping the pump at 3- to 5-minute intervals until the discharge runs clear. Water running back down the pump column just after the pump is stopped may cause the motor and impeller to turn in a reverse direction. Do not attempt to start pump during this reverse rotation.

3-3.2.1.8 Backwashing and Surging.

Backwash a well by allowing a large volume of water to rush down the casing if surging alone is not sufficient. Follow these steps:

a. Where bypass pump connections or wash-water lines are not included in the installation, remove the flap in the check valve.

b. Open the pump discharge valve and allow a full head of water from the storage tank to rush down the well casing. If the casing fills rapidly, it is because the screen is badly clogged. Caution: Before starting the backwash operation, be sure the pump and motor turn freely. Otherwise, the downrush of water may rotate the pump in the wrong direction and unscrew the pump shaft.

c. Allow the backwashing to continue for approximately 5 minutes then close the backwash valve, open the pump discharge valve, and start the pump. Run the discharge to waste until the water is clear. Repeat the operation. Check the results by measuring the water level and yield.

3-3.2.1.9 Backwashing and Backblowing.

Allow only experienced personnel to backwash with water and backblow with air only after pulling the well pump. The compressed air increases the surging action and provides air-lift pumping that removes dislodged sand. Follow these procedures:

a. Remove the well pump and insert a 4-in. eductor pipe to a depth according to Table 3-4. The arrangement of eductor pipe and airline is shown on Figure 3-3.

Table 3-4 Eductor Submergence Required for Various Well Depths

Depth of Well (ft)	Depth of Well (m)	Submergence of Eductor (percent of well depth)
10–50	(3.0–15.2)	70–66
51–100	(15.5–30.5)	65–55
101–200	(30.8–61.0)	54–50
201–300	(61.3–91.4)	49–43
301–400	(91.7–121.9)	42–40
401–500	(122.2–152.4)	39–33

m = meter

b. Cap the 4-in. (100-mm) eductor line with a tapped pipe plug through which the air line runs. Connect the air pipe by means of an air hose (or non-rigid system) to an air compressor having a minimum capacity of 110 cubic feet per minute (cfm) or 50 Lps.

c. With the eductor valve open, build up the air pressure until the water is discharged and pressure reaches a constant value. Pump the water until it runs clear.

d. Release the air pressure, close the 4-in. discharge valve, and apply air until static pressure is reached. At this point, air escapes from the bottom of the 4-in. eductor pipe and causes both air and water to surge through the screen and create movement in the sand and gravel.

e. Open the 4-in. (100-mm) valve and allow the air-lift to pump out the loosened sand and silt.

f. When the water is clear, repeat steps d and e above. Faster results can be obtained if water can be pumped into the well casing while the air is being added (step d above).

g. Check results after each series of operations. An increase in pumping pressure on the gage indicates increasing inflow into the well and less drawdown. Caution: When starting backblowing operations, do not start at maximum rates. Always keep the gravel chamber full to replace sand loss.

h. For this operation, provide excess air. The desirable amounts of excess air, with 50% submergence, are shown in Table 3-5.

Table 3-5 Air Requirements for Backwashing Well Screen with Air Lift

Lift		**Air Required per volume pumped**	
ft	**(m)**	**Cfm/gal**	**(Lps)**
100	(30.48)	0.5	(0.2)
200	(60.96)	0.7	(0.3)
400	(121.92)	1.0	(0.5)
500	(152.40)	1.5	(0.7)

cfm = cubic feet per minute; L = liters; min. = minute

3-3.2.2 Repairing Well Screens.

Check the wire windings, bail plug, and packer on all screens that are pulled. Replace damaged or corroded screens or return them to the factory for repair. It is not recommended to repair well screens in the field.

3-3.2.3 Abandonment of Wells.

Wells may be abandoned because of lowered water table, plugged screens, corroded casings that allow soil to enter the well, or objectionable sand pumping. For deep wells and driven wells, pull the casing and fill the hole with concrete. Securely cap the top of the well to prevent contamination of the aquifer and protect people or animals against falling into the well. Fill abandoned dug wells and springs as a safety measure.

3-3.2.4 Maintaining Specific Well Types.

In addition to the general maintenance items common to all wells, different types of wells require special care because of their construction or operation. Groundwater supply maintenance procedures are summarized in Table 3-6. The frequencies shown in Table 3-6 are suggested and may be modified by local command as individual installation conditions warrant.

Figure 3-3 Piping Arrangement for Backwashing and Backblowing

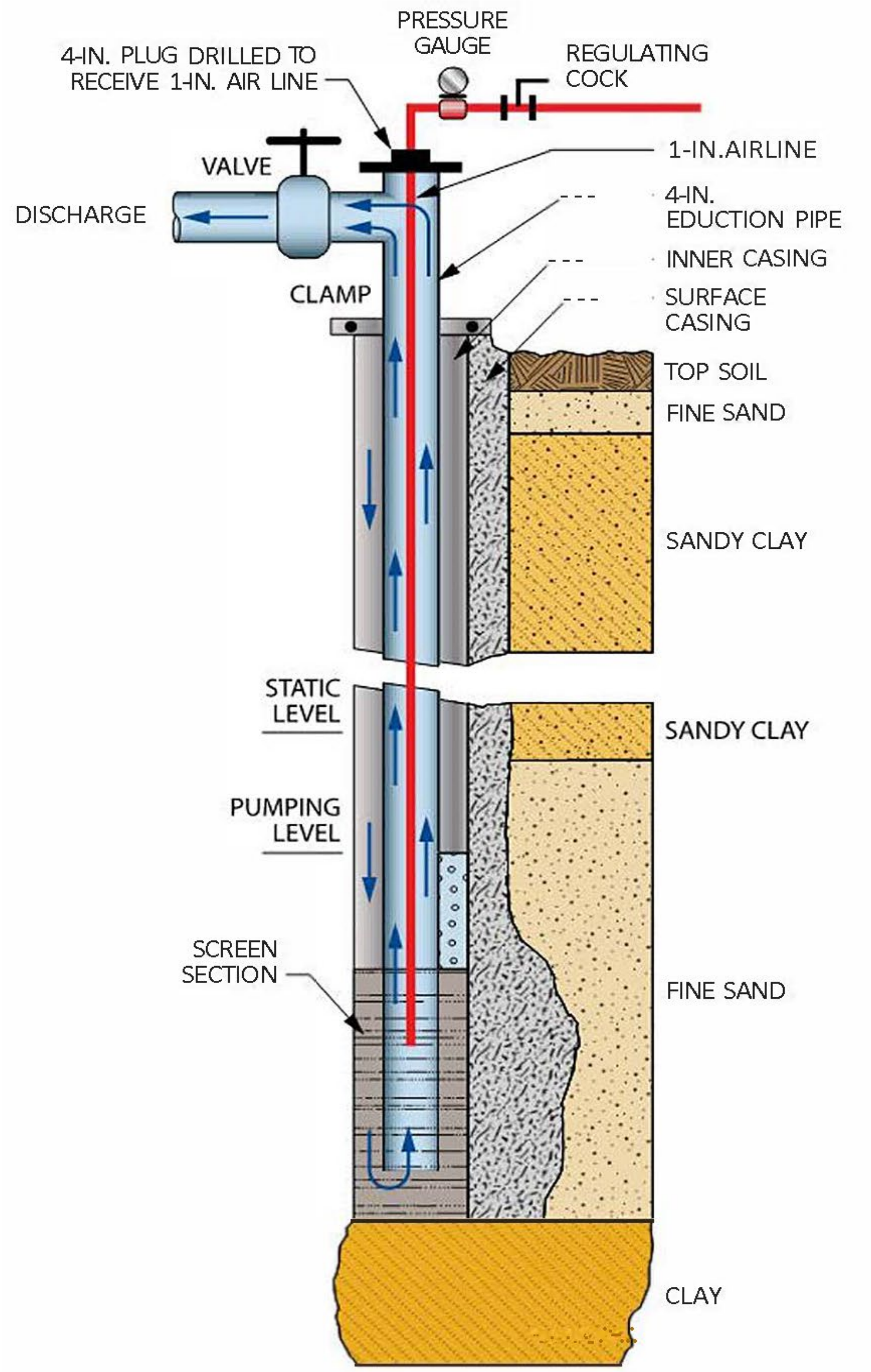


Table 3-6 Maintenance Checklist for Groundwater Supplies

Inspection	Action	Frequency
Operating record review	Ascertain changes in conditions since previous inspection and take necessary action.	Semi-annually
Sanitary conditions	Dig ditches to carry away standing water within 50 ft (15 m) of well, spring, or infiltration gallery.	Semi-annually
	Operator to ensure storm water flow does not flow across the well area. Divert storm water flow around well to prevent contamination.	Semi-annually
Pollution sources	Fence area to keep livestock at least 50 ft (15 m) from well or spring.	Semi-annually
	Remove cesspools, privies, or septic tanks; cover area with hypochlorite; fill any open excavations resulting from removal.	Semi-annually
Wells, springs, infiltration galleries, and silt	Remove accumulations of more than 1 ft (30 cm).	Variable
Concrete; cracks in housing; other watertight structures in wells, springs, infiltration galleries, and radial wells	Repair as necessary by making surface structure watertight.	Quarterly
	Shore up infiltration gallery wall structures.	Quarterly
Operating records and evidence of contamination	Disinfect wells, springs, and infiltration galleries, when indicated.	Variable
Well output loss and condition of well screen	Clean well screen by approved method.	Variable
Well equipment (well apron, top of casing, well	Repair as necessary to make all items watertight.	Semi-annually

Inspection	Action	Frequency
pits); cracks and possible leakage		
Well vents	Clean, repair, or replace if torn or clogged.	Monthly
Water use for equipment operation	Make certain water for bearing lubrication and pump priming are from a safe supply and that cooling water for engines and compressors is not returned to water system.	Semi-annually
Air intakes on compressors	Screen air intake if necessary, clean and replace air filters, and blow down air storage tanks to remove accumulated oil.	Monthly
Bored wells: casing failure	If water is turbid, the screen is defective; remove and replace.	Variable
Dug wells: silt accumulation; wall failure	Clean as necessary, repair cracked walls, and increase capacity if necessary by driving horizontal collector pipes.	Quarterly
Driven well: decrease in water yield; screen clogging	Try backwashing or pull the point and clean or replace.	Monthly
Gravel-packed wells: silt clogging of screen and gravel pack; gravel level	Clean as necessary; add new gravel as required to keep the level at proper elevation.	Monthly

3-3.2.4.1 Maintaining Bored Wells.

Casing failures and screen clogging are the primary causes of failure in bored wells. Clean or replace screens when experiencing high turbidity in the water.

3-3.2.4.2 Maintaining Dug Wells.

The masonry or concrete casings are subject to cracks and joint failure that can allow surface water into the well. Perform periodic removal of silt and sand accumulated at the well bottoms.

3-3.2.4.3 Maintaining Driven Wells.

Driving the well point may damage the screen or seal it off. If water yield decreases, suspect screen clogging and try backwashing. If this fails, pull the point and clean it or replace it with a new one.

3-3.2.4.4 Maintaining Drilled Wells.

Screens can become clogged and will require periodic cleaning. Inspecting or removing the screen requires a major effort. Cleaning the screen in place is the preferred method (see Chapter 3 paragraph titled Cleaning Well Screens). Alternatively, remove, clean, and replace the screen.

3-3.2.4.5 Maintaining Gravel-Packed Wells.

Both the gravel and screen may become clogged in a gravel-packed well. Add gravel periodically to keep the gravel level above the well screen.

3-3.2.5 Maintaining Springs.

Springs are subject to surface contamination. Inspect the area around the spring regularly to detect contamination and guide preventive measures for contamination control. If contamination is detected, thoroughly disinfect the spring before returning it to service.

3-3.2.6 Maintaining Infiltration Galleries.

In addition to silt accumulation, undermining of walls and failure of the wall structures may occur. Operating records on static level and drawdown will indicate whether the yield is being maintained. Perform maintenance functions such as cross bracing, adding sheet piles, and adding gravel to increase the service life of the structure. Consider driving wells in the bottom of galleries to increase the yield.

3-3.2.7 Maintaining Radial Wells.

Shallow radial water collectors may be subject to contamination from overlying ground pollution. Remove silt or sand that may accumulate in the caisson on a regular basis. Dewater the collector well and unite the surface if spalling of concrete walls is severe.

3-4 SURFACE WATER SUPPLIES.

General information on surface water supplies, water storage, intake structures, and low-lift pumping can be found in *AWWA M50*. Best practice reference information can also be found in *Water Treatment Plant Operation, Volumes 1 and 2*.

3-4.1 Operation.

Operating functions consist of surveying the watershed to locate possible contamination sources and controlling those sources as much as practical. Total ownership of the watershed is seldom possible, so agreements with others may be necessary to ensure a high-quality water source.

3-4.1.1 Intake Operation.

Many intakes are fitted with gates at various depths. Others have an adjustable suction pipe attached to a floating raft to draw water from the reservoir or lake at different levels. Experience will tell the operator which water intake depth yields the best water.

Damage by surface ice can be prevented by locating an intake below the ice level and placing lake intakes beyond the ice line of the lake. The intake structure, however, must be designed to withstand the pressure of the ice. If ice around an intake cannot be removed by scraping or other manual means, remove it by pumping water out of the intake (reverse flushing). If necessary, steam can be piped into the water to raise the temperature.

Table 3-7 provides inspection tasks and recommended frequencies. Actual frequencies may differ as determined by local command. Maintenance frequencies should follow best practice *Sacramento Course-Small Water System Operation and Maintenance*.

Table 3-7 Inspection and Maintenance Checklist for Surface Water Supplies

Inspection	Action	Frequency
Watershed area	Ensure that facilities are in working order for sewage disposal and garbage and trash removal. Remove debris.	Quarterly
Recreational facilities on watershed	Clean and repair facilities.	Monthly
Reservoirs	Remove vegetation in shallow water and vary water level a few inches for mosquito control.	Every 10 days (summer only)

Inspection	Action	Frequency
	Report algae blooms to operating staff.	Weekly (summer only)
	Dredge when there is extensive capacity loss by siltation; determine silting extent by comparing reservoir volume with the initial contour prior to sounding surveys and calculate storage capacities.	Annually
	Remove debris and extraneous vegetation from sides and bottom, if exposed. Grade sides to prevent erosion.	Weekly
Dams	Check for leakage and exposed surface conditions.	Monthly
	Verify that riprap on the upstream face is even and in good condition.	Annually
	Check for ice formations.	Daily (winter)
	Check spillway for trash, debris, and ice.	Daily (winter)
	Lubricate gates and appurtenances.	Monthly
Intake structures	Check for cracks, silt deposits, and ice clogging.	Weekly
	Check for material on screens not removable by regular operational procedures.	Weekly

3-4.2 Maintenance.

3-4.2.1 Intake Maintenance.

Intake stoppage may, in most cases, be cleared by backflushing the intake conduit or pipeline. When danger of intake stoppage exists, keep backflushing equipment readily available.

Maintenance operations on intakes in rivers, lakes, and impounded reservoirs involve the structures and their appurtenances.

- Inspect all structures periodically for cracks or structural defects.
- Measure the depth of the suction well to determine the accumulation of silt and sand. Dredge these accumulations as necessary.
- When ice conditions endanger the structure or clog the intake opening, take protective measures. Install log booms or bubble compressed air into the water at critical points to prevent freezing. Frazil ice can form in supercooled water and may cause complete blockage of intakes. Best practice information on frazil ice can be found in Water Treatment Plant Operation, Volumes 1 and 2.
- For the Army, see Preliminary Report: Field Test of Trash Rack Heating to Prevent Frazil Ice Blockage.
- Remove any material on screens that is not removable by ordinary operations. Lubricate and repair any accessory equipment to movable screens.

Table 3-8 Maintenance Checklist for Dams

Symptom	Possible Cause	Action
Excessive and, or, muddy seepage water exiting from a point	Water created an open pathway, channel, or pipe through the dam and is eroding and carrying embankment material.	Estimate or measure the outflow quantity. Determine whether it is increasing with time and if material transport by the flow is continuing.
		Lower the reservoir water level.
		Search for an opening on the upstream of the dam and plug it if possible.

Symptom	Possible Cause	Action
	Rodents, frost action, or poor construction allowed seepage water to create an open pathway.	Place filter sand at the seepage exit location to prevent material from being transported along with seepage. Place gravel initially, if needed, to slow the flow velocity and prevent the sand from washing away. Cover sand filter with gravel.
Seepage exiting from a point adjacent to the outlet pipe	A break or hole in the outlet pipe or poor compaction around the pipe allowed water to flow and create a pathway along the outside of the outlet pipe.	Determine if seepage is carrying soil particles (muddy water). Determine flow rate and if it is increasing with time. If flow increases or is carrying material, lower the reservoir level until seepage stops. Investigate the embankment along alignment of pipe to identify signs of settlement or sinkholes.
Seepage is exiting as a boil downstream from the dam	Part of the foundation material is supplying a path for reservoir seepage, possibly by sand or gravel layer in the foundation.	Examine the boil to see if foundation materials are being transported (typically expressed as a ring of material around the exit). If soil particles are building up at exist points, use sandbags or earth to create a dike around the boil. If the situation cannot be controlled with sandbags and soil materials are being carried by the flow, lower the reservoir water level.
		Measure outflow quantity and determine whether the seepage flows are

Symptom	Possible Cause	Action
		increasing with time and material is being transported.
		Lower the reservoir water level.
		Search for an opening on the upstream of the dam and plug it if possible.
Seepage water is existing at the abutment contact	Water flowing through pathways in the abutment or along embankment abutment contact resulted in erosion.	Place filter sand at the seepage exit location to prevent material from being transported along with seepage. Place gravel initially, if needed, to slow the flow velocity and prevent the sand from washing away. Cover sand filter with gravel.
		Check seepage and leakage outflows for muddy water.
		Inspect dam appurtenances for other anomalies (new seepage areas, depressions, cracks).
Sinkhole	Internal erosion (piping) or embankment materials or foundation.	Check seepage and leakage outflows for muddy water.
	Eroded cavern (cave-in).	Inspect dam appurtenances for other anomalies (new seepage areas, depressions, cracks).
	Small hole in the wall of an outlet pipe.	

Symptom	Possible Cause	Action
Slide, slump, or slip	Foundation movement or a too-steep slope caused earthfill to move along a slip plane.	Evaluate extent of the slide. Inspect for new or changed seepage conditions downstream of the slide area and for longitudinal and transverse cracks or scarps near the slide. Draw down the reservoir level.
Transverse cracking	Differential settlement between adjacent segments of the embankment.	Inspect the crack and record its location, length, width, depth, and other pertinent physical features. Stake out the crack limits.
		Under engineer's direction, excavate the crest along the crack to a point below the bottom of the crack. Backfill the excavation using suitable material and correct construction techniques. Visually monitor the crest routinely for evidence of future cracking.
Longitudinal cracking	Slope instability.	Inspect the crack and record its location, length, width, depth, and other pertinent physical features.
	Liquefaction of the foundation and, or, embankment materials after an earthquake.	Effectively seal the crack to prevent surface water infiltration.
	Differential settlement between zones or within embankment.	Visually monitor the crest routinely for evidence of future cracking.

Symptom	Possible Cause	Action
Rodent activity and animal impact	Cattail-filled areas and areas where trees are close to the reservoir provided an ideal habitat for animals.	Start a rodent control program.
	Overabundance of rodents increased the chances of burrowing, which created holes, tunnels, and caverns within the embankment dam.	Backfill existing rodent holes with suitable, well-compacted material.
		For large or deep holes, include a zone of filter material when backfilling.
Trees or obscuring vegetation	Natural vegetation obscured visual inspection and harbored animals.	Control vegetation that obscures visual inspection of the embankment.
	Large tree roots created seepage paths.	Under engineer's direction, remove all large, deep-rooted trees and shrubs on or near the embankment with care. Backfill voids promptly.
	Large trees blew over during a storm and damaged the dam.	Remove trees at the toe and groins of the dam to provide a 25- to 50-ft buffer. Monitor area for sinkholes and seepage paths after tree removal.
Surface erosion	Water from intense rainstorms or snowmelt carried surface materials down the slope and created continuous troughs, rills, and gullies.	If detected early, add protective grasses. Restore and protect eroded areas; add rock or riprap where appropriate.
	Upstream erosion from a face not protected with riprap.	Reestablish the normal slope. Place bedding material and properly sized riprap.

Symptom	Possible Cause	Action
Deteriorated or missing riprap	Poor quality riprap deteriorated.	Reestablish the normal slope. Place bedding material and properly sized riprap.
	Wave or ice action displaced riprap.	
	Riprap was improperly sized.	
Low area in dam crest	Excessive settlement of the embankment or internal erosion of embankment material.	Establish survey monuments or survey along the length of the crest from abutment to abutment to determine the exact amount, location, and extent of low spots on the crest. Use proper construction techniques to fill in the low area and reestablish the uniform elevation over the length of the crest. Routinely survey established monuments along the dam crest to detect any unusual settlement.
	Foundation spreading upstream and, or, downstream.	
	Prolonged wind erosion.	
	Improper final grading post-construction.	

3-5 WATER QUALITY.

Raw water supplies may be impacted by various materials, most of which are water soluble to some degree. Impurities and, or, contaminants can create undesirable qualities to water, pose a threat to humans, or cause no significant problems. The various water characteristics and contaminants that can impact water quality, are listed in Table 3-9.

Table 3-9 Water Quality Characteristics

Physical	Chemical	Biological	Radiological
Temperature	pH	Algae	Radionuclide contamination
Turbidity	Alkalinity	Bacteria	Industrial processes
Color	Hardness	Viruses	Medical processes
Taste	Calcium	Protozoa	
Odor	Stability	Macrophytes	
	Iron		
	Manganese		
	Dissolved oxygen (DO)		
	Fluoride		
	Organic chemicals		
	Inorganic chemicals		

CHAPTER 4 WATER TREATMENT

4-1 WATER TREATMENT.

Treatment consists of adding and, or, removing substances from water to bring about a desired change in quality. In general, treatment is provided to protect public health or improve the acceptability (aesthetic quality) of the finished product. This chapter is a guide to basic information on most of the common water treatment processes

4-2 TREATING WATER AT THE SOURCE.

Treatment of water supplies is generally done at a treatment plant where positive monitoring and control is possible. Sometimes, however, providing treatment at the source (in situ treatment) is more economical or practical. Treating reservoirs for algae or zebra mussel control is an example of in situ treatment. For detailed information on specific in situ treatment techniques, see *AWWA M7* and *AWWA M21.* For additional best practices use *Water Treatment Plant Operation, Volumes 1 and 2*.

4-3 UNIT TREATMENT PROCESSES.

See Chapter 10 for general maintenance routines and procedures for mechanical equipment associated with unit treatment processes.

4-4 TASTE AND ODOR CONTROL.

Controlling tastes and odors is one of the most troublesome problems in water treatment. Tastes and odors appear in both ground and surface water supplies. The main means of control are aeration, adsorption, and oxidation. Best practice information on taste and odor can be found in *Identification and Treatment of Tastes and Odors in Drinking Water*.

4-5 CONTROLLING ORGANIC CHEMICALS.

The SDWA regulates four categories of organic contaminants: pesticides, volatile organic compounds (VOCs), synthetic organic chemicals, and disinfection byproducts (DBPs). Effectively removing organic chemicals requires special treatment techniques. See Chapter 2 paragraph titled Regulations Affecting Water Systems for monitoring and reporting requirements.

4-5.1 Pesticides Group – Treatment.

Activated carbon adsorption is the most effective method available for removing pesticides. Some pesticide removal occurs during conventional treatment by coagulation, sedimentation, and filtration. However, removals are usually less than 10%. Chemical oxidation with chlorine, ozone, or potassium permanganate also removes less than 10% of pesticides.

Conventional water treatment followed by activated carbon adsorption effectively removes pesticides from drinking water. The effectiveness of carbon adsorption depends on the concentrations of absorbent and adsorbate, contact or residence time, competition for available adsorption sites, and the temperature and pH of the water. Dosage requirements can only be determined after sampling and by laboratory analysis or pilot plant operations.

- When adding powdered activated carbon (PAC), use multiple points of injection for maximum efficiency of the adsorbent and to maximize pesticide removal. A disadvantage of PAC is that the sludge formation after application requires further treatment.
- Provide continuous online operation when granular activated carbon (GAC) beds are used to protect against pesticide contamination. Demonstrations have shown that organic pesticides can be adsorbed with virgin or exhausted GAC used for odor control.

4-5.2 VOCs Group.

Volatile Organic Compounds (VOCs) are a group of organic chemicals that include any compounds of carbon that have photochemical reactivity in the atmosphere. These do not include carbon monoxide, carbon dioxide, carbonic acid, metallic carbides, carbonates and ammonium carbonate, or any carbon compound that has negligible photochemical activity, as designated by the EPA.

4-5.2.1 Sources of VOCs.

Water supplies derived from groundwater, as well as from surface water, may contain VOCs. Contamination is most common in urban or industrial areas and is generally believed to be from improper disposal of hazardous wastes and industrial discharges.

Many of the regulated VOCs are suspected carcinogens, and the others may damage the kidneys, liver, or nervous system. The presence of one of these compounds, even at a low level, is a concern because these are manufactured chemicals (not naturally occurring in the environment), and their presence indicates the potential for further contamination of that source water.

Groundwater is of concern in that these waters move slowly and do not have a rapid natural cleansing mechanism. Thus, once groundwaters are contaminated, they generally will remain so for many years or decades.

4-5.2.2 VOC Treatment.

Methods for removing VOCs include aeration and GAC. PAC treatment or conventional drinking water treatment (coagulation, sedimentation, and filtration) have not proven effective. Methods such as reverse osmosis and macromolecular resins eventually may prove useful in removing VOCs. Before implementing a VOC control strategy, check local environmental regulations and permit requirements. Aeration could cause a violation of air quality standards. Spent carbon from GAC adsorbers could be considered a hazardous waste.

4-5.3 DBPs Group.

4-5.3.1 Sources of DBPs.

Chlorine, when used for bacterial and viral disinfection of water supplies, interacts with organic precursors present in natural waters to form a variety of chlorinated organic compounds, collectively called disinfection byproducts. DBPs are associated with chronic health problems, including cancer. Because the natural organic precursors are more commonly found in surface waters, water taken from a surface source is more likely than groundwater (with some exceptions) to have high DBP levels after chlorination. Several DBPs have been targeted for regulation, including THMs and haloacetic acids. Other oxidants used for disinfection, i.e., ozone and chlorine dioxide, can also form DBPs (although not to the same extent as chlorine).

4-5.3.2 DBP Treatment.

4-5.3.2.1 Use treatment options available at the base to meet DBP standards by substituting new disinfectants for chlorine that do not generate or produce fewer DBPs; reduce organic precursor concentrations before chlorination; and remove DBPs after formation.

4-5.3.2.2 If available, select from the following alternate disinfectants: ozone, chlorine dioxide, and chloramine. Closely monitor the microbiological quality of the treated and distributed water during the transition period to an alternate disinfectant. Where the plant footprint allows, use UV disinfection as an alternate method to deactivate microorganisms without the production of DBPs.

4-5.3.2.3 To reduce precursor levels, use available treatment features such as offline raw water storage, aeration, improved coagulation, ion exchange resins, adsorption on PAC and GAC, ozone-enhanced biological activated carbon, and adjustment of the chlorine application point. Preform bench- and pilot-plant studies to determine which treatment process will most effectively reduce precursor levels.

- The air-water ratio required for aeration to effectively remove volatile organic precursors is higher than the air-water ratios needed for taste and odor control or iron and manganese removal. The high air-to-water ratio promotes the growth of aerobic organisms (such as algae) and can be a significant problem.
- Some organic precursors are removed during coagulation. These organics often adhere to the particulate matter that settles.
- High doses of PAC remove only a portion of the precursors. High costs and sludge problems limit the use of PAC for precursor control.

- GAC can adsorb a wide spectrum of organics. Frequently, GAC adsorbs enough precursor material so that chlorine disinfection can follow GAC treatment without forming excessive DBP precursors.
- One of the quickest and least expensive ways of maintaining low DBP levels in chlorine-treated water is to chlorinate the water with the lowest possible organic content. If water is filtered, the filter effluent is the water with the lowest possible organic content. However, contact tanks must be previously constructed to achieve the proper contact time for adequate disinfection of filter effluent. Chlorinating coagulated and settled water reduces but does not eliminate DBP formation potential in finished water because DBP precursors continue to form during distribution. Disinfection before filtration limits bacterial growth in the filters. The absence of a disinfectant at the beginning of treatment may cause problems because of the growth of algae, slime, and higher forms in the early part of water treatment plants. Monitor the use of pre-disinfection to prevent filter fouling versus the production of DBP precursors early in the process.

4-5.3.2.4 Technology available for DBP reduction includes PAC, ozonation, GAC, and aeration.

- High doses of PAC and ozone are required to get substantial (but not complete) DBP removal. These processes would be too expensive considering the removals obtained.
- GAC filters can effectively remove DBPs (as well as other organics) below contaminant levels.
- Locating the aeration process after chlorination will remove volatile DBPs from the finished water. However, organic precursors not removed in the water treatment process continue to react with the remaining chlorine residual after aeration to raise DBP levels in the distribution system. Therefore, removing volatile DBPs from finished water by aeration is not considered a viable control method.

4-5.3.3 State Approval of Treatment.

A facility must obtain state approval before significantly modifying its treatment process to comply with DBP requirements. The facility is required to submit a detailed plan of proposed modifications and safeguards it will implement to ensure that the bacteriological quality of the drinking water serviced is not decreased by such changes. Each system must comply with the provisions set forth in the state-approved plan.

4-6 TREATMENT PLANT INSTRUMENTATION AND CONTROL.

The references below include information on meters, recorders, alarms, and automatic control systems. SCADA should record all operation conditions of treatment plant systems. Instrumentation and control (I&C) is covered in Chapter 8. Specific information is provided on flow, pressure, and level measurement in *AWWA M2*, and *AWWA M33.*

Best practice information is contained in *Water Treatment Plant Operation, Volumes 1 and 2*.

4-7 CHEMICALS AND CHEMICAL APPLICATION.

Information about chemicals commonly used in the water works industry are listed in Table 4-1. For additional information on specific chemicals used in given unit processes—including application, storage, handling, and chemical safety—refer to the appropriate unit process heading in this section. The following manuals provide best practice guidance on water plant process control: *AWWA M4, AWWA M12, AWWA M20, AWWA M30, AWWA M37, AWWA M46, AWWA M56* and *AWWA M58*. Maintenance of mechanical equipment is covered in Chapter 10.

4-8 WATER TREATMENT PLANT RESIDUES.

The most common residues from water treatment processes are designated as either “slurries” or “sludges.” Slurry solids are usually spent activated carbon or waste diatomaceous earth from diatomaceous filters. Sludges may be mud-like, natural sediments; gelatinous aluminum, magnesium, or iron oxides and hydroxides; or calcium carbonate (lime sludge). Water treatment processes that produce these sludges are presedimentation of raw water; chemical coagulation, flocculation, and sedimentation; lime-soda ash softening; iron and manganese removal; and filter backwashing.

Other residues are surface water intake screenings; aqueous solutions of sodium, calcium, and magnesium chlorides that result from regeneration of cation exchange water softening resins; and reject stream from membrane processes.

Refer to the applicable paragraphs in this chapter for a discussion of the residue characteristics and appropriate solids concentration and dewatering techniques for the various water treatment processes.

4-8.1 Disposal Methods.

It is preferable to dispose of residues in a way that is both economically and environmentally acceptable. Recovery and disposal systems often require increasing the solids content of a residue by removing water. The required solids concentration (and the method of concentration) depends on the chemical recovery or final disposal alternatives used. Combining filter backwash and chemical clarification sludges is a cost-effective way to equalize the sludge and thicken it prior to disposal. Table 4-2 summarizes water treatment plant residue-handling systems currently in use.

Note: Do not discharge residue to a natural water course or public sewer without the approval of the applicable federal, state, and local authorities.

(1) For discharge to sanitary sewers, avoid cross connections and slug flow and always check possible damage to sewer system from residue discharge; effects of residues on liquid and solids treatment processes at the wastewater treatment plant; and hydraulic capacity of the wastewater treatment facilities.

(2) Sedimentation basins or solids contact reactions ahead of filters will generally remove 70-90% of total plant solids. The remainder of solids will appear in the filter wash water.

(3) Returning filter backwash and thickener overflow streams to plant influent may be viewed with disfavor by regulators because of the possibility of recycling pathogens. See US EPA's *Filter Backwash Recycling Rule* for information on recycle streams.

4-8.2 Recovery Processes.

Alum, ferric chloride, ferrous sulfate, magnesium carbonate, and lime can be recovered from waste sludge by various methods. However, recovery usually is not economical except at the largest municipal facilities and, thus, is not considered viable for military installations. However, manufacturers of alum and ferric coagulants will sometimes agree to accept waste sludges for reprocessing.

4-8.3 Ultimate Disposal.

Traditionally, water treatment plant wastes have been disposed of by discharge to rivers and lakes, either directly or by way of a storm sewer. Current environmental laws do not allow this because such discharge harms the receiving body of water (e.g., cloudy water, toxicity to aquatic life, formation of sludge banks). Following are alternative methods of ultimate sludge disposal, which, in some cases, may be economical and environmentally sound solutions.

4-8.3.1 Discharge to Sanitary Sewer.

In general, water treatment plant residues can be disposed of by discharge to a sanitary sewer without upsetting the wastewater treatment processes. However, problems can result if the amount of sludge is too great.

- The sewer can be overloaded hydraulically by large batch dumps of sludge. This problem can be handled by storing the sludge in a holding tank, then bleeding the sludge slowly into the sewer during periods of low wastewater flow (such as after midnight). However, sewer flow needs to be sufficient to prevent sludge solids from accumulating in the sewer since the solids may then clog the sewer.
- The water treatment sludge solids increase the amount of sludge to be disposed of at the sewage treatment plant. Therefore, the dewatering and disposal problems are not eliminated, but simply shifted elsewhere. Water treatment plant sludge is not affected by sludge digestion processes at the sewage treatment plant but does take up digester volume. In some cases, water plant sludges have been reported to clog digesters.

Table 4-1 Chemicals Used in Water Treatment

Chemical Name and Formula	Common or Trade Name	Shipping Containers	Suitable Handling Materials	Available Forms	Weight, lb/ft^3	Solubility, lb/gal	Commercial Strength	Characteristics	AWWA Standard
Coagulation									
Aluminum sulfate, $Al_2(SO_4)_3 \cdot 14H_20$	Alum, filter alum, sulfate of alumina	100-, 200-lb bags; 300-, 400-lb bbls.; bulk (carloads)	Dry—iron, steel; solution—lead-lined rubber, silicon, asphalt, 316 stainless steel	Ivory-colored: powder granule lump	38–45 60–63 62–67	4.2 (60 °F)	15–22% $A1_20_3$	pH of 1% solution, 3.4	B 403
	Liquid alum	Bulk; tank trucks, tank cars		Pale green liquid			8.3% $A1_20_3$ liquid	Crystallizes at 5 °F	
Ammonium aluminum sulfate, $A1_2(SO_4)_3(NH_4)_2SO_4 \cdot 24H_20$	Ammonia alum, crystal alum	Bags; bbls, bulk	Duriron, lead, rubber, silicon, iron, stoneware	Lump nut pea powdered	64–68 62 65 60	0.3 (32 °F), 8.3 (212 °F)	11% $A1_2O_3$	pH of 1% solution, 3.5	
Bentonite	Colloidal clay, volclay, wilkinite	100-lb bags; bulk	Iron, steel	Powder, pellet, mixed sizes	60	(Insoluble colloidal suspension used)			
Ferric chloride, (a) $FeCl_3$(35-45% solution)	“Ferrichlor,” chloride of iron	5-, 13-gal carboys; trucks; tank cars	Glass, rubber, stoneware, synthetic resins	Dark brown syrupy liquid		Complete	37–47% $FeCl_3$, 20–21% Fe		
(b) $FeC1_3 \cdot 6H_2O$	Crystal ferric chloride	300-lb bbls.		Yellow-brown lump			59–61% $FeCl_3$, 20–21% Fe	Hygroscopic (store lumps and powder in tight containers); no dry feed; optimum pH, 4.0–11.0	
(c) $FeC1_3$	Anhydrous ferric chloride	500-lb casks; 100-300-, 400-lb kegs		Green-black power			98% $FeCl_3$, 34% Fe		
Ferric sulfate $Fe_2(SO_4)_3 \cdot 9H_2O$	“Ferrifloc,” Ferrisul	100-, 175-lb bags; 400-425-lb drums	Ceramics, lead, plastic, rubber, 18-8 stainless steel	Red-brown powder 70 or granule 72		Soluble in 2-4 parts cold water	90-94% $Fe_2(SO_4)_3$, 25–26% Fe	Mildly hygroscopic; coagulant at pH 3.5–11.0	B 406
Ferrous sulfate, $FeSO_4 \cdot 7H_2O$	Copperas, green vitriol	Bags; bbls.; bulk	Asphalt, concrete, lead, tin, wood	Green crystal granule, lump	63–66	0.5 (32 °F), 1.0 (68 °F), 1.4 (86 °F)	55% $FeSO_4$, 20% Fe	Hygroscopic; cakes in storage; optimum pH, 8.5–11.0	B 402

Chemical Name and Formula	Common or Trade Name	Shipping Containers	Suitable Handling Materials	Available Forms	Weight, lb/ft^3	Solubility, lb/gal	Commercial Strength	Characteristics	AWWA Standard
Potassium aluminum sulfate, $K_2SO_4Al_2(SO_4)_3 \cdot 24H_2O$	Potash alum	Bags, lead-lined; bulk (carloads)	Lead, lead-lined, rubber, stoneware	Lump Granule Powder	62–67 60–65 60	3.0 (68 °F), 3.3 (86 °F)	10–11% Al_2O_3	Low, even solubility; pH of 1% solution, 3.5	
Sodium aluminate, $Na_2OAl_2O_3$	Soda alum	100-, 150-lb bags; 250-, 440-lb drums; solution	Iron, plastics, rubber, steel	Brown powder, liquid (27 °Bé)	50–60	Complete	70–80% $Na_2Al_2O_4$, min. 32% $NA_2A1_2O_4$	Hopper agitation required for dry feed	B 405
Sodium silicate, Na_2OSiO_2	Water glass	Drums; bulk (tank trucks, tank cars)	Cast iron, rubber, steel	Opaque, viscous liquid			38–42 Bé	Variable ratio of Na_2O to SiO_2; pH of 1% solution, 12.3	B 404
Disinfection and Dechlorinating Agents									
Ammonium aluminum sulfate, $Al_2(SO_4)_3(NH_4)_2SO_4 \cdot 24H_2O$	Ammonia alum, crystal alum	Bags; bbls.; bulk	Duriron, lead, rubber, silicon, iron, stoneware	Lump Nut Pea Powdered	64–68 62 65 60	0.3 (32 °F), 8.3 (212°F)	11% Al_2O_3	pH of 1% solution, 3.5	
Ammonium sulfate, $(NH_4)_2SO_4$	Sulfate of ammonia	100-lb bags	Ceramics, plastics, rubber, iron (dry)	White or brown crystal		42.5	6.3 (68 °F)	Cakes in dry feed; add $CaSO_4$ for free flow	B 302
Anhydrous ammonia, NH_3	Ammonia	50-, 100-, 150-lb cylinders; in bulk (tank cars and trucks)	Glass, iron, monel metal, nickel, steel	Colorless gas		3.9 (32 °F) 3.1 (60 °F) 1.8 (125 °F)	99–100% NH_3		
Aqua ammonia, NH_4OH	Ammonia water, ammonium hydrate, ammonium hydroxide	Carboys; 750- lb drums; 8,000-gal tank cars or trucks	Glass, iron, monel metal, nickel, steel	Colorless liquid		Complete	29.4% NH_2 (26 °Bé)		
Calcium hypochlorite, $CaOCl_2 \cdot 4H_2O$	"HTH," Perchloron, "Pittchlor"	5-lb cans; 100- , 300-, 800-lb drums	Glass, rubber, stoneware, wood	White granule, powder	52.5		70% available Cl_2	1–3% available $C1_2$, solution used	B 300
Chlorinated lime, $CaO\ 2CaOC1_2 \cdot 3H_2O$	Bleaching power, chloride of lime	100-, 300-, 800-lb drums	Glass, rubber, stoneware, wood	White powder	48		25–37% available Cl_2	Deteriorates	

Chemical Name and Formula	Common or Trade Name	Shipping Containers	Suitable Handling Materials	Available Forms	Weight, lb/ft^3	Solubility, lb/gal	Commercial Strength	Characteristics	AWWA Standard
Chlorine, Cl_2	Chlorine gas, liquid chlorine	100-, 150-lb cylinders; 1-ton containers; 16- , 30-, 55-, 85-, and 90-ton tank cars; tank trucks (about 15-16 tons)	Dry-black iron, copper, steel; wet gas-glass, hard rubber, silver	Liquefied gas under pressure	91.7	0.07 (60 °F), 0.04 (100 °F)	99.8% Cl_2		B 301
Chlorine dioxide, ClO_2	Chlorine dioxide	Generated as used	Plastics, soft rubber (avoid hard rubber)	Yellow-red gas		0.02 (30 mm)	26.3% available Cl_2		
Ozone, O_3	Ozone	Generated at site of application	Aluminum, ceramics, iron, steel, wood	Colorless gas					
Pyrosodium sulfite $Na_2O_5S_2$	Sodium meta-bisulfite	Bags; drums; bbls.	Iron, steel, wood	White crystal-line powder		Complete in water	Dry, 67% SO_2; sol. 33.3% SO_2	Sulfurous odor	
Sodium chlorite, $NaClO_2$	Technical sodium chlorite	100-lb drums	Metals (avoid cellulose materials)	Light orange powder, flake			82% $NaClO_2$, 30% available Cl_2	Generates ClO_2 at pH 3.0	B 303
Sodium hypochlorite, NaOCl	Sodium hypo-chlorite	5-, 13-gal carboy; 1,300-2,000-gal tank trucks	Ceramics, glass, plastics, rubber	Light yellow liquid			12–15% available Cl_2		B 300
Sodium sulfite, Na_2SO_3	Sulfite	Bags; drums; bbls.	Iron, steel, wood	White crystal-line powder		Complete in water	23% SO_3	Sulfurous taste and odor	
Sulfur dioxide, SO_2	Sulfurous acid anhydride	Steel cylinders; ton containers; tank cars or trucks	Aluminum, brass, Durco D- 10, stainless steel 316	Colorless gas		20% at 32 °F, complete in water	99% SO_2	Irritating gas	
Fluoridation and Fluoride Adjustment									
Ammonium silico fluoride, $(NH_4)_2\ SiF_6$	Ammonium fluor-silicate	100- and 400-lb drums	Steel, iron, lead	White crystals		1.7 (63 °F)	100%	White, free-flowing solid	
Calcium fluoride, CaF_2	Fluorspar	Bags; drums; bbls.; hopper cars; trucks	Steel, iron, lead	Powder		Very slight	85% CaF_2, less than 5% SiO_2		

Chemical Name and Formula	Common or Trade Name	Shipping Containers	Suitable Handling Materials	Available Forms	Weight, lb/ft^3	Solubility, lb/gal	Commercial Strength	Characteristics	AWWA Standard
Hydro-fluosilicic acid, H_2SiF_6	Fluo-silicic acid	Rubber-lined drums; trucks; or R.R. tank cars	Rubber-lined steel, PVC	Liquid		Approx. 1.2 (68 °F)	Approx. 35%		B 703
Hydrogen fluoride, HF	Hydro-fluoric acid	Steel drums; tank cars	Steel	Liquid			70%	Below 60%, steel cannot be used	
Sodium fluoride NaF_6	Fluoride	Bags; bbls.; fiber; drums; kegs	Iron, lead, steel	Nile blue or white powder; light dense	50 75	0.35 (most temps.)	90–95% NaF	pH of 4% solution, 6.6	B 701
Sodium silicofluoride, Na_2SiF_6	Sodium silico-fluoride	Bags; bbls.; fiber; drums	Iron, lead, steel	Nile blue or yellowish-white powder	75	0.03 (2 °F), 0.06 (72 °F), 0.12 (140 °F)	99% Na_2SiF_6	pH of 1% solution, 5.3	B 702
Fluoride Adjustment									
Aluminum oxide, Al_2O_3	Activated alumina	Bags; drums	Iron, lead, steel	Powder, granules (up to 1-1/2-in. diam)	Variable	Insoluble	100%		
Bone charcoal C	“Fluo-Carb”	Bags; drums; bulk	Wood, iron, steel	Granules	Variable			Black; best used in beds for presolution	
Tricalcium phosphate $Ca_3O_8P_2$	“Fluorex”	Bags; drums; bulk; bbls.	Iron, steel	Granular technical	50–63	Insoluble		Also available as white powder	
High-magnesium lime $CaMgO_2$	Dolomitic lime	Bags; bbls; bulk	Wood, iron, steel	Lump, pebble, ground		Slakes slowly	58% CaO_2 40% MgO_2		
Stabilization and Corrosion Control									
Carbon dioxide, CO_2	Carbon dioxide gas, liquid carbon dioxide	20-, 50-lb cylinders. Bulk; tank trucks, tank cars			47.4 @ 70 °F				
Disodium phosphate, $Na_2HPO_4 \cdot 12H_2O$	Basic sodium phosphate, DSP, secondary sodium phosphate	125-lb kegs; 200-lb bags; 325-lb bbls.	Cast iron, steel	Crystal	60–64	0.4 (32 °F), 6.4 (86 °F)	19.5% P_2O_5	Precipitates Ca, Mg; pH of 1% solution, 9.1	

Chemical Name and Formula	Common or Trade Name	Shipping Containers	Suitable Handling Materials	Available Forms	Weight, lb/ft^3	Solubility, lb/gal	Commercial Strength	Characteristics	AWWA Standard
Sodium hexameta-phosphate, $(NaPO_3)_6$	"Calgon," glassy phosphate, vitreous phosphate	100-lb bags	Hard rubber, plastics, stainless steel	Crystal, flake, powder	47	1–4.2	66% P_2O_5 (unadjusted)	pH of 0.25% solution, 6.0–8.3	
Sodium hydroxide, NaOH	Caustic soda, soda lye	100-700-lb drums; bulk (trucks, tank cars)	Cast iron, rubber, steel	Flake Lump Liquid		2.4 (32 °F) 4.4 (68 °F), 4.8 (104 °F)	98.9% NaOH, 74–76% NaO_2	Solid; hygroscopic; pH of 1% solution, 12.9	
Sulfuric acid, H_2SO_4	Oil of vitriol, vitriol	Bottles; carboys; drums; trucks, tank cars	Concentrated—iron, steel; dilute— glass, lead, porcelain, rubber	Solution (60-66 °Bé)		Complete	77.7% H_2SO_4 (60 ° Bé); 93.2% H_2SO_4 (66 °Bé)	Approx. pH of 0.5% solution, 1.2	
Tetrasodium pyrophosphate, $Na_4P_2O_7$•$1OH_2O$	Alkaline sodium pyrophos-phate, TSPP	125-lb kegs; 200-lb bags; 300-lb bbls.	Cast iron, steel	White powder	68	0.6 (80 °F), 3.3 (212 °F)	53% P_2O_5	pH of 1% solution, 10.8	
Trisodium phosphate, Na_3PO_4•$12H_2O$	Normal sodium phosphate, tertiary sodium phosphate, TSP	125-lb kegs; 200-lb bags; 325-lb bbls.	Cast iron, steel	Crystal: coarse medium standard	56 58 61	0.1 (32 °F), 13.0 (158 °F)	19% P_2O_5	pH of 1% solution, 11.9	
Softening									
Calcium hydroxide, $Ca(OH)_2$	Hydrated lime, slaked lime	0-lb bags; 100- lb bbls.; bulk (carloads) trucks	Asphalt, cement, iron, rubber, steel	White powder: light dense		0.014 (68 °F) 0.012 (90 °F)	85–99% $Ca(OH)_2$ 63–73% CaO	Hopper agitation required for dry feed of light form	B 202
Calcium oxide, CaO	Burnt lime, chemical lime, quick-lime, unslaked lime	50-lb bags; 100-lb bbls; bulk (carloads	Asphalt, cement, iron, rubber, steel	Lump, pebble, granule		Slakes to form hydrated lime	75–99% CaO	pH of saturated solution, 12.4; detention time, temperature, amount of water all critical for effluent slaking	B 202

Chemical Name and Formula	Common or Trade Name	Shipping Containers	Suitable Handling Materials	Available Forms	Weight, lb/ft^3	Solubility, lb/gal	Commercial Strength	Characteristics	AWWA Standard
Sodium carbonate, Na_2CO_3	Soda ash	Bags; bbls.; bulk (carloads, trucks)	Iron, rubber, steel	White powder: extra-light light dense	23 35 65	1.5 (68 °F), 2.3 (86 °F)	99.4% Na_2CO_3, 58% Na_2O	Hopper agitation required for dry feed of light and extra-light forms; pH of 1% solution, 11.3	B 201
Sodium chloride, NaC1	Common salt, salt	Bags; bbls.; bulk (carloads)	Bronze, cement, rubber	Rock fine		2.9 (32 °F), 3.0 (68 °F), 86 °F	98% NaC1		B 200
Taste and Odor Control									
Activated carbon, C	"Aqua Nuchar," "Hydro-darco," "Norite"	Bags; bulk	Dry—iron, steel; wet—rubber, silicon, iron, stainless steel	Black granules power	15	Insoluble (suspension used)			B 600 & B 604
Chlorine, $C1_2$	Chlorine gas, liquid chlorine	100-150-lb cylinders; 1-ton tanks; 16- 30-55-ton tank cars	Dry—black iron, copper, steel; wet gas—glass, hard rubber, silver	Liquefied gas under pressure	91.7	0.07 (60 °F), 0.04 (100 °F)	99.8% $C1_2$		B 301
Chlorine dioxide, ClO_2	Chlorine dioxide	Generated as used	Plastics, soft rubber (avoid hard rubber)	Yellow-red gas		0.02 (30 mm)	26.3% available $C1_2$		
Copper sulfate, $CuSO_4$•$5H_2O$	Blue vitriol, blue stone	100-lb bags; 450-lb bbls.; drums	Asphalt, silicon, iron, stainless steel	Crystal Lump Power	75–90 73–80 60–64	1.6 (32 °F), 2.2 (68 °F), 2.6 (86 °F)	99% $CuSO_4$		B 602
Ozone O_3	Ozone	Generated at site of application	Aluminum, ceramics, glass	Colorless gas					
Potassium permanganate, $KMnO_4$	Purple salt	Bulk; bbls.; drums	Iron, steel, wood	Purple crystals		0.23 (32 °F) 0.54 (68 °F) 1.05 (104 °F)	100%	Danger of explosion on contact with organic matters	B 603

Table 4-2 Water Treatment Plant Residue Disposal Summary

Type of Waste	Quantities and Characteristics	Treatment Required	Disposal Possibilities
Screenings	Vary widely; evaluate particular water source; check other plants using same water source or other similar plants.	None	Return to watercourse if quantities are small.
			Truck to landfill along with other plant solid waste.
			Investigate disposal with wastewater treatment plant screenings.
Presedimentation Sludges	Vary widely; evaluate particular water source; check other plants using same water source or other similar plants.	Dewatering in lagoon, sand drying bed, or mechanical unit may be required.	Dredging or draglining and hauling to landfill; multiple, drainage basins make cleaning easier.
Chemical clarification sludges	Composed of raw water impurities and coagulation chemicals. Solids content - 0.1 to 2%; 75 to 90% of total is suspended; 20 to 40% of total is volatile. Dry unit weight 75 to 95 lbs/ft^3. Gelatinous.	Gravity thickening is often desirable, recycling supernatant to plant influent. (3)	Send concentrated sludge or continuously withdrawn sludge to wastewater treatment plant. (1)
		Sludge concentrations of 0.5 to 1.0% can be obtained.	Haul dried sludge, a minimum of 15% solids, off-site in accordance with state requirements and permit to a municipal landfill.
		In addition to gravity thickening, dewatering processes may also be used: Drying beds. Freeze/thaw treatment processes are effective for alum sludge dewatering but expensive except in climates where sludges can be	

Type of Waste	Quantities and Characteristics	Treatment Required	Disposal Possibilities
		placed in a lagoon and frozen naturally. Centrifuges and vacuum filters dewater sludges up to about 15% solids. Pre-coat vacuum filters dewater sludge up to 25% solids. Pressure filtration dewaters sludge to 25 to 40% solids, often requiring lime as conditioner.	
Filter wash water (2)	Normal wash generates about 150 gallons per square foot filter area. Chemically-precipitated raw water impurities and coagulation chemicals. For alum plants, total solids vary, with an average of 400 mg/L and a maximum of 1,000 mg/L. Plants removing iron and manganese may produce 4 times higher total solids.	Flow equalization and concentration through sedimentation and decanting.	Same as for coagulation sludges. Combine with coagulation sludge where applicable. Where no coagulation used, dispose as softening sludge. Gradually return entire flow to plant influent. (3)
Lime softening sludges	Assume 3 lb dry sludge solids per lb quicklime added.	Dewatering lime softening sludges is not particularly difficult. The following methods can be used following thickening:	Discharge to wastewater treatment plants (1)

Type of Waste	Quantities and Characteristics	Treatment Required	Disposal Possibilities
	Clarifier underflow	Lagooning (up to 50% solids). Vacuum filtration (40 to 50% solids). Centrifuging (50 to 60% solids). Return to water plant influent.	Dewatered sludge hauled to landfill (agricultural applications possible).
	Solids concentration generally is approximately 5% but may range from 2 to 30%. Non-gelatinous. Typically, 85 to 95% calcium carbonate, with some magnesium hydroxide.		Recalcining generally limited to large plants (>20 million gallons per day [mgd]) by economic considerations.
Diatomaceous earth sludges	See filter manufacturer's literature for quantities. Solids normally 60 to 70% diatomaceous earth; remainder raw water impurities; dry density about 10 lb/ft^3; specific gravity 2.	Lagooning, with supernatant recycled to plant influent.	Haul solids from lagoon to landfill.
Carbon slurries	Quantities and characteristics variable.	Granular carbon can be regenerated and recycled. Powdered carbon cannot be regenerated; dispose of powdered carbon following dewatering.	Haul solids to landfill. Incinerate dewatered solids (high heating value).
Cation exchange resin regeneration brines	See manufacturer's literature for quantities. Total dissolved solids up to 45,000 mg/L. Chlorides up to 112,000+mg/L. Almost no suspended solids.	Evaporation lagoons where concentration is desired and climate permits	Best solution is ocean disposal. Return to watercourse only if brine can be greatly diluted. Discharge to wastewater treatment plant only if greatly diluted. Disposal wells possible but suitability is site-specific.

4-8.3.2 Landfill.

Modern sanitary landfills are designed and operated to keep the amount of water leaching from the filled material to a minimum. For this reason, landfill regulations often require that sludges contain at least 20% dry solids and sometimes require as high as 50 to 60%. Wet sludges are not acceptable because they are difficult to mix well with other solid wastes before covering and because the large amount of water could percolate through the soil and pollute water supplies.

4-8.3.3 Lagoons.

Disposal lagoons are simply dewatering lagoons that are never cleaned out, thus, eliminating the main operating problem of drying lagoons. The main disadvantage is that large land areas are permanently committed for use as lagoons. For plants with small sludge quantities and plentiful land, lagoons can be practical for sludge disposal.

4-8.3.4 Land Spreading of Lime Sludge.

In many agricultural areas, particularly in the Midwest, farming practices require that lime or limestone be added to the fields periodically to control soil pH. Sludge from lime water softening processes can be used for this purpose if it is sufficiently dewatered to allow easy handling.

4-8.4 Laboratory Control Tests.

The main control tests involved in sludge handling and disposal are the solids tests (total solids and suspended solids) used to determine the effectiveness of dewatering processes. Some recycling processes require testing for hazardous materials. Ocean disposal may require bioassay testing to determine the effect on the aquatic environment.

4-8.5 Maintaining Records.

The dewatering and ultimate disposal of water plant sludges and other residues are expensive. To manage water treatment plant residues adequately, maintain records on residue quantities and characteristics, chemical quantities used for residue treatment processes, results of laboratory control tests, and operating notes.

4-9 DESALINATION.

Some geographic locations, including coastal areas, islands, and some inland regions, have little or no fresh water even though unlimited supplies of saline water are available.

When it is necessary to establish and maintain military installations in such areas, the water supply generally is derived by converting saline water into fresh water. Several methods are available, but they are expensive and complicated to use. These methods include distillation, ion exchange, electrodialysis, and reverse osmosis. Other methods (such as freezing, hydrate formations, solvent extractions, and solar evaporation) are not considered practical desalination methods.

For more information on desalination, see *USAID Desalination Manual*.

4-10 WATER SAMPLING AND ANALYSIS.

Sampling and analysis for plant quality control differs from testing conducted to monitor compliance with the SDWA. Process tests are generally conducted by treatment plant personnel, are used to enhance and control plant performance, and are not required by law. Applicable process control tests for each unit process are something that the actual Facilities O&M manual should discuss and provide to ensure the water treatment plan runs smoothly. Operators should refer to the O&M manual so that effective and efficient operations are maintained.

Process controls should include sampling for specific process parameters at various points in the treatment process. The various analysis is used to determine if the treatment is effective and optimized before there is a failure in the process that can lead to a regulatory violation. Sampling examples include parameters such as:

- pH of raw water and after addition of pretreatment chemicals
- pH of process water at midpoint in treatment to ensure adequate chemical dosing
- Turbidity readings prior to filtration to determine how effective pretreatment is

Complete sampling in accordance with *Standard Methods for the Examination of Water and Wastewater* per *AWWA G100.* Compliance monitoring is covered in Chapter 2 paragraph titled Regulations Affecting Water Systems. Required information on sampling and analysis can be found in *APHA/AWWA/ WEF Standard Methods for the Examination of Water and Wastewater*. Best practice info can be found in *Water Treatment Plant Operation, Volumes 1 and 2.*

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CHAPTER 5 PUMPS AND DRIVERS

5-1 CHAPTER OVERVIEW.

This chapter covers the operation of pumps used in water supply facilities. It also covers the motors, engines, and accessories (together called pump drivers) that provide the mechanical source of energy to pumps.

5-2 PUMPS.

Velocity pumps and positive-displacement pumps are the two categories of pumps commonly used in water supply operations. Velocity pumps, which include centrifugal and vertical turbine pumps, are used for most distribution system applications. Positive-displacement pumps, which include rotary and reciprocating pumps, most commonly are used in water treatment plants for chemical metering and pumping sludge. Additional technical descriptions of the pump types commonly used in water supply systems, along with applications, operating characteristics, and a listing of general advantages and disadvantages, can be found in best practice *Water Treatment Plant Operation, Volumes 1 and 2*.

Specific information on vertical turbine pumps is contained in *AWWA E103*. Table 5-1 lists maximum capacity and discharge head values for several general pump types.

Table 5-1 Comparison of Pump Discharge and Head

Pump Type	Maximum Capacity		Maximum Discharge Head	
	gpm	(Lps)	feet of water	(kg/sq cm)
Air lift	3,000	(190)	700	(21)
Centrifugal				
Axial Flow (propeller)	200,000+	(12,600)	50	(2)
Diffuser	700	(45)	1,000	(30)
Mixed Flow	250,000+	(15,800)	100	(3)
Regenerative Turbine	100	(6)	600	(18)
Vertical Turbine	30,000	(1,890)	>1,500	(45)
Volute	40,000	(2,500)	500	(15)
Ejector (jet)	50	(3)	150	(5)

Pump Type	Maximum Capacity		Maximum Discharge Head	
	gpm	(Lps)	feet of water	(kg/sq cm)
Progressive Cavity (helical rotor)	1,200	(75)	2,300	(70)
Reciprocating Displacement Diaphragm	300	(20)	800	(25)
Piston	300	(20)	800	(25)
Plunger	300	(20)	800	(2)
Rotary Displacement	55	(3)	1,000	(30)

5-3 OPERATION OF PUMPS.

Operate all mechanical equipment, including pumps, in accordance with the manufacturer's instructions. General O&M information, including starting and stopping procedures, flow control, and performance monitoring. Some best practice information on this, can be found in *Water Treatment Plant Operation, Volumes 1 and 2*.

Pumps are occasionally installed to increase the pressure in a pipeline or in a specific zone of a distribution system to help meet peak demands such as fire flow and to supply water to elevated storage tanks. Pump stations are particularly suited for a distribution system located in hilly country where there are two or more pressure zones, or on the periphery of an overextended or overloaded distribution system. Pumping stations are usually automatically and remotely controlled from the main pumping station and are normally equipped with electrically driven centrifugal pumps.

For operator training assistance with calculating pumping rates, pump heads, horsepower and efficiency, and reading pump curves, see best practice *Water Treatment Plant Operation, Volumes 1 and 2*.

5-3.1 General Operating Instructions for Centrifugal Pumps.

A quick reference checklist for starting and stopping centrifugal pumps is provided in Table 5-2. Procedures may vary for different pump types and pump applications. Know what to expect when the equipment starts.

Table 5-2 Routine Operation-s Checklist for Centrifugal Pumps

Inspection	Action
Prestart Checks	
Valves	Open the valve in the cooling liquid supply to the bearing if the bearings are liquid cooled.
	Open the valve in the flushing water supply to the stuffing boxes if so equipped.
	Open the valve in the sealing liquid supply to the stuffing boxes or mechanical seals if so equipped.
	Open or close the discharge valves according to the manufacturer's manual.
Rotors	Check the rotor to see that it is free. If equipment is isolated correctly following proper lockout/tagout procedures, you should be able to turn the rotor shaft by hand. Do not start the pump until any difficulty is corrected.
	Prime centrifugal pumps before startup. The equipment will not pump water unless air in the pump and suction piping is replaced with water. In addition, the rotating element may seize from a lack of lubrication.
	Use one of the following methods to prime the pump, depending on operating conditions: positive suction head (1) or negative suction head (2).
Starting the Pump	Always start the pump according to the manufacturer's manual.
Equipment Area	Ensure that all personnel are clear of dangerous areas.
Valves	For pumps started with discharge valves closed, open valves slowly after pump approaches operating speed. Do not operate the pump with a closed discharge valve.

Inspection	Action
Stuffing Boxes and Packing	Observe leakage from the stuffing boxes and adjust the sealing liquid valve for proper flow to ensure packing lubrication. For new packing, allow pump to run for 10 to 15 minutes before tightening the stuffing box gland. Gradually tighten the stuffing box gland until leakage slows to a constant drip.
Pump and Driver	Check the general mechanical operation of the pump and driver. Ensure that working parts are free to move without damage.
Stopping the Pump	Always review instructions for disconnecting and securing drive and rotating equipment.
Valves	As a rule, there is a check valve in the discharge line close to the pump. In such cases, shut down the pump by stopping the driver according to the manufacturer's manual.
	Then close all valves, except the check valve, in this order: discharge, suction, pump cooling water supply, and other connections leading to the pump or system.
	In some instances, however, the use of a check valve is not feasible because the sudden closing of the valve under high discharge pressure might create pressure surges or water hammer. In such cases, close the discharge valve slowly to avoid water hammer.
Monitoring Operations Unusual Sounds	 Learn to recognize the normal sounds and conditions of a properly run pump. Listen to the sounds of the pump on regular inspection tours and investigate any abnormal sounds at once.
Bearings	Check bearing temperature and lubrication. Where petroleum-based lubricants are used, follow the manufacturer's manual and do not over lubricate.
Suction and Discharge Readings	Check these readings and compare with "normal" valves. Make sure valves are set as required. Check shaft packing. Check discharge rate. Check driving equipment.

(1) Positive Suction Head. When the intake (suction) side of the pump is under pressure, use the following priming sequence:

a. Open all suction valves to allow water to enter the suction pipe and pump casing.

b. Open all vents located on the highest point of the pump casing to allow trapped air to be released.

Note: The pump is properly primed when water flows from all open vents in a steady stream.

(2) Negative Suction Head. Two priming methods are available for a negative suction head condition—that is, when the pump lifts water to the intake (suction lift).

a. Vacuum Pump or Ejection Method. When steam, high-pressure water, or compressed air is available, prime the pump by attaching an ejector to the highest point in the pump casing for evacuating the air from the suction piping and casing. A vacuum may be substituted for the above equipment. Start the ejector or vacuum pump to exhaust the air from the pump casing and suction pipe. When water discharges from the ejector or vacuum pump, start the centrifugal pump, but continue priming until the centrifugal pump has reached operating speed.

b. Priming a Pump with a Foot Valve. A foot valve is used at the lowest point on the suction pipe. The foot valve retains water in the suction pipe and pump casing after the pump has been initially primed. To prime, open the suction valve, if one is installed. Open vent valves at the highest points on the pump casing. Fill the pump and suction line from an independent water supply. Allow to fill until a steady stream flows from the vent valves.

5-3.2 Troubleshooting Centrifugal Pumps.

Symptoms and possible causes of operating difficulties are listed in Table 5-3. For more troubleshooting help, see the specific pump vendor O&M manual. The *Water Treatment Plant Operation, Volumes 1 and 2 provides some general best practice information*.

See also Table 5-10, a troubleshooting checklist for vertical turbine well pumps, which are a class of centrifugal pump.

5-3.2.1 Cavitation Problems.

Cavitation is one of the most serious operational problems with centrifugal pumps. Cavitation occurs when cavities or bubbles of vapor form in the liquid. The bubbles collapse against the impeller, making a sound as though there were rocks in the pump. If left uncorrected, cavitation will seriously damage the pump.

Table 5-3 Troubleshooting Checklist for Centrifugal Pumps

Symptom	Possible Cause
Pump does not deliver water.	Pump not primed.
	Pump or suction pipe not completely filled with water.
	Suction lift too high.
	Air pocket in suction line.
	Inlet of suction pipe insufficiently submerged. Suction valve not open or partially open.
	Discharge valve not open. Speed too low.
	Wrong direction of rotation.
	Total head of system higher than design head of pump.
	Parallel operation of pumps unsuitable for existing conditions.
	Foreign matter in impeller.
Insufficient capacity delivered.	Pump or suction pipe not completely filled with water.
	Suction lift too high.
	Excessive amount of air or gas in water. Air pocket in suction line.
	Air leaks into suction line.
	Air leaks into pump through stuffing boxes. Foot valve too small.
	Foot valve partially clogged.
	Inlet of suction pipe insufficiently submerged.
	Suction valve only partially open. Discharge valve only partially open. Speed too low.

Symptom	Possible Cause
	Total head of system higher than design head of pump.
	Parallel operation of pumps unsuitable for such operation.
	Foreign matter in impeller. Wearing rings worn.
	Impeller damaged.
	Casing gasket defective, permitting internal leakage.
Insufficient pressure developed.	Excessive amount of air or gas in water. Speed too low.
	Wrong direction of rotation.
	Total head of system higher than design head of pump.
	Parallel operation of pumps unsuitable for existing conditions.
	Wearing rings worn. Impeller damaged.
	Casing gasket defective, permitting internal leakage.
Pump loses prime after starting.	Pump or suction pipe not completely filled with water.
	Suction lift too high.
	Excessive amount of air or gas in water. Air pocket in suction line.
	Air leaks into suction line.
	Air leaks into pump through stuffing boxes. Inlet of suction pipe insufficiently submerged. Water-seal pipe plugged.
	Seal cage improperly located in stuffing box, preventing sealing fluid from entering space to form the seal.

Symptom	Possible Cause
	Speed too high
Pump requires excessive power.	Wrong direction of rotation.
	Total head of system higher than design head of pump.
	Total head of system lower than pump design head.
	Foreign matter in impeller existing conditions.
	Misalignment.
	Shaft bent.
	Rotating part rubbing on stationary part. Wearing rings worn.
	Packing improperly installed.
	Incorrect type of packing for operating conditions.
	Gland too tight resulting in no flow of liquid to lubricate packing.
Stuffing box leaks excessively.	Seal cage improperly located in stuffing box, preventing sealing fluid entering space to form the seal.
	Misalignment. Shaft bent.
	Shaft or shaft sleeves worn or scored at the packing. Packing improperly installed.
	Incorrect type of packing for operating conditions.
	Shaft running off center because of worn bearings or misalignment.
	Rotor out of balance, resulting in vibration.

Symptom	Possible Cause
	Gland too tight, resulting in no flow of liquid to lubricate packing.
	Excessive clearance at bottom of stuffing box between shaft and casing, causing packing to be forced into pump interior.
	Dirt or grit in sealing liquid, leading to scoring of shaft or shaft sleeve.
Packing has short life.	Water-seal pipe plugged.
	Seal cage improperly located in stuffing box, preventing sealing fluid from entering space to form the seal.
	Misalignment. Shaft bent.
	Bearings worn.
	Shaft or shaft sleeves worn or scored at the packing.
	Packing improperly installed.
	Incorrect type of packing for operating conditions.
	Shaft running off center because of worn bearings or misalignment.
	Rotor out of balance, resulting in vibration.
	Gland too tight, resulting in no flow of liquid to lubricate packing.
	Failure to provide cooling liquid to water-cooled stuffing boxes.
	Excessive clearance at bottom of stuffing box between shaft and casing, causing packing to be forced into pump interior.

Symptom	Possible Cause
	Dirt or grit in sealing liquid, leading to scoring of shaft or shaft sleeve.
	Foundations not rigid. Shaft bent.
	Rotating part rubbing on stationary part. Bearings worn.
	Impeller damaged.
	Shaft running off center because of worn bearings or misalignment.
	Rotor out of balance, resulting in vibration.
	Dirt or grit in sealing liquid, leading to scoring of shaft or shaft sleeve.
	Excessive grease or oil in antifriction-bearing housing, or lack of cooling, causing excessive bearing temperature.
	Lack of lubrication.
	Improper installation of antifriction bearings (damage during assembly, incorrect assembly of stacked bearings, use of unmatched bearings as a pair, etc.).
	Dirt getting into bearings.
	Rusting of bearings because of water getting into housing.
	Excessive cooling of water-cooled bearing resulting in condensation in the bearing housing of moisture from the atmosphere.
Pump vibrates or is noisy.	Pump or suction pipe not completely filled with water.
	Suction lift too high. Foot valve too small.
	Foot valve partially clogged.

Symptom	Possible Cause
	Inlet of suction pipe insufficiently submerged.
	Operation at very low capacity.
	Foreign matter in impeller. Misalignment.
Bearings have short life.	Misalignment. Shaft bent.
	Rotating part rubbing on stationary part. Bearings worn.
	Shaft running off center because of worn bearings or misalignment.
	Rotor out of balance, resulting in vibration.
	Excessive thrust caused by a mechanical failure inside the pump or by the failure of the hydraulic balancing device, if any.
	Excessive grease or oil in antifriction-bearing housing or lack of cooling, causing excessive bearing temperature.
	Lack of lubrication.
	Improper installation of antifriction bearings (damage during assembly, incorrect assembly of stacked bearings, use of unmatched bearings as a pair, etc.).
	Dirt getting into bearings.
	Rusting of bearings because of water getting into housing.
	Excessive cooling of water-cooled bearing, resulting in condensation in the bearing housing of moisture from the temperature.
Pump overheats and seizes.	Pump not primed.
	Operation at very low capacity.

Symptom	Possible Cause
	Parallel operation of pumps unsuitable for existing conditions.
	Misalignment.
	Rotating part rubbing on stationary part. Bearings worn.
	Shaft running off center because of worn bearings or misalignment.
	Rotor out of balance, resulting in vibration.
	Excessive thrust caused by a mechanical failure inside the pump or by the failure of the hydraulic balancing device, if any.
	Lack of lubrication.

5-3.2.2 Causes of Cavitation.

Conditions that typically cause cavitation include operating the pump with too great a suction lift or an insufficiently submerged suction inlet. Cavitation develops when normal pump operating conditions have been exceeded. Noise, vibration, impeller erosion, and reduction in total head and efficiency result from cavitation. Cavitation in a centrifugal pump may be caused by any of the following:

- The impeller vane is traveling at higher revolutions per minutes than the liquid.
- Suction is restricted.
- Note: Do not throttle the suction of a centrifugal pump.
- The required net positive suction head (NPSH) is equal to or greater than the available NPSH.
- The specific pump speed is too high for the operating conditions.
- The liquid temperature is too high for the suction conditions

5-3.2.3 Water Hammer.

- Water hammer may occur when flowing water within a water system is abruptly stopped or a change in direction occurs, creating a pressure surge. The following are tips to reduce water hammer. Reduce sharp turns and elbows to reduce mechanical stresses.

- Calculate the amplitudes of water hammer on long lines. Provide the appropriate devices to dampen or eliminate any water hammer effects such as valves, valve controllers, or surge tanks.
- Utilize computer programs for water hammer analysis for large pumps stations.
- Install variable speed pumps for ground storage tanks to help eliminate the potential for water hammer.

5-3.3 Operating Instructions for Ejector (Jet) Pumps.

Jet pumps are a type of centrifugal pump. Because of their relatively low efficiency, they are rarely used for public water systems. However, jet pumps are inexpensive, require little maintenance, and may be used on wells supplying small, low-demand systems. The operating principle of these pumps is described in the specific pump vendor O&M manual. The *Water Treatment Plant Operation, Volumes 1 and 2* provides general operator information.

Note: All operating rules and troubleshooting checks that apply to centrifugal pumps apply to ejector pumps.

Start the pump and adjust the manual back pressure valve until the correct operating cycle is achieved. Do not change the adjustment after the pump is operating. If pump discharge decreases, check troubleshooting guides for centrifugal pumps. Also inspect the ejector nozzle and throat for deposits and check nozzle submergence.

5-3.4 Operating Instructions for Progressive Cavity Pumps.

Progressive or helical-rotor pumps are positive displacement pumps and not subject to the same problems as centrifugal pumps. Operate according to the manufacturer’s instructions.

Caution: Do not run dry.

Common operating problems encountered with progressive cavity pumps and possible causes are given in Table 5-4.

5-3.4.1 Operating Instructions for Rotary and Reciprocating Displacement Pumps.

A general description of positive displacement pumps is provided in the specific pump vendor O&M manual. The *Water Treatment Plant Operation, Volumes 1 and 2* provides general operator information.

5-3.4.2 Prestart.

Rotary- and reciprocating-displacement pumps do not usually require priming. However, when priming is necessary, follow priming procedures for centrifugal pumps.

Table 5-4 Troubleshooting Checklist for Progressive-Cavity Pumps

Symptom	Possible Cause
No water is delivered.	Broken or disconnected shaft.
	Excessive discharge head.
	Plugged or non-submerged suction.
Pump does not deliver rated capacity.	Speed too low.
	Suction lift excessive.
	Suction partially plugged.
	Mechanical defect.
Pressure is too low.	Discharge head too high.
	Speed too low.
	Pressure relief valve set too low.
	Mechanical defect.
Pump stops after starting to operate.	Bent column shaft.
	Clogged suction.

5-3.4.3 Starting and Operating.

Always start and operate rotary- and reciprocating-displacement pumps with both suction and discharge valves open to prevent motor overload and pump damage.

5-3.4.4 Operating Precautions.

- Rotary- and reciprocating-displacement pumps depend on clearances for efficiency. Keep grit or other abrasive material out of the liquid being pumped to prevent excessive wear and rapid loss of efficiency and self-priming ability.

- A pressure-relief valve that discharges back to the suction side of the pump is usually provided on the outlet piping. Adjust this valve for a relief pressure that does not overload the motor. Make sure the check valves seat properly at normal pressures. Otherwise, loss of efficiency and priming ability result.
- Use the manufacturer's manuals to develop a checklist for the rotary- or reciprocating-displacement pump being used.

5-4 PUMP MAINTENANCE.

Information contained in the following paragraphs is general and not intended to replace maintenance procedures provided by the equipment manufacturer and the specific pump vendor O&M manual. Additional general information on pump maintenance can be found in the publications listed in *Water Treatment Plant Operation, Volumes 1 and 2*, and *Centrifugal Pumps and Motors: Operation and Maintenance.*

5-4.1 Maintenance Procedures for Centrifugal Pumps.

The following paragraphs describe general maintenance procedures for all types of horizontal and vertical centrifugal pumps. For details of procedures that apply specifically to volute, diffuser, regenerative-turbine, split-case, and multistage design, consult the manufacturer's manuals.

5-4.1.1 Lubrication.

General lubrication instructions are provided in Chapter 10 paragraph titled Lubrication. Manufacturer's manuals cover lubrication frequency for special cases, but the following generally applies. Pump running times longer than 5 minutes will require increasing oiling rates.

Caution: Do not lubricate totally enclosed equipment or insufficiently guarded equipment while it is moving.

- To avoid errors, establish a marking system to make sure that the proper lubricant is used. Make sure the same product symbol and identifying color are marked on lubricant containers, lubricant applicators, and locations near lubrication points.
- Never over lubricate. Over lubrication causes antifriction bearings to overheat and may damage the grease seals. Over lubrication may also damage electric motor windings.
- For simplified operation, provide the same type of grease gun fitting (zerk) at all points using the same type of grease. The fewer the types of grease used, the fewer grease guns required and the less likelihood of improper grease being used.

- Table 5-5 provides a general lubrication schedule for centrifugal-type pumps. When hand oilers are used to lubricate the shaft bearings, check the settings daily and adjust them according to Table 5-6.

5-4.1.2 Packing.

Selection of packing is usually done in accordance with the manufacturer’s recommendations or assistance. For pumping water, packing types include non-reinforced woven or braided cotton asbestos, semi-metallic plastic, or a combination of the two. If you require the manufacturer’s assistance to select packing, supply detailed information to the manufacturer on the following items:

- Description of liquid handled, including percentage concentration, temperature, and impurities.
- Amount of abrasive present.
- Stuffing box dimensions (depth of box, outside diameter, and shaft or sleeve diameter) and stuffing box pressure and temperature.
- Shaft speeds.
- Sealing cage (lantern gland) location and width.
- Shaft or seal material and hardness.

A guide for stuffing box inspection is provided in Table 5-7.

Table 5-5 Lubrication Schedule for Centrifugal-Type Pumps

Lubrication Point	Action Required	Frequency
Antifriction bearing	Check temperature (with thermometer); if running hot, bearing is probably over lubricated; remove excess lubricant.	Monthly
	Drain lubricant; flush lubricant wells and bearings with kerosene; add clean fresh lubricant.	Quarterly
Ball-thrust bearing	Add fresh grease to grease cups, but do not attempt to keep grease from coming out around the collar seal.	Monthly
	Change the grease in the grease cup if the pump operates more than 50 times a day; otherwise, change yearly.	Quarterly

Lubrication Point	Action Required	Frequency
Bearing housing	Check oil level in oil housing; do not add oil with pump running; remove oil vent plug when adding oil.	Daily
	Open housing; flush with kerosene; add clean fresh lubricant.	Quarterly
Enclosed shaft-type bearing	Check oil cup; add lubricant as necessary.	Weekly
Grease-sealed packing gland	Check spring-loaded grease cup; refill as necessary; adjust spring tension to maintain grease discharge through packing at approximately 1 ounce per day.	Daily
Guide bearing	Add grease through fittings provided.	Monthly
Sealing water system	Check packing gland assembly; adjust packing if excessive seal-water leakage is noticed, allow 60 drops per minute with pump running.	Daily
	Check stuffing box for free movement of gland.	Semi-annually
Hand oiler	According to Table 15.	Each shift
Solenoid oiler	Check that leads are connected; check needle valve for clogging; adjust for 2 to 4 drops per minute; refill container as necessary.	Daily
Sleeve bearing	Check bearing temperature; if too hot, add lubricant.	Monthly
	Drain lubricant; wash wells and bearing with kerosene.	Quarterly
Universal joint coupling	Lubricate couplings and slip splines with fresh grease.	Semi-annually

Table 5-6 Hand Oiler Adjustment

Pump Operation Schedule (times per day)	Pump Running Time (minutes)	Oiler Rate
Maximum of 2	Not over 5 (a)	1 drop/15 min
3 to 12	Not over 5 (a)	1 drop/4 min
12 to 50	Not over 5 (a)	1 drop/2 min
More than 50		2 to 4 drops/min

5-4.1.3 Sealing Water Systems.

Make the daily checks for the sealing water system that are listed in Table 5-5. If the leakage cannot be adjusted properly, repack the stuffing box according to Chapter 5 paragraph titled Packing and Table 5-7. Confirm the frequencies in Table 5-7 with local command. Disassemble the sealing water lines and valves annually to verify that the water passages are open.

Table 5-7 Guide for Stuffing Box Inspection

Inspection/Procedure	Action	Frequency
Inspect stuffing box	Ensure that stuffing box glands are moving freely and that gland bolts and nuts are oiled.	Semi-annually
	Check for excessive leakage that cannot be reduced by gland adjustment; if found, proceed according to the steps below:	
Remove old packing	a. Remove old packing and clean box. If the box has a seal cage, make sure it is located opposite the sealing liquid inlet. b. Use packing recommended by manufacturer. c. Measure the depth of box and sealing liquid inlet tap. Place enough rings of packing in the bottom of the box that seal cage is in proper position once	Varies

Inspection/Procedure	Action	Frequency
	packing is compressed. Do not try to pack a pump by renewing only the last three or four rings.	
Check packing ring joints	a. Make sure the packing ring joints are staggered.	Varies
Add new packing	a. Cut the packing so that the joints are square after the packing is bent around the shaft. Cut packing about 1/16 in. longer than measured to be sure that the outside diameter of the ring hugs the stuffing box wall rather than the sleeve. Use care in cutting the rings. b. Except as detailed below, use the follower gland and a few convenient equal-length spacers to compress each ring firmly into place before inserting the next ring. c. Stagger the joints, and make sure that the lantern ring is centered under the water supply connection. d. After the last piece of packing has been placed, tighten the follower gland nuts until finger tight.	Varies
Woven or braided packing	a. Dip each ring of packing in oil before adding it to the stuffing box. b. Woven or braided packing does not have to be added one ring at a time. Fill the box half full. Then draw the rings up snug by taking up on the packing sleeves and gland. Release the follower, add the remainder of the packing, and draw up snug. Then back off the gland until finger tight.	
Plastic or metal packing	a. Plastic and metallic packing must be compressed individually. Dip each ring in oil, insert in the stuffing box,	

Inspection/Procedure	Action	Frequency
	and draw up tight by split-packing rings and gland. Hand turn the shaft a few times to gloss the packing. b. Always use metallic or jacketed rings next to the bottom of the box, bushings, seal cages, or glands because non-jacketed plastic rings will squeeze into the clearances provided at these locations.	
Combustion-type packing	a. Follow instructions supplied by the manufacturer when using combustion-type packing.	
Position lantern rings	a. If a lantern ring is used, be sure it is positioned correctly; if grease sealing is used, be sure the lantern ring is filled with grease before the remaining rings are put in place.	Varies
Run-in new packing	a. New packing has to be run-in. b. Start the pump with the stuffing box gland quite loose. Allow the pump to run 10 to 15 minutes. c. Gradually tighten the stuffing box gland until leakage is reduced to a constant drip. Packing that is too tight in the box causes undue friction, creates heat, glazes the packing, and may score the shaft sleeves. Packing must remain soft and pliable. d. Use drip leakage to ensure proper lubrication throughout the packing box.	Varies
Inspect packing gland	If the stuffing box leaks too much, tighten the gland. If this does not help, remove the packing and inspect the shaft sleeve.	Weekly

5-4.1.4 Rotary Seals.

If a pump has seals that do not have the conventional follower and pliable, replaceable packing, consult the manufacturer’s manual.

5-4.1.5 Shafts and Shaft Sleeves.

\1 When the pump is dismantled, examine the shaft carefully at the impeller hub, under the shaft sleeves, and at the bearings. **/1/**

- Shafts. The shaft may be damaged by rusting or pitting caused by leakage along the shaft at the impeller or shaft sleeves. If antifriction bearings are improperly fitted to the pump shaft, the inner race rotates on the pump shaft and damages the shaft. Excessive thermal stresses or corrosion may loosen the impeller on the shaft and subject the keyway to shock. Replace any shaft that is bent or distorted. After replacing the shaft, check it for possible runout. The maximum allowable is 0.002 in. (51 microns [µ]).
- Shaft Sleeves. Inspect shaft sleeves each year. They are subject to wear and may require replacement, depending on the severity of service. Replace the sleeve when it is appreciably worn, and the packing cannot be adjusted to prevent leakage. Otherwise, excessively grooved or scored sleeves will pare and score new packing as soon as it is inserted into the stuffing box.
- Bearings. Inspect the bearings and add lubricant according to the procedures described in Table 5-8. **\1** Maintenance frequencies are recommended and may vary based on manufacturer’s recommended maintenance frequency. Confirm maintenance frequencies with local command. **/1/**

Table 5-8 Maintenance Checklist for Bearings

Inspection	Action	Frequency
Check bearing temperature	Check with a standard thermometer. Antifriction bearings that are running too hot probably have too much lubricant.	Monthly
Change lubricant	Change lubricant according to Table 5-5. If lubricant change does not prevent overheating, disassemble and inspect the bearing. If nothing appears to be wrong, check the pump and motor alignment.	Quarterly
Check clearances	During the quarterly lubrication change, check the clearances. Recommended clearance is 0.002 in. (51 µ), plus 0.001 in. (25 µ) for each inch (25 mm) of the shaft-journal diameter.	Quarterly
Check bearing condition	Each year, when the pump is dismantled, check the condition of the bearings and the bearing race; replace as necessary.	Annually
	The preferred method in general use for mounting a bearing on a pump shaft is to heat the bearing to expand the inner race and shrink it on the shaft. The bearing is heated in an oil bath or electric oven to a uniform temperature of 200 to 250 °F (93 to 121 °C). When heated, quickly mount the bearing on the shaft.	
	An alternate method uses force exerted by an arbor press or hammer blows. In forcing a bearing onto a shaft, be sure that the race is never cocked during the operation. Firmly press the bearing position on the shaft against the shaft shoulder.	
	Check with a feeler gage.	

Sleeve bearings	Check with a standard thermometer. Sleeve bearings that are running too hot probably have too much lubricant.	Monthly
Change lubricant	Change lubricant according to Table 5-5. If lubricant change does not solve the overheating problem, disassemble and inspect the bearing. If the bearing is in good condition, check the pump and motor alignment.	Quarterly
Check clearances	During the quarterly lubrication change, check the clearances. Normal clearance is 0.002 in. (51 µ), plus 0.001 in. (25 µ) for each in. (25 mm) of the shaft-journal diameter. Make sure that the oil rings are free to turn with the shaft. Repair or replace oil rings when necessary.	Quarterly
Check bearing condition	**\1** When the pump is dismantled, check the condition of the bearings and the bearing race; replace as necessary. **/1/** Sleeve bearings are usually split-type and can be easily removed and installed. Rotation of the bearing is prevented by a pin in the top half of the bearing housing.	Annually

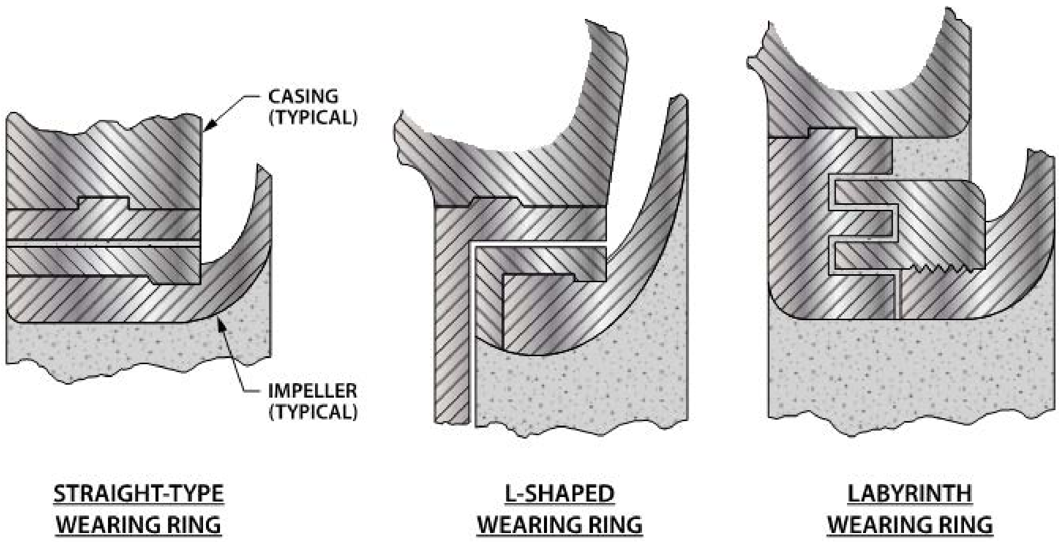
5-4.1.6 Wearing or Sealing Rings.

Each year inspect the wearing or sealing rings that seal the discharge water from suction water in rotating pumps. These are not perfect seals and do allow some leakage. Do not allow this leakage to become excessive because of worn rings or the pump efficiency will be impaired. Three types of wearing rings are shown on Figure 5-1.

- Proper wearing ring clearance is important. In the straight-type wearing ring - the most common type - the diametrical clearance need not be less than 0.025 in. (0.64 mm) and should not be greater than 0.050 in. (1.25 mm).
- In the L-shaped type, clearance in the space parallel to the shaft should be the same as for the straight-type. The clearance of the space at the right angle to the shaft is governed by the end-play tolerances in the bearing.

- For specification information on the L-shape and labyrinth-type rings, consult the manufacturer's manual.

Figure 5-1 Types of Wearing (Sealing) Ring



5-4.1.7 Impeller.

Each year remove the rotating element and inspect it thoroughly for wear (see Chapter 5, "Overhaul Procedures" for dismantling procedures).

- Remove any deposits or scaling.
- Check for erosion and cavitation effects. Cavitation causes severe pitting and a spongy appearance in the metal.
- If cavitation effects are severe, some changes in pump design or use may be necessary. Report the matter to the supervisor.

5-4.1.8 Casing Maintenance.

Keep the waterways clean and clear of rust. When the unit is dismantled, clean and paint the waterway with a suitable paint that will adhere firmly to the metal. A routine program of cleaning and repainting helps prevent complete erosion of the protective coat before replacement.

5-4.1.9 Pump Shutdown.

When a pump is shut down for an extended period, or for overhaul inspection and maintenance, the following procedures apply:

a. Shut off all valves on suction discharge, waterseal, and priming lines. Drain the pump completely by removing vent and drain plugs until the water has run off. This operation protects against corrosion, sedimentation, and freezing.

b. Disconnect the switch to the motor and remove the fuses.

c. Drain the bearing housing. If the shutdown is to be followed by an inactive period, purge all the old grease. Otherwise, refill with fresh grease. If an overhaul is scheduled, do not refill the oil or grease receptacles until the pump is reassembled.

5-4.1.10 Overhaul Procedures.

The frequency of complete overhaul depends on the hours of pump operation, the severity of service conditions, the construction material of the pump, and the care the pump receives during its operation. If the pump is not operated continuously, opening the pump for inspection is not necessary unless there is definite evidence that the capacity has fallen off excessively or if there is an indication of trouble inside the pump or in the bearings. In general, it is good practice to dismantle pumps in relatively continuous operation once a year. Because pump designs and construction vary from model to model, and from one manufacturer to another, there is no set of specific procedures for dismantling and reassembling. Rules (a) through (d) below are basic. For detailed procedures, consult the manufacturer’s manual.

a. Use extreme care in dismantling the pump to avoid damaging internal parts. For convenience in reassembly, lay out all parts in the order they are removed. Protect all machined faces against metal-to-metal contact and corrosion. Do not remove ball bearings unless absolutely necessary.

b. While the pump is dismantled, examine the foot and check valves to make sure they are seating and functioning properly.

c. To assemble the pump, reverse the dismantling procedure. Follow the manufacturer’s manual explicitly.

d. Check the pump and motor alignment after reassembly.

5-4.2 Rotary-Displacement Pumps.

There are numerous types of rotary displacement pumps and, therefore, it is not possible to set up detailed maintenance procedures that apply to all types. Establish individual maintenance procedures according to the manufacturer’s manual. Using the manual, set up procedures similar to those presented for a centrifugal-type pump. At annual intervals, disassemble the pumps and clean both exterior and interior surfaces.

5-4.2.1 Clearances.

Check clearances for tolerances listed in the manufacturer’s manual.

5-4.2.2 Packing.

Check the packing assembly and repack as needed.

5-4.2.3 Bearings and Alignment.

Check the bearings and the alignment of the pump and motor.

5-4.2.4 Checklist Items.

Check all items included in the checklist previously determined from the manufacturer's manual and the listings for centrifugal-type pumps.

5-4.2.5 Painting.

Paint exterior surfaces and interior surfaces subject to rust with a suitable underwater paint or effective protective coating.

5-4.3 Reciprocating-Displacement Pumps.

There are three types of reciprocating pumps: plunger, piston, and diaphragm. Consult the manufacturer's manual for each individual pump.

5-4.3.1 Calculations.

5-4.3.1.1 Slippage.

Calculate the delivery of piston and plunger pumps every year. The decrease in percent delivery from the volumetric displacement per pump stroke is termed "slippage." Excessive slippages indicate the need for maintenance and possible repair.

5-4.3.1.2 Volumetric Displacement.

Compute the volumetric displacement by multiplying the piston or plunger area by the length of stroke. Make proper allowance for double-action pumps.

5-4.3.1.3 Delivery.

Calculate the percent delivery from a comparison of the measured delivery per stroke and the computed volumetric displacement per stroke. If delivery is less than 90% of the volumetric displacement, check the valves, pistons, and packing for leakage. Make any necessary replacements to maintain the desired efficiency.

5-4.3.2 Pump Inspection.

Dismantle the pump and inspect thoroughly each year according to the following schedule:

a. Remove and examine all valves, valve seats, and springs. Reface valves and valve seats as necessary and replace worn or defective parts.

b. Remove all old packing and repack.

c. Check the pump and driver alignment.

d. Check the plunger or rod for scoring or grooving.

e. Clean the interior and exterior surfaces. Paint the interior with suitable underwater paint or protective coating. Paint the exterior.

5-4.4 Sludge Pumps.

Two types of sludge pumps, reciprocating and progressive cavity, are discussed here. Maintain centrifugal-type sludge pumps according to the procedures previously presented for centrifugal-type pumps. Modify the procedures listed to conform to manufacturers' manuals. For lubrication requirements of all sludge pumps, consult the manufacturer's manual.

5-4.4.1 Packing Procedures for Reciprocating Sludge Pumps.

Daily, or more frequently if necessary, check the sight-feed oil cup if one is provided for lubrication between the plunger and the stuffing box. Add a squirt of oil around the plunger as often as necessary.

At varying intervals, renew the packing when no take up is left on the packing-gland bolts.

a. Remove the old packing and clean the cylinder and piston walls. Place new packing in the cylinder and tamp each ring into place. Be sure that the packing ring joints are staggered.

b. To break the packing, run the pump for a few minutes with the sludge line closed and the valve covers open.

c. Turn down the gland nuts, no more than is necessary, to keep sludge from getting past the packing. Be sure all packing-gland nuts are tightened uniformly. When chevron-type packing is used, make sure that the nuts holding the packing gland are only finger tight to prevent ruining the packing and scoring the plunger.

Check the packing-gland adjustment each week to make sure that the gland is just tight enough to keep sludge from leaking through the gland, making sure that the piston walls are not being scored. Before operating a pump, especially after it has been standing idle, loosen all nuts on the packing gland.

5-4.4.2 Bearings and Gear Transmission for Reciprocating Sludge Pumps.

Daily (or once per shift), lubricate the bearings and the gear transmissions with a grease gun. If the pump runs continuously, grease more often than once a shift.

Check the gear transmission each month and keep it filled to the proper level with the proper oil. Open the drain to eliminate accumulated moisture.

Change the oil every 3 months to prevent excessive emulsification.

5-4.4.3 Shear Pins in Reciprocating Sludge Pumps.

a. Check the shear-pin adjustment each week. Set the eccentric by placing a shear pin through the proper hole in eccentric flanges to give the required stroke. Tighten the hexagonal nuts on the eccentric flanges just enough to take the spring out of the lock washers.

b. If shear pins fail, check for a solid object lodged under the piston, a clogged discharge line, or a stuck or wedged valve.

c. When a shear pin fails, the eccentric moves to the neutral position and prevents damage to the pump. Remove the cause of failure and insert a new shear pin.

5-4.4.4 Ball Valves in Reciprocating Sludge Pumps.

Perform an inspection of ball valves every 3 months. Replace valve balls that are worn small enough to jam into the valve chamber. A decrease in diameter of 1/2 in. (13 mm) is sufficient to cause this difficulty. Check the valve chamber gaskets and replace them when necessary.

5-4.4.5 Eccentrics in Reciprocating Sludge Pumps.

Each year, remove the brass shims from the eccentric strap to take up the Babbitt bearing. After removing the shims, operate the pump for 1 hour and check the eccentric to be sure it is not running hot.

5-4.4.6 Progressive Cavity Sludge Pumps.

5-4.4.6.1 Seals.

When grease seals are used instead of water seals, check the grease pressure in the seals daily.

a. For water seals, allow about 60 drops of leakage per minute when the pump is running.

b. If leakage is high, tighten the two gland nuts evenly a few turns, but do not draw the glands too tight. After adjusting the gland, turn the shaft by hand to make sure it turns freely.

5-4.4.6.2 Bearings.

Lubricate the sludge pump through the grease connections on the bearing housing each week. Flush out the bearing housing each year. Then refill with new grease.

5-4.4.6.3 Packing Glands.

Check the packing glands for leakage each week.

5-4.5 Well Pumps.

Well-pump types are centrifugal pumps, reciprocating (piston or plunger) pumps, and jet (ejector) pumps.

5-4.5.1 Centrifugal Well Pumps.

The turbine well pump is the most widely used type of well pump. Use the maintenance items listed for centrifugal-type pumps (Chapter 5 paragraph titled Maintenance Procedures for Centrifugal Pumps) and the manufacturer's manual to develop maintenance charts for turbine well pumps. In addition, check the following items:

5-4.5.1.1 Types of Lubrication.

5-4.5.1.1.1 Oil-Lubricated Pump and Bearings.

Make sure that the oil tubing and lubricators are filled each day. Check the solenoid oilers for proper operation and see that they are filled. Check the oil level in the sight gage lubricator for underwater bearings. Make sure that the oil feed is at an average rate of 3 to 4 drops per minute.

5-4.5.1.1.2 Water-Lubricated Pump and Bearings.

This type of design requires lubrication with clear water. Daily, make sure that the pre-lubrication tank is full when the pump is in use.

a. When filling the tank by pump, close the tank-filling valve when the tank is full. Open the lubrication valve to allow water to reach the bearings before the pump is started.

b. If the bearings are lubricated from main pressure, close the lubricating valve after the pump is started.

c. If the pump operates automatically and has a lubrication-delayed solenoid valve, wait 1 minute before checking the lubricating valve for proper operation. Check operation of the solenoid valve and check the packing for excessive leakage.

d. Check the pre-lubrication control on pumps that have safety controls to prevent starting before lubrication water is turned on. Make sure that this water flows to the bearings when the equipment is supposed to function.

e. Check the time-delay relay for proper functioning and compare with the manufacturer’s recommendation.

f. Clean and lubricate the guides and linkages.

5-4.5.1.2 Impeller Adjustment.

Every 3 months check the impeller for maximum efficiency setting and adjust if necessary. On hollow-shaft motors, the adjustment nut is on the top of the motor. Consult the manufacturer’s manual for the detailed adjustment procedure.

5-4.5.1.3 Impeller Fitting.

When the pump is pulled for inspection, note signs of pitting or wear on the impellers.

- **Cavitation.** Pitting in the lower stages may be from cavitation.
- **Sand Erosion.** Sand in the water erodes the impellers. If sand is the cause of difficulty, check the well screen and replace if necessary. Where the erosion effect is appreciable, repair or replace impellers that are not likely to last until the next inspection.
- **Clearances.** Repair or replace impellers, as necessary, to maintain the close clearance required for pump efficiency. See the manufacturer’s manual regarding pump clearances and efficiencies.

5-4.5.1.4 Bowls and Waterways.

When the pump is pulled for inspection, inspect the bowls and water passage for pitting, wear, and corrosion.

5-4.5.1.5 Overhaul Procedures.

5-4.5.1.5.1 Frequency.

As with the centrifugal pumps, the frequency of complete overhaul depends on the hours of operation and severity of operation, water quality and operating environment. Generally, however, a pump in continuous operation should be pulled for inspection and overhaul annually. Perform the overhaul under experienced supervision and in strict accordance with the manufacturer’s manual. Overhaul the pump if any of the following conditions exist regardless of scheduled maintenance frequency:

- The pump shaft does not turn freely because parts below the pump head are binding.
- The pump shows excessive vibration.

- A performance test shows a decrease of 25% in capacity under normal head and speed conditions.

5-4.5.1.5.2 Clearances.

When a pump is pulled, check the diametrical clearance of each bearing ring to make sure it is between 0.025 and 0.050 in. (0.64 and 1.25 mm). Allow a maximum diametrical clearance of 0.025 in. (0.64 mm) on oil-lubricated bearings. Maximum allowable clearances for water-lubricated cut-less rubber bearings are 0.040 in. (1.0 mm) for shaft diameters up to 1.5 in. (40 mm) and 0.070 in. (1.8 mm) for shaft diameters 1.5 to 4 in. (40 to 100 mm).

5-4.5.1.5.3 Dismantling and Reassembly.

Follow the same procedures listed for centrifugal-type pumps.

5-4.5.1.5.4 Alignment.

Check the pump and motor alignment each year.

5-4.5.1.5.5 Painting.

Annually, or when the pump is pulled, paint all iron parts with a good grade underwater paint or effective protective coating on the exterior of the pump and, if possible, on the interior parts subject to rust. Apply the paint only to surfaces that are clean and dry. Do not paint the data plate.

5-4.5.2 Reciprocating Well Pumps.

5-4.5.2.1 General Information.

Use the manufacturer’s manual to develop checklists for each reciprocating well pump.

5-4.5.2.2 Delivery.

Measure the pump output twice a year for a known number of strokes. Delivery per stroke should be at least 90% of the volumetric displacement of the pump (plunger area times stroke length). When the pump delivery drops to 50% or less, or when the pump delivery is between 50 and 90% but less than the installed water requirements, remove the pump from the well and check the valves and cup leathers. Before removing the pump, consult the manufacturer’s method for picking up the foot valve and for additional maintenance procedures.

5-4.5.2.3 Overhaul Procedures.

Inspect the pump jack for wear each year. Replace worn bearings and parts. Check the packing assembly and repack as necessary. If the pump delivery is satisfactory, do not overhaul the pump parts in the well. Paint the exterior of the pump as necessary.

5-4.5.3 Ejector Pumps.

5-4.5.3.1 Centrifugal Pump.

Maintain the centrifugal pump portion of the system according to the maintenance items listed for centrifugal pumps in Chapter 5 paragraph titled Maintenance Procedures for Centrifugal Pumps.

5-4.5.3.2 Ejector Assembly.

Each year, or as directed by the utility's manager, remove the ejector, the foot valve, and the screen from the well. Examine all parts for wear and corrosion and repair or replace any defective parts. Paint the exterior of the pump in accordance with *UFC 3-190-06*. If practical, paint interior iron with a good grade underwater paint or effective protective coating meeting *NSF/ANSI 61*.

5-4.5.4 Starting a New Well Pump.

Table 5-9 lists startup procedures for vertical turbine well pumps. While plant operators generally will not be responsible for performing these initial procedures, they may be charged with overseeing the contractors performing installation, and they should be familiar with the startup tasks. Figure 5-2 shows the necessary water-level checks. If problems occur, refer to the troubleshooting checklist provided in Table 5-10.

Table 5-9 Startup Checklist for Vertical Turbine Well Pumps

Inspection	Action
Prestart Inspection Well	Disinfect according to Chapter 3 paragraph titled Well Disinfection.
Pump equipment	Check alignment.
Valve and piping system	Check for proper operation. Check for leaks. Set valves so water pumped at startup does not feed into distribution system until bacteriological quality has been tested and clearance received.
Bearings	Pre-lubricate bearings on water-lubricated, line-shaft pumps with settings of more than 50 feet.
Electrical connections	Make sure that all electrical connections are correct and that terminals are tight.

Inspection	Action
Instrumentation	Make sure all instrumentation is hooked up according to the manufacturer's instructions.
Startup Inspection Pump	 Start pump. Check immediately for evidence of malfunction or excessive heat or vibration. Check operating power input.
Motor	Check for malfunction or excessive heat or vibration. Check rotation direction of motor. Check water or oil lubrication system.
Instrumentation	Observe how quickly motor comes up to operating speed; check final operation speed.
Bearings	Check for excessive heat or vibration.
Post-Startup Inspection Well	 Check for abrasive material (sand pumping) or the presence of gas within the well.
Water level	Make immediate check of water level and record data for future reference. Perform pumping and recovery water-level checks as shown in Figure 5-2.
Pressure tests	Check pump pressure and flow output. Determine the corresponding pumping level in the well. Compute the field head (1) and compare it to the pump curve supplied by the manufacturer (2).
Water quality	After pumping for 24 hours, collect a water sample for microbiological analysis to ensure water is free from disease-causing organisms.

(1) Field head is computed as follows: calculate the static and dynamic head losses being overcome by the pump. The total field head equals (a) the friction losses in the pump column and through the pump discharge elbow to the location of the pressure gage on the pump plus (b) the vertical distance from the pumping level in the well to the pressure gage plus (c) the pressure gage reading converted to feet of head.

(2) The manufacturer's pump curve should be a combined curve showing a composite assembly rating for multistage pumps, not a single-bowl-assembly curve used for a single-stage pump.

For additional help reading pump curves or calculating head losses, consult Chapter 2 paragraph titled Water Source. A sample field head calculation is provided in Appendix B.

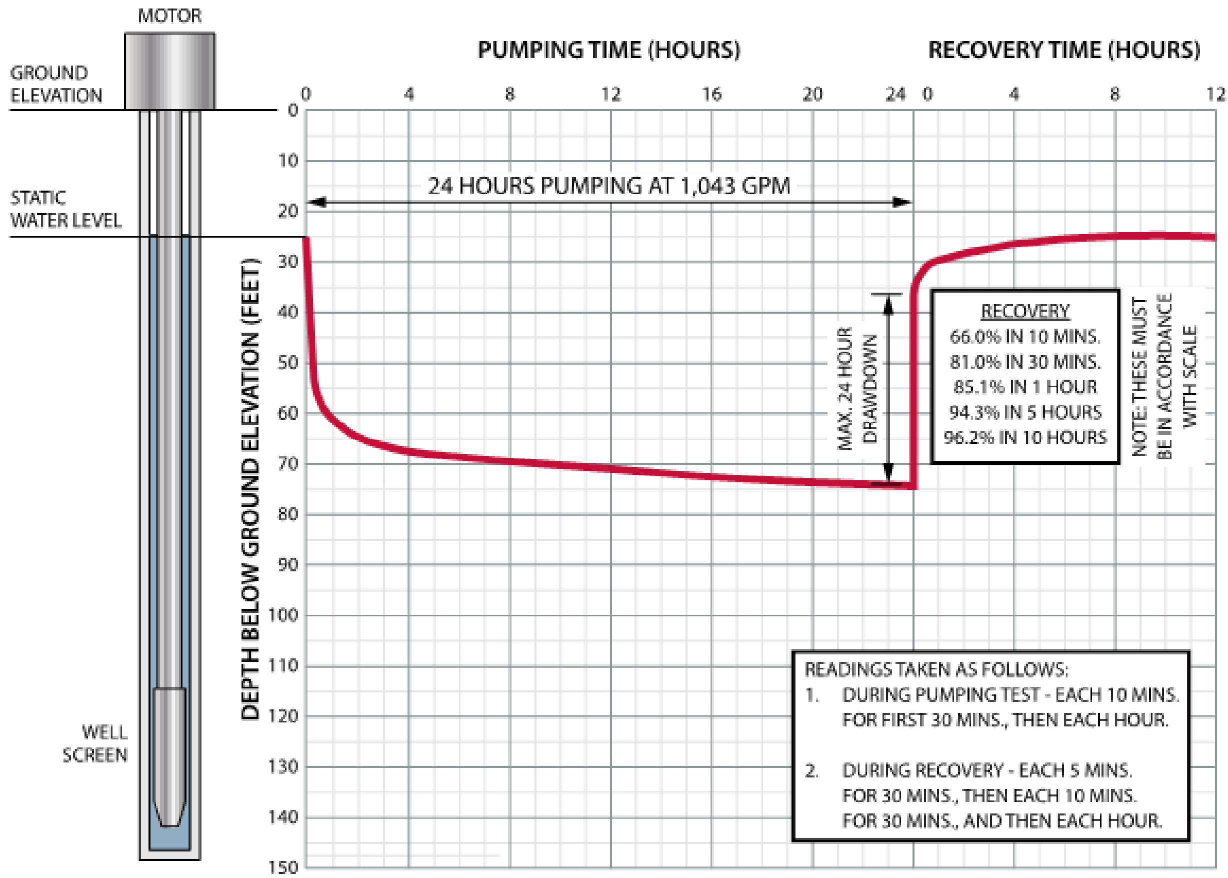
Table 5-10 Troubleshooting Checklist for Vertical Turbine Well Pumps

Symptom	Cause of Trouble	Remedy
Pump fails to start.	Bearing friction	Check tube tension nut for tightness; check for bent shaft and proper anchoring; check oil.
	Corrosion products or biological growth	Check, particularly on out-of-service pumps. Where necessary, flush with acid, chlorine, and, or, hexametaphosphate.
	Fuses burned out	Check voltages at each phase of motor terminals.
	Impeller locked	Check for sand; raise or lower impeller; backwash. Pull pump if necessary. Also check impeller adjustment; raise impeller to allow shaft to stretch for hydraulic thrust.
	Faulty driver	Disconnect from pump and check starting.
	Power not available	Check circuit breaker, fuse, and starter.
	Overload relay trip	Reset.
	Trash in casing	Check. If necessary, pull pump and clean.
	Low voltage	Check.
	Well cave-in	Check; pull pump; repair well.

Symptom	Cause of Trouble	Remedy
Pump does not deliver water.	Pump not primed	Check for proper pump submergence. Vent well to atmosphere to eliminate vacuum at pump suction.
	Discharge head too high	Check for closed discharge valves or stuck check valves.
	Pump parts failure	Check for broken shaft, broken bowl assembly, loose impellers, and loose column-pipe joints.
	Wrong direction of rotation	Check for switched power leads.
	Speed too low	Check power supply voltage and frequency. Check for bearing friction and impeller corrosion or obstruction.
	Suction clogged	Backwash or use chemical treatment to clean.
	Operating water level low	Check static level and drawdown. Lower pump, clean screen, and decrease pumping rate.
	Low speed	Check power supply voltage and frequency; check for excessive bearing friction and impeller corrosion or obstruction.
	Low water level in well	Check well vent. Check pump inlet for turbulence, vortexing, or eddies. Check well screen for sand, rust, or biological growth.
	Faulty instruments	Correct instrument readings.
Pump requires excessive power.	Impeller rub	Check adjustment of impeller height.
	Wrong lubricant	Compare manufacturer’s instructions with lubricant being used.
	Misalignment	Check for tight bearings; check for pump and casing vibration.

Symptom	Cause of Trouble	Remedy
	Packing too tight	Check for proper leakage to provide shaft lubrication.
	Pump selection wrong	Check capacity rating, etc.
	Wrong direction of rotation	Check power leads.
	Excessive speed	Check power frequency and voltage; check gear ratios.
Pump vibrates excessively.	Air entering pump	Check on over-pumping and water level drawdown; check leaks in well vent.
	Bearing trouble	Check for sand in water. Check lubricant (oil and grease) for proper grade.
	Rough operation	Check disconnected motor. Check for sand in impeller or bowl. Check for wear in rotating parts.

Figure 5-2 Typical Well Pumping and Recovery Test



5-5 PUMP DRIVERS.

Pump drivers provide the mechanical source of energy to pumps. The driver is usually an electric motor, gasoline, or diesel engine. More general operator training/knowledge-based information on pump drivers is provided in *Water Treatment Plant Operation, Volumes 1 and 2*.

5-5.1 Electric Motors.

Electric motors are the most common drive used in military water systems. Proper operation of an electric motor requires that the operator can recognize the normal sounds and conditions of a properly running motor. In general, investigate any change in the sound or operating condition detected during the regular inspection. Table 5-11 includes a list of routine operating checks for electric motors.

Table 5-11 Routine Operations Checklist for Electric Motors

Inspection	Action
Motor	Keep the motor free from dirt or moisture.
	Keep the operating space free from articles that may obstruct air circulation.
	Check the bearings for oil leakage.
Unusual Conditions Unusual noises in operation Motor fails to start or to come up to speed normally Motor or bearings feel or smell hot Continuous or excessive sparking at commutator Hot commutator Blackened commutator Sparking at brushes Fine dust under couplings with rubber buffers or pins Smoke, charred insulation, or solder whiskers extending from armature Excessive hum Regular clicking Rapid knocking Chattering brush Vibration	Check regularly for these unusual conditions. Report any irregularities to the plant superintendent for correction by the electrical shop.

5-5.1.1 Maintenance.

As a rule, the electrical shop is responsible for routine maintenance of electrical motors. Under some circumstances, the responsibility for cleaning and servicing antifriction bearings may be delegated to the operator. General guidance for routine maintenance of electrical equipment is provided in Chapter 10 paragraph titled Electrical Equipment and some best practice information is in *Water Treatment Plant Operation, Volumes 1 and 2*.

5-5.2 Gasoline and Diesel Engines.

Gasoline and diesel engines are commonly used for emergency, standby, and portable pumping units. The operator is usually responsible for performing operating checks. Table 5-12 lists items to check before, during, and after starting gasoline and diesel engines. Use this checklist as a general guide only. Obtain specific details from the manufacturer's manual for each unit, and perform any additional services specified in the manual.

Table 5-12 Operations Checklist for Gasoline and Diesel Engines

Inspection	Action
Prestart Checks Motor	Check equipment for signs of tampering or leaks.
Fire extinguisher	Ensure extinguisher is in working order.
Gages	Check all fuel, oil, and water levels.
Accessories and drives	Inspect according to manufacturer's instructions.
Battery	Check for cracks and leaks.
Air breather	Make sure breather is free of obstruction.
Startup/Warmup Checks Choke or primer	Check for proper operation.
Indicator lights	Ensure oil gage or indicator lights are in working order.
Other instruments	Check that ammeter, tachometer, fuel gage, voltmeter, and temperature gage are working.
Operating Checks Clutch	Ensure clutch is working properly.
Transmission and engine/controls	Check for unusual sounds, vibration, overheating, etc.

Inspection	Action
Instruments	Check that all instruments are registering readings.
Post-Shutdown Checks Gages	 Check fuel, oil, and water levels.
Instruments	Check indicators. Indicators should return to zero when engine is not running.
Battery and voltmeter	Check that battery has not run down and retains sufficient charge.
Accessories and belts	Check for signs of wear.
Electrical Wiring	Inspect wire integrity (no frayed or charred wires; no loose wires).
Air cleaner and breather caps	Look for obstructions or clogs.
Fuel filters	Be sure filters are not clogged or dirty. Change or clean as required or at regular intervals.
Engine controls	Controls should move freely. Check for binding, sticking, etc.
Leakage	Look for oil and coolant leaks.
Gear oil levels	Check level.

In addition to the checks listed in Table 5-12, perform the following tasks:

- **Unit Readiness Checks.** Operate all emergency and standby units at full load for the time specified by the equipment manufacturer. One hour each week is often recommended to ensure unit readiness.
- **Routine Maintenance.** Operators are generally responsible for operating checks and routine maintenance.

5-6 ACCESSORIES.

Accessories include belt drives, gear drives, variable speed drives, and couplings that connect the driver to the pump.

5-6.1 Belt Drives.

Two types of belts are used for belt drivers: V-belts and flat belts. Maintaining proper tension and alignment of belt drives ensures long life of belts and sheaves. Incorrect alignment causes poor operation and excessive belt wear. Inadequate tension reduces the belt grip and causes high belt loads, snapping, and unusual wear. Keep belts and sheaves clean and free of oil, which deteriorates belts. Replace belts as soon as they become frayed, worn, or cracked.

5-6.1.1 Installing Belts.

Before installing belts, replace worn or damaged sheaves. Check alignment with a straight edge or string and make the necessary corrections to keep the pulleys in line. Loosen the belt tensioning adjustment enough to remove and install belts without the use of force. Never use a screwdriver or other lever to force belts onto sheaves. Check multiple belts for matching size and length. It is not good practice to replace only one V-belt on a multiple belt assembly. Instead, replace the complete set with a set of matching belts. After belts are installed, adjust the tension. Recheck the tension after 8 hours of operation.

5-6.1.2 Checking Tension.

Check belt tension each week and adjust, as required, to prevent slipping or excessive wear on the belts.

5-6.2 Right-Angle Gear Drives.

O&M procedures for right-angle gear drives should follow manufacturer's recommendations. Immediately after starting a right-angle gear drive, remove the inspection plate and check for proper flow of lubricant. If there is no flow, stop the motion and check for mechanical defects. If no mechanical defect is found, it may be necessary to change the lubricant or drain and warm the old lubricant. Temperature or service conditions may require changing the lubricant type. To avoid detrimental effects of possible water-oil emulsion, drain old oil and refill with fresh recommended lubricant quarterly or about every 500 hours of operation, whichever is more frequent. The choice of lubricant depends on prevailing air temperatures and the manufacturer's recommendations.

5-6.3 O&M for Variable-Speed Drives.

5-6.3.1 Procedures.

Variable-speed drives are commonly used in water systems. Designs vary considerably from manufacturer to manufacturer. Therefore, consult the manufacturer's manual to determine O&M requirements. Items common to most variable-speed drives are listed below.

- Check for Normal Operation. Observe the drive each shift and note any abnormal conditions.
- Clean Discs. Remove grease, acid, and water from the disc face and thoroughly dry it. Use clear solvents that leave no residue.

- Check Speed-Change Mechanisms. Shift drive through the entire speed range to make sure that shafts and bearings are lubricated and discs move freely in a lateral direction on shafts.
- Check V-Belt. Make sure the belt runs level and true. If one side rides high, a disc is sticking on the shaft because of insufficient lubrication or the wrong lubricant. In that case, stop the drive, remove the V-belt, and clean the disc and shaft thoroughly with kerosene until the disc moves freely.
- Check Lubrication. Be sure to apply lubricant at all force-feed lubrication fittings and grease cup fittings. Refer to the manufacturer's manual for proper lubricants.

    a. Once every 10 to 14 days, add two or three strokes of grease through the force-feed fittings at the end of the shifting screw and variable shaft to lubricate the bearings of movable discs. Shift the drive from one extreme speed to the other to thoroughly distribute the lubricant over the disc-hub bearings.

    b. Every 60 days add two or three shots of grease through the force-feed fittings that lubricate the frame bearings on the variable-speed shaft.

    c. Every 60 days add grease to grease the cup that lubricates the thrust bearings on the constant-speed shaft.

    d. Every 60 days add two or three strokes of grease through the force-feed fittings on motor-frame bearings. Do not use hard grease or grease that contains graphite.

    e. Check the reducer oil level every 30 days and add oil when necessary. Drain and replace the oil according to the manufacturer's recommendations.

5-6.3.2 Remove Unit from Service.

If the drive will not be operated for 30 days or more, shift the unit to minimum speed. This places the springs on the variable-speed shaft on minimum tension and relieves the belt of excessive pressure and tension.

5-6.4 Couplings.

Unless couplings between the driving and driven elements of a pump or any other piece of equipment are kept properly aligned, breaking or excessive wear occurs in the coupling, the driving machinery, or the driver. Worn or broken couplings, burned out bearings, sprung or broken shafts, and excessively worn or ruined gears are some of the damages caused by misalignment. To prevent outages and the expense of installing replacement parts, check the alignment of the equipment before damage occurs.

5-6.4.1 Checking Coupling Alignment.

Excessive bearing and motor temperatures caused by overload, noticeable vibration, or unusual noises may all be warnings of misalignment. Realign when necessary, using a straight edge and thickness gage or wedge. To ensure satisfactory operation, level up the gap to within 1.5 in. (127×10^{-3} mm), as follows:

a. Remove coupling pins.

b. Rigidly tighten any driven equipment to its base. Slightly tighten the bolts holding the driver to its base.

c. To correct horizontal and vertical alignment, shift or shim the driver to bring coupling halves into position so no light can be seen under a straight edge laid across them. Lay the straight edge in at quarter points of the circumference, holding a light behind the straight edge to help ensure accuracy.

d. Check for angular misalignment with a thickness or feeler gage inserted at the same four places to make sure that the space between coupling halves is equal at all points.

e. If the equipment is properly aligned, coupling pins can be put in place easily (using only finger pressure). Do not hammer pins into place.

f. If the equipment is still misaligned, repeat the procedure.

5-6.4.2 Lubrication.

Use lubrication procedures and lubricants recommended by the manufacturer and in Chapter 10 paragraph titled Lubrication.

5-7 RECORDKEEPING.

Keep equipment and maintenance records for each pump and drive assembly. The method used is prescribed by local command. In general, records will contain entries for routine maintenance (lubrication and equipment checks, repacking, and cleaning), scheduled overhauls, and nonscheduled repairs. A description of the work done, the date, and the name of the person doing the work are minimum entries. Since a pump's condition is best evaluated by comparing its current performance to its original performance, a record of flow, pressure, pump speed, amperage, and other test data determined immediately following installation is recommended.

5-8 PUMP SAFETY.

Specific hazards related to operating and servicing pumps include rotating equipment, lifting heavy machinery, using hand tools, working with electrical devices, and fires.

Always stop machinery before it is cleaned, oiled, or adjusted. Lock out the controlling switchgear before any work begins so that the machinery cannot be started by another person. Post a conspicuous tag on or over the control panel, giving notice that the equipment is under repair and should not be restarted. Also note the name of the person who locked out the equipment.

Caution: Remove guards for maintenance only when the machinery is not in operation.

5-8.1 Motor and Engine Safety.

Follow special safety precautions when dealing with motors and engines. In addition to all the other safety concerns associated with water distribution (as discussed in other chapters), be cautious around electrical devices and be aware of fire safety guidelines.

5-8.2 Electrical Devices.

No safety tool can protect absolutely against electrical shock. Use plastic hard hats, rubber gloves, rubber floor mats, and insulated tools when working around electrical equipment. These insulating devices cannot guarantee protection, however, and no one using them should be lulled into a false sense of security.

Electrical shocks from sensors are possible in many facilities, such as pumping stations, because many instruments do not have a power switch disconnect. It is important to tag such an instrument with the number of its circuit breaker so that the breaker can be identified quickly. After the circuit breaker has been shut off, tag or lock the breaker so other personnel will not re-energize the circuit while repairs are being performed. Even after a circuit is disconnected, it is good practice to check the circuit with a voltmeter to be certain that all electrical power has been removed. Make sure switches are locked open and properly tagged when personnel are working on equipment. Use fully enclosed, shockproof panels when possible. Such equipment should be provided with interlocks so it cannot be opened while the power is on.

Use extreme care in working around transformer installations.

CHAPTER 6 DISTRIBUTION AND STORAGE

6-1 DISTRIBUTION SYSTEM DESIGN AND INSTALLATION.

Use UFC 3-230-01 for the design and installation of distribution systems.

6-2 DISTRIBUTION SYSTEM OPERATION.

Proper operation of the distribution system is required to maintain a dependable water distribution system, ensure water quality, provide adequate flows for protection against fire (fire flow), and maintain adequate pressure. Set and operate valves, keep records of water flows and levels, and correctly balance the system flow to maintain the desired pressure in all parts of the system. Records contain current system maps, maintenance records of all leaks and breaks, repair type, pipe condition, joint type, fire-flow tests, C-factor tests, pressure gauges, surrounding soil types, corrosion potential, and any hazardous material sites nearby. Implement a program for evaluating and upgrading existing portions of the distribution system as required. General information on system O&M can be found in *AWWA M31. Some best practice information is in Water Treatment Plant Operation, Volumes 1 and 2.*

6-2.1 Leak Inspection.

Leaking pipes waste water, reduce water pressure, and potentially create public safety hazards. Conduct leak detection surveys at the time of minimum water use. Shut off all valves, except those that will direct the water flow through the section under study.

Caution: Good practice requires that the firefighting authorities be notified before closing any section of the system.

Specific directions for leak detection and repair may be found in these publications; *AWWA M36*, and *AWWA M51, additional operational best practice information can be found in Water Treatment Plant Operation, Volumes 1 and 2*.

6-3 DISTRIBUTION SYSTEM MAINTENANCE.

Table 6-1 covers leak repair procedures for various distribution system problems.

Table 6-1 Checklist for Distribution System Maintenance

Problem Type	Repair Procedure
Joint leak	Caulk the joint (if caulk was used in the joint)
Cracked main	Cut out the section of cracked pipe and replace it with a stub of new pipe and mechanical couplings. Flush and disinfect.
Large section of corroded or leaking main in high-cost digging area	Hire outside professionals to perform slip lining, in situ formed-tube lining, cement-mortar lining, or other appropriate techniques.
Poor aesthetic water quality (taste, odor, color, turbidity)	Flush and disinfect the main. If the problem persists, modify chlorination procedures in the problem area or replace dead-ends or low points, if applicable.
Deposits or silt buildup in main	Flush and disinfect the main.
System flow below fire flow requirements	Hire outside professionals to mechanically clean mains. Line the mains post-cleaning or immediately begin chemical treatment.
Corrosive source water aggravating tuberculation	Stabilize water and increase pH. For more information on corrosion control, see Chapter 4.
Frozen pipes	Electrically or steam thaw pipes

6-3.1 Main Breaks.

If a break or leak is found, include the pipe location, material, size, type of leak or break, visual assessment of surrounding soil type, pipe depth, and assessment of saturation conditions of soil and proximity to water table in the maintenance record.

Establish procedures for water main repairs and ensure that personnel are trained to perform them. Perform the following tasks to eliminate delay in beginning the repairs:

- Post telephone numbers of key personnel conspicuously in the water plant.

- Keep the following items available and ready for use: valve keys, hand tools, digging tools, pavement breakers, trench-shoring material, a portable centrifugal pump, floodlights, an emergency chlorinator, and calcium hypochlorite.
- Keep a stock of split-sleeve and mechanical-joint repair fittings in sizes that fit critical mains.
- Make advance arrangements with a municipal utility, public works department, or an outside contractor for the use of large construction equipment (e.g., power shovels and cranes) that may be needed but are not normally stocked by the installation.

Select the proper leak repair technique. Understanding the methods of installation and the most advantageous use of each technique will help you make the proper selection for the repair.

6-3.1.1 Pipe Replacement.

Assess the physical condition of pipes. All materials used for pipe replacement shall conform to applicable AWWA and NSF/ANSI standards. The joints used in pipe replacement shall also meet AWWA standards. Mechanical joints shall have slip-on joints with rubber gaskets. Use transition joints between dissimilar piping materials.

6-3.2 Water Main Tapping Procedures.

Perform a wet tap of an existing water main where connection must be performed without turning off the water or interrupting service to existing customers. More detailed information on tapping valves and procedures may be obtained from the pipe manufacturer or from the publication listed in best practice *AWWA M44 Chapter 2*.

6-3.2.1 Pipe Lining.

Consider lining existing water mains as an alternative where high-cost digging is required, such as under pavements and in industrial areas. Lining a pipe can eliminate the need for frequent or continuous flushing. A smooth lining in a corroding pipe maximizes hydraulic carrying capacity and minimizes pumping costs. Additionally, linings can correct the structural failures, and bridge breaks and missing sections in corroded pipe, thus restoring service through a continuous pipeline. More information on cleaning and lining may be found in *AWWA M28. Additional operations best practices can be found in Water Treatment Plant Operation, Volumes 1 and 2*.

6-3.3 Flushing.

Remove matter deposited in the distribution system over time by annually flushing the system. Flushing and disinfection are required whenever mains are opened for repair in addition to annual flushing.

Flushing water mains near a nuisance, particularly at dead ends, may remove or reduce problems with taste, odor, color, or turbidity. If complaints about quality are received, investigate the possibility that stagnant water in dead-end lines may be the cause and take remedial action. Find and eliminate conditions that make repeated flushing necessary: a dead end or a low point in the main may allow sediment to accumulate, or growth of slime organisms may be caused by insufficient chlorination. Flushing is also helpful in clearing the non-potable part of the water system.

6-3.3.1 Water Age.

6-3.3.1.1 Pipe and storage is oversized for many installations based on overestimated fire hazard ratings and population. The oversized infrastructure leads to reduced turnover and therefore increased water age. Aggressive water conservation strategies have also decreased water turnover. Low density land-use planning strategies and outlying facilities located in far off dead-end zones can be designed with one pipe supply for both fire and potable use, which increases water age.

6-3.3.1.2 The amount of water turnover must be sufficient to remove old water and provide thorough mixing of the contents of the storage facility. It is generally recommended that a least 30% turnover be achieved daily. Maximize mixing and cycling in storage reservoirs and eliminate short-circuiting.

6-3.3.1.3 It is important to manage water age in the overall distribution and tank system as it relates to managing indicators of water quality problems, nitrification control, and DBP –TTHMs. Utilities are increasingly interested in modeling the water quality within a distribution system, particularly the decay of chlorine residual by using computer models to compute water age, track disinfectant residuals, and reduce disinfection by-products in a distribution system

6-3.3.1.4 Refer to *AWWA M32* and *AWWA M56* for best management information on water age management, modeling and nitrification prevention and control.

6-3.3.2 Flushing Procedure.

Start flushing at the supply source and continue to the ends of the distribution system. Do not start flushing at the ends of the system because accumulated debris must be drawn through the entire length of the system. For maximum scouring velocity, flush each section of pipe independently by closing off intersecting pipelines. This process directs the full flow through the section to be flushed. A velocity of 6 feet per second (fps) (1.8 meters per second [mps]) is recommended for flushing. Dechlorinate any water discharged to state waters. Table 6-2 gives the number of hydrant outlets required to flush various size water mains at the recommended pressure of 30 psi (207 kPa).

Table 6-2 Flow Rate and Number of Hydrant Outlets Required to Flush Water Mains with 30 psi (207 kPa) of Pressure

Pipe Diameter		Flow Required for 6 fps (1.8 mps) velocity		Number of 2.5-in. (65-mm) Hydrant Outlets	Number of 4-in. (100-mm) Hydrant Outlets
in.	(mm)	gpm	(m^3/hr)		
4	(100)	235	(50)	1	
6	(150)	525	(120)	1	
8	(200)	940	(210)	1	
10	(250)	1,970	(330)	2	1
12	(300)	2,010	(460)	2	1
16	(400)	3,750	(850)	3	2
18	(460)	4,750	(1,080)		2
24	(610)	8,450	(1,920)		3

6-3.3.2.2 Flushing Plan.

a. Using distribution maps, prepare a list of hydrants and blow-offs to be opened in an order that will flush the system from source to ends.

b. List, in correct order, valves to be closed and opened for each flushing point.

c. If service in any section will be disrupted by the plan, arrange to flush it at night. Notify heating plant and firefighting personnel in such sections.

6-3.3.2.3 Operating Guides.

a. Remove service meters from the section being flushed.

b. Flush each pipe section until water is reasonably clear.

c. Take care not to damage unpaved roads, walks, or improved grounds. If necessary, use a section of lightweight pipe to direct flows so that damage does not occur.

d. Place all valves in normal operating position before proceeding to the next flushing point.

e. To permit flushing dead ends, install a blow-off at the end of each end main. Paint the blow-off hydrants a different color than fire hydrants and prominently mark them as blow-off hydrants. Dead ends may need flushing more often than other sections of the system.

For information on hydrant flushing, see Chapter 7.

6-3.4 Cleaning.

Corrosion, scale, and deposited matter cannot normally be removed with simple flushing. When increased system head loss reduces system capacity below fire flow requirements, mechanical cleaning is necessary. As a rule, this work is done on a contract basis by firms specializing in main cleaning. After cleaning, the mains may be relined to restore original smoothness of the interior. If this is properly done, 95% or more of the original capacity can be restored. If the mains are not lined with a corrosion-resistant material after cleaning, start chemical treatment to prevent accelerated corrosion and red water. Best practice information on cleaning water mains can be found in *AWWA M28*, and *AWWA M51. Some operational best practices can be found in Water Treatment Plant Operation, Volumes 1 and 2*.

6-3.5 Electrical Thawing of Frozen Systems.

Pipes may freeze in temperate as well as frigid zones. In frigid climates, freezing presents a major problem to a water distribution system, and pipes are normally insulated and heated. In areas where the ground is permanently frozen, water pipes are placed in heated conduits. In temperate climates where freezing is only a seasonal problem, pipes are typically buried below frost penetration depth. It is also necessary to heat stored water in cold areas. Even with proper protection against freezing, pipes may freeze. When this happens, thaw pipes by electrical thawing. Perform electrical thawing by means of hot wire tape. The use of generator welding machines to thaw pipe is not acceptable.

Table 6-3 Current and Voltage Required to Thaw Wrought-Iron and Cast-Iron Pipe

	Pipe Size		Pipe Length		Approx. Volts	Approx. Amps
	Inches	(mm)	gpm	(Lps)		
Wrought iron	3/4	(20)	600	(180)	60	250
	1	(25)	600	(180)	60	300
	1-1/2	(40)	600	(180)	60	350
	2	(50)	500	(150)	55	400
	3	(75)	400	(120)	50	450
Cast iron	4	(100)	400	(120)	50	500
	6	(150)	400	(120)	50	600
	8	(200)	300	(90)	40	600

- Current and Voltage. Data concerning the current and voltage required to thaw various sizes of wrought-iron and cast-iron pipe are given in Table 6-3.
- Required Time. The time required for electrical thawing varies from 5 minutes to over 2 hours, depending on the pipe size and length, the intensity of freezing, and other factors. The best practice is to supply current until the water flows freely.
- Do not use a current higher than the one listed for the pipe size in Table 6-3. When in doubt, use a lower current for a longer period.
- Select contact points on the pipe as close as possible to the frozen section.
- Make sure contact points are free of rust, grease, or scale.
- Remove meters, electrical ground connections, and couplings to building plumbing from the line to be thawed.
- If pipe joints have gaskets or other insulation, thaw the pipe in sections between the joints or use copper jumpers to pass the current around the insulated joints.

6-3.6 Steam Thawing.

Steam thawing is slower than electrical thawing and used only when insulating material in pipe joints or couplings makes the use of electricity impractical. In steam thawing, a hose connected to a boiler is inserted through a disconnected fitting and gradually advanced as the steam melts the ice. Steam thawing is commonly used on fire hydrants.

6-3.7 Instrumentation, Control, and Information Management.

Information on these topics can be found in *AWWA M2*.

6-4 STORAGE FACILITY OPERATION.

Drain finished water to the ground and dechlorinate as necessary prior to introducing it into the storm sewer drains. Perform storage tank O&M in accordance with the facility's written inspection program and *AWWA G200* Section 4.3.1. Inspect tanks, regardless of tank material, by dry, underwater, or robotic inspection and in accordance with AWWA M42 Chapters 8 and 9 and AWWA C652 Section 4.4. Use dry inspection when possible to allow for the cleaning of the tank prior to inspection by trained technicians. Underwater evaluation is performed in accordance with AWWA M42 Chapter 9. Inspection by remotely operated vehicle (ROV) is performed in accordance with the requirements in AWWA C652 Forward II and AWWA M42 Chapter 9 Periodic Reinspection. Perform inspection in accordance with above standards, as indicated by the operating permit and by state or local requirements, whichever is more stringent.

6-5 STORAGE FACILITY MAINTENANCE.

Guidance on specific maintenance procedures and paint systems applicable to water storage facilities can be found in Chapter 10 paragraph titled Tanks and Reservoirs. Paint or coat exterior of tanks in accordance with *ANSI/AWWA D102.*

6-5.1 Safety.

Only trained and experienced operators are permitted to work on elevated and ground-level storage tanks and standpipes. This work is hazardous and dangerous for untrained workers. Special precautions are also needed for work on or in tanks. In these confined working areas, workers need to guard against slipping or falling from dangerous heights. Refer to *DoDD 4715.1E, OSHA Part 1910.146* and *AWWA M3*.

The following guidelines apply to working in and around storage facilities.

- Read, understand, and follow all applicable safety directives, including those pertaining to confined-space entry.
- Check the security of ladders frequently. Provide required safety cages or safety cable equipment.
- Provide workers with boots and clothing for working in wet and slippery conditions.
- Provide workers performing disinfection with special protective goggles and gloves.
- Install special fans or other ventilation equipment inside tanks while work is being done there.
- Provide adequate light inside tanks so that personnel can perform their work properly and safely. Take special care to use waterproof wiring and light units to prevent shocks in a wet environment.

CHAPTER 7 VALVES AND HYDRANTS

7-1 VALVES AND VALVE OPERATION.

Valves are used in water supply systems to start and stop flow, throttle or control the quantity of water, regulate pressures within the system, and prevent backflow. Valves typically are operated using manual, electrical, hydraulic, or pneumatic operators. Most valves used in water systems fall into one of the following general valve classifications: gate, globe, needle, pressure relief, air/vacuum relief, diaphragm, punch, and rotary. The type of valve and the method used to operate it depends on the use of the valve, its function in the water system, and the source of energy available.

7-1.1 Manual Operation.

Small valves or valves that are used infrequently generally are operated manually. Open manually-operated valves all the way, then close one-quarter turn of the handwheel. This prevents the valve from sticking in the open position. Open and close the valve slowly and at an even rate to reduce the hazard of a hammer. Open the valve by turning the handwheel or key counterclockwise or in the direction identified by the open arrow on the valve. Always consult the manufacturer’s instructions for operating a specific type of valve. It is good practice to operate (exercise) valves periodically.

7-1.2 Power Operation.

Only minimal attention is required for operating power-operated valves, except in the case of power failure. In this event, consult the manufacturer’s instructions for emergency manual operation. Most power-operated valves are equipped with safety devices to allow for emergency manual operation.

7-1.3 General Maintenance of Valves, Valve Boxes, and Accessories.

A general valve maintenance schedule is presented in Table 7-1. Specific maintenance procedures for various valve types and valve accessories are provided in literature supplied by the valve manufacturer. Maintain valve boxes on the same basis as the valve maintenance schedule in Table 7-1 or as directed by local command. Maintain a record of all valve physical, location, and operational characteristics along with the manufacturer, year installed, model, depth to operating nut, and any existing work orders.

Table 7-1 Valves and Accessories Maintenance Checklist

Inspection	Action	Frequency
Gate valves/ distribution system valves	Locate, check operation, lubricate stem packing; if packing leaks, dig up valve and tighten packing gland or replace packing; check stem alignment; check for broken stem or stripped stem or chewed nut.	Semi-annually
Valve bypass	Check for position, inspect, and lubricate.	Semi-annually
Gears	Check and lubricate; correct any deficiencies.	Semi-annually
Vault	Check condition, clean, and check masonry; make repairs as necessary.	Semi-annually
Treatment plant valves	Operate inactive valves.	Quarterly
	Lubricate as required (including gears).	Annually
	Replace or resurface leaking valve seats.	Variable
	Lubricate chain wheels.	Quarterly
Butterfly valves	Check valve stem for watertightness and adjust if necessary.	Semi-annually
	Check operation and inspect for tight closure.	Annually
Rotary valves/ cone valves/ ball valves	Operate; lubricate metal-to-metal contacts in pilot mechanism; lubricate packing glands; lubricate all parts of seating and rotating mechanisms.	Monthly
	Dismantle, remove corrosion products, wire brush plug and valve body; paint valves with corrosion-resistant paints.	Annually
Plug valves	Lubricate with lubricant stick.	Quarterly
	Operate all valves; check for corrosion and foreign matter between plug and seat; lubricate gearing.	Quarterly

Inspection	Action	Frequency
	Inspect; dismantle if necessary; clean, wire brush, re-machine plug and body or replace if condition is beyond re-machining.	Annually
Curb stops	Remove and replace whenever necessary.	Variable
Multiport valves	Lubricate with grease.	Semi-annually
Globe valves	Operate valve to prevent sticking; check for leakage, adjust packing nut, and replace packing if necessary.	Quarterly
	Check valve closure for tight shutoff; if valve does not hold, remove valve stem and disk and regrind seat and disk.	Semi-annually
Diaphragm valves	Operate valve; check valve stem and lubricate as necessary; check for tight closing.	Quarterly
	Check diaphragm for cracks; renew as necessary.	Annually
Sluice gates	Operate inactive gates; lubricate stem screws and gears.	Monthly
	Clean valve with wire brush and paint with corrosion-protective paint.	Annually
	Check seating wedges on valves seating against pressure.	Annually
Backflow preventers	Test tightness of unit if there is reduced pressure.	Monthly
Hydraulic cylinder	Check through one valve operation cycle.	Monthly
Piston rod and tell-tale rod	Oil packing; tighten packing gland if leakage exists; replace packing if necessary.	Monthly
Waste line discharge	Check for water flow when valve is wide open and shut; if leakage occurs, disassemble valve and piston, check leathers for wear and replace as necessary.	Monthly

Inspection	Action	Frequency
Cylinder and piston	Disassemble; inspect for scoring and corrosion; check cup leathers; polish any scored areas; remove corrosion products from piston surfaces and cylinder heads.	Annually
Pneumatic valve operators	Check packing and air hose; lubricate as necessary.	Monthly
	Check piston, cylinder, and leathers; polish any scored areas; remove corrosion products from piston surfaces and cylinder heads.	Annually
Motorized valve operators	Operate valve and check for tight closing.	Quarterly
	Change gear drive lubricant.	Quarterly or after 500 hours of operation, whichever is more frequent
	Maintain electric motors as described in Chapter 10 paragraph titled Electric Motors.	
Valve operator pilot controls	Check control through one full cycle of operation.	Monthly
	Lubricate pins, linkage, packing glands, and adjustment rod threads as necessary; remove corrosion products; check for leakage and repair.	Monthly
	Disassemble; inspect unit and clean strainers; examine diaphragm for failure; regrind or replace worn valve seats.	Annually
Air-release valves, valve unit	Remove valve from service; inspect float for leaks, and pins and linkage for corrosion; remove corrosion products; clean orifices.	Annually
Vault	Inspect for condition of masonry, steps, and manhole covers; repair as necessary.	Annually

Inspection	Action	Frequency
Altitude valve pilot controls	Inspect and lubricate.	Monthly
Valve unit and operator	Disassemble; inspect hydraulic cylinder and repair; inspect valve, repair, and paint, as necessary.	Annually
Check valves	Inspect the closure control mechanism (if any); clean and adjust as necessary; check pin wear if balanced disk type; check seating on ball type.	Annually
	Disassemble; clean, reseat, and repair as necessary.	Variable
Float valves	Inspect float; repair as necessary.	Monthly
	Inspect valve and valve operating mechanism.	Annually
Pressure-regulating valves	Inspect, clean, adjust, disassemble, and repair as necessary (see manufacturer's instructions).	Annually
Gear boxes	Lubricate gears (see manufacturer's instructions).	Monthly or weekly
	Check gear operation through full operating cycle and listen for undue noise, check for vibrations or any other restrictions to operation.	Semi-annually
	Check housing for corrosion; paint as necessary.	Annually
Valve boxes	Clean debris out of box; inspect for corrosion; check alignment and adjust as necessary.	Semi-annually
Floor stands	Lubricate stem and indicator collars.	Quarterly
	Inspect condition; clean and paint.	Annually
Post indicators	Lubricate.	Quarterly
Electric position indicators	Check contact points and wiring.	Annually

7-1.4 Distribution System Valves.

Distribution system valves are normally buried gate valves. These valves are usually equipped with a 2-in.-square (50-mm-square) operating nut, accessible through a valve box, that requires a valve key for operation. Common difficulties with distribution system valves are "lost" valves, inoperable valves, and valve boxes that have been covered by road work or filled with foreign matter.

7-1.4.1 Lost Valves.

The lost valve problem can be avoided by using an indexed valve record book in which all pertinent data are recorded, including all valve locations. Identify valves using geographic information system coordinates and save the coordinates in the valve record book. If a valve is lost, use a dip needle, miner's compass, or metal detector to locate the valve box. Once a lost valve is located, update the coordinates in the record book. A good valve record includes information on maintenance operations performed, tells whether the valve was opened or closed at the time of inspection, and lists any errors in location. Keep one copy of the valve record book with the maintenance crew and keep one on file.

7-1.4.2 Maintenance Procedures.

Distribution system valves are usually left open and operated only during emergencies. Establish a valve exercising program per best practice *AWWA M44 Chapter 5*. The program should include goals on how often each valve is exercised, measures to verify goals are met, and written procedures for follow-up and maintenance/replacement if goals are not met and should identify critical valves in the system to ensure they are exercised more frequently.

To check the operation of the valve, first close the valve completely and then open it completely. Back off on the valve about one turn to avoid locking the valve in an open position. If the valve does not operate properly, perform necessary maintenance and repair at once. Note all maintenance and repair in the valve record book. Guidelines for valve replacement and repair are available in further detail in *AWWA M44*. Turns-to-open should be recorded in the asset inventory and compared to the installation record to ensure full valve mobility. Table 7-2 lists potential valve issues and solutions.

Table 7-2 Distribution System Valve Maintenance Checklist

Item	Problem	Solution
Valve seating	Foreign matter lodged on the valve seat	Open valve slightly to give a high-velocity flow across the valve seat. Open a hydrant to increase flow, if necessary, to flush the foreign matter out of the valve seat.
Valve stem sealing	Packing is dry	Check and lubricate the valve-stem packaging. Dry packing will impede valve closure at all points of the stem movement. Lubricate dry packing by pouring a mixture of half kerosene and half lubricating oil down a ½-in. (13-mm) pipe to discharge the mixture onto the stem below the operating nut.
	Packing is leaking	Dig up the valve, tighten the packing gland, or replace the packing as necessary. To reduce leaking while replacing packing, open the valve as wide as possible.
	O-ring seals are leaking	If water is leaking around the stem, replace the O-rings (if applicable).
Valve stem	Valve stem is out of alignment, broken, or has stripped threads	If the valve stem is out of alignment, the valve operates easily near open or closed positions but not when the valve is partially closed. Replace the valve stem, following the manufacturer’s instructions. If the valve-stem nut is missing or damaged, replace it.
	Valve stem is broken	A broken or stripped stem permits unlimited turning of the stem without closing the valve. Replace the valve stem, following the manufacturer’s instructions. If the valve-stem nut is missing or damaged, replace it.
Valve seat refacing	Leaking gate valve seat	Follow manufacturer’s instructions to remove and reface the valve seat, including the following: remove the bonnet and inspect and clean all working parts; check all working parts for signs of wear or deterioration; remove old packing or O-rings; refinish working parts by grinding, sanding or polishing, and lapping; replace all parts

Item	Problem	Solution
		beyond repair; and replace the valve parts and repack and test the valve for proper operation.

7-2 HYDRANTS.

Fire hydrants are mainly used for fire protection. Other uses include flushing water mains and sewers and filling tank trucks for street washing and tree spraying. Hydrants may also be used as a temporary water source for construction jobs. General information related to types of hydrants, component parts, O&M, common operating problems, records, and hydrant safety is included in *PAWSOS: Water Transmission and Distribution* and *AWWA M51*. Keep maintenance and testing records and analyze them periodically to identify any long-term loss in distribution system carrying capacity.

7-2.1 Hydrant O&M.

Hydrants should maintain a minimum residual pressure of 20 psi when delivering fire flow. A hydrant maintenance and fire-flow testing program should be in-place. The program should include a goal for the hydrants to be inspected and tested annually, procedures for opening and closing the hydrants to minimize potential system damage, testing requirements, and a replacement goal for inoperable hydrants. Maintenance procedures for specific types of hydrants are provided in *AWWA M17*, including hydrant inspection and flow tests. Manufacturer-specific procedures should always be followed, including inspection frequency and lubrication. Use UFC 3-601-02 for technical guidance related to hydrant and flow testing. Additional details are provided below.

7-2.1.1 Hydrant Inspection.

Inspect hydrants annually and after each use at a minimum. Inspection crew should be equipped to repair hydrants at the time of their inspection. The hydrants should be tested by personnel familiar with the water system and coordinated by the fire marshal, according to command and field engineering office directives. Hydrants can usually be maintained by replacing all worn parts and seats through the top of the hydrant. The operator is generally responsible for ensuring that the proper tools are used. Specific inspection procedures, by hydrant type, are available in *AWWA M17*. Each year test the hydrant for tightness of joints and fittings in the following manner.

Remove one hydrant cap and replace it with a cap fitted with a pressure gauge. Open the valve slowly until it is wide open. Record the pressure. Check for leakage at the following points:

a. Hydrant Top. If a leak is found, remove the cover plate and tighten or repack the seal.

b. Nozzles Entering Barrel. For leaks here, caulk the connection with lead.

c. Nozzle Caps. If the nozzle caps are leaking, replace any defective gaskets.

d. Cracks in Barrel. For leaks from cracks in the barrel, install a new barrel or a new hydrant.

Table 7-3 Maintenance Checklist for Fire Hydrants

Inspection	Action	Frequency
Dry-barrel hydrants	Check drain valve to be sure it opens.	Annually
	Where ground water level rises into barrel, plug drain valve and dewater barrel by a pump.	Annually
Wet-barrel hydrants	Check packing glands and valve seats; repair as necessary,	Annually
Pit-type hydrants	Check for water accumulation; dewater as necessary.	Annually
Hydrants on dead-ends	Flush; check barrel after flushing.	Annually
Hydrants not on dead-ends	Flush; check barrel after flushing.	Annually
	Check water flow.	Annually
	Repair as necessary; if main shut down is required, notify public works and the fire department.	Variable
Drain valve	Inspect all places where leaks might occur; repair as necessary.	Monthly
Operating nut	Check for rounded corners; replace as necessary; lubricate.	Annually
Nozzle threads	Check for damage; replace as necessary.	Annually
Chains	Check for paint fouling; clean.	Annually

7-2.1.2 Hydrant-Flow Tests.

Flow tests are conducted to determine pressure and flow within the distribution system. They can also detect closed valves within the system, identify water available for firefighting, and determine the general condition of the system. Conduct flow tests on all parts of the distribution system every 5 years, at a minimum. Maintain records for each flow test performed.

During flow tests, the hydrant nozzle needs to be unobstructed, so the only way of protecting property is to choose the nozzle that will do the least damage. Provide barricades to divert traffic and take any other precautions necessary to minimize property damage and prevent personal injury. Conduct hydrant-flow testing in accordance with *AWWA M17, AWWA M31,* and *NFPA 291*. Best practice reference is *Water Treatment Plant Operation, Volumes 1 and 2*.

If a water system model exists for the facility, the operator should request that engineering public works provide a table listing all the fire hydrants in the model and project the flow at 20 psi residual for each hydrant. When the operator runs a hydrant test, this information for comparison would be useful. If the results are off any significant amount, it would be an indicator that some of the valves in the network are closed, partially closed, or damaged in some way.

7-2.1.3 Hydrant Flushing.

Flush hydrants to prevent sediment buildup in the hydrant and its connecting piping. Hydrant flushing should occur annually at a minimum and coincide with hydrant inspection. **\1** Take care to prevent damage to the hydrant main valve during flushing. To flush the hydrant, open the hydrant slowly by rotating the stem nut on top of the hydrant using a hydrant wrench. Open the hydrant gate valve to begin flowing water. High-pressure water cleaning should be conducted in accordance with the hydrant and hydrant pipe manufacturer’s recommendations. **/1/**

Water flow rates required for flushing water mains is given in *AWWA M31*. Before beginning the flushing, plan to divert flushing flow to prevent property damage. Use flow diffusers or a length of fire hose where necessary to direct the flow into a gutter or drainage ditch. Do not use a rigid pipe connected to a hydrant outlet and turned at an angle to divert flow down a gutter; the torque produced by the angular flow could be enough to twist or otherwise damage the hydrant.

7-2.2 Hydrant Safety.

In addition to the general safety precautions detailed in *AWWA M3*, special precautions must be taken to prevent injury and damage to private property during hydrant flushing. Divert the flow from traffic areas as necessary to prevent obstruction of traffic or freezing on road surfaces. If flow from the hydrant is diverted with a hose, the hose must be securely anchored. If the hose is inserted into a storm sewer, take care not to create a cross-connection.

CHAPTER 8 INSTRUMENTATION AND CONTROL AND WATER METERS

8-1 OVERVIEW.

This chapter contains information on primary instrumentation (sensors), secondary instrumentation (transmitters and recorders), and control systems as well as SCADA systems, which are relatively new tools for controlling and monitoring water treatment systems. Remote monitoring and control systems must meet the Installation's IT security requirements and standards. Special attention is given to O&M of water meters and other flow measuring devices, such as weirs and flumes.

8-2 INSTRUMENTATION AND CONTROL.

The term "instrumentation," as used in the water works industry, refers to a range of equipment used for observation, measurement, and control. Equipment types range from simple mechanical, direct-reading meters and gauges to complex electronic, automatic monitoring/control systems. All I&C systems have a sensing device. More complex systems will include one or more of the following elements: transmitter, indicator, and recorder. Modern I&C equipment allows an operator to monitor and control equipment, flow rates, pressures, levels, and processes not only at the water treatment plant but for all parts of the distribution network as well.

8-2.1 Water Meters.

The primary function of water meters is to measure and record the volume of water flowing in a line. Flow is the most important measurement made at water supply facilities. Flow data are used to account for the water treated and pumped to distribution, chemical flow pacing, and long-range planning. Various types of meters and flow measuring devices, including flumes and weirs, as well as installation, testing procedures and test equipment, recordkeeping, general maintenance, and repair of meters may be found in *AWWA G200, AWWA M6,* and *AWWA M33.*

8-2.2 Meter Reading.

Meters are generally furnished with registers that measure water flow in terms of flow rate or total volume. Water meter registers are typically of two general types: the straight-reading type and the circular-reading type. The straight-reading type is read like the odometer on a car. The meter register reports the number indicated by the counting wheels. Fixed zeroes to the right of the counting wheel window should be included in the meter reading. The circular reading dial is somewhat difficult to read and has been gradually replaced by straight registers on new meters. When a hand on any scale is between two numbers of a circular reading dial, the lower number is read. If the hand seems exactly on any figure, check the hand on the next lower scale. If that hand is on the left side of zero, read the figure on which the hand lies. Otherwise, read the next lower figure.

Because the registers are never reset while the meters are in service, the amounts recorded for any given period are determined by subtraction. To obtain the volume of water that passed through the meter since the previous reading, subtract the previously recorded reading from the present reading. The maximum amount that can be indicated on the usual line meter before it turns to all zeros and starts over again is 99,999 cubic feet, or 999,999 gallons. Thus, to get a current measurement when the reading is lower than the last previous one, add 100,000 to the present reading on a cubic feet meter or 1,000,000 to the present reading on a gallon meter. The small denomination scale giving fractions of 1 cubic foot or 10 gallons is used for testing purposes only and is disregarded in the regular reading.

Best practice information regarding direct meter readout and remote reading may be found in *AWWA M6*.

8-2.2.1 Automatic Meter Reading.

Automatic meter reading (AMR) is a technology where meters can send data directly from the meter to a remote reading device. AMR can be done by drive-by systems or by using a fixed network. One of the most common forms of AMR uses the drive-by gathering method. Data is transmitted from the meter to a mobile collection device or location at the water utility via telephone network, cable TV system, electrical power main, or radio frequency-based system, where the data can be received at a certain distance from the meter. Usually, the transmission from the meter can be picked up by an on-board recording device while driving by the residential or commercial buildings. The ease of gathering the data allows meter readings to be done more frequently. Another method used is a fixed network system. Data collectors are installed at points in the service area that collect meter data. This allows data to be collected as often as the utility desires and can give the utility and customer more accurate data about water usage. The real-time data gives customers more information and can be very helpful in resolving meter reading disputes. A combination of fixed network and drive-by may be the best AMR solution due to the varying degrees of population density.

One of the obvious benefits of both drive-by AMR and fixed network AMR is a decrease in meter reading costs. Without this technology, access to each meter or external encoder is required to get the meter reading. Additionally, an indoor meter may not be accessible if a customer is not at home. Since AMR readings are easier to get, readings can be done more frequently, and billing can be done monthly instead of quarterly, improving cash flow for the utility. Where meters are to be replaced, replace them with models that can easily be converted to AMR systems in the future. When qualifying and selecting meter manufacturers, investigate the compatibility of the meters offered by manufacturer with the existing or planned AMR infrastructure.

8-3 INSTRUMENTATION MAINTENANCE AND REPAIR.

The success of water instrument maintenance procedures is based on knowledge of the construction, operation, and adjustment of the equipment; availability of the necessary special tools; and stored spare parts and special instructions from manufacturers. For the special knowledge necessary, maintenance personnel are advised to consult the manufacturer’s instructions. Best practice information on maintaining water meters can be found in *AWWA M2*, *AWWA M6*, *AWWA M33*, and *AWWA M51*. Troubleshooting checklists and flowcharts for various I&C equipment can be found in *AWWA M2*.

8-3.1 Maintenance Schedules.

The design and intricacy of meters, instrumentation, and automatic control systems depend on the function to be performed and the manufacturer's particular equipment. Because there are many manufacturers of meters, instruments, and automatic controls, listing specific maintenance procedures that apply to all units is not possible. The procedures here are basic and the minimum required for the most common types of units. When developing maintenance schedules, personnel may adapt the procedures given here to specific directions Issued by the manufacturers.

8-3.2 Inspection and Maintenance Records.

Maintain a log of all inspection and maintenance actions. Use a card file for each piece of equipment, showing the type of equipment, the manufacturer's serial number, the date installed, the location, and the frequency of scheduled maintenance. Arrange cards chronologically so that the card will come to the attention of maintenance personnel at the proper time for the inspection to be made.

Where a computer system is used on the base, enter the service or meter history card information to establish a permanent record, and assign a control number for each service or meter. Include the following information in the record: meter size, make, model, type, serial number, date of purchase, current location, previous locations, repair history, and testing history. Future information concerning work on a service line or meter testing and repairs are to be entered for the appropriate control number. More information management guidance can be found in *AWWA M2*.

8-3.3 Sensor Maintenance.

Maintenance procedures for flow, pressure, and level-sensing devices are given in Table 8-1. Confirm frequency with local command.

Table 8-1 Maintenance Checklist for Flow, Pressure, and Level Sensors

Inspection	Action	Frequency
Flow Sensors		
Venturi-type devices		
Annular chamber	Flush and clean annular chamber, throat and inlet; purge trapped air from chamber and connecting piping; flush piezometer pressure taps.	Quarterly
Exterior	Clean and paint as necessary.	Annually
Interior	Check interior for corrosion; dismantle, clean, and restore smoothness of interior surfaces as necessary; for flanged joints, check possible intrusion of gasket into interior; replace if necessary.	Annually
Orifice plates	Remove plate, dress off roughness; flush sediment traps.	Annually
Pitot tube	On permanent installations, check tips and clean.	Quarterly
Flow tube	Check instrument taps; flush if necessary.	Quarterly
Pressure Sensors		
Diaphragm	Disassemble and check for condition and leaks; clean, adjust, repair, or renew as necessary; check calibration.	Annually
Bourdon tube	Check calibration, clean and adjust as necessary.	Annually
Manometer	Clean tubes and gage unit as necessary.	Semi-annually
	Check mercury level and add mercury if necessary; clean or replace mercury if necessary.	Annually or Variable

Inspection	Action	Frequency
Level Sensors		
Floats	Check for bent rod, binding, or other damage; correct undesirable conditions; apply light oil to moving parts; check alarm system.	Monthly
Bubble pipe	Check air discharge pipe for freeness; check air compressor system; clean, repair, or renew worn parts as necessary.	Quarterly
Probes	Check contacts, wiring, and electrical connections; repair as necessary.	Quarterly
	Check probe surface; check calibration; clean, repair, or renew as necessary.	Semi-annually

8-3.4 Transmission System Maintenance.

Information needs to be transmitted from the sensing device, which measures the variable, to the instruments that indicate, record, or total it. The transmission system may be mechanical, hydraulic, pneumatic, or electrical. Each system consists of two components—the transmitter and the transmission link. Maintenance procedures for transmission systems are summarized in Table 8-2. Confirm frequency with local command.

Table 8-2 Maintenance Checklist for Transmission Systems

Inspection	Action	Frequency
Mechanical	Direct links—make certain pulley, drums, cable, etc., work freely and are not corroded; clean, lubricate, and adjust.	Quarterly
Hydraulic	Pressure links-blow down pressure lines, make certain there are no restrictions; correct adverse conditions.	Semi-annually
Pneumatic		
Transmitter	Flush liquid side of air-relay units; clean; if necessary check diaphragm; check air-input orifice, clean, blow out moisture traps.	Daily
	Disassemble, repair, or renew as necessary.	Variable
Link	Check connecting tubing for condition; check nozzle system for leaks.	Semi-annually
Electrical		
Transmitter	Service transmitter; check signal interval length over instrument range.	Monthly
	Check mercury switch and magnet; adjust as necessary.	Quarterly
	Remove old lubricant, add new.	Semi-annually
Link	Check wires whenever necessary.	Variable
Indicators	Clean cover and glass of gauges.	Semi-annually
	Check zero setting and calibration	Annually
Mechanical transmission	Inspect and service as for transmitter.	Quarterly

Inspection	Action	Frequency
Hydraulic transmission	Vent air from mercury wells; check pulley shaft, chain, cam, stuffing box, and other parts.	Weekly
	Check mercury wells; add new mercury if necessary; clean or replace mercury if necessary.	Annually
Pneumatic transmission	Service on same schedule and in same manner as transmitter.	
Electrical transmission	Service generally on same schedule as transmitter.	
	Clean unit, especially dials.	Semi-annually
	Check operation, adjust and repair as necessary.	Annually
Recorders	Clean pen; check ink flow; check cam cycle and pulley freedom.	Bi-weekly
	Check zero position; adjust and lubricate.	Quarterly
	Check contact points, armature, clutch, clutch cups, etc.; clean, adjust, repair, or renew parts.	Semi-annually
	Renew modular unit if necessary.	Variable
	Renew illumination lamp as necessary.	Variable
Totalizers	Inspect, clean, adjust or repair on same schedule as recorders.	
Combination	Check, clean, adjust or repair on same schedule as individual components.	

8-3.5 Indicator, Register, and Recorder Maintenance.

Besides transmission devices, secondary instruments include indicators or gages (momentary indication of discrete information), recorders (chart record of information by time), and registers or totalizers (also termed “integrators”). The latter category expresses the total quantity of measured variable from start to current time. There are many styles and designs of each basic type, and various combinations of these types. Therefore, no detailed maintenance procedure can cover all types, designs, and combinations. Maintenance procedures depend not only on the type of receiver (indicator, recorder, or register) but also on the type of transmission system used. Maintenance personnel should study the manufacturer’s instructions for detailed procedures in addition to following the basic maintenance procedures for indicators, registers, and recorders summarized in Table 8-3. Confirm frequency with local command.

Table 8-3 Maintenance Checklist for Indicators, Registers, and Recorders

Inspection	Action	Frequency
Indicators l	Clean cover and glass of gages.	Semi-annually
	Check zero setting and calibration.	Annually
Mechanical transmission	Inspect and service as for transmitter.	Quarterly
Hydraulic transmission	Vent air from mercury wells; check pulley shaft, chain, cam, stuffing box, and other parts.	Weekly
	Check mercury wells; add new mercury if necessary; clean or replace mercury if necessary. Use caution when handling mercury to avoid spills – mercury fumes are poisonous.	Annually
Pneumatic transmission	Service on same schedule and in same manner as transmitter.	
Electrical transmission	Service generally on same schedule as transmitter.	
	Clean unit, especially dials.	Semi-annually
	Check operation; adjust and repair as necessary.	Annually
Recorders	Clean pen; check ink flow; check cam cycle and pulley freedom.	Bi-weekly

Inspection	Action	Frequency
	Check zero position; adjust and lubricate.	Quarterly
	Check contact points, armature, clutch, clutch cups, etc.; clean, adjust, repair, or renew parts.	Semi-annually
	Renew modular unit if necessary.	Variable
	Renew illumination lamp as necessary.	Variable
Totalizers	Inspect, clean, adjust or repair on same schedule as recorders.	
Combination	Check, clean, adjust or repair on same schedule as individual components.	

8-3.5.1 Recorders.

Recording instruments have all the fundamental elements of an indicator unit and contain a clock mechanism (spring or electrical), a chart, and a marking pen. Charts may be either circular or strip and are changed on schedule by operating personnel. Maintenance procedures depend on the type of transmission system employed, the design, and other factors. Consult the manufacturer's instructions for detailed procedures. General maintenance procedures are included in Table 8-3.

8-3.5.2 Totalizers or Registers.

This type of receiver has internal components similar to those in recorders. In addition, it contains an integrator mechanism that converts transmitted signals into a sum of the total quantity of material that has moved past the point of measurement from the beginning of the measured period to the time of observation. This total appears on a numerical register similar to an automobile odometer. Clean, service, and adjust registers according to the manufacturer's instructions on the same general schedule as recorders.

8-3.5.3 Combination Totalizer Indicator-Recorder.

There are various combinations, designs, and styles of instruments in this classification. There are also devices that sum totals from various individual totalizers or show ratios of one flow to another. In general, the maintenance procedures and schedules for this category are a combination of the procedures for the individual units above. Develop a maintenance schedule according to the manufacturer's instructions.

8-3.6 Water Meter Maintenance.

Maintenance procedures for water meters are summarized in Table 8-4. Further guidance on meter maintenance and repair is available in *AWWA M6*. The accuracy of cold water meters can be tested by the volumetric method, using volumetric tanks, or the gravimetric method, using weight scales. Various *AWWA C700*-series standards contain accuracy standards for new meters. See *AWWA M6* Table 5-2 for the recommended water meter testing intervals by state. Test rates for a variety of meter types are present in Table 5-3 of *AWWA M6*. All necessary testing equipment is also outlined in Chapter 5 of *AWWA M6*.

Table 8-4 Maintenance Checklist for Water Meters

Inspection	Action	Frequency
Volume meters	Check operation; check for noise.	Monthly
	Check mounting and alignment.	Annually
Velocity-type meters	Check operation; check for noise.	Monthly
Meter pit	Clean, remove water before freezing season.	Semi-annually
Exterior	Paint as necessary	Annually
Interior	Check for worn parts, repair or replace as necessary.	Variable
Proportional meters	Check on same program as velocity meters	Variable
Compound meters	Check large-flow component on same schedule as velocity-type meters	Monthly
Magnetic flow meters	Check electrical connections.	Annually
Meter pit	Check, clean, remove water to protect against freezing.	Annually (Fall)
Measuring unit	Check for possible hot water damage	Annually
Unit parts	Check for worn parts, repair or replace as necessary; clean and brighten.	Variable

8-3.7 Weir and Flume Maintenance.

All types of head-area meters are used for open-flow measurement, and their proper operation depends on the absence of any kind of interference at the discharge opening. Maintenance procedures for weirs and flumes are summarized in Table 8-5.

Table 8-5 Maintenance Checklist for Weirs and Flumes

Inspection	Action	Frequency
Weirs	Check weir edge to make certain it is clean.	Daily
	Check and open breather pipe, if any.	Monthly
	Drain weir to check evenness of water break- over; check for tuberculation or corrosion; dress-off rough spots	Annually
Parshall Flume	Check throat section to be sure it is clean and free of growths.	Monthly
	Clean stilling well and connecting pipes.	Quarterly

8-4 SAFETY.

General hazards connected with servicing I&C systems include use of hand tools, working in confined spaces, and electric shocks. Special attention should be given to prevent electrical shock that may be caused by improper grounding of building electrical systems onto the plumbing system. If residential water meters are not mounted on a yoke or if a permanent jumper wire is not provided across the meter connections, use a separate wire with large alligator clips as a temporary bridge between the pipes when meters are removed or installed.

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CHAPTER 9 CROSS-CONNECTION CONTROL AND BACKFLOW PREVENTION

9-1 CROSS-CONNECTIONS AND BACKFLOW.

Cross-connections are the physical links through which contaminated materials can enter a potable water supply. The contaminant enters the potable water supply when the pressure of the polluted source exceeds the pressure of the potable source. The flow of contaminated water to the potable system is called "backflow." Backflow results from either back pressure or back siphonage. Backflow due to back pressure occurs when the user's water system is under higher pressure than the public water supply system. Back siphonage is caused by the development of negative or sub-atmospheric pressures in the water supply piping. This condition occurs when system pressure is lowered by pump malfunction or high fire flow.

Use UFC 3-230-01, UFC 3-420-01 and UFC 3-600-01 for backflow prevention and cross connection control.

For the Army, University of Southern California Foundation for Cross Connection Control and Hydraulic Research *Manual of Cross-Connection Control* shall be a requirement for backflow prevention devices.

9-2 \2\ DEGREE OF HAZARD /2/.

\2 Backflow hazards have been divided into two classes: low health hazard (non-health hazard) and high health hazard (heath hazard). ***/2/***

9-2.1 \2\ Low Hazard /2/.

\2 Refer to the IPC for a definition of pollution, also referred to as low hazard or low health hazard as defined by AWWA M14. ***/2/***

9-2.2 \2\ Not Used /2/.

\2\ /2/

9-2.3 \2\ High Hazard /2/.

\2 Refer to the IPC for a definition of contamination, also referred to as high hazard or high health hazard as defined by AWWA M14. ***/2/***

9-3 BACKFLOW PREVENTION.

Use UFC 3-230-01, UFC 3-420-01 and UFC 3-600-01 for the selection of backflow prevention devices and assemblies.

For the Army, for backflow prevention between potable water lines, irrigation systems, and for fire protection connections, use devices listed in IPC Chapter 6 and the University of Southern California Foundation for Cross Connection Control and

Hydraulic Research *Manual of Cross-Connection Control*. Find additional descriptions of backflow prevention devices in best practice *AWWA M14*. *Unified Facilities Guide Specifications Section 33 11 00 Water Utility Distribution Piping* shall be a requirement for backflow prevention devices and the *Manual of Cross-Connection Control*.

For the Air Force, **\1** *AFMAN 32-1067* **/1/** shall be a requirement for backflow prevention devices.

9-4 INSPECTION AND TESTING SCHEDULE.

\2 Conduct inspection and testing in accordance with UFC 3-420-01, state or local regulations, whichever is more stringent. **/2/**

9-4.1 Inspection.

\2 Inspect backflow prevention devices and air gaps installed in lieu of backflow prevention devices or assemblies. Ensure:

- Backflow prevention devices are in good condition, and
- An adequate air gap is maintained where an air gap is used in lieu of a backflow prevention device or assembly.

Keep the inspection in the recurring work program. Use a certified backflow inspector, third party to the contractor, or qualified installation personnel to perform inspections. **/2/**

9-4.2 Testing \2\ Backflow Prevention Assemblies /2/.

\2 Test backflow prevention assemblies using a certified backflow inspector, third party to the contractor, or qualified installation personnel. Repair and retest any assembly found to be defective until it passes. During testing ensure that backflow prevention assemblies are in good condition, are properly installed, and function without interference. **/2/**

9-5 MAINTENANCE OF BACKFLOW PREVENTERS.

\2 Backflow prevention devices and assemblies are mechanical and subject to breakdown. Backflow prevention assemblies will need to be isolated during testing and repair. If there is only one service line from the potable water system and if water service is required 100% of the time, install a second backflow preventer assembly of similar type to provide an uninterrupted supply of potable water. **/2/**

9-6 ADMINISTRATIVE.

Legislation, education, and licensing are discussed in the publication listed in *AWWA M14*.

For the Air Force, see **\1** *AFMAN 32-1067* **/1/.**

9-7 RECORDS OF INSPECTION \2\ AND TESTING /2/.

Develop and use an appropriate form to record data on all **\2** inspections and tests. Provide the location, degree of hazard, and description of protective device installed on the form. After each backflow preventer device inspection, record the date of inspection, observations, corrective action taken, and name of the inspector on the appropriate form. After each air gap inspection, record the date of inspection, observations, corrective action taken, and name of the inspector on the appropriate form. After each backflow preventer assembly test, record the date of test, test results, observations, corrective action taken, and name of the inspector on the appropriate form. **/2/**

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CHAPTER 10 GENERAL MAINTENANCE

10-1 GENERAL.

Inspections and general maintenance services are required at military water supply systems. In addition, this chapter contains tables specifying tools and equipment, lubricants, and materials and supplies required to perform general and specific equipment maintenance tasks.

10-2 MAINTENANCE INSPECTIONS AND REPAIRS.

10-2.1 Types of Inspection and Repair.

10-2.1.1 Operator’s Inspection.

Regular inspection of equipment is part of an operator’s routine duties to ensure proper functioning of the system. Such inspection includes lubrication, minor adjustments, and renewal of parts that do not require major overhaul or repairs. The operator’s inspection also entails detecting and reporting (to the proper authority) any abnormal conditions (e.g., appearance, leaks, unusual noises).

10-2.1.2 Preventative Maintenance Inspection.

Cleaning, lubricating, adjusting, and renewing parts that do not require major overhaul and repairs, plus detecting and reporting (to the proper authority) any abnormal conditions (e.g., appearance, leaks, unusual noises) also comprise preventive maintenance inspection. Such inspections may be conducted by personnel who have been assigned specific areas of inspection responsibility or by personnel operating a particular piece of equipment or system.

10-2.1.3 Control Inspection.

Scheduled examinations or tests are made to determine the physical condition of utilities. These examinations are termed control inspections and performed jointly by engineering and operating personnel. Control inspection includes electrical, mechanical, and structural inspection.

10-2.1.4 Major Overhaul and Repairs.

As a rule, major overhaul and repairs are not made by operating personnel. This work is usually performed under contract.

10-2.2 Personnel.

Generally, well-trained personnel should perform inspections, repairs, and preventive maintenance tasks. Personnel assigned to these tasks should possess a thorough knowledge of the functions and operations of the equipment and the procedures for servicing it safely.

10-2.3 Maintenance Information.

Water supply system personnel need ready access to equipment O&M information. Keep this information on file and update it as necessary. The best sources of maintenance information are the manufacturers' instruction manuals provided with each piece of equipment. Include specific parameters such as model, serial number, warranty, map of equipment locations, and contact number for repairs. This material should be bound and organized according to equipment type and be kept in good order for quick reference. The following information typically is included in these manuals: descriptive literature (catalog cuts and data sheets); parts lists; instructions for installation, operation, maintenance, and repair; performance data (i.e., pump performance curves); electrical diagrams; and schedules of required lubricants and chemicals. It is normally recommended that operating personnel be familiar with each piece of equipment through careful examination of these instruction manuals.

The material contained in this UFC is designed as a general overview of maintenance requirements and may not contain answers for specific maintenance questions. Consult the manufacturers' instruction manuals for specific maintenance information. The specifications, shop drawings, and as-built drawings, which should be kept on file, show dimensions of each piece of equipment and provide information on pipe sizes and materials, valve types, and equipment types. They are available to plant personnel if the schematic drawings and valve and equipment schedules in this manual do not provide sufficient information.

10-2.4 Maintenance Management System.

Regularly scheduled preventive maintenance is essential for keeping equipment in good running order. Daily tasks may be incorporated into the sampling and laboratory testing routine to make the most efficient use of the operator's time. If possible, perform routine tasks on the same day of the week or month to avoid confusion about when they were last performed. For example, each Monday can be set aside for performing weekly tasks, and the first Tuesday of the month can be set aside for monthly tasks. Annual lubrication can be performed during January.

Since operating personnel cannot be expected to remember the service requirements for every piece of equipment, a system of preventive maintenance is essential. To ensure the system is successfully implemented and maintained, it should be relatively simple to operate, producing maximum output for minimum input. The following paragraphs describe the components of a good maintenance system. Best practice information on maintenance management systems can be found in *AWWA M5* and *G100-11*. Supplemental best practice information can be found in *Water Treatment Plant Operation, Volumes 1 and 2*.

10-2.4.1 Goals.

An effective maintenance management system is designed to achieve the following goals:

- Provide periodic, timely, standardized, and complete equipment maintenance.
- Prevent excessive maintenance, such as over greasing bearings.
- Increase system reliability by preventing or providing early detection of equipment malfunction.
- Improve the efficiency of equipment operation.
- Extend equipment life.
- Improve safety by reducing unexpected breakdowns and providing safety precautions along with maintenance and service procedures.
- Reduce overall maintenance costs.
- Provide a complete record system covering equipment history, maintenance costs, and workloads.
- Management system should keep records regarding whether the goals are being accomplished, have a periodic review, and take documented action if goals are not being achieved.

10-2.4.2 Components.

The following components are necessary for a maintenance management system:

- Complete equipment records and maintenance history
- Preventive maintenance scheduling
- Corrective maintenance cost reporting
- Standardized preventive maintenance procedures
- Management reports on maintenance costs, overdue tasks, and employee utilization
- Records management policies (document control) with examples of documentation/forms to be used
- Forecasting for future needs
- Mapping
- Evaluation of the actions taken for maintenance issues
- Technology, including decision models and tools and software as listed in AWWA G410

10-2.4.3 Maintenance Personnel.

Another component of an effective maintenance management system is efficient organization of maintenance personnel. This includes providing adequate staffing, developing job descriptions and an organizational chart, providing maintenance training programs, and holding periodic staff meetings. Continued training and scenario-based training should be scheduled for all personnel. Keep records of personnel training, skills, and experience.

Job descriptions often are developed for use in assessing the skill level required to perform particular tasks in a maintenance program. Depending on the size of the facility, complexity of equipment, and size of the maintenance department, various skill levels may be required (e.g., Operator I and II, Mechanic, Electrician). In many facilities, specialized equipment maintenance may require the use of outside contractors.

10-2.5 Spare Parts and Stock Control.

Keep sufficient types and quantities of materials and stock on hand to ensure practical, economical, and continuous service. This includes an inventory of spare and repair parts and equipment on-site. A review of the equipment and the manufacturers' recommendations will aid in determining which spare parts and miscellaneous supplies should be included in the inventory.

10-2.5.1 Expendable Stock.

Stock levels for expendable items used at a fairly uniform rate (such as pump packing, treatment chemicals, and laboratory reagents) are based on maintenance experience and operating reports. However, levels may be modified for reasons of economy. Thus, savings can sometimes result if treatment chemicals are bought in large quantities.

10-2.5.2 Standby Items.

Seldom-used materials needed to safeguard health, ensure uninterrupted operation of installation facilities, or prevent destruction of property are classed as standby items. Typical examples are chlorinator parts, such as a spare flowmeter, auxiliary chlorine valves, and cylinder connections. Hold materials to be stocked as standby items to a minimum, based on a detailed study of the water supply system. Consider these issues in setting up stocks of standby items.

- Non-critical parts immediately available from nearby installations, municipalities, or supply houses are not stocked. Critical parts are stocked.
- Much repair work at pumping stations and treatment plants can be anticipated, and parts for these repairs can be secured when needed.
- Only major sizes of pipe and fittings are stocked in large amounts.
- If the plant has several similar units, parts that are interchangeable need not be stocked for each unit.
- As soon as an item is drawn from standby stock, a replacement is ordered.

10-2.5.3 Supply of Material.

Watch stock levels closely and order essential materials far enough in advance to ensure continuous service. Supervisors should be familiar with normal and alternate sources of supply and the time each source usually needs to make delivery. Supervisors generally will follow up orders and help supply personnel find alternate supply sources if delivery is delayed. Supplies will be obtained according to normal supply procedures.

10-2.6 Removing Equipment from Service.

Provisions should be in place to mitigate the impact of less frequent equipment failures that cause equipment to be removed from service, which can have serious and immediate effects on the quality of water. These failures may be plant-specific or weather-related and can be identified through hazard analysis and planning. Develop redundancy plans for facilities that cannot be taken out of service for routine maintenance in accordance with *AWWA G410.*

10-2.6.1 Short Period.

Take precautions to prevent damage to equipment removed from service for a short time. Factors to be considered and precautions to be taken depend on the type of equipment and outside conditions. If the outage is likely to last more than 1 week, test operate the equipment once a week during that time.

10-2.6.2 Protracted Period.

Special precautions are necessary for equipment that is to be out of service for long periods. Failure to retire or adequately protect equipment may cause serious damage during idleness or on resumption of operation. When it is known that the outage will be protracted, dismantle the equipment, if practical, and protect it against corrosion and other damage with suitable greases, oils, and rust-preventative compounds or coverings.

10-2.7 Operating Under Winter Conditions.

Protecting operating and standby equipment against damage is especially important in cold climates. Make sure lubricants are changed to winter grades. Drain equipment that is temporarily out of use or on standby service or provide proper antifreeze coolant to prevent units (such as the housings of pumps, radiators, piping and similar items) from freezing or bursting.

Best practice information on operating equipment under winter conditions can be found in *Water Treatment Plant Operation, Volumes 1 and 2*.

10-3 ELECTRICAL EQUIPMENT.

The following maintenance instructions are general. Perform maintenance of individual pieces of equipment according to the recommendations of the manufacturer. Operating procedures and ambient conditions, such as dirt and vibration, may dictate maintenance schedules different from those recommended here.

10-3.1 General.

Major electrical equipment is best maintained by qualified, experienced electricians and in accordance with the manufacturer's recommendations. Water system personnel may perform some inspections, lubrication, and simple routine maintenance. In general, follow flash protection guidelines and do not open an electrical control panel unless properly trained and qualified to do it. De-energize electrical equipment at the motor control center and at the equipment itself before working on it. Always tag the open breaker and, if possible, lock it in the "open" position.

10-3.2 Routine Inspections.

Visually inspect electrical equipment every day. Keep area clean. Look for the source of any leaks or unusual heat, noise, or odors. On rotating equipment with sleeve bearings, check the oil level and see that oil rings turn with the shaft. On rotating equipment with slip rings or commutators, check for excessive sparking.

Inspect motors on rotating equipment weekly. Be sure that the shaft is free of oil and, or, grease from the bearings and start the motor to make sure it comes up to speed in normal time. Check the bearings for excessive heat or noise. Check slip rings and commutators for excessive sparking during starting.

Lubricate bearings according to the manufacturer's recommendations. Do not lubricate excessively; lubrication on insulating surfaces will deteriorate the insulation and gather dirt, which decreases the effectiveness of the insulation.

10-3.3 Switch Gear.

Perform the following work items in accordance with the manufacturer's instructions but not less than once per year. Perform the work more often if the equipment is exposed to excessive dirt or vibration.

These maintenance procedures apply to all electrical equipment that has contact-making devices (e.g., circuit breakers, contactors, switches, relays), electrical coils (e.g., transformers, reactors, solenoids), electrical terminations, insulators, or accessible electrical wiring or busses. Overall basic best practice information on motor control equipment can be found in *Water Treatment Plant Operation, Volumes 1 and 2*.

a. Open equipment panel and wipe insulators and busses with clean, soft, lint-free rags. Clean interior with soft brushes or a vacuum cleaner.

b. Check all accessible electrical terminations and connections, including terminations of power and control cables, bolted bus connections, and all accessible ground connections. Taped connections need not be checked. Check visually and tighten loose connections with a screwdriver or wrench.

c. Record the voltage at the secondary terminal of each power and distribution transformer, both loaded and unloaded. Compare this reading with previous readings. Change taps or contact the power company if the voltage is more than 5% high or low.

d. Inspect contacts on switches, contactors, circuit breakers, disconnects, and relays if the contacts are accessible. Dress or replace contacts if they are pitted or burned. Replace contacts in pairs, not singly.

10-3.4 Electric Motors.

Perform the following work items in accordance with the manufacturer's instructions but not less than once per year. Perform the work more often if the equipment is exposed to excessive dirt or vibration. Overall basic best practice information on motorized equipment can be found in *Water Treatment Plant Operation, Volumes 1 and 2*.

a. Blow dirt from the windings. Clean out magnetic particles that may be hanging on poles.

b. Drain, wash, and renew oil in sleeve bearings. Clean and renew grease in ball-and-roller bearings. Check air gaps. Inspect bearings for excessive wear.

c. Check end play. Under load, machines without thrust bearings should have the rotor within the end play. That is, the rotor should not be riding against the thrust collar of either bearing. This condition can cause heating and failure of the bearing; it can be corrected by shifting the rotor on the shaft or by shifting the laminations. Consult the manufacturer.

d. On rotating equipment with commutators or slip rings, check brush tension and brush wear. Make sure brushes are free in the brush holder. Replace brushes as required. Sand-in new brushes. Check commutators and slip rings for wear, scratches, or pitting. Dress as required.

e. Megger low-voltage rotating equipment using a 500-volt megger. Megger reading should be 1 megohm at minimum, but readings should be compared with previous readings because a decreasing megger reading indicates deteriorating insulation or excessive dirt or moisture.

f. Check foot bolts, end shield bolts, pulleys, couplings, gear and journal set screws, and keys. Ensure that all covers and guards for pulleys and couplings are in good condition and securely fastened. Observe operation during starting and running.

10-3.5 Standby Power Generators.

Operate emergency generators once a week, if possible, to ensure they will work properly when needed. Operate the generators in accordance with the manufacturer's instruction (operation at full load for at least 1 hour is commonly recommended). Normal power sources must be disconnected to operate standby power at full load. Engine generators should comply with all applicable regulations regarding exhaust emissions.

10-3.6 Instrumentation and Controls.

The following paragraphs address maintenance and calibration issues. Remote monitoring and control systems must meet the Installation's IT security requirements and standards. Additional information on instrumentation and controls, including general troubleshooting guidelines, can be found in Chapter 8. Some overall best practice information can be found in *Water Treatment Plant Operation, Volumes 1 and 2*.

10-3.6.1 Regular Maintenance.

If kept in the proper environment, modern electronic equipment requires only periodic cleanings. Every 3 months, instruments should be opened or withdrawn from their cases, inspected, and cleaned with a soft brush. Instruments with moving parts should be lightly lubricated in accordance with the manufacturers' instructions. Do not over-lubricate. Check for interferences between moving parts. Fill ink wells on recorders as needed. Look for source of unusual heat, sound, or odors.

10-3.6.2 Calibration.

Check calibration annually on instruments, gages, and pressure switches. If possible, calibrate equipment in place using the piping, wiring, and fluids of the processes and calibrate a whole subsystem at once. Since this method does not require removing the instrument, it avoids errors such as bad connections and leaks on reinstallation. The disadvantages are that in-place calibration may disrupt the process, and it may be difficult to get sufficient accuracy and range. Calibrate pressure gages and pressure switches by connecting them to a pressure header with a bleed valve and a pressure valve connected to an air tank. Use a gage of known accuracy and recent calibration for a reference. Check set points of pressure switches on increasing or decreasing pressure. Gages and pressure switches should be checked annually. Contract independent instrumentation companies to calibrate critical equipment meters annually to ensure accurate recording and independent verification.

10-3.7 Tools and Equipment.

To maintain, repair, and troubleshoot electrical equipment and circuits, the proper tools are required. In addition to a normal complement of small hand tools (see Chapter 10 paragraph titled Tools and Equipment), a voltage tester with sufficient range to measure the highest voltage expected, a clamp-on type ammeter, a megger (a device for checking the insulation resistance), and an ohmmeter or circuit tester are required.

10-4 MECHANICAL EQUIPMENT.

Operating logs or SCADA should record operational conditions for each piece of mechanical equipment within the system. The data should be used for identifying maintenance frequency, depending on the manufacturer recommendations. The following maintenance instructions are general. Maintain individual pieces of equipment according to the recommendations of the manufacturer. Operating procedures and ambient conditions, such as dirt and vibration, may dictate maintenance schedules different from those recommended here.

10-4.1 Aerators.

Maintenance frequencies for aeration equipment are summarized in Table 10-1.

Table 10-1 Maintenance Checklist for Aeration Equipment

Inspection	Action	Frequency
Waterfall type aerators (cascade)	Inspect aerator surfaces; remove algae; clean.	Daily
Waterfall type aerators (tray)	Clean and repair trays; clean coke or replace.	Semi-annually
Waterfall type aerators (cascade)	Repair or replace surfaces as necessary.	Annually
Packed tower aerators (strippers)	Inspect packing for scale buildup.	Weekly
Packed tower aerators (strippers)	Clean with acid. Caution: Handle acids very carefully. Do not pour water into sulfuric or chromic acid. These acids cause severe burns to skin and clothing. Perform acid treatment only on the approval of the officer in charge and under the supervision of a chemist or other qualified technician.	Biweekly or as required
Diffuser type aerators Porous ceramic plate or tube	Check discharge pressure. If clogging is evident, dewater tank and clean diffusers.	Variable

Inspection	Action	Frequency
Porous ceramic plate or tube	Drain aeration tank. Check for joint leaks, broken diffusers, and clogging. Note: Chlorine gas introduced into the air line at intervals between inspections helps hold down organic growths. Removable plates should be soaked in 50% nitric acid. Plates grouted in place cannot be treated with nitric acid, but instead with chromic acid (1g sodium dichromate to 50 mL sulfuric acid). Pour 2 fluid ounces on each plate on 2 succeeding days.	Semi-annually
Water side of ceramic diffusers	Clean with acid in place or remove and soak in acid. See Caution information in packed tower aerators (strippers).	Semi-annually
Air side of ceramic diffusers	If plates are clogged with iron oxide, treat with 30% HCl; if clogged with dust, soot, oil, etc., remove diffusers and burn off extraneous material in a furnace following the manufacturer's instructions.	Semi-annually
Porous saran-wound tube diffusers	Inspect and clean as required. As the component materials cannot be subjected to strong acid or heat, scrub the diffusers with a brush and detergent.	Semi-annually
Injection nozzles	Inspect and clean.	Semi-annually
Spray nozzle aerators Nozzles	Check for clogging. Clean, removing nozzles if necessary. Do not use a pipe wrench to remove the nozzles.	Weekly
Manifolds	Remove caps and clean out sediment. Check pipe supports and repair as necessary. Paint as necessary.	Quarterly
Spray fence	Paint.	Annually
Blowers and accessory equipment		

Inspection	Action	Frequency
Compressor or blower	Lubricate. Check output pressure for indications of clogging.	Daily
Air filters	Clean, repair, or replace.	Weekly
Compressor or blower	Open, inspect, clean, repair, and paint exterior surfaces.	Annually

10-4.2 Rapid-Mix Basins and Equipment.

Because rapid-mix devices revolve at great speed, do not attempt to check the rotation of the mixer paddles during operation, except by visual observation. When the mixing basin is empty, check the condition of the paddles, bearings, drive shaft, and motor. Then clean, lubricate, and paint as necessary. Table 10-2 presents a summary of maintenance procedures for rapid-mix basins.

Table 10-2 Maintenance Checklist for Rapid Mix, Flocculation, and Sedimentation Basins

Inspection	Action	Frequency
Rapid-mix basins	Drain, wash down walls, flush sediment to waste line. Do not allow cross-connections to the drinking water supply system.	Semi-annually
Baffled mixing chambers	Clean baffles and repair as necessary.	Semi-annually
Flocculator basins	Check paddle rotation to ascertain whether any flocculators are inoperative.	Monthly
	Clean and lubricate drive, bearings, gears, and other mechanical parts. Check underwater bearings for silt penetration. Replace scored bearings.	Semi-annually
Rapid (or flash) mixers	Check paddles. Clean bearings and drive shaft. Lubricate and paint as necessary.	Semi-annually
Revolving-sludge-collector basins	Drain tank. Check submerged parts.	Semi-annually

Inspection	Action	Frequency
Operating parts	Lubricate.	Daily or Weekly
Speed reducers and oil baths	Remove water and grit. Replace oil as necessary.	Weekly
Drive head	Lubricate (but do not over lubricate).	Daily
Worm gear	Check oil level.	Weekly
	Drain water from housing.	Monthly
Turntable bearings	Lubricate.	Monthly
	Change oil.	Semi-annually
Chains	Drain off water, add oil as necessary.	Monthly
	Change oil.	Semi-annually
Annular ball bearings	Lubricate.	Daily
	Inspect condition.	Monthly
Center bearings, shaft bearings, bushings, etc.	See manufacturer's instructions.	Variable
Tank equipment	Tighten bolts and nuts. Check for excessive wear. Flush and backblow sludge line. Check motors, couplings, and shear pins. Check rakes. Clean and paint equipment.	Annually
Conveyor type collector basins	See above and consult manufacturer's instructions.	Variable
Upflow or solids-contact clarifier	See manufacturer's instructions.	Variable

10-4.3 Flocculators.

Use Table 10-2 for flocculator maintenance.

10-4.4 Sedimentation Basins and Clarifiers.

All types of settling basins require the same basic maintenance (lubrication, cleaning, flushing, and painting). Maintain basins that incorporate proprietary mechanisms or devices according to the manufacturer's instructions. Basins with mechanical equipment for removing settled sludge usually clean themselves satisfactorily during normal operations. Table 10-2 presents a summary of maintenance procedures for sedimentation basins.

10-4.4.1 Non-Mechanically Cleaned Sedimentation Basins.

Clean non-mechanically cleaned sedimentation basins every 3 months, when an odor develops, or when rising floc particles indicate development of septic sludge conditions, whichever is more frequent. Drain the basin and clean the tank and mechanism with a high-pressure water hose.

10-4.4.2 Lubrication Requirements.

Regular lubrication is required when the basin is in continuous operation. Intermittent operation may allow an increase in the lubrication interval. If operating periods are intermittent and infrequent, operate the mechanism briefly between operating periods and lubricate accordingly. Devices subject to wide seasonal temperature variations will require seasonal changes in lubricant grades, especially when summer grade oils thicken at lower temperatures and reduce the flow capability. Daily or weekly lubrication of operating units is part of the operator's inspection. The choice of lubricant and its frequency of application are established by the manufacturer or by local command. Inspect the speed reducer each week to make sure that the oil is at the proper level, free of water and grit, and of a suitable viscosity. If a reducer runs hot during its operation, the oil level may be too high or too low. When the reducer is out of service for extended periods, make sure that it is filled completely to prevent seals from drying out. Replace oil when necessary.

10-4.4.3 Overload Alarm.

If the equipment has an overload alarm, check it for operation. If the alarm sounds at any time, shut off the equipment, locate the source of trouble, and rectify the situation. Disabling the alarm switch is not recommended. It is important that the alarm provide continuous operation under overload (high-torque) conditions. If the overload is caused by a sludge buildup leading to cut-out of the starter switch or pin shearing, drain the tank and flush out the sludge.

10-4.4.4 Upflow Clarifiers and Solids Contact Units.

These are all proprietary items; maintain them according to the manufacturer's instructions. Devices that use rotating parts have motors and gears that require maintenance.

10-4.4.4.1 Operator's Inspection.

Check for leaks in valves and piping each month. Make sure that sludge valves function properly. Also check time clock and other accessories that control sludge valve operation.

10-4.4.4.2 Cleaning Maintenance.

Drain unit, clean, and inspect wearing parts twice a year. Remove encrustation where it may interfere with operating parts; follow the manufacturer's instructions in this operation. Check chemical feed lines to make sure that they are not clogged and are in good condition.

10-4.5 Gravity Filters.

This paragraph deals with maintenance of conventional or rapid filters, formerly known as "rapid sand filters." Media commonly used in rapid filters include graded sand, crushed anthracite, GAC, and garnet or ilmenite. Media types may be used alone, as in traditional sand filters and deep-bed monomedia filters, or in combination, as in dual and tri- or mixed-media filters. The following maintenance procedures supplement (but do not substitute for) requirements established by the equipment manufacturers. Best practice information on filtration can be found in *AWWA M30* and *AWWA M37*. A quick reference guide to maintenance of gravity filters appears in Table 10-3.

Table 10-3 Maintenance Checklist for Gravity Filtration Equipment

Inspection	Action	Frequency
Filter media	Inspect surface for unevenness, sink holes, cracks, algae, mud balls or slime.	Monthly
	Dig out sand and gravel at craters of appreciable size.	Variable
	Locate and repair underdrain system breaks.	Variable
	Chlorinate to kill algae growths.	Quarterly
	Probe for hard spots and uneven gravel layers; if present, treat filter with acid.	Semi-annually
	Check wash water rise rate and sand expansion during backwashing.	Semi-annually
	Check sand condition for grain size growth; sample sand, determine weight loss on acid digestion, and run sieve test; acid-treat if necessary, or replace sand, if necessary.	Annually
Gravel	Check elevation of gravel surface.	Monthly
	Examine gravel for encrustation, cementation, alum penetration, or mud balls; if necessary, remove, clean, and re-lay gravel.	Semi-annually
Underdrain system	Remove sand from an area 10 feet square (1 sq m) and inspect an area of gravel 2 feet square (0.2 sq m) or larger. If underdrains are deteriorated, remove all sand and gravel, repair underdrains, and replace gravel and sand.	Annually
	If underdrain is porous and clogged by alum floc, treat with 2% NaOH solution for 12 to 16 hours.	Variable

Inspection	Action	Frequency
Wash water troughs	Check level and elevation; adjust.	Quarterly
	Check for corrosion; if present, dry troughs, wire brush, and paint.	Semi-annually
Operating tables	Clean table (console or panel) inside and out.	Weekly
Cables	Adjust tension	Variable
Hydraulic lines (or pneumatic)	Check for leakage, repair as required.	Variable
4-way transfer valves	Adjust, tighten packing glands or add new packing.	Monthly
	Lubricate with grease.	Monthly
	Adjust valve position indicator, if necessary.	Monthly
	Disassemble, clean, lubricate, and replace worn parts	Annually
Table	Paint inside.	Annually
Rate controllers Direct-acting General	Clean exterior, check diaphragm leakage, tighten packing, and check freedom of movement and zero differential.	Weekly
Diaphragm pot	Disassemble, clean, and replace.	Annually or Variable
Controller mechanism	Disassemble and service; clean venturi; paint surfaces needing protection.	Every 3 years

Inspection	Action	Frequency
Indirect-acting		
General	Clean outside; adjust packing; lubricate and tighten fittings; check knife edges; check piston travel; repack as necessary.	Weekly
Pilot valves	Disassemble, clean, and lubricate; check piston travel; clean piping and strainers; check for leaks in diaphragm.	Annually
Controller mechanism	Disassemble and service; clean venturi; clean hydraulic cylinders; paint as necessary.	Every 3 years
Mechanically operated loss-of-head gages	Check zero setting; adjust stop collars or cable; release air from float chamber.	Monthly
Mud leg	Flush out sediment.	Monthly
Float chamber	Remove float and clean, replace mercury if necessary, check pressure pipelines, paint interior and exterior.	Annually
Diaphragm-pendulum loss-of-head unit	Check zero setting; purge diaphragm cases of air; check cable at segment; remove dirt from knife edges; tighten cam hubs on shafts; drain mud from mud leg.	Monthly
Pipelines to diaphragm	Check for free flow and absence of encrustation.	Semi-annually
Diaphragm-pendulum unit	Check for leakage; disassemble unit, clean, and lubricate; check working parts and cables; repack stuffing box; check knife edges.	Annually
Mercury-float-type rate-of-flow gages	Check at zero differential; adjust indicator arm and recording pens; check stop collars on cables.	Monthly
	Check accuracy and percent error; if greater than ±3%, adjust.	Semi-annually

Inspection	Action	Frequency
Pressure lines	Check and clean as necessary.	Semi-annually
Float chamber	Clean float and check mercury; paint all parts requiring protection.	Annually
Piping and valves	Check for joint leaks; check pipe hangars and replace, if necessary; paint as necessary.	Monthly

10-4.5.1 Filter Media.

10-4.5.1.1 Monthly.

Drain the filter to the surface of the filter medium. Inspect the surface for unevenness, sinkholes, cracks, and evidence of algae, mud balls, or slime.

a. If depressions or craters on the surface area are of appreciable size, dig out the sand and gravel, and locate and repair any break in the underdrain system.

b. Remove mud balls manually or break them up with high-pressure sprays.

c. If severe algae growths exist on media or walls, remove the filter from service and treat it with a strong hypochlorite solution. Add enough hypochlorite to produce 2 to 4 mg/L of free residual chlorine in a volume of water 6 in. deep above the filter surface. Draw down the filter until the water level is just above the bed surface. Allow the filter to stand 6 to 8 hours, then backwash the surface. Follow this procedure with a complete backwashing. Repeat if necessary.

10-4.5.1.2 Quarterly

Probe the filter for hard spots and uneven gravel. Examine the sand below the surface by digging to gravel with the water drawn down to the gravel level. Clogs may appear because sand grains have cemented with mud balls or because grains have increased in size due to calcium carbonate deposit encrustation (e.g., in softening plants or where lime and ferrous sulfate are used for coagulation). If so, clean the sand by treating the idle filter with inhibited muriatic acid (hydrochloric acid to which a chemical has been added to reduce corrosion of metal) or sulfurous acid. It is good practice to notify the utility managers before these chemicals are used.

a. Add the inhibited muriatic acid at the surface and allow it to pass downward through the bed and out the filter drain or “rewash” line.

Alternatively, add it to an empty filter through a small tap on the bed side of the wash water supply line.

b. Use sulfurous acid as follows. Allow the sulfur dioxide gas from a cylinder to discharge into the filter wash water supply line while slowly filling the filter bed with wash water. Use one 150-lb cylinder with 6,000 gallons of water to produce a 0.3% solution. Allow solution to stand for 6 hours.

10-4.5.1.3 Twice a Year.

Usually when seasonal water temperature changes occur, determine any change in the rate of wash water rinse and check sand expansion as follows:

a. The flow rate of backwash water should be sufficient for cleaning the media but should not provide so much pressure that loss of media results. In general, the backwash flow rate should be at least 15 gallons per minute (min.) per square (sq) ft (10 liters per second per square meter [Lps/sq m]), which is equivalent to a rise rate of 2 ft per min. (600 mm/min.) as measured by a hook gage. Higher rates may be required for some types of filter media, but rapid sand filters typically backwash at a rise rate of about 2.0 to 2.5 ft per min. (600 to 750 mm/min.). The highest rate for each filter should be determined by actual experience at the plant. The rise rate is related to the backwash rate, as illustrated in the following calculation:

Equation 10-1. Backwash Flow Rate

$$\left(\frac{15gal}{\min * sf}\right)*\left(\frac{1cf}{7.48gal}\right)=\frac{2\,ft}{\min}$$

$$\left(\frac{10L}{\sec * m^2}\right)*\left(\frac{1m^3}{1000L}\right)=\frac{0.01m}{\sec}$$

$$\left(\frac{0.01m}{\sec}\right)*\left(\frac{60\sec}{\min}\right)*\left(\frac{1000mm}{m}\right)=\frac{600mm}{\min}$$

b. **Media Expansion.** Filter media should be expanded at least 20 to 25% for good cleaning action, although a greater expansion may be optimum in some cases. Higher expansions risk washing out some filter media along with the accumulated solids. The degree of expansion is affected by many variables associated with the filter media and the water. Filter media variables include size and gradation as well as shape and density. Water variables include viscosity and density which, in turn, vary with water temperature. Figure 10-1 relates media size and specific gravity to backwash rate and gives approximate temperature correction factors.

Media cleaning is also affected by interparticle abrasion, although the bulk of the cleaning action is due to the force of the rising backwash water. Expansion can be measured by attaching cups to a pole at suitable intervals, then dipping the pole into the backwashing filter bed; the highest cup that contains sand indicates the height of bed expansion. A waterproof flashlight attached to a pole works well to show the top of the sand but only after the backwash water becomes relatively clear.

c. **Hook Gage.** A multiple hook gage (Figure 10-2) is a series of vertical, sharp, pointed rods held in a frame that may be hung on the side of the filter. The tips of the sharp, pointed rods are set accurately at 2- or 3-in. (50- to 75-mm) spacings. The hook can be used to check the rate of filtration or backwashing, although its primary use is for measuring backwash flow rate. Hang the frame on the side of the filter and accurately record the time required for the water level to fall or rise between the points. The volume of water in the filter box between the gage points can easily be calculated. From the recorded time, the flow rate can be determined accurately.

10-4.5.1.4 Inspect the Media Twice a Year.

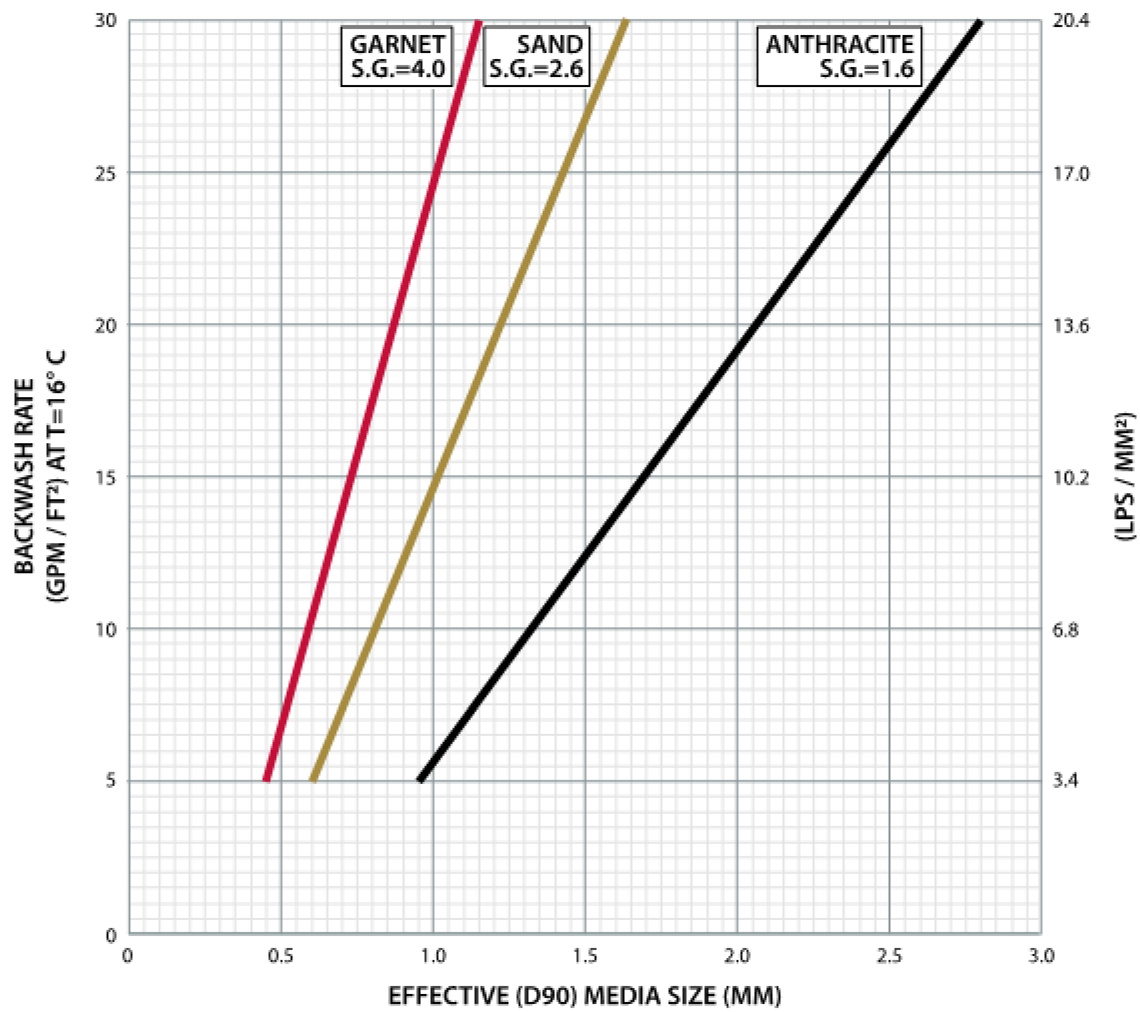
If visual inspection does not reveal the condition of the media, locate the elevation of the top of the bed to determine if the bed has “grown” in depth. Also, remove a media sample and analyze it as follows:

a. Make a sampling tube 12 in. (300 mm) square by 36 in. (1 m) deep. Force a tube into the gravel and drain the bed. Remove the sand from the tube. Collect several such samples from well-scattered locations on the filter bed, mix thoroughly, and reduce sample size by quartering until about 2 lb (1 kg) remain. Dry this sample and mix, quarter, and reduce it to a usable sample size.

b. Determine the loss of weight of a 10-g sample during acid treatment. Treat the sample with 10% hydrochloric acid in a Pyrex evaporating dish on a water bath for 24 hours. Replace acid loss during the treatment period. Wash, dry, and weigh the sand. Determine the weight loss and compare it to the previous analysis.

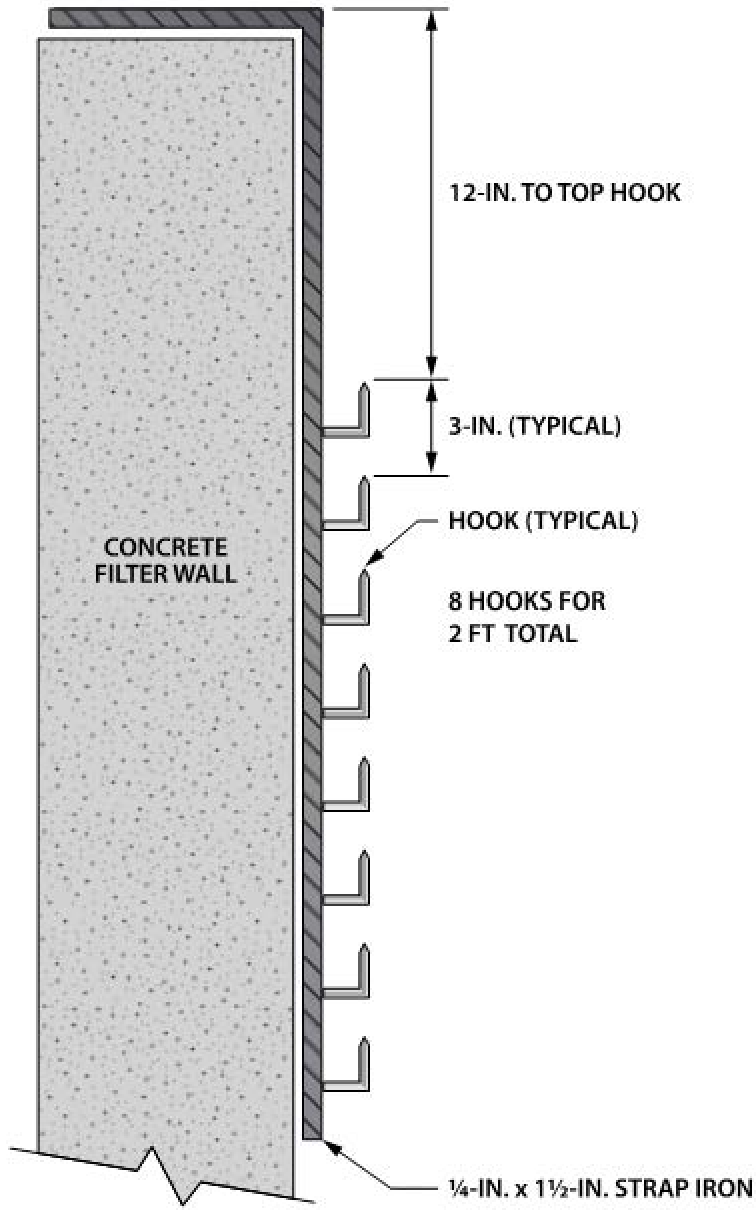
c. From the rest of the sand sample, remove 100 g and run a sieve test. Pass the sand through several standard sieve sizes, weighing the sand grains retained on each sieve. Compare the results to a previous test. Retention of greater amounts of sand on the larger sieve sizes indicates growth of the filter media.

Figure 10-1 Backwash Rate for Media Cleaning



TEMPERATURE CORRECTION: APPROXIMATE CORRECTION FACTORS TO BE APPLIED FOR TEMPERATURES OTHER THAN 16° C		
TEMPERATURE		MULTIPLY THE 16° C BACKWASH RATE BY
31° C	88° F	1.32
26° C	79° F	1.20
21° C	70° F	1.09
16° C	61° F	1.00
11° C	52° F	0.91
6° C	43° F	0.83

Figure 10-2 Multiple Hook Gauge



d. If visual inspection, weight loss, or sieve analysis shows growth of sand grains to a point that filtration efficiency is impaired, treat the sand as outlined in Chapter 10 paragraph titled Filter Media and adjust the water treatment process as necessary. If treatment is not effective, remove and replace the filter media.

10-4.5.2 Loss of Filter Media.

Media can be washed from the filter along with the backwash water or can filter through the gravel layer along with the product water. Losses of media in the backwash water can be kept to a minimum by controlling the backwash flow rate, maintaining level backwash troughs at the proper elevation above the media surface, and controlling hydraulic short circuiting because of clogged media or gravel. Losses through the filter gravel can be controlled by placing a layer of coarse garnet or ilmenite between the media and the gravel and controlling mounding of the filter gravel. Leakage of media can be detected by a small trap located in the effluent line from each filter. Many new filters leak sand for a period and then stop. Such leakage poses no real problem. However, if sand leakage increases over a period, it is probably an indication of mounded gravel.

10-4.5.3 Gravel Inspection.

Gravel inspection includes the procedures described in a. through c. below.

At monthly intervals, use a probe to check the gravel bed surface for unevenness. If ridges or sinkholes are indicated, the filter may need overhauling.

- **Probing a Filter During Backwash.** This method uses a metal rod long enough that the operator can reach the gravel layer while standing on the top of the filter. The rod has a heavy grade screen attached to the end so that it can penetrate the expanded filter media bed (the rod is stopped by the gravel layer). By probing every few feet along the filter, mounds or holes in the gravel layer can be discovered. A variation in the gravel level of over 2 in. (50 mm) indicates serious problems.
- **Probing a Filter at Rest.** The filter can be probed at rest using a metal rod of about 1/4-in. (6-mm) diameter that penetrates the sand layer but not the underlying gravel.
- Remove media from an area of about 3 sq ft (0.3 sq m) twice a year, taking care not to disturb the gravel. Examine the gravel by hand to determine whether it is cemented with encrustation or mud balls and whether it is layered improperly.
- If any undesirable conditions exist to a marked degree, remove the media and re-lay the filter gravel. If unevenness or layer mixing is caused by a faulty underdrain system, repair it; if it is caused by faulty backwashing, correct the backwashing procedure.

10-4.5.4 Filter Underdrain System.

Inspect the filter bottom as needed. Sand boils (during backwashing), sand craters on the surface, or marked unevenness of the gravel layers indicate trouble in the underdrain system. Inspection and treatment procedures are as follows:

a. To inspect the bottom, remove the media over an area of about 10 sq ft (1 sq m). Select an area where sand boils or other indications of trouble have been noticed. Place planking over the gravel to stand on and remove gravel from areas about 2 ft sq (0.2 sq m). Check underdrains for deterioration of any nature. If underdrains need repair, remove all sand and gravel, make repairs, and replace gravel and sand in proper layers.

b. Where underdrains are of the porous-plate type and clogged with alum floc penetration, flood the underdrain system with a 2% sodium hydroxide (caustic soda) solution for 12 to 16 hours.

10-4.5.5 Wash Water Troughs.

At quarterly intervals, check the level and elevation of troughs. Draw water below the trough weirs, crack the wash water valve, and observe any low points where water spills over the weir before the weir is covered completely.

a. Adjust the troughs as necessary to produce an even flow throughout their lengths on both sides.

b. Twice a year, inspect the metal troughs for corrosion. If corrosion exists, allow the troughs to dry, clean by wire brushing, and paint with an appropriate protective paint or coating.

10-4.5.6 Operating Console.

Operating controls for filter valves may be mounted on a console, panel, or table. The controls actuate filter valves that may be powered either by hydraulic or pneumatic means. The controls may be connected to the valve mechanism either by cable or chain and operated through electrical, hydraulic, or pneumatic connections.

Perform these maintenance operations each week:

a. Clean the table, console, or panel inside and out, using soap and water if necessary.

b. If the console is cable-operated, inspect it for leaks and stop any leakage; if it is pneumatically operated, check tubing for possible leakage.

Perform transfer-valve maintenance as follows:

a. Adjust 4-way transfer valves and handles each month to make sure that all filter valves open at the same rate. Tighten packing glands or add new packing as necessary.

b. Lubricate transfer valves with grease each month. Do not over lubricate the valves; one-half turn of the grease screw is generally sufficient.

c. Inspect the valve position indicator each month and adjust it to read correctly in all positions.

d. Disassemble the 4-way transfer valves in the table each year. Clean or replace any worn parts, seats, or washers.

Paint the inside of the table, console, or panel each year to protect against corrosion.

10-4.5.7 Rate Controllers.

Rate-of-flow controllers may be either direct-acting or indirect-acting. Maintenance procedures for both types follow.

10-4.5.7.1 Direct-Acting Controllers:

a. Each week, clean exterior, check for leakage through diaphragm pot, and lubricate or tighten packing to stop any existing leakage. Also, make sure that both the diaphragm and the control gate move freely between zero differential and the open and closed positions.

b. At regular intervals, remove and disassemble the diaphragm pot, including the rubber diaphragm. If the water does not cause tubercles, this operation may only need to be performed once every 3 to 5 years.

c. Every 3 years, disassemble and service the controller gate and mechanism. Inspect the venturi throat. Paint or apply protective coating as necessary.

10-4.5.7.2 Indirect-Acting Controllers:

a. Each week, clean the outside of the controller, adjust the packing, and lubricate or tighten the fittings as necessary to stop any leakage from the hydraulic cylinder, the controller valve, the piping, or the pilot valve. Make sure that the knife edges seat correctly and are free of paint and other foreign matter. Also, be sure that the piston has free vertical travel and does not bind. Replace the packing if necessary.

b. Each year, disassemble, clean, and lubricate the pilot valve. Remove foreign matter from the piston with a cloth. Do not use an abrasive to clean the piston. Make sure that the piston is moving freely. Disconnect and clean the pilot valve piping and strainers; make sure that no foreign matter enters the pilot valve during the cleaning operation. Check for leaks or cracks in the diaphragm.

10-4.5.8 Gauges.

Indicating and recording instruments mounted on the operating table or control panel may include a filter rate controller, loss-of-head gage, flow-rate gage, water level, backwash flow rate meter, wash water rise indicator, and summation gage for total filter output.

Mechanically Operated Loss-of-Head Gauge. The equipment that operates the indicator, or indicator recorder instrument, requires the maintenance operations described in the following paragraphs. The inspector should follow these instructions in general and consult the manufacturer’s instructions for detailed adjustments.

a. Each month check the zero setting in the following way. Open the equalizing valve on mercury float-type head gages and make certain that the indicator arm and the recording pen return to zero. Note the reason for any incorrect reading, and adjust the stop collar or wire cable, if necessary, to bring the indicator to the proper zero reading. On floats and float chambers that are so equipped, release the air. (On some models it is possible to release the air by jerking the wire cable lightly.)

b. Each month, remove the float from the float chamber, wash the float, and remove encrustations. Use care not to mar the float. Replace the mercury, if necessary, avoiding any spillage. When replacing the mercury, be sure that the amount is correct. Also, paint the interior and exterior of the float chamber and other parts each year to prevent corrosion. In addition, check the pressure pipelines to the float chamber and remove any encrustation.

Caution: Mercury fumes are poisonous. Handle mercury carefully since a spill creates a continuing health hazard and is difficult to clean up.

10-4.5.8.1 Diaphragm-Pendulum Unit Loss-of-Head Gauge.

When the actuating mechanism is of this type, the following general maintenance procedures apply. For a more detailed discussion of the procedures, consult the manufacturer’s instruction.

a. Each month purge the diaphragm cases of air and check the cable to be sure that it leaves the segment at a tangent to the lower end when the unit reads zero. Remove dirt from the knife edges; if necessary, tighten the cam hubs on their shafts. Drain mud from the mud leg as described in Chapter 10 paragraph titled Gauges above.

b. Check the pipelines to the diaphragm twice a year to make sure that they are open and free of encrustation.

c. Inspect the diaphragms each year for leakage. Replace if necessary.

Note: Spare diaphragms should be kept underwater.

d. Disassemble the unit to clean and lubricate it when necessary. Check the working parts and the cables (they should be free of knots, splices, or fraying). Repack the stuffing box if it is leaking. Make sure the knife edges rest solely on their edges when the pendulum is hung vertically and be sure all cable ends are knotted tightly.

10-4.5.8.2 Mercury-Float-Type Rate-of-Flow Gauges.

General maintenance procedures are outlined below. For more detailed procedures, consult the manufacturer’s instructions.

a. Once a month, check the unit by opening the equalizing valve to eliminate the differential pressure in the gauge. Adjust the indicator, the recording pens, and the register to zero. Check the position of the stop collars on the cables and inspect and clean the stops on the indicator and recording pen.

b. Every 6 months check the accuracy of the rate-of-flow gauges in the following way. Determine the exact time for the water to drop 1 ft (30 cm), using hook gauges. Determine the amount of water in this 1 ft (30 cm) depth (calculate, allowing for inlets, gullets, structural members, or measure the input, if possible, from the wash water rinse or the drop in the level of the wash water tank). During the period timed for the drop in the water level of 1 ft (30 cm), note and record the reading of the flow rate. Calculate the rate of flow and percent error, according to Equations 10-2 and 10-3.

c. Twice a year, check the pressure pipelines to the float chamber and clean and remove encrustation to allow for free flow.

d. Once a year, clean the float and check the mercury for replacement. If necessary, paint the interior and the exterior of the float chamber and other parts to protect against corrosion

Equation 10-2. Rate of Flow

$$Gpm = \frac{V * 60}{T}$$

Where:
V = volume in 1 ft depth of water (gallons or liters)
T = drop time (seconds)

Equation 10-3. Percent Error

$$Percent = \frac{F_1 - F_2}{F_2} * 100$$

Where:
Percent = percent of error
F_1 = indicated flow rate (gpm or L/min)
F_2 = measured flow rate (gpm or L/min)

Note: If the error is greater than ±3%, make the necessary adjustments.

10-4.5.9 Piping and Valves.

Each month check for leaks at the joints. Also check the pipe hangers and replace any that have deteriorated. Paint piping, valves, and hangers if necessary to prevent corrosion. See maintenance procedures for valves in Chapter 7.

10-4.5.10 Maintenance Schedule.

The maintenance operation frequency and schedule of inspections for filtration are presented in Table 10-3.

10-4.6 Pressure Filters.

Pressure filters need the same care and attention as gravity filters. Open these filters regularly and inspect them carefully. The following maintenance procedures apply:

Inspect piping and valves for leaks each week. Lubricate and repack valves if necessary.

Open the pressure shell and inspect the filter bed surface each month. Follow procedures described in (a) through (f).

a. Use a garden rake or probe during backwashing (while the manhole is open) to test for mud balls in the lower part of the filter bed and evenness of the gravel layer surface.

b. Determine whether the sand bed level has changed since the last inspection by comparing the bed surface elevation with some reference point.

c. If the filter does not have a surface wash system and shows evidence of mud balls, backwash it at the highest rate possible while jetting the surface with a stream of water from a high-pressure hose. Install a permanent surface wash system.

d. Open the filter each year and remove the sand from an area large enough to allow inspection of the gravel. If the sand or gravel distribution indicates non-uniform distribution of backwash water, the filter media and gravel may need to be removed and the underdrain system checked.

e. Clean and paint the exterior of the shell each year.

f. Every 3 years (or more often if necessary), remove the filter medium and gravel and check the underdrain system for wash water distribution. Repair if necessary. Clean the underdrain system and paint it or apply a protective coating to all parts subject to corrosion, including the inside of the shell. Replace the gravel and the filter media.

10-4.7 Precoat Filters.

In general, the maintenance procedures for cleaning the filter element are the same for both pressure- or vacuum-filter types. The following procedures apply.

Each month, or as often as operating conditions require, check the filter elements. The need for cleaning is evident when the precoat shows bare spots on the elements. Iron oxide deposits, manganese dioxide deposits, and algae growths cause element clogging.

For iron oxide removal, treat the elements with a 0.5% solution of oxalic acid. Information is available from the manufacturer on the amount of oxalic acid to use for units of different sizes. The following procedures are used:

a. Start with an empty filter after a regular washing.

b. Close the drain valve and the main outlet valve; open the recirculation valve.

c. Fill the tank to a level covering the top of the elements.

d. Add the proper quantity of oxalic acid and recirculate for 1 hour.

e. Drain and hose down the elements and the tank interior.

f. Close the drain valve; refill, circulate a few minutes, and then drain again. If the cleaning is not completely effective, repeat the procedure.

The procedure for manganese dioxide removal is the same as the procedure for iron oxide removal, except that anhydrous sodium bisulfite is added to the solution rather than oxalic acid (see the manufacturer's instructions for the correct amount).

To remove algae growths, add a 12.5% hypochlorite solution to the tank volume after filling the tank to the proper level (see the manufacturer's instructions for the proper amounts to use for units of different sizes).

Check the piping and valves and appurtenant equipment twice a year, including the body-feed equipment. Make any adjustments the manufacturer's instructions indicate are necessary. Clean and paint all exterior surfaces, if necessary.

Ion-exchange maintenance schedule is summarized in Table 10-4.

10-4.7.1 Operating Conditions.

Determine the operating condition of the softener each quarter. Refer to operating records and make such tests and meter readings as are necessary to determine the following information:

10-4.7.1.1 Flow Rate.

Natural ion exchangers can operate satisfactorily at a flow rate of 5 gpm/sq ft (3.5 Lps/sq m); synthetic resins operate at a rate of 6 to 7 gpm/sq ft (4 to 5 Lps/sq m). Rates higher than these cause undesirable head loss through the bed and bed packing. Adjust the controls of the flow rate each quarter.

Table 10-4 Maintenance Checklist for Ion-Exchange Softening Units

Inspection	Action	Frequency
Softener unit Shell	Clean and wire brush; paint.	Annually
Valves and fittings	Check for obstructions, corrosion, and fastness.	Quarterly
	Check for leaks; repack if necessary.	Semi-annually
Ion-exchange medium	Check bed surface for dirt, fines, and organic growths; remove foreign matter and add resin to desired level.	Quarterly
Gravel	Probe through resin to determine gravel surface; level gravel surface with rake during backwash flow; replace gravel when caked or if resin is being lost to effluent; wash and grade gravel and place in four separate layers; use new lime-free gravel at discretion of inspector.	Quarterly
Underdrains	Check pressure drop through underdrains; if necessary, remove manifold or plate underdrains; clean and replace.	Annually or Variable
Regeneration equipment Salt-storage unit	Clean tank as necessary to remove dirt.	Variable
Brine tank	Clean out dirt and insolubles; allow to dry; paint both exterior and interior surface.	Semi-annually

Inspection	Action	Frequency
Ejector	Clean, disassemble, check erosion and corrosion; clear clogged pipes; assemble and replace.	Annually
Operating conditions		
Flow rates	Check rate of flow through bed; adjust controls to optimum rate, depending on type of resin.	Quarterly
Backwash rates	Check rate and adjust controls to optimum rate.	Quarterly
Pressure	Check difference between inlet and outlet pressures; if undesirable changes in pressure drop have occurred, seek cause and remedy.	Quarterly
Efficiency	Compare total softening capacity with previous inspection; determine cause of decrease, if any, and remedy situation.	Quarterly
Out-of-service softeners	Drain; keep synthetic resins damp; do not regenerate before draining.	Variable
Demineralization equipment	Maintain according to manufacturer’s instructions.	Variable

10-4.7.1.2 Backwash Rate.

The rate of backwash should be 6 to 8 gpm/sq ft (4 to 6 Lps/sq m) of bed surface. Rates below this value do not clean the bed properly. Rates too high wash some of the resin out of the softener and reduce its softening capacity. Adjust the flow rate control to produce the best backwash rate each quarter.

10-4.7.1.3 Pressure.

Each quarter check operating records for any change in the difference between inlet and outlet pressure. Any change in head loss through the softener indicates a problem. A decrease in pressure drop may indicate improper valve closure or a channelized bed. An increase in pressure drop may indicate a valve not completely opened, a dirty bed, clogged gravel, or a clogged underdrain system.

10-4.7.1.4 Softening Efficiency.

Each quarter check the records to determine the softening capacity between the regeneration periods. Compare the current amount of hardness removal with that recorded when the ion-exchange resin bed was new, and calculate the efficiency based on the original capacity as 100%. A decrease in efficiency may be caused by a dirty bed, coated resin grains, loss of ion-exchange bed, or improper regeneration (either by weak brine solution or under-regeneration or over- regeneration). Replace resin bed if the efficiency has decreased by 25% and it cannot be almost completely restored by cleaning and using special procedures recommended by the manufacturer.

10-4.7.2 Demineralization Equipment.

Ion-exchange equipment used for demineralization is highly specialized. Maintain it according to the manufacturer's instructions.

10-4.8 Recarbonization Equipment.

10-4.8.1 Combustion Units.

Maintenance of combustion units depends on the equipment used, fuel impurities, effectiveness of the scrubber and drier, and construction materials. Consult the manufacturer's instructions for maintenance of the compressor or blower.

10-4.8.1.1 Operator's Inspection.

Each day, check burners, compressor, gages, and traps. Adjust the equipment to ensure top-level operation.

10-4.8.1.2 Drier, Scrubber, and Traps.

Each month check material in the drier and replace as necessary. Adjust the spray and clean out connecting piping; clean the gas traps.

10-4.8.1.3 Corrosion Inspection.

Every 6 months inspect all equipment for internal and external corrosion. Repair the equipment if necessary and paint it or use protective coatings.

10-4.8.2 Carbon Dioxide Gas Feeders and Evaporator Units.

Maintenance of carbon dioxide gas feeders and evaporator units generally will follow the procedures outlined in Chapter 10 paragraph titled Gas Chlorinators for vacuum-operated gas feed chlorinators and liquid chlorine evaporators. Consult the manufacturer's instruction for specific maintenance requirements.

10-4.9 Distillation Equipment.

Required maintenance for distillation equipment is presented in Table 10-5.

Table 10-5 Maintenance Checklist for Distillation Equipment

Inspection	Action	Frequency
Distillation equipment Multiple-effect evaporators Submerged tube/ Tubes or coils	Remove scale by cracking or acid wash (see manufacturer's instructions).	Variable
Zinc plates	Remove and replace when reduced to one-quarter of their original size.	Variable
Condenser or cooler tubes	Clean, as necessary, by wire brushing and flushing.	Variable
Flash-type evaporators Evaporator stages	Check for corrosion or encrustation; clean and repair as necessary.	Quarterly
Stream side of evaporator	Clean and repair.	Semi-annually
Entire unit	Check for signs of deterioration; repair or renew parts as necessary; paint exterior.	Annually
Vapor-compression distillation units Tubes in evaporator	Clean.	Every 200 to 400 hours
	Chemically.	Variable
	Mechanically.	Variable
Mechanical and electrical controls	Inspect, clean, and repair or replace worn parts.	Quarterly

Inspection	Action	Frequency
Engine, vapor compressors, vent condenser, heat exchanger, cooler system, etc.	Inspect, clean, repair, and adjust.	Semi-annually
Entire unit	Check, clean, repair, and paint as necessary.	Annually

10-4.9.1 Multiple-Effect Evaporators

These evaporators may be of two types:

10-4.9.1.1 Submerged-Tube Evaporators.

As a general practice, remove scale from the evaporator tubes as soon as it becomes 1/16 in. thick, regardless of the model or manufacturer.

Thermal Cracking of Scale. In the tube model, the scale may be cracked by suddenly flooding the shell with cold water after the tubes have been preheated with steam at the first effect coil steam pressure. This method of cracking is the most satisfactory when the scale is less than 1/16 in. thick.

Mechanical Cracking of Scale. Where thermal cracking is not effective, mechanical cracking may be used.

- Tube Model. Crack the scale by inserting a bar between the lines of tubes.
- Coil Model. Manually crack the scale by bouncing the coils on a hardwood block to crack the heavier coating, then wire brush the coils. Consult the manufacturer’s instructions for specific instructions.

Caution: Using a chipping hammer to remove the scale may seriously damage the coils.

Acid Cleaning. In the coil model, scale generally may be dissolved quickly by immersing the coil in a 20% solution of inhibited muriatic acid (commercial hydrochloric acid). Wash the coils thoroughly in water before reinstalling them in the evaporator.

Zinc Plate Replacement. Replace the zinc plates when they have been reduced to about one-quarter of their original size.

Condenser and Cooler Tube Cleaning. Clean these tubes (if used) by flushing, wire brushing or scraping, and flushing again before reinstalling them.

Shutdown Protection. If the plant is to be shut down for an indefinite period and is subject to freezing conditions, remove all water from all parts of the evaporator.

10-4.9.1.2 Flash-Type Evaporators.

Specific maintenance instructions are provided by the manufacturer. The following procedures are the recommended minimum:

- Check the evaporator stages for corrosion or encrustation each quarter; clean and repair the evaporator as necessary.
- Check the steam tube side of the evaporator twice a year and repair it if necessary.
- Each year, inspect all parts of the unit (both interior and exterior) for signs of deterioration and inspect the piping and valves. Repair or renew parts as necessary; paint interiors.

10-4.9.2 Vapor-Compression Distillation Units.

Detailed maintenance procedures are found in the manufacturer's instructions. The following procedures are the minimum required:

After 200 to 400 hours of operation, check the evaporator for corrosion or encrustation. If the tubes are encrusted, use either chemical or mechanical means for scale removal. Mechanical cleaning is used for hard scale that cannot be removed by chemical treatment.

- For chemical treatment, add sodium bisulfate directly, or in solution, to the evaporator. Sulfuric acid and inhibited muriatic acid are better than sodium bisulfate; however, in general they should be used only if approved by the utility managers. The amount of acid to be added varies, depending on the size and type of the unit. Consult the manufacturer's instructions. Generally, the acid cleaning is continued during a 2-hour recirculation period; methyl orange is used as the indicator to show when the acid is spent. After treatment, drain the unit, flush well, rinse with alkaline solution to neutralize any remaining acid, and return to service.
- The equipment needed to remove scale formation mechanically includes an electric drill with bit and wire brush attachments that fit the evaporator tubes. The tubes must be wet before the drilling is started. Water is fed through the drill bit during operation. Drill each tube and then wire brush. Remove scale from the evaporator shell or head by scraping; remove all dislodged particles of scale from the evaporator. Reassemble the evaporator and return it to service.
- Note: For safety, ground the electric drill used for removing scale and protect the operator from electrical shock resulting from using an electric drill in a wet environment.

- Check all mechanical controls, fuel lines, electrical connections, lubrication points, and valves each quarter.
- Check the engine, vapor compressors, vent condensers, heat exchanger, cooler system, and instrumentation twice a year. Clean, adjust, and repair this equipment as necessary.
- Check the entire system. Clean, repair each year, and paint as necessary.

10-4.9.3 Maintenance Procedure Schedule.

Maintenance operation frequencies and the schedule of inspection for distillation equipment are summarized in Table 11-5.

10-4.10 Electrodialysis Equipment.

When establishing maintenance procedures, follow the detailed instructions provided by the equipment manufacturer. General maintenance procedures for electrodialysis equipment can be found in best practice *AWWA M38*.

10-4.11 Reverse Osmosis Equipment.

Membrane equipment is specialized. Maintain it in accordance with the manufacturer’s instructions. General information on reverse osmosis equipment maintenance - including daily, weekly, and monthly monitoring; membrane cleaning; and troubleshooting procedures for a variety of operating problems - can be found in *AWWA M46* and *Reverse Osmosis: A Practical Guide for Industrial Users*.

10-4.12 Backflow Preventers.

See Chapter 9 paragraph titled Backflow Prevention Devices.

10-4.13 Valves.

See Chapter 7 paragraph titled Valves and Valve Operation.

10-4.14 Pumps.

See Chapter 5 paragraph titled Pump Maintenance.

10-4.15 Compressors.

Table 10-6 is a checklist of the procedures for maintaining compressors. Note that these procedures are general. Always read and follow the manufacturer’s instructions for mechanical equipment.

Table 10-6 Maintenance Checklist for Compressors

Inspection	Action	Frequency
Intake Filters	Inspect the compressor filter. Inspect more frequently (daily) in areas with severe dust. Never operate a compressor without the suction filter because dirt and foreign materials will collect on the rotors, pistons, or blades and cause excessive wear.	Monthly
	Clean or replace as indicated for each filter type.	Semi-annually
Impregnated paper filter	Replace when dirty.	
Cloth filter	Wash with soap and water, dry, and reinstall. Keep spare filter on hand for use when main filter is being washed.	
Wire mesh and oil-bath filter	Clean with a standard solvent; reoil or drain and refill oil bath; reuse.	
Bearings	Inspect bearings and lubricate if necessary. Most compressors have bearings that require oiling.	Daily
Crankcase reservoir	Examine the reservoir dipstick or sight glass for oil level. Keep reservoir full but do not overfill as excess oil can lock up or damage compressor. Heat from the compressor tends to break down oil quickly. Thus, most compressor manufacturers specify particular oils for their equipment and frequent oil changes are recommended. Heat from the compressor tends to break down oil quickly. Thus, most compressor manufacturers specify particular oils for their equipment and frequent oil changes are recommended.	Daily
	Change compressor oil when necessary. If there are filters in the oil system, change these regularly as well.	Quarterly

Inspection	Action	Frequency
Drip-feed oiler	Check drip rate.	Daily
Force-feed oiler	Check pressure.	Daily
Grease fittings	Ensure fittings are greased.	Quarterly
Cylinder or casing fins	Clean with compressed air or vacuum to ensure proper cooling of the compressor.	Weekly
Unloader	Check that compressor comes up to speed and that the unloader changes at start of the compression cycle. Listen for a change in sound. When the compressor stops, you will hear a small pop and the air bleeding off the cylinders. If the unloader is not functioning properly, the compressor will stall when starting, fail to start, or (if belt driven) burn off the belts.	Daily
Safety Valves	Test weekly. Do not change pre-set cutoff settings in high-pressure cutoff switches, low oil pressure switches, and high temperature cutoff switches. If any of these safety switches are not functioning properly, correct the problem before starting the compressor again. Record the safety switch settings and maintain record in the equipment file.	Weekly
Air receiver	Drain the condensate from the air receiver using the valve located at the bottom of the tank. If the air receiver is equipped with automatic drain valves, inspect periodically for proper functioning.	Daily
Belts	Inspect the belt tension by pressing the belt down approximately 3/4 in. between the two pulleys. Make sure the compressor is locked off before performing this test. Do not over tighten belts.	Semi-annually
Operating Controls	Examine regularly. Make sure compressor is stopping and starting at the proper settings. For dual installations, make sure compressors are alternating (if so	Quarterly

Inspection	Action	Frequency
	designed); inspect gage for accuracy. Compare readings with recorded startup values or other known, accurate readings.	
Tool oilers	If your compressor has a tool oiler on the receiver, check the reservoir and fill with rock drill oil when necessary.	Weekly
Entire unit	Clean all compressors thoroughly at least once a month. Dirt, oil, grease, and other materials should be cleaned off the compressor and surrounding area. Compressors tend to lose oil around piping, fittings, and shafts; therefore, diligent cleaning is required by the maintenance operator to ensure proper and safe operation.	Monthly

10-5 LUBRICATION.

Proper lubrication prevents damage to wearing surfaces, reduces the maintenance required, and cuts power costs and equipment outages. The instructions that follow list the recommended lubricants for various uses. Directions for lubricating specific equipment are presented in tabular form and, where desirable, are repeated in the text that applies to the specific equipment items. These instructions may be modified by the operator to meet individual situations, but in general, such modifications require the approval of the utility manager.

10-5.1 Types of Lubricants.

Oils, greases, and preservatives for waterworks are listed in Table 10-7. This list does not contain all the lubricants available under military specifications, but it has been developed to establish good lubrication practice for normal operating conditions with as few good lubricants as is feasible. Following Table 10-7 and Table 10-8 (a list of uses for oils and greases) does not relieve the operator from using lubricants that meet the requirements of the equipment manufacturer’s recommendations. The information in Table 10-7 should be familiar to all maintenance and operating personnel. This list is subject to modification at the judgment of maintenance personnel, providing the modification is approved by the utility manager.

Table 10-7 Lubricating Oils, Greases, and Preservatives

Product	Military Specification Number	Symbol	Approximate SAE Grade (a)	National Stock Number (b)	Temperature Range
Lubricating oil, general purpose	MIL-L-15016A	2075 2110(c) 2135 2190 2250 3050(c) 3065 3080 3150	20W 10W-75W 20W-75W 30W 40W 20W 30W-80W 40W-90W 140W	-- 9150-00-223-4137 9150-00-231-6664 9150-00-231-6639 -- 9150-00-223-4138 -- 9150-00-223-8890 9150-00-240-2258	10 °F (-23 °C) 0 °F (-18 °C) 0 °F (-18 °C) 35 °F (2 °C) 35 °F (2 °C) 0 °F (-18 °C) 5 °F (-15 °C) 15 °F (-9 °C) 25 °F (4 °C)
Lubricating oil, compounded	MIL-L-15019B	4065 6135 8190	40W 140W 30W	9150-00-243-3196 9150-00-231-6645 9150-00-231-9033	35 °F (2 °C) 60 °F (16 °C) 35 °F (2 °C)
Lubricating oil, mineral, cylinder	MIL-L-15018B	5190	140W	9150-00-240-2260	60 °F (16 °C)
Lubricating oil, stream turbine (noncorrosive)	MIL-L-17331B	2190TEP	30W	9150-00-235-9061	60 °F (16 °C)
Lubricating oil, internal combustion engine, subzero	MIL-L-10295A	OES	--	9150-00-242-7603	-65 to 0 °F (-54 to -18 °C)
Lubricating oil, instrument jewel-bearing, nonspreading low temperature	MIL-L-3918	OCW	--	9150-00-270-0063	-40 °F (-40 °C)
Lubricants; chain, exposed-gear and wire rope	VV-L-751A	CW-11B	--	9150-00-246-3276	All
Lubricating oil, internal combustion engine	MIL-L-2104A	OE-10 OE-30 OE-50	10W 30W 50W	9150-00-265-9425 9150-00-265-9433 9150-00-265-9440	-20 °F (-29 °C) 0 °F (-18 °C) 15 °F (-9 °C)

Product	Military Specification Number	Symbol	Approximate SAE Grade (a)	National Stock Number (b)	Temperature Range
Grease, automotive and artillery	MIL-G-10924A	GAA	--	9150-00-190-0907	-65 to 125 °F (-54 to 52 °C)
Grease, ball and roller bearing	MIL-G-18709	BR	--	9150-00-249-0908	125 to 200 °F (52 to 93 °C)
Grease, graphite	VV-G-671C	GG-1	--	9150-00-272-7652	125 °F max. (52 °C)
Lubricating oil, internal combustion, preservative	MIL-L-21260	PE-1	--	9150-00-111-0208	
Lubricating oil, preservative, medium	--	PL-MED	--	9150-00-231-2356	
Corrosion preventive, petroleum, hot application	MIL-G-11796A	CL-3	--	8030-00-231-2353	
Corrosion preventive, compound, solvent cutback, cold application	MIL-C-16173B	CT-1	--	8030-00-231-2362	

(a) SAE numbers 10W through 50W are for crankcase lubrication. SAE numbers 75W through 140W are for transmission lubrication.

(b) National stock numbers are for 5-gallon containers for lubricating oils and 35-pound containers for grease, except 1/2-ounce can for MIL-L-3918. For other containers see Federal Supply Catalog.

(c) Quenched.

10-5.2 Lubricant Uses.

Different authorities may make conflicting lube recommendations for essentially the same item; however, general reference material is available to help select the correct lubricant for a specific application.

Grease is graded on a number scale, or viscosity index, by the National Lubricating Grease Institute. For example, No. 0 is very soft; No. 6 is quite stiff. A typical grease for most treatment plant applications might be a No. 2 lithium or sodium compound grease, which is used for operating temperatures up to 250 degrees F (120 degrees C).

A list of uses for lubricants that are generally satisfactory when used on equipment operating under normal ranges of temperature, pressure, and corrosion is contained in Table 10-8. However, in view of the wide variation in characteristics of equipment and conditions of operation, the manufacturer's instructions for lubrication should be checked to make sure that listed lubricants meet the requirements of the manufacturer's recommended lubricants.

Table 10-8 Lubricating Oil and Grease Uses

Equipment	Oil or Grease Symbol
Air compressors Vertical with splash lubrication	 2110, 3050
Gage pressure less than 100 psi	2135, 2190, 3050
Gage pressure greater than 100 psi	2135, 2190, 3050
Horizontal External lubrication, sight feed, wick feed, hand oiling.	 2135, 2190, 3050
External lubrication, circulating system or splash type crankcase	2110, 2135, 3050
Cylinders Wet conditions	 8190
Dry conditions	2190. 2250, 3065
Bearings Ball, all temperatures to 200 °F (93 °C)	 BR
Ball, low-pitch line speed Operating temperature below 32 °F (0 °C)	 2075
Operating temperature 32 to 150 °F (0 to 66 °C)	2190, 2250, 3065

Equipment	Oil or Grease Symbol
Ball, medium-pitch line speed Operating temperature below 32 °F (0 °C)	2075
Operating temperature 32 to 150 °F (0 to 66 °C)	2135, 3050
Ball, high-pitch line speed Operating temperature below 32 °F (0 °C)	2075
Operating temperature 32 to 150 °F (0 to 66 °C)	2110, 3050
Ring-oiled, small, miscellaneous	2110
Kingsbury thrust bearing	2190 TEP
Thrust (other than Kingsbury, subject to water)	4065
Thrust (other than Kingsbury, not subject to water)	2135, 2190
Bronze guide	GAA
Countershaft	CG-1
Differential (enclosed)	3150, 5190, 6135
Eccentric	3065
Guide	GAA, CG-1
Oilite bronze bushings	OE10, OE30
Pillow-block	GAA
Underwater-babbitted	GAA, CG-1
Universal joint, slip splines	BR
Chain Drives Roller	3080-GAA, CG-1
Roller (enclosed)	Winter 2075; Summer 3065

Equipment	Oil or Grease Symbol
Roller (semi-enclosed)	Winter 3080; Summer 6135
Slow-speed	CW-IIB
Medium-speed	5190
Chemical feeders	See manufacturer's instructions.
Clarifier equipment	Do
Couplings	6135
Drive jaw clutch	OE50
Gear case or gear head	Low temperature 3080; High temperature 5190
Gears Herringbone	 Winter 2075; Summer 3065
Helical	Do
Motor reducers	Winter 3050; Summer 2135
Open	5190
Planetary	Winter 2075, 2110; Summer 2135
Worm and pump transmission	Winter 3080; Summer 6135
Instruments	OCW
Motors	See manufacturer's instructions.
Packing, sludge pumps	4065, 6135
Pumps	See manufacturer's instructions.

Equipment	Oil or Grease Symbol
Seal packings	GAA
Shafting Large	 2190, 3065
Small	2110, 2135, 3050
Shear pins	WB
Sheaves	CG-1, GAA
Solenoid oilers	3050
Valve stems	GAA

10-5.3 Lubricating Precautions.

To avoid plant failures due to improper lubrication, take the following precautions:

- Do not over lubricate. Over lubrication causes antifriction bearings to heat and may damage grease seals; it may also cause damage to the windings in electric motors.
- Do not lubricate totally enclosed or insufficiently guarded equipment while the equipment is in motion.
- Temperature compatibility of grease and service duty required for equipment is critical. Equipment manuals must be specifically checked for proper lubricants as recommended and authorized by the equipment manufacturer.

10-5.3.1 Overfilling.

Every operator should be aware of the dangers of overfilling with either grease or oil. Overfilling can result in high pressures and temperatures, and ruined seals or other components. It has been observed that more antifriction bearings are ruined by over greasing than by neglect.

10-5.3.2 Temperature.

A thermometer can tell a great deal about the condition of a bearing. Ball bearings generally are in trouble above 180 degrees F (82 degrees C). Grease-packed bearings typically run 10 to 50 degrees F (5 to 30 degrees C) above ambient temperature

10-5.4 Lubricating Procedures.

Lubricate greased bearings as follows:

a. Shut off, lock out, tag, and block the unit if moving parts that might be a safety hazard are close to the grease fitting or drain plugs.

b. Remove the drain plug from the bearing housing.

c. Remove the grease fitting protective cap and wipe off the grease fitting. Be sure that you do not force dirt into the bearing housing along with the clean grease.

d. Pump in clean grease until the grease coming out of the drain hole is clean. Do not pump grease into a bearing with the drain plug in place. This could build up enough pressure to blow out the seals.

e. Put the protective cap back on the grease fitting.

f. With the drain plug still removed, put the unit back in service. As the bearing warms up, excess grease will be expelled from the drain hole. After the unit has been running for a few hours, the drain plug may be put back in place. Special drain plugs with spring-loaded check valves are recommended because they will protect against further buildup.

10-5.4.1 Flushing and Repacking.

Generally, the time between flushing and repacking for greased bearings should be divided by 2 for every 25 degrees F (14 degrees C) above 150 degrees F (65 degrees C) operating temperature. Also, generally, the time between lubrications should not be allowed to exceed 48 months because lube component separation and oxidation can become significant after this period of time, regardless of amount of use.

Another point worth noting is that grease is normally not suitable for moving elements with speeds exceeding 12,000 in. per min. (5 mps). Usually, oil lubricating systems are used for higher speeds. Lighter viscosity oils are recommended for high speeds, and, within the same speed and temperature range, a roller bearing normally will require one grade heavier viscosity than a ball bearing

10-5.4.2 Lubricant Storage and Use.

Keep lubricant containers tightly closed, except when in use, to prevent contamination of the lubricant by the entrance of dust, grit, and abrasives. Store lubricants in dust-free areas. Before using lubricant containers, wipe the spouts and lips; before using grease guns, wipe the gun and fitting to ensure the absence of foreign matter.

A good rule of thumb is to change and flush oil completely at the end of 600 hours of operation or 3 months, whichever occurs first. More specific procedures for flushing and changing lubricants are outlined by most equipment manufacturers.

10-5.4.3 Proper Lubricant System Inspection and Choices.

For clarifier drive units, which are almost always located outdoors, condensation presents a dangerous problem for the lubrication system. Most units of current design have a condensate bailing system to remove water from the gear housing by displacement. These units should be checked often for proper operation, particularly during seasons of wide air temperature fluctuation.

Pumps incorporate many types of seals and gaskets constructed of combinations of elastomers and metals. As for lubricants, conflicting advice can be obtained. A file containing data on general properties of materials used can help in the choice of lubricant.

10-5.5 Grease Fittings.

The same grease gun fitting should be provided on all lubrication points requiring the same grease. This practice reduces the number of grease guns required, keeps the use of improper lubricants to a minimum, and simplifies operation.

10-5.6 Identifying Lubricant Items.

The product symbol and identifying color should be marked on lubricant containers and grease guns and at or near all oil cups and grease fittings to ensure the choice of the proper lubricant for that location.

Best practice information on lubricants can be found in the publications listed in *Plant Engineering Magazine's Exclusive Guide to Interchangeable Industrial Lubricants* and *Plant Engineering Magazine's Exclusive Guide to Synthetic Lubricants*.

10-6 COMBUSTION ENGINES.

Few water system operators repair gasoline- or diesel-powered engines. However, several inspections and routine procedures are needed to ensure that these engines are well maintained. A checklist of these procedures can be found in the manufactures O&M manual for the equipment.

10-7 CHEMICAL STORAGE AND FEEDERS.

Different chemical feeders work on different principles. Each water treatment facility will require several chemical feeders to accurately control chemical application to the process. Some general information is provided in this chapter and in Chapter 4 under process headings that require use of chemical feeders. Always read and follow the manufacturer's instructions for mechanical equipment. DOD facilities must comply with

Fluoridation at DoD Owned or Operated Potable Water Treatment Plants. For best practice information, use *AWWA M4.*

10-7.1 Lime Slakers.

a. Clean the dust-removal and the vapor-removal equipment during every shift. Make sure that dust and moisture do not reach the chemical feeding mechanism and cause caking or corrosion. Remove clinkers or grit not removed by regular operations.

b. While the slaker is out of service each week, clean grit out of each compartment. Wipe off the outside of the slaker with an oily rag. (The thin film of oil prevents the adherence of moisture or lime solution and thus protects paint.) Clean the vapor-removal system and check the mechanism for proper functioning. Clean all appurtenances.

c. Each month, check agitators, stirrers, and heat exchangers; replace any impellers on baffles in front of the heat exchanger that show appreciable wear. Inspect and repair, or replace as necessary, all wiring defects or metal deteriorations. Tighten bolts, eliminate vibration, tighten belts, and paint the equipment where necessary. Every 1,000 to 1,500 hours, lubricate the support bearing-drive with grease (do not use oil).

d. Overhaul lime slakers each year. Drain and clean the slaker and dust-removal system. Check the slaker bottom and sides for wear and repair them as necessary. Paint the exterior and inside top edges of the slaker lids to protect them from corrosion. Check for leaks and scale in the heat exchanger. Clean the thermometers and check their accuracy. Clean and lubricate all bearings. Repair controls, floats, piping, screens, valves, and vapor-removal equipment. Paint all equipment where necessary

10-7.2 Gas Chlorinators.

The operator should be familiar with the equipment to be maintained. An instruction book is furnished with every chlorinator; consult it for specific steps to follow in servicing. Should the book be lost, the manufacturer can supply a duplicate (as long as the model and serial numbers are included with the request for replacement). Follow the manufacturer’s suggestions for O&M. This paragraph offers general maintenance procedures that apply to all gas chlorinators. A troubleshooting chart for solution-feed, vacuum-operated gas chlorinators is included as Table 10-9. General maintenance procedures for chlorination equipment are summarized in Table 10-10.

10-7.2.1 Inspect Chlorinator for Leaks.

Examine the chlorinator and all piping for chlorine or water leaks each day. All chlorine leaks are serious because they increase rapidly in size and cause extensive corrosion and damage. Red discoloration at gas header connections means a leak is corroding the fittings. Use an ammonia-water bottle to locate the chlorine gas leak. Do not pour ammonia water on the suspected leak. Rather, waft the open bottle near the suspected leak. If chlorine vapor is present, a dense white cloud will appear. Use litharge and glycerin cement or Teflon tape in making all metal-threaded pipe connections. Do not use grease or oil.

10-7.2.2 Operate the Chlorine Valves.

Open and close all chlorine valves each day to ensure proper and complete operation. Do not use force in closing a valve. Repair or replace any faulty valves at once.

10-7.2.3 Check the Water System.

Each month clean the water strainers and check the pressure-reducing valve for proper operation. Clean the injector nozzle and throat once a year. (Insufficient injector vacuum usually indicates that cleaning is required.) Muriatic acid may be used for cleaning mineral deposits from the injector nozzle and throat.

10-7.2.4 Check the Gas System.

Check all piping and parts carrying chlorine gas to verify they are operating properly. Check flexible connectors at the gas-supply containers. (To maintain a gas-tight seal, use a new lead gasket each time a valve or tube is connected, including each time an empty chlorine cylinder is replaced.) Remove and clean gas filters periodically. Check the heater each day to make sure it is warm. Verify that the metering devices, pressure-reducing and shutoff valves, hose lines, and gauges all work properly. Disassemble and clean when necessary to determine the cause of the fault. At the first sign of weakening, replace any faulty parts.

10-7.2.5 Clean the Cabinet and Critical Working Parts.

Thoroughly clean the chlorinator cabinet, glass parts, flowmeter, rate valve, vacuum regulator valve, and other parts in which dirt may interfere with operations or make equipment unsightly. Clean and cover unpainted metal that is subject to corrosion with a proper protective coating.

Table 10-9 Troubleshooting Checklist for Solution-Feed, Vacuum-Operated Gas Chlorinators

Symptom	Possible Cause
Flowmeter fails to indicate gas flow.	Gas supply valve closed.
	Gas supply cylinder(s) empty.
	Insufficient ejector vacuum.

Symptom	Possible Cause
	Filter in gas-inlet connection block dirty. Dirty flowmeter.
	Rate valve closed. Rate valve dirty.
	Air leakage in regulator stack.
	Vacuum regulator valve plug stuck in closed position.
Ejector vacuum is insufficient.	Ejector water supply valve closed. Solution line valve closed.
	Dirty strainer.
	Dirty ejector.
	Partially or fully blocked solution line.
	Ejector throat not full of water (applies only when ejector is mounted in horizontal position and back pressure is zero or less).
	Insufficient water supply flow rate and pressure for existing back pressure conditions. Drain valve leaking air.
	Insufficient pump discharge pressure.
Gas flow rate cannot be controlled.	Condensed gas vapor (liquid chlorine) in chlorinator. Dirty vacuum regulator valve.
	Air leakage in regulator stack.
	Insufficient ejector vacuum.
Maximum gas flow rate produces too low a residual in the treated process liquid	Chlorinator capacity too low.
	Air leakage caused by dirty sealing surfaces.

Symptom	Possible Cause
Minimum gas flow rate produces too high a residual in the treated process liquid.	Chlorinator capacity range too high.
Flowmeter continues to indicate flow when ejector water supply valve is closed.	Condensed gas vapors (liquid chemicals) in chlorinator.
	Vacuum regulator valve stuck in the open position.
	Solution line draining due to a back pressure of zero or less.
	Ball stuck in flowmeter.
Water leaks from ejector into gas line.	Diaphragm backflow check valve not seating properly.

Table 10-10 Maintenance Checklist for Chlorination Equipment

Inspection	Action	Frequency
Operation maintenance	Insert a new lead gasket in the chlorine valves or tubes to cylinders or equipment.	Variable
Condensation on chlorine cylinders	Ventilate.	Variable
Chlorine leak detection	Use an unstopped bottle of aqua-ammonia to detect leaks; repair immediately.	Daily
Gas system	Disassemble, clean, and replace faulty parts in piping, meters, valves, and tubing.	Daily
Chlorine valves	Open and close valves to assure that all are operable; check stuffing boxes and repair or replace faulty valves or packing.	Daily
Chlorine solution tubes	Look for location of potential leaks, and for iron and manganese deposits; if iron or manganese are present, treat with a solution of hexametaphosphate in makeup water.	Annually
Chlorine feeder water supply	Clean water strainers and pressure reducing valves; adjust float valves and ejector capacity.	Monthly

Inspection	Action	Frequency
Hard-rubber threads, valves and parts	Disassemble or operate; use graphite grease to prevent freezing; hand tighten only—do not use tools.	Quarterly
Vacuum relief	Clean out any obstruction.	Daily
Cabinet and working	Clean all parts where accumulation may interfere with proper operation.	Weekly
Overhaul	Disassemble and clean all parts thoroughly; paint cabinet inside and out; examine parts and repair or replace as needed; use care in choice of cleaning agents and lubricants.	Annually
Direct-feed chlorinators	Use same procedures as for solution-feed machine where they apply.	

10-7.3 Liquid Chlorine Evaporators.

The chlorine vessel on the inside of the evaporator and the water bath mechanism are the primary components requiring maintenance. The chlorine vessel is subject to internal corrosion from chlorine and external corrosion from the water bath. The chlorine vessel and the water bath are normally cleaned and inspected every 2 years or after evaporating 250 tons of chlorine, whichever occurs first. The sacrificial anodes in the cathodic protection system in the evaporator should be replaced when the evaporator is taken apart for cleaning and inspection. Follow these steps to clean the evaporator.

a. Dismantle and remove the chlorine vessel from the evaporator.

b. Flush the chlorine vessel with cold water to remove corrosion products from the inside.

c. Visually inspect the interior for pitting. If pitting is severe, replace the chlorine vessel.

d. Remove all flushing water and reassemble the evaporator.

e. Fill the water bath and heat it to 180 degrees F (82 degrees C). Attach an aspirator so that a vacuum can be exerted on the inside of the chlorine vessel. The vacuum should be about 25 in. (635 mm) of mercury and held for 24 hours with the water bath at 180 degrees F (82 degrees C) to make sure that all moisture is removed from the inside of the chlorine vessel.

10-7.4 Hypochlorite Solution Feeders.

a. Hypochlorite solutions are highly alkaline. The reaction of this alkaline material with the hardness in the makeup water results in carbonate scale deposits in the pump head and tubing and in the solution diffuser at the point of application. Dilute (5%) hydrochloric (muriatic) acid solution can be pumped through the hypochlorinator to remove this scale. Be sure to flush out the hypochlorite solution with water first.

b. The diaphragm continually flexes. Inspect it to make sure it operates properly.

c. Check valves and seats for corrosion, hardening, swelling, scale, or foreign material that might prevent proper seating.

10-7.5 Dry Chemical Feeders.

Maintenance procedures for dry chemical feeders are summarized in Table 10-11.

Table 10-11 Maintenance Checklist for Dry Chemical Feeders

Inspection	Action	Frequency
Dry feeders	Remove chemical dust accumulations; check feeder performance; check for loose bolts; clean solution tank of accumulated sediment; lubricate moving parts.	Daily
Drive mechanisms and moving parts	Service and lubricate.	Quarterly
Calibration	Check feed-rate accuracy and adjust, as necessary	Monthly
Overhaul feeders	Thoroughly clean feeder and feeding mechanism; paint; service and lubricate drive mechanisms and bearings; clean and paint solution tanks.	Annually
Feeders out of service	Clean; remove all chemicals from hopper and feeder mechanisms.	Variable
Disc feeders	Clean rotating disc and plow.	Variable
Oscillating feeders	Check and adjust mechanism and adjustable stroke rod.	Monthly
Rotary gate feeders	Clean pockets of star feeder and scraper.	Monthly
Belt-type feeders	Check vibratory mechanism, tare-balance, feeding gate, belt drive and belt; calibrate delivery.	Monthly
Loss-in-weight feeders	Check feeder scale sensitivity, tare-weight, and null balance.	Monthly
Screw feeders	Clean screw, check ratchet drive or variable speed drive.	Monthly
Dust collectors		
Motors	Lubricate motors	Variable
Filter bags	Check condition and attachment. Securely attach sound bags; replace damaged or torn bags.	Variable

10-7.6 Test Calibration.

Make monthly calibrations to check the accuracy of feed-rate and control mechanisms. Indicate or record feed rates and amounts. The test procedures in Table 10-12 apply to various feeders.

Table 10-12 Calibration Tests for Dry Chemical Feeders

Inspection	Action	Frequency
Volumetric dry feeders		
Test calibration and adjust feeder	Perform the test described below for your type of volumetric dry feeder (with or without scale) and repeat several times.	Weekly
	Average the data from several tests to compare with the rate setting, rate indicator, and recorder (if one is used). Take particular care in the timing and weighing operations.	
	Make any adjustments necessary to bring the feed rate within ± 5% by weight of the rate setting.	
Feeders not on a scale	Make at least three tests within the normal operating range of the feeder.	Weekly
	Use a pan or other container of known weight to catch the discharge of the feeder for a definite period. Weigh the discharged material, calculate the rate of feed per hour, and compare the results with the rate setting, rate indicator, and recorder (if one is used).	
Feeders on a platform scale	Balance the scale or record initial reading while the feeder is stopped; start the feeder and run for a definite period; rebalance the scale (i.e., record weight loss).	Weekly

Inspection	Action	Frequency
	From the difference in the two scale readings, calculate the amount fed in the measured time and then calculate the feeding rate in pounds per hour.	
Belt-type gravimetric feeders	Calibrate weekly or whenever the feeder is used for a different chemical.	Weekly or Variable
Clean belt and feeder	Clean according to manufacturer's instructions	Weekly or Variable
Set initial balance	Balance the scale and operate the feeder until the feeder scale beam is in full balance and indicates a proper load on the belt. If the feeder is proportionally paced, set the proportioning equipment on "manual control." Set the rate-of-feed at maximum and proceed with the following calibration test.	Weekly or Variable
	Stop the feeder and make sure the scale moves freely and is in exact balance.	
	Adjust the amount of chemical on the belts by adding or removing chemical at the rear of the belt, until an exact balance is obtained.	
	Zero the belt revolution counter or weight integrator, start the feeder, and run it until a definite weight of chemical has been discharged (about two-thirds of a belt load). Then stop the feeder.	

Inspection	Action	Frequency
Determine weight of material discharged	Rebalance the scale precisely.	Weekly or Variable
	The difference between this scale reading and the one taken during the test is the weight of material discharged.	
Compare balance and revolution counter; adjust poise if necessary	Check the calculated amount of material discharged against the number of pounds fed as indicated by the revolution counter. If the weight of the chemical delivered differs from that indicated by more than + 1%, adjust the poise on the scale beam and repeat the test. (Moving the poise to a lower value reduces the loading on the belt and vice versa.)	Weekly or Variable
	Repeat testing and adjustment until a belt loading is found that agrees with the amount fed, as indicated by the totalizer counter.	
	Note: Some belt type gravimetric feeders may be made to discharge into a container of known weight, in which the feed rate may be checked by actually weighing the amount discharged at a definite time.	
Loss-in-weight gravimetric feeder	Test calibration of this feeder is similar to the test calibration method used for the belt-type gravimetric feeder.	Weekly or Variable
	When the feeder is empty, check the tare weight to make sure that the scale shows 0 weight. All other determinations and adjustments are similar to the belt-type gravimetric feeder described above.	

10-7.7 Solution Feeders.

Maintenance procedures for solution feeders are summarized in Table 10-13.

Table 10-13 Maintenance Checklist for Solution Chemical Feeders

Inspection	Action	Frequency
Pot feeders		
Flow through pot	Determine amount of chemical fed to ascertain if flow through pot is effective.	Daily
Sediment trap	Clean trap and check needle valve.	Monthly
Chemical pot	Clean pot and orifice.	Semi-annually
Overhaul	Clean and paint pot feeder and appurtenances.	Annually
Differential solution feeders		
Chemical storage tank	Inspect and clean.	Semi-annually
Oil volume	Check and replenish.	Semi-annually
Pitot tubes and needle valve	Check and replace as necessary.	Annually
All equipment	Paint as necessary.	Variable
Decanter feeders		
Swing-pipe	Check to make sure it does not bind.	Monthly
Motor ratchet, pawl, reducing gears	Check and lubricate.	Semi-annually
Overhaul	Inspect, clean, repair, and paint all parts as necessary.	Annually or Variable
Rotating dipper feeders		
Motor	Follow manufacturer’s instructions	Variable
Transmission	Change oil after 100 hours of operation.	Every 100 hours
Shaft bearings	Lubricate.	Weekly

Inspection	Action	Frequency
Drive chain	Clean, check alignment; check sprocket teeth; lubricate chain and sprockets.	Monthly
Agitator	If used, clean and lubricate according to manufacturer's instructions.	Variable
Belt drives	Check alignment, tension, and inner cords of belt drives.	Monthly
Dipper and float valve	Check dipper clearance and adjust float valve setting	Semi-annually
Proportioning pumps Operator's inspection	Inspect sight feeders, rate of flow, piping, joints.	Daily
Feeder	Clean feeder.	Weekly
Solution tank	Clean	Monthly
Linings	If cracks occur, special linings should be repaired.	Annually
Overhaul	Disassemble, clean, and overhaul.	Annually

10-8 TANKS AND RESERVOIRS.

Water storage facilities are maintained according to the procedures listed in Table 10-14. The following paragraphs cover the activities involved in painting tanks: surface preparation, paint application methods, and paint selection. Best practice information on tank inspection, painting, and maintenance can be found in *AWWA M51*.

Table 10-14 Maintenance Checklist for Storage Facilities

Inspection	Action	Frequency
Complete inspection	Drain, clean, and examine interior surfaces. Repair as required. Disinfect before returning to service.	Every 3 to 5 years
Foundations, wood	Check for settlement, cracks, spalling, and exposed reinforcing; repair as necessary with 1 part cement to 1 part sand.	Semi-annually
Foundations, concrete	Check wood foundations and pads for checked, split, rotted or termite-infested members; also check for direct contact of untreated wood with soil. Repair or eliminate undesirable conditions as necessary.	Semi-annually
Concrete tanks (ground-level storage)	Check exterior for seepage; mark spots.	Semi-annually
Walls	Check exterior and interior for cracks, leaks, spalling, etc.	Annually (Spring)
	Remove loose, scaly, or crumbly concrete; patch with rich cement grout; paint grout with iron waterproofing compound.	Annually
	Chip out cracks and repair with cement slurry.	Annually
	For cracks in prestressed tanks, consult designing and, or, erecting company.	Annually
Expansion joints	Check for leakage; check for missing filler; clean and repair as necessary.	Semi-annually
Roofs	Check condition; check hatches; check screens on openings. Clean as necessary.	Semi-annually

Inspection	Action	Frequency
Earth embankments	Check for erosion, burrowing animals, improper drainage, and leakage through embankment. Repair as necessary. If leakage through the embankment exists, drain tank and look for cracks in tank walls or bottom.	Semi-annually
Concrete tanks (underground storage)	Check interior walls, roof, appurtenances and embankment; if leakage is evident, excavate and repair walls.	Semi-annually
Concrete tanks (elevated storage)	Check and repair.	Semi-annually or Annually
Steel tanks (ground-level storage)	Check for ice damage in spring; repair as necessary.	Annually
Walls and bottom	Examine exterior and interior for rust, corrosion products, loose scale, leaky seams, and rivets and for condition of paint.	Semi-annually
	Replace rivets or patch leaking areas, as necessary.	Variable
	Check painted surfaces for deterioration; paint as necessary.	Semi-annually
Roofs	Check condition, hatches, screens, manholes and paint; lock hatches; remove spider rods if corroded; repair, replace, or paint, as necessary.	Semi-annually
Steel tanks (standpipes)	If problem is noted during inspection, arrange for an outside contractor to repair the steel tank.	Semi-annually
Steel tanks (underground storage)	Check tank interior, roof, and appurtenances.	Semi-annually
Steel tanks (elevated storage)	If problem is noted during inspection, arrange for an outside contractor to repair the steel tank.	Semi-annually

Inspection	Action	Frequency
Tanks	Use contractor.	Semi-annually
Tower structures	Check for corrosion and for loose, missing, bowed, bent, or broken members; loose sway bracing; misalignment of tower legs; or evidence of instability. Repair as necessary.	Semi-annually
Roofs	Check obstruction and navigation lights, hoods, shields, receptacle, and fittings for missing or damaged parts or in operation; also check lightning rods, terminals, cables, and ground connections; repair, replace, or renew; paint as necessary.	Semi-annually
Risers and heating systems	Two months before freezing weather, check riser pipe insulation and repair as necessary; also check heating system operation.	Annually
	One month before freezing weather, operate heating system for 8 hours; repair or adjust defective parts.	Annually
Cathodic protection	Check flow of current; if absent, check fuses, anodes, ground wire connections and immersion of electrodes; adjust or repair as necessary. If current flow or amperage is above desired level, adjust as necessary; make certain that connections to rectifier are not reversed.	Variable
	Check anode condition; replace as necessary.	Variable
Wooden Tanks Towers	Check for loose, missing, twisted, bowed, cracked or split pieces; also check for termite infestation, misalignment of legs, and evidence of loose sway bracing; repair and eliminate undesirable conditions; paint as necessary.	Semi-annually

Inspection	Action	Frequency
Tanks	Check operating records to make certain tank is kept filled; also check structural condition of tank for soundness, evidence of leakage, and corrosion of steel bands. Check all appurtenances, ladders, roofs, screens, etc.; make any repairs or adjustments necessary.	Semi-annually
	Paint metal parts; paint timber only if necessary for appearance.	Annually
Pneumatic tanks	Inspect air pump and motor; check operating record of time cycle; check for air leaks, if time cycle is too short; check valve operations, particularly pressure relief valves.	Quarterly
	Check tank for signs of corrosion; take steps necessary to eliminate corrosion or protect against it.	Annually
Appurtenances	Check ladders, walkways, guardrails, handrails, stairways, and risers for rust, corrosion, poor anchorage, missing pieces, general deterioration or damage; replace or repair parts as necessary.	Semi-annually
Miscellaneous appurtenances	Check all electrical connections and conduits leading to tanks; make any repairs or adjustments necessary.	Semi-annually
Grounds	Check for accumulations of debris, trash, and foliage; clean the area.	Semi-annually

10-8.1 Paint Systems for Steel Storage Tanks.

10-8.1.1 Surface Preparation.

Good surface preparation is required to ensure adequate bonding of the paint to the metal to be protected. See Chapter 10 “Paint Application Methods.”

a. If the original surface preparation was poor and the mill scale was not removed when the tank was originally painted, blast cleaning is required before repainting. If the original surface preparation was adequate, but the old paint has completely broken down, blast cleaning of areas with loose or failing paint usually is warranted. If the old paint is still in good condition, only those areas with loose paint need to be removed by wire brushing or sanding.

b. All areas that have been cleaned of loose paint down to the bare metal need to be primed before rust has a chance to form. Follow Steel Structures Painting Council specifications.

10-8.1.2 Paint Application Methods.

Paint may be applied by several methods:

- Brushing
- Air spraying
- Airless spraying
- Roller application
- Special methods for applying heavy coatings.

The method best suited for application depends on the type of paint, degree of complexity of the surface being painted, paint viscosity, and other considerations, such as the amount of spray carryover with spray-painting techniques. The paint manufacturer and a professional painting contractor can advise installation personnel of the best application method for the tank being painted. Apply paint according to the instructions in *UFC 3-190-06*.

10-8.1.3 Paint Selection.

- Select protective coatings in accordance with *UFC 3-190-06*. It is normally recommended that only paints meeting *NSF/ANSI 61* be used on surfaces in contact with potable water. Environmental conditions affecting the exterior of the tank and water characteristics within the tank result in varying painting system requirements. A reputable paint manufacturer can provide valuable guidance in paint selection, based on laboratory testing results and experience with painting systems on similar tasks.
- Paint testing may be required on tanks for which a particular paint system has proven unsatisfactory. Various painting systems can be used on different areas of the tank to determine which system performs the best.
- The thickness of the dried paint film should be specified and measured after the painting has been completed. Various paints require varying dry film thickness for optimum life.

- In general, it is best to use paints that require similar surface preparation procedures for both the interior and exterior of the tank, since these procedures are usually conducted in a single operation.
- *AWWA D102* includes standards for several outside and inside paint systems. The standard gives general information on the suitability of the paint systems under varying conditions and information about surface preparation, paint film thickness, and procedures for applying paint. Paint systems used for painting tanks on military installations should meet or exceed the requirements established in this standard.

10-8.2 Cathodic Protection for Steel Tanks.

Design standards and specifications for cathodic and impressed current protection of steel water tanks may be found in *NACE SP0196* and *NACE SP0388*. For general information on corrosion of exposed and buried metals, refer to *AWWA M27*. Use *UFC 3-570-06* for the operation and maintenance of cathodic protection systems.

10-8.2.1 Limitations.

Cathodic protection is limited to structures in contact with an electrolyte, such as soil or water. In steel-elevated water storage tanks, only the inside surfaces of the riser and the submerged bowl can be protected. Protect the outside of the tank from atmospheric corrosion by some other means.

10-9 PIPELINES.

Although pipes are normally buried and out of sight, their maintenance should not be neglected. Components of a pipeline maintenance program include inspection, leak detection and repair, flushing, pigging, slip-lining, cement-mortar lining, wrapping, and cathodic protection. These and other aspects of pipeline maintenance are covered in *AWWA M51*, and *NACE SP0169*.

10-9.1 General Information.

The prevention of corrosion and surface deterioration is standard maintenance practice in waterworks. Protect all exposed surfaces, whether external or internal. Protective coatings and linings may be nonmetallic or metallic. The former includes paint, enamel, bitumen, cement, plastic, and rubber. Metallic coatings include zinc, aluminum, and lead. Other corrosion-control treatments are used on metal equipment surfaces that cannot be painted. Cathodic protection is used where electrolytic corrosion occurs.

10-9.2 Paint Protection.

Surface coating with paint is the most general method of corrosion prevention. Try to select paint to meet the existing conditions; the choice depends on if the equipment or structure is indoors or outdoors.

10-9.3 Paint Application.

Prepare and apply surface paints according to the procedures detailed in *UFC 3-190-06*.

10-9.3.1 Surface Preparation.

Before applying the paint, prepare all surfaces. Foreign substances on the surface interfere with the protective action of the coating. Therefore, remove loose scale, rust, dust, oil, or grease completely. For best results, paint only clean surfaces. Sandblast metal surfaces if required. Use sandpaper or a wire brush where required. Wipe off dust and clean greasy or oily surfaces with solvent cleaners. Take special precautions when removing lead-based paints. See *UFC 3-190-06*.

10-9.3.2 Preparation of Paint.

Paint should be mixed properly and screened, if necessary, to remove grit and film. Cover paint containers when not in use. Clean brushes, rollers, and spray applicators before and after use. For damp surfaces where drying temperatures are less than 40 degrees F (4 degrees C), specially prepared paints are normally used.

10-9.4 Corrosive-Preventative Compounds.

Corrosion-preventive compounds are used in pits, pump dry-wells, and damp areas. Paint does not serve this purpose. Table 10-7 shows two corrosion-preventive compounds commonly used in waterworks.

10-10 CHAIN DRIVE.

Chain drives may be designed for slow, medium, or high speeds. Follow these steps to maintain chain drives:

10-10.1 Check Operation.

Check general operating conditions during regular tours of duty.

10-10.2 Check Chain Slack.

The correct amount of slack is essential for proper chain drive operation. Unlike belts, chains should not be tight around the sprocket. When chains are tight, working parts carry a much heavier load than necessary. Too much slack is also harmful. A properly installed chain has a slight sag or looseness on the return run. All drive chains should have a tightener.

10-10.3 Check Alignment.

If sprockets are not in line or if shafts are not parallel, excessive sprocket and chain wear results. To check alignment, remove the chain and place a straight edge against sides of the sprocket where no wear has occurred. Replace sprockets and chain if they are excessively worn.

10-10.4 Lubricate.

Lubrication depends on the drive speeds. Refer to the manufacturer's manual and Chapter 10 "Types of Lubricants" for lubricant types. Lubrication for different types of drives includes the following methods:

10-10.4.1 Slow-Speed Drives.

Because slow-speed drives are not usually enclosed, adequate lubrication is difficult. Heavy oil applied to the outside of the chain seldom reaches the working parts; in addition, the oil catches dirt and grit and becomes abrasive. Soak exposed-type chains in a recommended lubricant to restore lubricating film. Remove excess lubricant by hanging the chains up to drain. Do not lubricate chains on elevators, conveyers, or feeders that handle dirty, gritty material. Dust and grit combine with lubricants to form a cutting compound that reduces chain life. Do not lubricate underwater chains that operate in contact with considerable grit. If the water is clean, lubricate the chain with the recommended lubricant with a brush while the chain is running.

10-10.4.2 Medium-Speed Drives.

Continuously lubricate medium-speed drives with a drip- or sight-feed oiler. The lubricant type depends on temperature conditions.

10-10.4.3 High-Speed Drives.

High-speed drives should be completely enclosed in an oil-type case and the oil maintained at proper level. Oil type depends on temperature conditions. Drain the oil and refill the case to the proper level according to the manufacturer's recommendations.

10-10.5 Clean and Inspect:

a. On enclosed types, flush the chain and enclosure with kerosene. On exposed types, remove the chain. Soak and wash it in kerosene. Clean the sprockets, install the chain, and adjust the tension.

b. Note and correct abnormal conditions before serious damage results. Do not put a new chain on old sprockets. Always replace old sprockets when replacing a chain. Old, out-of-pitch sprockets cause as much chain wear in a few hours as years of normal operation.

10-10.6 Troubleshooting.

A troubleshooting checklist for chain drives is included as Table 10-15.

Table 10-15 Troubleshooting Checklist for Chain Drives

Symptom	Cause of Trouble	Remedy
Broken pins or rollers.	Shock leads or chain speed too high for pitch.	If speed-pitch relation is cause, use chain of shorter pitch.
Chain climbs sprockets.	Poor fit or severe overload.	If sprockets fit poorly, renew; make sure tightener is installed in drive chain.
Chain clings to sprockets.	Possibly incorrect or worn sprockets or heavy tacky lubricants.	Renew or reverse sprockets or change to proper lubricant.
Chain gets stiff.	Poor alignment or excessive overload.	Correct alignment and eliminate overload.
Chain whips.	Too long centers; or high pulsating loads.	Correct either condition.
Noise.	Misalignment; improper slack, loose bolts.	Correct alignment; adjust slack; tighten bolts; reverse or renew worn chain.
Wear on chain side walls or sides of teeth.	Misalignment.	Remove chain and correct alignment.

10-11 TOOLS AND EQUIPMENT.

10-11.1 Tool Inventory.

Effective maintenance requires that the tools needed to service the facility properly be readily available. Table 10-16 provides a list of suggested tools to keep at the facility for general maintenance use. Authorization for specific tools is issued by individual services. Specialized equipment may require specific tools. Special test equipment may also be needed. Consult the manufacturer’s instructions for such equipment needs.

Table 10-16 Suggested Tools for Water Treatment Plants

Tools	
Axes, spare ax handles Awls Bars Crow Wrecking Bit brace and assortment of bits for wood and metal Blacksmith's anvil, tools, forge, and hand blower Bolt stock and dies Breast drill and assortment of drills Calipers Inside and outside Micrometer Caulking tools, water main type (assorted sizes and types) Chisels Assorted Bull point Cape Cold Diamond point Round nose Assorted, wood Assorted, for air hammer Hand Press, bench type Star drills of various sizes	"C" clamps, assorted Cotter pin puller Countersink, assorted for wood or metal Cutters, wire Cutters, 1/2-in. (10-mm) bolt Dies, assorted for bolt and pipe threading stocks Drills, assorted 1/2-in. (13-mm) electric, portable with drill press stand mount 3/8-in. (10-mm) electric, cordless, 12-voltDrills, assorted (continued) 1/4-in. hand drill, heavy duty 1/4-in. hand drill, heavy duty Drill bits Twist drills, high speed fractional set 1/16- to 1/2-in. x 64ths Twist drills, high speed metric set 1.0-mm to 13 mm x 0.5 mm Spade bits 1/4- to 1-1/2-in. by 1/8ths (6-mm to 40-mm) Masonry bits, carbide tip, for rotary drills 1/4-in. x 4-in., 5/16-in. x 4-in., 3/8-in. x 4-in., 1/2-in. x 6-in. (6-mm x 100-mm, 8-mm x 100-mm, 10-mm x 100-mm, 13-mm x 150-mm)

Tools	
Extractors, screw, various sizes Files Assorted sizes Flat Half round Round Taper (triangular) Wood rasp Fire pot, including metal foot and wrought steel ladle for use with B and S cast iron pipe Flanging tools, for use with copper pipe Flaring tools, for use with copper pipe Fuse puller Gages Set of shims Test for pressure and vacuum Glass cutter Grinder Electric or hand, bench type Wheels, coarse, fine, and wire brush Hacksaw, adjustable frame with extra blade	Hammers Ball peen, assorted sizes Blacksmith's type Claw Mason's Caulking Sledge-type, various sizes Hatchet Jacks, screw or hydraulic, various sizes Joint runner, asbestos, for use with lead joints Lathe Metal, 12-in. (300-mm) swing, 24-in. (600-mm) centers Tools and appurtenances Lead pot and ladles Levels Line Spirit, metal frame, 18-in. (500-mm) Line, Mason Manhole-cover lifting hooks Mattock Nail sets, various sizes Oil cans, several types and sizes as required

Tools	
Packing hooks Packing tools, assorted Pipe Cutter Pipe Cutter, wheels (spare) Pipe taps Pipe thread taps (combination), 1/4- to 2-in. (6- to 50-mm) Pipe threading stock with assorted dies Pipe tripod Plane, smooth, bench, 7-in. (180-mm) Pliers Assorted sizes Diagonal cutting Gas Combination slip joint Needlenose Wrench Plumb bob Puller, gear set Punches, assorted sizes, center, drift Putty knives Reamers, hand, taper, pipe expansion Rules, 6-foot folding	Saws, rip, crosscut, compass and keyhole Screwdrivers, various sizes Saw set Saw vise Scale platform Screw pitch gage Scribers Sharpening stone Shovels Square point, long and short handle Round point, long and short handle Snake, 25-foot (8-m) spiral Soldering iron and appurtenances Specific tools for specialized equipment Square, steel, large and small Stamping tools, steel, letters and numeral Straight edge, steel Tampers Tape, 50-foot (15-m) steel Tar pot Torch, blow and gasoline

Tools	
Trowels	Wrenches
Floats, steel, and cork assorted	Adjustable, various sizes
Pointing	Allen set screw
Valve resetting tool	Box wrench set
Vises, bench and pipe, portable chain vise and stand	Hydrant
	Monkey
Voltage tester	Open end, various sizes
	Ratchet, socket set
Wall scrapers	Socket, set of various sizes
Washer or gasket cutter for making own washers	Spanner
	Stillson, various sizes
Welding outfit with appurtenances, goggles and gloves	Torque
	Valve
Wire stripper	

10-11.1.1 Tool Care and Usage.

Tools have specific uses and in general should not be used for other purposes. When the proper tool is not available, try to obtain it.

10-11.1.2 Tool Storage.

For easy retrieval, keep tools on a tool board or in a toolbox. Keep the board or box clean and, if appropriate, paint it once a year. In general, tools not in their proper places should be in use; if not, find them and return them to their proper places.

10-11.1.3 Tool Inspection.

It is a good practice to inspect tools every month. Damaged or worn tools can be replaced and edged tools (chisels, planes) kept sharp if they are regularly checked. Clean and lubricate tools before returning them to storage.

10-11.1.4 Caution and Use.

Do not use a screwdriver as a chisel, pliers as a wrench, or a wrench as a hammer. Do not use toothed-jaw (Stillson-type) wrenches on hard rubber pipe, bolts, or nuts.

10-11.2 Equipment and Supplies.

In addition to proper tools, a water treatment plant should be adequately supplied with the equipment, implements, and supplies that are essential to proper maintenance. Good housekeeping is a part of maintaining buildings and grounds and a part of operating equipment. Thus, in-house equipment and materials usually include housekeeping and gardening tools, equipment, and supplies. Table 10-17 lists the suggested implements. Table 10-18 lists materials and supplies to keep at the facility.

Table 10-17 Suggested Equipment for Water Treatment Plants

Equipment	
Alemite or zerk grease guns for plant equipment	Paint sprayer
Block and tackle for 1/2- and 3/4-in. rope (10- to 20-mm)	Pick
Boots, rubber	Rope, 1/2-, 3/4-, 1-in., 10-, 20-, 25-mm) and sash cord.
Brooms, street, ordinary, industrial	Safety equipment:
Brushes, flue, paint and whitewash, scrubbing, wire	Barricades
Caulking gun for windows	Electric blankets
Chain hoist, 1-ton (1,000-kg) capacity	First aid equipment
Electric drop light, explosion-proof with 200-foot (60-m) extension cord	Gas detector
Electric torch light, 1-1/2 or 3-volt	Gas mask (chlorine)
Flashlights, hand	Harness (safety belt) with 25 feet (8 m) x of 3/4-in. (20-mm) rope
Gloves, rubber and canvas work	Respirator for paint spraying, dust, etc.
Hydrometers, battery and alcohol	Warning signals
Ladders, step, extension (20-foot)	Squeegees, floor and window
Lanterns, red and white globe	Torches, bomb-type
Leak detectors	Two-wheel hand trucks
Manhole lifter	Vacuum cleaner
Mop and handle	Valve key
	Waste cans
	Wheel barrow, rubber-tired
	Wringer buckets

Garden Implements	
Brush hooks	Lawn mower (hand or motor)
Garden trowel	Pruning shears
Hedge clippers	Rakes, wood, steel
Hoe	Scythe
Hose: Garden type (300-foot)	Sickle
Nozzle (Shut-off type)	Spade
Insect sprayer	Sprinklers
Lawn roller	

Table 10-18 Suggested Materials and Supplies for Water Treatment Plants

Materials	
Alcohol or antifreeze	Graphite
Assortment of bolts, nuts, washers, screws, cotterpins, rivets, lock washers, cap screws, stud bolt, etc., stored in jars or cans	Grease, for lubrication
Bricks, common	Hose, nipples, and clamps for garden hose, extra
Calcium chloride (for icy pavements) Caulking compound	Iron and boiler cement
Caulking compounds, Durolite or equal, for glass house windows	Kerosene
Caulking yarn	Lead and lead wool
Cement	Light bulbs
Cement, asbestos	Measures, oil, 1-quart and 1-pint
Chain, assorted sizes and lengths	Mops
Chamois skins	Nails, assorted sizes
Cleaning powders, assorted	Oakum
Cleaning solvents (kerosene, dry-cleaning solvent, wood alcohol)	Oil for lubrication
Cups, drinking	Oil, rust removing, penetrating
Cutter wheels, spare	Packing for pumps
Disinfectants	Paint remover
Emery cloth, assorted grades	Painter's drop-clothes
Fittings, brass or iron, assorted sizes	Paints, turpentine, linseed oil, thinners, etc.
Flashlight batteries	Pipe joint compound
Fuses, assorted Glass	Pipe stock, depending on system
	Plugs, rubber expansion

Materials	
Polish, brass Putty Rags, clean and sterilized Sand, stone or gravel Sandpaper, assorted grades Soap Solder Soldering paste Spare handles for hammers, hatches and axes Spare parts for all machines and apparatus	Sponges Steel wool Tape, friction and electrician's Thermometers, assorted Toilet paper Towels Valve grinding compound Waste, wiping Wicks, for torches and lanterns Wire, annealed No. 10 and No. 16

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CHAPTER 11 SWIMMING POOL OPERATIONS

11-1 RESPONSIBILITIES.

Water system operators typically are not responsible for the operation, purification, and sanitation of swimming pools and spas at military installations. At some Army facilities they may be required to oversee the chemical balance, regulatory monitoring, and maintenance.

For the Army, follow *TB MED 575* and *TM 5-662.*

Responsibilities generally include monitoring water chemistry and maintaining pool equipment, including filters, pumps, and valves. In addition, operators may oversee emergency and accident procedures, administrative practices, and safety measures.

11-2 OPERATIONS.

Detailed best practice information about pool equipment and management can be found in *Pool-Spa Operators Handbook*. This reference guide covers the following topics:

- Types of pools
- Filters and filtration
- Pool circulation and recirculation equipment
- Pool water sanitizing, chemical balance, water testing, management, and maintenance
- Operational problems and chemical adjustments
- Care of seasonal pools
- Disease and accident prevention

Refer to *The Complete Swimming Pool Reference* for best practice information including the monthly operating checklist for swimming pool management in Table 11-1.

Table 11-1 Monthly Operating Checklist for Swimming Pools

Monthly Inspection	Specific Procedure/Requirement
Clean chemical feeders	Follow manufacturer's recommendations for cleaning feeders. Alternatively, follow the steps outlined below: a. Turn off the feeder. b. Remove the foot valve and strainer from the chemical solution being pumped. c. Place the assembly in fresh water and pump for 5 minutes to remove all chemicals. d. Place the foot and strainer in a 10% solution of muriatic acid. Turn on the pump. Run at least 1 pint of the acid through the unit. e. Remove the assembly from the acid solution and submerge in fresh water to remove all acid from the unit. Pump fresh water for at least 5 minutes to remove all acid before returning the unit to its original chemical solution.
Check gas chlorinators	See Chapter 10 paragraph titled Gas Chlorinators.
Check filter media	For sand filters: check for mud balls, channeling, or abnormalities; rake sand clean; add or replace sand if necessary.
	For D.E. filters: check filter septa for tears or holes; repair if necessary.
	For cartridge filters: soak in a cleaner to remove excess oils.
Check safety equipment and barriers	Inspect light fixtures, electronic surveillance equipment, GFIs, and fire extinguishers.
	Check integrity of all barriers, doors, locks and latches.

11-3 MAINTENANCE.

Refer to service-specific policy statements for guidance and direction regarding the responsibilities of operating personnel in providing O&M services at swimming pools and spas. If problems occur, refer to the troubleshooting checklist provided in Table 11-2. Do not perform troubleshooting of the pool water quality before ensuring that the pH is within the proper range.

Table 11-2 Troubleshooting Checklist for Swimming Pools

Symptom	Possible Cause of Trouble	Remedy
Cloudy water	Poor coagulation and filtration	Establish correct alum dosage; backwash filters and apply fresh floc to filters; maintain proper chlorine residual.
Cloudy water: greenish	Algae: chlorine too low	Maintain proper chlorine residual.
	Copper corrosion: pH low	Adjust pH by adding soda ash; maintain Langelier saturation index within recommended range.
Cloudy water: milky	pH low	Adjust pH by adding soda ash.
	PH high in hard waters	Adjust pH by adding sodium bisulfate or dilute hydrochloric acid. (Note: Use of these chemicals is for special cases only and requires permission of base medical officer.)
	Too much alum	Reduce alum dosage.
	Defective diatomaceous earth filter element	Repair or replace.
Cloudy water: rusty	Iron corrosion: pH low	Adjust by adding soda ash; maintain Langelier saturation index within recommended range.
	Iron in makeup: poor filtration	Establish correct alum dosage; backwash filters and apply fresh floc to filters; maintain proper chlorine residual. Ensure filters are in proper operational order by conducting required inspection and maintenance.

Symptom	Possible Cause of Trouble	Remedy
Discolored side walls or bottom: green	Algae: chlorine too low	Maintain proper chlorine residual. If adjustment of chlorine residual does not adequately remove the problem, drain pool and scrub walls and bottom with 5 mg/L chlorine solution. Rinse well before refilling pool.
	Copper corrosion: pH low	Adjust pH by adding soda ash; maintain Langelier saturation index within recommended range.
Discolored side walls or bottom: rusty	Iron corrosion: pH low	Adjust pH by adding soda ash; maintain Langelier saturation index within recommended range. If problem is severe, drain pool and scrub walls with strong soap solution. If soap fails to remove stain, scrub with 2 to 5% solution of muriatic acid. Rinse well and refill pool.
	Iron in makeup: poor filtration	Establish correct alum dosage; backwash filters and apply fresh floc to filters; maintain proper chlorine residual. Ensure filters are in proper operational order by conducting required inspection and maintenance. If problem is severe, drain pool and scrub with strong soap solution. If soap fails to remove stain, scrub with 2 to 5% solution of muriatic acid. Rinse well and refill pool.
Eye irritation	pH low Chlorine high	Adjust pH by adding soda ash. Adjust chlorinator to maintain proper chlorine residual.
	Chlorine low	Adjust chlorinator to maintain proper chlorine residual.

Symptom	Possible Cause of Trouble	Remedy
Inlet flow low	Pumps not operating	Look for clogged suction or discharge lines or air leaks in suction line. Check pump switches, valves, stuffing box, and internal parts. See pump maintenance procedures in Chapter 6 paragraph titled Storage Facility Maintenance.
	Hair catcher needs cleaning	Clean.
Filter runs short Skin irritation	Too much alum pH high	Reduce alum dosage. Adjust pH by adding sodium bisulfate or dilute hydrochloric acid. (Note: Use of these chemicals is for special cases only and requires permission of base medical officer.)
Slime on sides or bottom	Chlorine too low	Drain pool and scrub walls and bottom with 5 mg/L chlorine solution. Rinse well before refilling pool. Maintain proper chlorine residual.
Water feels slippery	pH high	Adjust pH by adding sodium bisulfate or dilute hydrochloric acid. (Note: Use of these chemicals is for special cases only and requires permission of base medical officer.)

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APPENDIX A BEST PRACTICES

A-1 MEASURING WATER LEVELS AND DRAWDOWN.

Well tests are necessary to evaluate the performance of a well. These tests include measuring the static water level, pumping rate, pumping levels at various times after pumping has started, and the increasing water levels after pumping has stopped. Measure the static level, pumping level, and drawdown on each well as often as practical. If a daily measurement cannot be made owing to a large number of wells or difficulty in taking the measurements, measure the level in each well at least twice a month at as near the same time as possible. A sample calculation for static level, pumping level, and drawdown is included below.

Orifices, meters, and pitot tubes are used to measure flow rates described in *AWWA M2 and AWWA M33.* Measure water levels using the air-line method, electric sounders, wetted tape, or electrical depth gauges. The most common method of depth measurement is the air-line method, which is explained below and depicted on Figure B-1.

a. Place an air-line of known length in a well (unless one has been permanently attached) to a depth below the expected pumping level. Connect the surface end of the line to an air pump and connect a pressure gage to the line so that air pressure in the line can be read. Make all joints airtight.

b. With the well pump shut down, apply air pressure through the air pump until the gauge needle no longer registers any increase in pressure. The gage reading then shows the amount of pressure that was necessary to force the standing water out of the air line. This is directly proportional to the height of the water standing in the well above the bottom of the air line. Multiply the gage pressure in psi by 2.31 to determine the height in feet; multiply kiloPascals by 10.1973 to obtain centimeters of water.

c. Some gauges measure feet of water in addition to air pressure; if available, use a gage that indicates feet of water. To determine the distance below the air gage at which the water stands in the well, subtract the calculated height of water above the bottom of the air line from the known length of the air-line below the well top. This value is the static level.

d. Start the well pump and observe the air gauge until the reading no longer changes, pumping in additional air to make up for any leakage. Convert this pressure reading to feet. This measurement is the height at which water stands in the well above the bottom of the air line during pumping. Deduct this value from the length of the air pipe below the well top to get the pumping level. The drawdown is the difference between the static level and the pumping level.

- Maintain careful records of static level and drawdown correlated with the capacity or pumping rate. This information can help you anticipate difficulties and provide data for proper maintenance measures:
- A falling static level indicates gradual lowering of the water table or interference by other wells.
- An increased drawdown may indicate receding groundwater level, well interference, or leaky casing or delivery pipes. Increased drawdown may also suggest a clogged, scaled, or corroded well screen; a sand- or silt-packed gravel area and adjacent stratum; or a cave-in of the water-bearing stratum.

Take measurements periodically to develop a well chart like the one shown in Figure 5-2 (Chapter 5). The pumping rate can be kept constant using a valve in the discharge line. Start the test with the valve one-half to three-fourths open at the desired flow rate. Compare well charts with prior test results to detect changes that require attention.

A-2 5/3 RULE SAMPLE CALCULATION.

Working hours required per position per year. A work position entails a commitment of 8 work hours per work position per day.

Equation A-1 Work Hours per Work Position per Day

$$\frac{8 hours}{day} * \frac{365 days}{year} = \frac{2{,}920 hours}{year}$$

Equation A-2 Paid Hours per Work Year

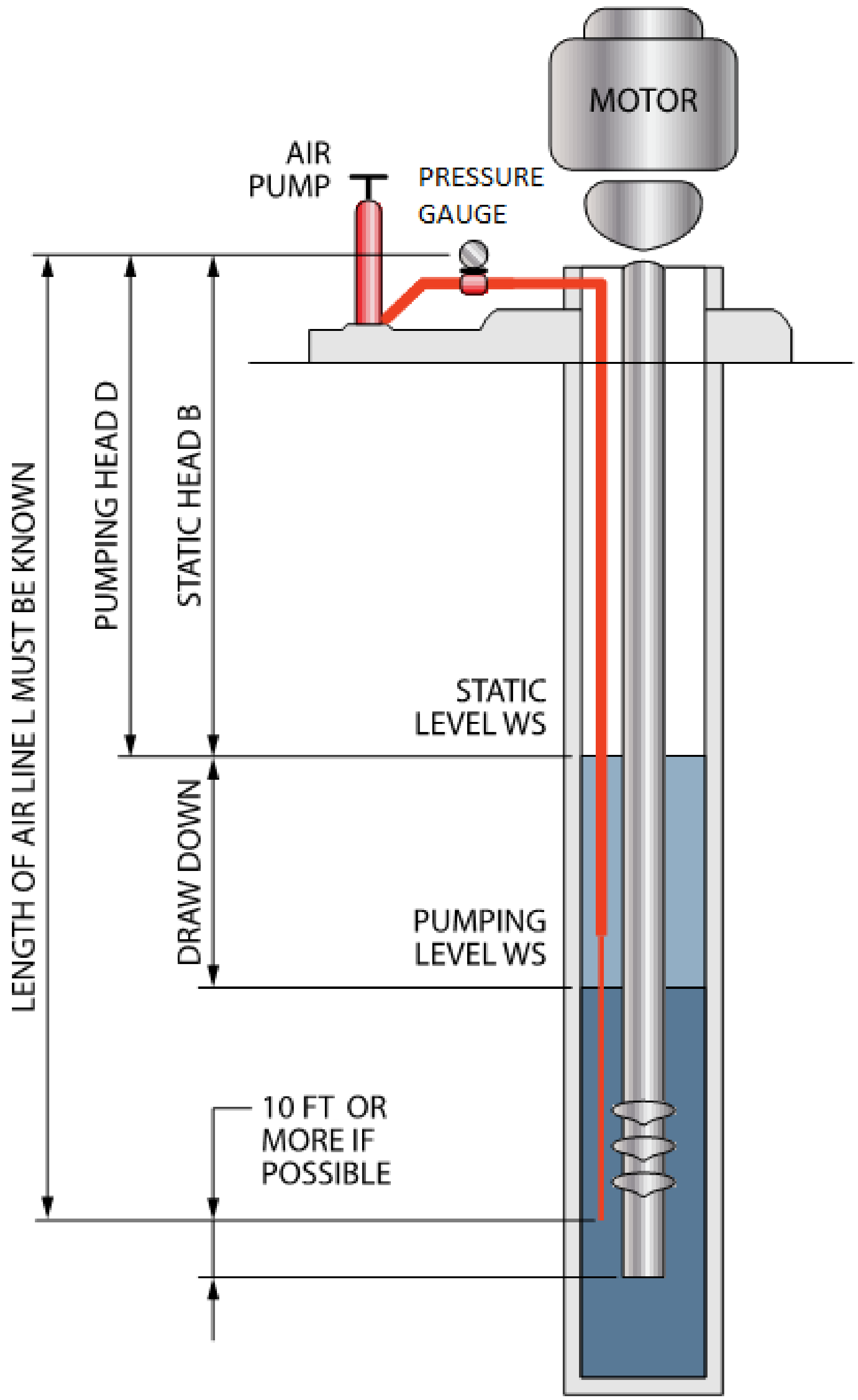
$$\frac{40 hours}{week} * \frac{52 weeks}{year} = \frac{2{,}080 hours}{year}$$

Non-productive hours typically vacation (160 hours), sick leave (40 hours), holiday (80 hours), training (48 hours): Approximately 328 hours total per year.

Equation A-3 Hours Worked per Year

$$\frac{2{,}080 hours}{year} - \frac{328 hours}{year} = \frac{1{,}752 hours}{year}$$

Figure A-1 Using Air Line to Find Depth of Water Level



Equation A-4 Number of Employees Required to Staff One Position per Shift

$$\frac{\frac{2{,}920 hours}{year}}{\frac{1{,}752 hours}{year}} = \frac{1.667 employees}{position / shift}$$

Equation A-5 Number of Employees Required to Staff One Position for Three Shifts

$$\frac{1.667 employees}{position / shift} * 3 shifts = \frac{5 employees}{position}$$

Labor Rate (actual cost to agency): Approximately $20.66 per hour.

Equation A-6 Agency Cost to Staff One Position

$$\frac{1.667 employees}{position} * \frac{2{,}080 hours}{year} * \frac{\$20.66}{hours} = \frac{\$71{,}636}{position}$$

A-3 STATIC LEVEL, PUMPING LEVEL, AND DRAWDOWN CALCULATION.

Assume a length of air line of 150 ft. Assume that the pressure gage reading before starting the pump is 25 psi. Assume that the gage reading during pumping is 18 psi.

Equation A-7 Static Water Level Calculation

$$B = L - \left(P_1 * 2.31 \frac{ft}{psi} \right)$$

Equation A-8 Pumping Level Calculation

$$D = L - \left(P_2 * 2.31 \frac{ft}{psi} \right)$$

Equation A-9 Drawdown Calculations

$$D - B = 108.4 - 92.3 = 16.1 ft$$

$$A - C = 57.7 - 41.6 = 16.1 ft$$

$$P_1 - P_2 = 25 - 18 = 7\,psi * 2.31 = 16.1\,ft$$

Where:
A = pressure before pump start expressed as ft of water
B = static water level (ft)
C = pressure during pump operation expressed as ft of water
D = pumping level (ft)
L = length of air line (ft)
P1 = pressure gauge before pump start (psi)
P_2 = pressure gauge during pump operation (psi)

A-4 METRIC STATIC LEVEL, PUMPING LEVEL, AND DRAWDOWN CALCULATION.

Assume a length of air line (L) of 45.7 m. Assume that the pressure gage reading (P1) before starting the pump is 172 kPa.

Convert pressure to meters of water (A) to determine the height of water above the bottom of the air line:

Equation A-10 Converting Pressure to Meters of Water (Metric)

$$kPa * \frac{4.0147 in.H_2O}{kPa} * \frac{0.0254m}{in.}$$

$$A = 172kPa * \frac{4.0147 in.H_2O}{kPa} * \frac{0.0254m}{in.} = 17.5m$$

Calculate the static water level (B) by subtracting the calculated height from the known airline length:

Equation A-11 Static Water Level (Metric)

$$B = L - A = 45.5 - 17.5 = 28.2m$$

Assume that the gage reading (P2) during pumping is 124 kPa. Convert this pressure to meters (C) using Equation B-10 to determine the height at which water stands in the well above the bottom of the air line during pumping:

$$C = 124kPa * \frac{4.0147 in.H_2O}{kPa} * \frac{0.0254m}{in.} = 12.6m$$

Calculate the pumping level (D) by subtracting (C) from the known length of air line using Equation B-12:

Equation A-12 Pumping Level Calculation (Metric)

$$D = L - C = 45.7 - 12.6 = 33.1m$$

Determine the drawdown using any of the following methods in Equation B-13:

Equation A-13 Drawdown Calculations (Metric)

$$D - B = 33.1 - 28.7 = 4.9m$$

$$A - C = 17.5 - 12.6 = 4.9m$$

$$P_1 - P_2 = (172 - 124) * 0.102 = 4.9m$$

Where:
A = pressure before pump start expressed as m of water
B = static water level (m)
C = pressure during pump operation expressed as m of water
D = pumping level (m)
L = length of air line (m)
P1 = pressure gauge before pump start (kPa)
P_2 = pressure gauge during pump operation (kPa)

A-5 FIELD HEAD CALCULATION.

Assume that a pressure gage located on the discharge of a well pump indicates a pressure of 35 psi for a discharge of 500 gpm. The corresponding pumping level in the well is 60 ft below the elevation of the pressure gage. The pump column is 8 in. in diameter and extends into the well 100 ft below the pump discharge.

The friction loss for 500 gpm of water through an 8-in. pipe, with a roughness coefficient (C) of 100, is 8.1 ft divided by 1,000 ft. The equivalent length of an 8-in.-long sweep elbow is 13 ft. Thus, the friction loss through the column and discharge elbow can be calculated as follows:

Equation A-14 Friction Loss Through Column and Discharge Elbow

$$113\,ft * \frac{8.1\,ft}{1{,}000\,ft} = 0.9\,ft$$

For help with head loss calculations, refer to best practice guidelines in *Water Treatment Plant Operation, Volumes 1 and 2*.

The vertical distance from the well pumping level to the pressure gage was given as 60 ft.

Equation A-15 Pressure Gage as Feet of Head

$$35\,psi * \frac{2.31\,ft}{psi} = 80.9\,ft$$

The total field head is the sum of the friction loss, vertical distance, and presence of ft of head:

Equation A-16 Total Field Head

$$0.9\,ft + 60\,ft + 80.9\,ft = 141.8\,ft$$

A-6 METRIC FIELD HEAD CALCULATION.

Assume that a pressure gage located on the discharge of a well pump indicates a pressure of 240 kPa for a discharge of 30 Lps. The corresponding pumping level in the well is 18 m below the elevation of the pressure gage. The pump column is 200 mm in diameter and extends into the well 30 m below the pump discharge.

The friction loss for 30 Lps of water through a 200-mm pipe, with a roughness coefficient (C) of 100, is 2.5 m divided by 300 m. The equivalent length of a 200-mm-long sweep elbow is 4 m. Thus, the friction loss through the column and discharge elbow can be calculated as follows:

Equation A-17 Friction Loss Through Column and Discharge Elbow (Metric)

$$34m * \frac{2.5m}{300m} = 0.3m$$

For help with head loss calculations, refer to best practice guidelines in *Water Treatment Plant Operation, Volumes 1 and 2*.

The vertical distance from the well pumping level to the pressure gage was given as 18.0 m.

Equation A-18 Pressure Gage as Feet of Head (Metric)

$$240kPa * \frac{0.1020m}{kPa} = 24.5m$$

Total field head is the sum of the friction loss, vertical distance, and pressure in feet of head:

Equation A-19 Total Field Head (Metric)

$$0.3m + 18.0m + 24.5m = 42.8m$$

A-7 BEST PRACTICE PUBLICATIONS.

Included are similar industry guidance references some that have not been specifically identified within the text. These provide additional proven facility solutions, systems, and lessons learned.

A-7.1 American Public Health Association Publications.

800 I St NW, Washington, DC 20001, 202-777-2446, https://www.apha.org

Standard Methods for the Examination of Water and Wastewater, American Public Health Association (APHA), 2013, APHA with the Water Environment Federation (WEF) and AWWA

A-7.2 American Society of Civil Engineers Publications.

1801 Alexander Bell Drive, Reston, Virginia, 20191, www.pubs.asce.org

ASCE 56-10, *Guidelines for the Physical Security of Water Utilities*, 1 January 2011

A-7.3 American Water Works Association Publications.

6666 West Quincy Avenue, Denver, CO, 80235-3098, 800-926-7337, www.awwa.org

Advances in Taste-and-Odor Treatment and Control, 1 May 1995

ANSI/AWWA A100, *Water Wells*, 7 June 2015

ANSI/AWWA B300, *Hypochlorites*, 1 April 2010

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AWWA C510, *Double Check Valve Backflow Prevention Assembly*, 1 September 2017

AWWA C511, *Reduced-Pressure Principle Backflow-Prevention Assembly*, 1 September 2017

AWWA C600, *Installation of Ductile-Iron Water Mains and Their Appurtenances*, 1 July 2017

AWWA C651, *Disinfecting Water Mains*, 8 June 2014

AWWA C654, *Disinfection of Wells*, 1 July 2013

ANSI/AWWA D102, *Coating Steel Water-Storage Tanks*, 8 June 2014

AWWA E103, *Horizontal and Vertical Line-Shaft Pumps*, 7 June 2015

AWWA G100, *Water Treatment Plant Operation and Management*, 1 August 2017

AWWA G200, *Distribution Systems Operation and Management*, 1 May 2015

AWWA G400, *Utility Management System*, 1 August 2009

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AWWA G430, *Security Practices for Operation and Management*, 1 November 2014

AWWA G440, *Emergency Preparedness Practices*, 1 August 2017

AWWA J100 (R2013), *Risk Analysis and Management for Critical Asset Protection (RAMCAP) Risk and Resilience Management of Water and Wastewater Systems*, 1 July 2010

AWWA M3, *Manual of Water Supply Practices:* Safety Practices for Water Utilities, 1 June 2014

AWWA M7, *Manual of Water Supply Practices: Problem Organisms in Water - Identification and Treatment*, 1 January 2004

AWWA M14, *Manual of Water Supply Practices: Recommended Practice for Backflow Prevention and Cross-Connection Control*, 8 January 2015

AWWA M21, *Manual of Water Supply Practices: Groundwater*, 1 January 2014

AWWA M38, *Manual of Water Supply Practices: Electrodialysis and Electrodialysis Reversal*, 1 January 1995

AWWA M44, *Manual of Water Supply Practices: Distribution Valves - Selection Installation, Field Testing, and Maintenance*, 1 March 2016

Centrifugal Pumps and Motors: Operation and Maintenance, 1992

Corrosion Control for Operators, 1986

Distribution System Maintenance Techniques, 1987

Drinking Water Handbook for Public Officials, 15 November 2006

Filtration Strategies to Meet the Surface Water Treatment Rule, 1991

Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources, 1991

Identification and Treatment of Tastes and Odors in Drinking Water, 1987

Maintenance Management for Water Utilities, 2010

Minimizing Earthquake Damage – A Guide for Water Utilities, 1994

Principles and Practices of Water Supply Operations Series: Basic Science Concepts and Applications, 2003

Principles and Practices of Water Supply Operations Series: Water Quality, 2010, Joseph A. Ritter

Principles and Practices of Water Supply Operations Series: Water Sources, 2010, Paul Koch

Principles and Practices of Water Supply Operations Series: Water Transmission and Distribution, 2003

Principles and Practices of Water Supply Operations Series: Water Treatment, 2010, Nicholas G. Pizzi

Procedures Manual for Selection of Coagulant, Filtration, and Sludge Conditioning AIDS in Water Treatment, 1986, Steven K. Dentel

SDWA Advisor: Regulatory Update Service, 1994, Frederick W. Pontius

Sludge, Handling and Disposal, 1989

Water Quality and Treatment: A Handbook of Community Water Supplies, 1 October 1999, American Water Works Association, McGraw-Hill, 2 Penn Plaza, 10th Floor, New York, NY

Work Practices for Asbestos-Cement Pipe, 1995

Water Treatment Plant Operation, Volume 1, January 2008, California State University Sacramento Office of Water Programs and American Water Works Association

Water Treatment Plant Operation, Volume 2, 2015, Ken Kerri, California State University Sacramento Office of Water Programs and American Water Works Association

A-7.4 American Water Works Association Water Research Foundation Publications.

6666 West Quincy Avenue, Denver, CO, 80235-3098, 303-347-6100, www.waterrf.org

Assessment of Existing and Developing Water Main Rehabilitation Practices, 1991

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Lead Control Strategies, 1990

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EPA 816-R-02-014, *Filter Backwash Recycling Rule Technical Guidance Manual*, December 2002, Office of Ground Water and Drinking Water (4606M) www.epa.gov/safewater

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FEMA P-911, *Pocket Safety Guide for Dams and Impoundments*, October 2016, Federal Emergency Management Agency, 500 C Street S.W., Washington, D.C. 20472, https://www.fema.gov/

FEMA P-957, *Snow Load Safety Guide,* January 2013, Federal Emergency Management Agency, 500 C Street S.W., Washington, D.C. 20472, https://www.fema.gov/

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State of Colorado, *Drinking water: Operations and maintenance (O&M) manual tools*, https://colorado.gov/pacific/cdphe/drinking-water-operations-and-maintenance-om-manual

A-7.6 National Lime Association Publications.

3601 N. Fairfax Dr., Alexandria, VA 22201, https://www.lime.org/

Bulletin 213, *Lime Handling, Application and Storage in Treatment Processes*, 1971, Robert S Boynton

A-7.7 Non-Government Publications

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Ozone in Water Treatment: Application and Engineering, 1991, Bruno Langlais, David A. Recknow, and Deborah R. Brink, eds., Lewis Publishers and AWWARF

"Plant Engineering Magazine's Exclusive Guide to Interchangeable Industrial Lubricants", *Plant Engineering Vol. 49 No. 13,* October 9, 1995, Ron Holzhauer

"Plant Engineering Magazine's Exclusive Guide to Synthetic Lubricants," *Plant Engineering Vol. 48 No. 16*, December 1994, Ron Holzhauer. https://www.controleng.com/single-article/plant-engineering-magazine-s-exclusive-guide-to-synthetic-lubricants

Recommended Standards for Water Works 2012 Policies for the Review and Approval of Plans and Specifications for Public Water Supplies, Water Supply Committee of the Great Lakes--Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers, Health Research Inc., Health Education Services Division, P.O. Box 7126, Albany, NY 12224, 518-439-7286, http://www.healthresearch.org

Reverse Osmosis: A Practical Guide for Industrial Users, 1995, Wes Bryne, Littleton, Colorado, Tall Oaks Publishing, Inc.

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APPENDIX B GLOSSARY

B-1 ACRONYMS.

µ	microns
ABC	Association of Boards of Certification for Operating Personnel in Water Utilities and Pollution Control Systems
AC	alternating current
AFGM	Air Force Guidance Memorandum
AFI	Air Force Instruction
AFMAN	Air Force Manual
AFPD	Air Force Policy Directive
ANSI	American National Standards Institute
AR	Army Regulation
ASCE	American Society of Civil Engineers
AWWA	American Water Works Association
AWWARF	American Water Works Association Research Foundation
bbl	barrel unit
BIA	Bilateral Infrastructure Agreement
C	Centigrade; also Hazen and Williams pipe friction coefficient
CERL TR	Construction Engineering Research Laboratory Technical Report
cfm	cubic feet per minute
cm	centimeter
CRREL	Cold Regions Research and Engineering Laboratory
DBP	disinfection byproduct
DC	direct current
DEM	digital elevation model
DO	dissolved oxygen

DoD	U.S. Department of Defense
DTM	digital terrain model
EO	Executive Order
EPA	United States Environmental Protection Agency
F	Fahrenheit
FEMA	Federal Emergency Management Agency
FFHC	fit for human consumption
FGS	Final Governing Standards
ft	feet
g	gram
GAC	granular activated carbon
gal	gallon
GIS	Geographic Information System
gpm	gallons per minute
HNFA	Host Nation Funded Construction Agreement
I&C	instrumentation and control
in.	inch
jet	ejector
kg	kilogram
kPa	kiloPascals
kg/sq cm	kilograms per square centimeter
L	liter
lb	pound
lb/ft^3	pounds per cubic foot
Lps	liters per second

Lps/sq m	liters per second per square meter
m	meter
mg/L	milligrams per liter
min.	minute
mm	millimeter
MCO	Marine Corps Order
MOR	monthly operating report
NACE	National Association of Corrosion Engineers
NAVFAC	Naval Facilities Engineering Command
NFPA	National Fire Protection Association
NPSH	net positive suction head
NSF	National Sanitation Foundation
NSPF	National Swimming Pool Foundation
O&M	operations and maintenance
OSHA	Occupational Safety and Health Administration
PAC	powdered activated carbon
pH	hydrogen-ion concentration
ppm	parts per million
psi	pounds per square inch
PWTB	Public Works Technical Bulletin
RAMCAP	Risk Analysis and Management for Critical Asset Protection
SCADA	supervisory control and data acquisition
SDWA	Safe Drinking Water Act
SOFA	Status of Forces Agreement
sq	square

TB MED	Technical Bulletin-Medical
THM	trihalomethanes
UFC	Unified Facilities Criteria
UFGS	Unified Facilities Guide Specifications
UV	ultraviolet
VOC	volatile organic compound (also volatile synthetic organic chemical compound)
WEF	Water Environment Federation

B-2 DEFINITION OF TERMS.

The definition of each term is that as defined in the applicable standard.

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Change 2, 1 May 2020

UNIFIED FACILITIES CRITERIA (UFC)

WATER TREATMENT

UNIFIED FACILITIES CRITERIA (UFC)

WATER TREATMENT

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING COMMAND (Preparing Activity)

AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

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

Change No.	Date	Location
1	1 May 2016	1. Updated information in 1-2, and 1-3.1. 2. Added reference to UFC 3-201-01 in paragraph 2-1. 3. Revised reference to DoD Instruction in paragraph 1-3.2. 4. Revised design requirements in paragraph 2-1.1. 5. Revised 2-1.2 and 3-1 to revise requirements and remove CONUS and OCONUS. 6. Revised AWWA reference in 2-1.3 and 3-5. 7. Revised requirements in paragraphs 2-1.1, 3-2, 3-3.1.1, 3-3.1.2, 3-3.2 and 3-4 to coordinate with changes to UFC 3-230-01. 8. Updated references in Appendixes A and B.
2	1 May 2020	1. Updated paragraphs 3-2 and 4-3.1 to coordinate with revision of UFC 3-240-01. 2. Updated reference to UFC 1-200-01, DoD Building Code in paragraph 1-3.1. 3. Updated references in Appendix A.

This UFC supersedes UFC 3-230-08A and UFC 3-230-12A, both dated 16 January 2004.

FOREWORD

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

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Center for Engineering and the Environment (AFCEE) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale should be sent to the respective service proponent office by the following electronic form: Criteria Change Request. The form is also accessible from the Internet sites listed below.

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

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

Hard copies of UFC printed from electronic media should be checked against the current electronic version prior to use to ensure that they are current.

JAMES C. DALTON, P.E. Chief, Engineering and Construction U.S. Army Corps of Engineers	JOSEPH E. GOTT, P.E. Chief Engineer Naval Facilities Engineering Command
TERRY G. EDWARDS, P.E. Director, Air Force Center for Engineering and the Environment Department of the Air Force	MICHAEL McANDREW Director, Facilities Investment and Management Office of the Deputy Under Secretary of Defense (Installations and Environment)

UNIFIED FACILITIES CRITERIA (UFC)
REVISION SUMMARY SHEET

Title: UFC 3-230-03, Water Treatment

Superseding: UFC 3-230-08A and UFC 3-230-12A.

Description: This new UFC 3-230-03 consolidates into one Tri-Service document the civil engineering criteria applicable to water treatment that were formerly in the superseded documents. This UFC – through succinct reference to industry and government standards, codes and references – makes possible the replacement and/or consolidation of numerous criteria documents.

The complete list of water engineering documents referenced in this UFC can be found in Appendices A and B.

Reasons for Document:

- The new UFC updates the guidance and requirements for water treatment contained in several existing engineering documents and efficiently consolidates them into a single UFC.
- The superseded UFC documents included requirements that were not consistent with industry standards or utilized different industry standards.

Impact:

This unification effort will result in the more effective use of DoD funds in the following ways:

- By significantly improving the design process for DoD projects and facilities, through a more efficient application of facilities criteria and enabling more efficient maintenance of facilities criteria.

- The consolidation of the UFC 3-230-03 will positively impact the project costs incurred, as a result of the following direct benefits:

  - Reduction in the number of civil references used for military construction provides more clear and efficient guidance for the design and construction of DoD facilities.
  - Improved clarity and convenience results in reduced time required for execution of project designs.
  - Reduction in ambiguity and the need for interpretation reduces the potential for design and construction conflicts.
  - The reduction in the number of documents and the use of industry standards improves the ease of updating and revising this reference document as better information becomes available.

Non Unified Issues: No major unification issues.

TABLE CONTENTS

TABLES

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CHAPTER 1 INTRODUCTION

1-1 PURPOSE AND SCOPE.

This Unified Facilities Criteria (UFC) provides requirements for typical water treatment systems for the Department of Defense (DoD). These minimum technical requirements are based on UFC 1-200-01. Where other statutory or regulatory requirements are referenced in the contract, the more stringent requirement must be met.

1-2 APPLICABILITY.

\1\This UFC applies to service elements and contractors involved in the planning, design and construction of permanent DoD facilities worldwide. It is applicable to all methods of project delivery and levels of construction.

1-2.1 Foreign Countries.

All design and construction outside of the United States and United States territories is governed by international agreements, such as the Status of Forces Agreements (SOFA), Host Nation-Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA), and country-specific Final Environmental Governing Standards (FGS) or the DoD *Overseas Environmental Baseline Guidance Document,* DoD 4715.05G. The OEBGD applies when there are no FGSs in place. Therefore, in foreign countries this UFC will be used for DoD projects to the extent that it is allowed by and does not conflict with the applicable international agreements and the applicable FGS or OEBGD./1/

1-3 OTHER CRITERIA.

1-3.1 General Building Requirements.

\1\Comply with UFC 1-200-01, DoD Building Code \2\ /2/./1/ UFC 1-200-01 provides applicability of model building codes and government-unique criteria for typical design disciplines and building systems, as well as for accessibility, antiterrorism, security, sustainability, low impact development (LID) and safety. Use this UFC in addition to UFC 1-200-01 and the UFCs and government criteria referenced therein.

1-3.2 Safety.

All DoD facilities must comply with \1\DoDI 6055.01/1/ and applicable Occupational Safety and Health Administration (OSHA) safety and health standards.

1-3.3 Antiterrorism and Security.

Specific security concerns for Water Treatment Facilities are addressed in the “Policy Statement on Infrastructure Security for Public Water Supplies” of the *Ten State Standards*. Use Best Practices document, ASCE/AWWA Draft American National

Standard for Trial Use, *Guidelines for the Physical Security of Water Utilities*, for latest guidelines for protection of water utility systems.

1-4 REFERENCES.

Appendix A contains the list of references used in this document. The publication date of the code or standard is not included in this document. In general, the latest available issuance of the reference is used.

1-5 BEST PRACTICES.

Appendix B identifies background information and practices for accomplishing certain water treatment design and engineering services. The Designer of Record (DoR) is expected to review and interpret this guidance as it conforms to criteria and contract requirements, and apply the information according to the needs of the project. If a Best Practices document has guidelines or requirements that differ from the Unified Facilities Guide Specifications (UFGS) or UFC, the UFGS and the UFC must prevail. If a Best Practices document has guidelines or requirements that are not discussed in the Unified Facilities Guide specification (UFGS) or UFC, the DoR must submit a list of the guidelines or requirements being used for the project with sufficient documentation to the Government Project Manager for review and approval prior to completing design.

CHAPTER 2 GENERAL DESIGN REQUIREMENTS

2-1 DESIGN.

\1\Use UFC 3-201-01 for preliminary site analysis, site design, storm drainage systems, and pavements./1/

2-1.1 Design Criteria.

Design water treatment systems to meet the drinking water quality requirements of applicable federal, state and local government agencies or overseas equivalent.\1\

2-1.1.1 Within The United States.

Use UFC 3-230-01.

2-1.1.2 Foreign Countries.

Use UFC 3-230-01./1/

2-1.2 Design Approval.

\1\The DoR must identify, assist, and provide, as applicable, all permits, approvals, and fees required for the design and construction of the new project from Federal, state and local regulatory authorities or overseas equivalent. The Civil Engineering Designer of Record must be a Professional Civil Engineer experienced and licensed; licensure in the location of the project may be required to obtain permits and approvals. For new water treatment systems, rehabilitation or replacement of existing water treatment systems to water treatment systems, coordinate with the Safe Drinking Water Act primacy agency, as applicable, to determine primacy agency requirements. In the United States and its territories and possessions the Government will review plans for acceptability. In locations outside of the United States and its territories and possessions with Host Nation agreements, follow design approval procedure as directed in project scope and by Government Project Manager. In areas outside of the United States and its territories and possessions without Host Nation agreements, the Government will review and approve plans for compliance.

Consult with the Government Project Manager to determine the appropriate signatories for permit applications./1/

2-1.3 Planning for Non-War Emergencies.

Refer to Best Practices document \1\AWWA M19/1/, for non-war emergencies such as earthquakes, hurricanes, tornadoes, floods and vandalism.

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CHAPTER 3 \1\SYSTEM/1/ SOURCES AND FLOWS

\1\The design capacity of the water treatment plant, including water system source and equalization storage, as indicated in UFC 3-230-01 chapter titled *Finished Water Storage*, must be able to accommodate the design flow./1/

3-1 \1\SYSTEM/1/ SOURCES.

Unless otherwise directed by the Government Project Manager, obtain potable water supply from a nearby public system. If this is not practical, sources must be developed for the Military activity.

The selection of a water supply source involves a review of the alternative sources available and their respective characteristics. Consider water quality and quantity data for the supply source over a significant period of time to sufficiently assess seasonal and long-term variability. Consider the following factors when selecting a water supply source:

- Safe yield
- Water quality
- Collection requirements (intake structure, wells, etc.)
- Treatment requirements (including the cost and feasibility of residue disposal)
- Transmission and distribution requirements

A complete discussion of water source selection and development is beyond the scope of this document. Refer to state waterworks regulations or overseas equivalent for the project location. \1\For areas outside of the United States and its territories and possessions/1/, evaluate all possible alternative sources, including cost, relations with the Host Nation, and antiterrorism considerations. Brackish or salt water must be used only when other sources are unavailable and must be converted to fresh water by a suitable process. Refer to AWWA's *Water Quality and Treatment*.

3-2 DESIGN POPULATION.

Refer to \2\ UFC 3-240-01, paragraph 3-1.1/2/.

3-3 \1\DESIGN FLOW.

The design flow is the greater of:

- peak hourly demand.

- maximum daily demand plus required fire flow.

When computing the design flow, account for other demands such as industrial demands./1/

3-3.1 Domestic \1\Demands/1/.

Domestic uses include drinking water, household uses and household lawn irrigation.

3-3.1.1 Per Capita Requirements.

\1\Use reliable water meter records to compute flows. If reliable water meter records are not available, use state regulations or overseas equivalent. Compute flows based/1/ on daily water consumption rates for the types of facilities included in state regulations or overseas equivalent. In locations where state regulations or overseas equivalent do not address types of facilities, obtain typical water demand from Table 3-1.

Table 3-1: Daily Domestic Consumption Rates [1]

Use Category [2]	**Flow Requirement** (gpcd) (m^3/cap/s)
Unaccompanied Personnel Housing [2]	110 (4.82×10^{-6})
Family Housing [2,3]	125 (5.48×10^{-6})
Nonresident Personnel and Civilian Employees (per 8 hr. shift)	30 (1.31×10^{-6})
Military Training Camps [2]	50 (2.19×10^{-6})

[1] Allowances do not include industrial \1\demands/1/.
[2] These values represent domestic \1\water rates/1/ for resident personnel averaged over the entire installation for a 24-hour period.
[3] In family housing areas, each housing unit must be assigned 3.6 residents for the purpose of calculating populations.

In addition to Table 3-1, other buildings and establishments normally found on military installations must be assigned typical daily water consumption rates obtained from the latest edition of Best Practices document, \1\MWH's/1/ *Water Treatment: Principles and Design*. Do not use these typical daily water consumption rates for contingency operations.

3-3.1.2 Controlling Demands.

The \1\Average Daily Demand/1/ must be calculated as follows:

Average \1\Daily/1/ Demand (gpd) (m^3/s) = (gpcd) (m^3/cap/s) x Design Population

Demand variations must be evaluated by the following:

Maximum Demand = \1\Average Daily/1/ Demand x K

\1\Compute Maximum Daily Demand and Maximum Peak Hourly Demand using the average daily demand and the coefficients indicated in Table 3-2. Use the greater of the computed demand or historical water meter records/1/.

Table 3-2: Demand Variations (Coefficient K)

Demand	Units of Demand	Coefficient K	
		Population < 5000	Population > 5000
Maximum \1\Daily Demand/1/	gpd (m^3/s)	2.25	2
\1\Peak Hourly Demand/1/	gpm (m^3/s)	4.0	3.5

The designer may make allowances in per capita demand, as deemed necessary, for small activities where all or nearly all demand occurs during working hours. Also account for a planned buildup or population decrease.

3-3.2 \1\Industrial Demands.

Use reliable water meter measurements to determine industrial demands. If reliable historical water records are not available, compute industrial demands based on actual conditions. Water meter records for similar types of facilities having similar uses to those anticipated may be used but must be adjusted to account for facility differences and regional conditions. When computing industrial demands consider processes such as cooling water systems, issues to ships, irrigation, swimming pools, shops, laundries, dining, processing, flushing, air conditioning, wash racks, rinse racks, and boiler makeup./1/ Confirm water characteristics required for industrial processes to determine appropriate treatment.

3-3.3 \1\Fire Demands.

Fire system demands must be derived from UFC 3-600-01./1/

3-4 \1\/1/

3-5 MATERIALS SELECTION.

Approach selection of equipment, piping, materials and coatings for water treatment systems in accordance with current AWWA standards. \1\Use AWWA M27 for the selection of materials, coatings, linings, and protective methods for specific pipe material, or a cathodic protection system to protect from external corrosion. Explicit approval by the Government is required prior to providing a cathodic protection system on a buried pipeline. Ensure compliance with NSF Standard 60 and NSF Standard 61./1/

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CHAPTER 4 SITE SELECTION

4-1 LOCATION.

Water treatment plants must be located above the projected 100 year flood elevation according to UFC 3-201-01. Government approval is required for lower elevations to be considered even if it can be adequately shown that the proposed treatment plant can be protected from flooding.

Consider the following for a treatment plant site:

- Proximity to the source of raw water.
- Proximity to the area to be served.
- Potential for flooding of the site.
- Availability and reliability of electric power from more than one source of outside power.
- Geology and topography of the site.
- Size of the site, both for original and for anticipated expansions.
- Legal obligations or restrictions.
- Environmental considerations.
- Antiterrorism integrity.

4-2 ACCESS.

The site must be selected so that an all-weather road is available or can be provided for access to the plant. Consideration must be given, during layout of buildings, roads, fencing and appurtenances, to winter conditions, especially of snow drifting and removal.

4-3 FIELD INVESTIGATION.

4-3.1 Existing and Proposed Service Areas.

Utilize Installation's existing utility maps and proposed planning documents to develop existing and proposed service areas for present \1\and future conditions. Estimate future growth as required by \2\ Chapter 3 /2/./1/

4-3.2 Topographic Survey.

Provide a topographic survey of project area including locations of existing utilities in accordance with UFC 3-201-01.

4-3.3 Soils.

Evaluate geotechnical data on existing soils \1\for/1/ corrosivity, if existing operating records, visual observations, inspections or testing indicates a need for corrosion control. \1\When required by the contract/1/, provide an evaluation of existing soils at the proposed depths and locations of the water system components in accordance with

\1\AWWA M27, Chapter 3 entitled “Evaluating the Potential for Corrosion”/1/ and provide recommendations on materials and positive corrosion protection systems.

4-3.4 Environmental Considerations.

Contact the Installation’s Environmental Reviewer prior to design and evaluate site for environmental concerns and known contamination. Notify Government Project Manager of known environmental contamination to ensure adequate funding in current project.

CHAPTER 5 TREATMENT PROCESS SELECTION

The selection of treatment facilities must be determined by feasibility studies, considering all engineering, economic, energy and environmental factors. All legitimate alternatives must be identified and evaluated by life cycle cost analyses. Additionally, energy use between candidate processes must be considered. For the purpose of energy consumption, only the energy purchased or procured will be included in the usage evaluation. All treatment process systems must be compared with a basic treatment process system, which is that system accomplishing the required treatment at the lowest first cost. Pilot or laboratory analysis must be used in conjunction with published design data of similar existing plants to assure the optimal treatment. It is the responsibility of the Civil Engineering Designer of Record to ensure that the selected water treatment plant process complies with the National Primary Drinking Water Standards of the Safe Drinking Water Act or overseas equivalent, State and local regulations, whichever is more stringent.

5-1 PROCESS SELECTION FACTOR.

Consider the following factors in the choice of a water treatment process:

- Water supply source quality
- Desired finished water quality
- Reliability of process equipment
- Operational requirements and personnel capabilities
- Flexibility in dealing with changing water quality and equipment malfunctions
- Available space for construction and future expansion of treatment facilities
- Waste disposal constraints
- Capital and operating costs (including chemical availability)
- Process susceptibility to intentional contamination or disruption of operation

5-2 FLUORIDATION.

All designs of new DoD water treatment systems serving 3300 people or greater must include the ability to treat drinking water to the optimally adjusted concentrations of fluoride indicated in the latest Center for Disease Control's (CDC) National Guidelines For Fluoride Use found in *Recommendations for Using Fluoride to Prevent and Control Dental Caries in the United States*. All treatment systems serving less than 3300 people will be determined on a case by case basis.

5-3 CORROSION CONTROL TREATMENT.

Provide corrosion control treatment in accordance with AWWA M58, *Internal Corrosion of Water Distribution Systems* if there is evidence of internal corrosion of distribution system piping and building plumbing.

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CHAPTER 6 SMALL WATER TREATMENT SYSTEMS

6-1 GENERAL DESIGN CRITERIA.

Design upgrades to existing treatment facilities and construction of new treatment facilities based on the criteria indicated in paragraph entitled "*Design Criteria*".

Design potable water systems treating less than 100,000 gallons per day (4.38 x 10^{-3} m^3/s) in accordance with EM 1110-2-503. Use Best Practices document, AWWA's *Design and Construction of Small Water Systems*, for design guidance.

If the Civil Engineering Designer of Record utilizes a particular water treatment system, technology, component or device, more than one manufacturer must be listed in the construction documents in accordance with the latest FAR regulations. The manufacturers' systems or components indicated must be currently approved for commercial use for the proposed application and project conditions in the State where the project is located. If the State does not maintain an approved water treatment system or components list or the project is in a location not subject to state water works regulations, then documentation must be provided to the Government indicating that each manufacturer's proposed water system or component is approved in at least one other state for commercial use for a similar application.

6-2 TYPICAL MILITARY APPLICATIONS.

Most small potable water systems on military installations that do not obtain water from a municipality use a groundwater source with limited or specialized treatment systems.

6-3 PACKAGED TREATMENT PLANTS.

Many small treatment systems on military installations are packaged treatment plants. These systems combine processes such as flocculation, aeration, sedimentation, and filtration in a single multicompartment tank. Typical types include demineralization, reverse osmosis, electrodeionization, and sea water desalination. Various processes may include proprietary components.

6-4 DISINFECTION.

Disinfection of the effluent must be provided as necessary to meet applicable drinking water quality standards.

Chlorine gas must not be used for disinfection for a small water treatment system.

6-5 RELIABILITY.

Multiple process units capable of independent operation must be provided for redundancy at all plants.

Provide for emergency power operation, such as a dedicated standby emergency generator or a portable generator, in conformance with applicable regulatory and utility provider requirements.

If the delivery of crucial chemical supplies is uncertain, larger than normal stores of these chemicals must be kept on hand, which will necessitate larger than normal chemical storage areas. Caution on the size of selected vessels and storage of chemicals must be exercised. The expected “shelf life” of chemicals and the operating environment must be taken into account. In addition, the procurement process for the facility must be understood before the finalization of any design project that requires ordering and storage of chemicals.

6-6 OPERATING CONSIDERATIONS.

To simplify plant operations, consider the following during the design stage:

Locate operations requiring frequent attention from plant operators reasonably close together. The most attention is generally required for operation of filters, flocculators and chemical feeding equipment.

Simplify chemical handling and feeding as much as possible. Locate unloading and storage areas for chemicals to be easily maintained and readily accessible and be close to the point of application of chemicals. Care must be exercised in the design of storage area ventilation system to ensure that normal and emergency discharges do not affect other areas or personnel.

Plants treating river water must provide the flexibility in treatment processes needed to cope with raw water quality changes such as high turbidity during rain/flood season.

Typically Operation and Maintenance Support Information (OMSI) manuals are required for treatment plants. OMSI manuals include preparation of the plant operating procedures and controls including a complete description of the treatment process flow.

6-7 ALTERNATIVE TECHNOLOGIES.

Consider technologies that can pre-condition water such that subsequent processing may be able to eliminate unit processes such that only simple technology or conventional treatment is required. Pilot testing to “prove” these assertions must be performed as appropriate.

CHAPTER 7 MEASUREMENT AND CONTROL

The primary purpose for instrumentation and control is to produce high quality aesthetic acceptable water compliant with regulatory primary drinking water standards and provide proactive alarms to treatment process malfunction.

7-1 MEASUREMENT OF PROCESS VARIABLES.

In order to determine the degree of effectiveness of the different treatment processes, several physical and chemical parameters associated with water treatment must be measured. After they are measured, the information must be evaluated so that necessary adjustments can be made in the treatment processes.

7-1.1 Minimum Analyses for Military Water Treatment Plants.

The type of water quality parameters and frequency of analysis to ensure drinking water is compliant with the National Primary Drinking Water Standards of the Safe Drinking Water Act or overseas equivalent are determined by the size of the system, treatment required, and water quality regulations. These requirements are typically set by state and local regulations. The frequency of analyses must also be adjusted locally to meet changing raw water characteristics. Minimum analyses frequencies and laboratory equipment requirements must comply with the more stringent requirements of individual state and local requirements. For locations outside the United States and United States territories refer to paragraph entitled "*Design Criteria*", for applicable requirements. Analyses conducted to determine compliance with drinking water regulations must be performed in an appropriately certified laboratory in accordance with the *Standard Methods for the Examination of Water and Wastewater* or approved alternative methods. Physical and chemical testing must be performed by trained and certified treatment plant operators or local laboratory personnel. Provide equipment to ensure proper process control must be required to be provided by the construction contractor or other suitable means prior to the plant coming online.

7-2 INSTRUMENTATION AND CONTROLS.

Provide for remote monitoring, such as telemetry, in conformance with applicable regulatory and utility provider requirements. If required, provide off site operation capability from a central location. Remote monitoring and control systems must meet the Installation's IT security requirements and standards.

Refer to AWWA's *Water Treatment Plant Design* for a detailed discussion of Process Instrumentation and Controls.

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CHAPTER 8 CHEMICAL TREATMENT

8-1 CHEMICAL PROPERTIES AND STANDARDS.

All chemicals used in water treatment operation must meet the purity requirements of the AWWA standard specifications and comply with NSF Standard 60. Design must be based on the assumption that chemicals will be purchased in normal shipping containers (such as bags, drums, cylinders, or carboys) rather than bulk car or truckloads. Functions of various chemicals and chemical strengths are provided in AWWA's *Water Treatment Plant Design.* For remote locations where delivery is difficult, give priority to chemicals that are stable in storage and slow to degrade or lose potency.

8-2 CHEMICAL HANDLING, STORAGE AND APPLICATION.

Refer to AWWA's *Water Treatment Plant Design* and *Ten State Standards,* Part 5 for discussions of chemical handling, storage and application procedures.

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CHAPTER 9 WATER TREATMENT WASTE RESIDUALS

9-1 QUANTITIES AND CHARACTERISTICS OF WASTE RESIDUALS.

In connection with water treatment plant location and design, the disposal of the wastes generated during the various treatment processes must receive careful consideration. Among these wastes are sludge from pre-sedimentation basins, coagulation and/or softening sludge, filter wash water, spent regenerant and rinse water from ion-exchange softeners, diatomite filter sludge and mineral wastes from desalination facilities. Ensure acceptable point of discharge for brine (mineral wastes) from desalination plants. Quantities of materials contained in the waste stream will be dependent on the type of treatment processes utilized and the quantity of water treated. A determination of the expected quantity of the various types of waste must be made and proper disposal methods identified during the design process.

9-2 WASTE MANAGEMENT.

For information regarding management and disposal of wastes generated by water treatment plants refer to AWWA's *Water Treatment Design*; AWWA's *Water Quality and Treatment*; and *Ten State Standards,* Part 9.

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APPENDIX A REFERENCES

GOVERNMENT PUBLICATIONS

UNIFIED FACILITIES CRITERIA (UFC), DEPARTMENT OF DEFENSE (DoD)
http://dod.wbdg.org/

\2\ UFC 1-200-01, *General Building Requirements* /2/

\1\UFC 1-200-02, *High Performance And Sustainable Building Requirements*/1/

UFC 3-201-01, *Civil Engineering*\1\ /1/.

\1\UFC 3-230-01, *Water Storage and Distribution*/1/

\2\ UFC 3-240-01, *Wastewater Collection and Treatment* /2/

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

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

UFC 4-020-01, *DoD Security Engineering: Facilities Planning Manual*

DEPARTMENT OF DEFENSE (DoD)
http://www.wbdg.org/ccb/browse_cat.php?o=29&c=76

DoD 4715.5-G, *Overseas Environmental Baseline Guidance Document*

\1\DoDI 6055.01, *DoD Safety and Occupational Health (SOH) Program,*
http://www.dtic.mil/whs/directives/corres/pdf/605501p.pdf /1/

UNITED STATES ARMY

EM 1110-2-503, *Design of Small Water Systems*

NON-GOVERNMENT PUBLICATIONS

AMERICAN WATER WORKS ASSOCIATION, 6666 W. QUINCY AVENUE, DENVER, CO 80235

AWWA M27, \1*External Corrosion Control for Infrastructure Sustainability*/1/

Standard Methods for the Examination of Water and Wastewater, latest edition

Water Quality and Treatment, latest edition

Water Treatment Plant Design, latest edition

CENTER FOR DISEASE CONTROL AND PREVENTION (CDC), 1600 CLIFTON ROAD, ATLANTA, GA 30333, cdcinfo@cdc.gov

Recommendations for Using Fluoride to Prevent and Control Dental Caries in the United States

GREAT LAKES – UPPER MISSISSIPPI RIVER BOARD OF STATE AND PROVINCIAL PUBLIC HEALTH AND ENVIRONMENTAL MANAGERS

Recommended Standards for Water Works, latest edition

APPENDIX B BEST PRACTICES

Appendix B identifies background information and practices for accomplishing certain water treatment design and engineering services. The Civil Engineering Designer of Record (DoR) is expected to review and interpret this guidance and apply the information according to the needs of the project. If a Best Practices document has guidelines or requirements that differ from the UFGS or Unified Facilities Criteria, the UFGS and the UFC must prevail. If a Best Practices document has guidelines or requirements that are not discussed in the Unified Facilities Guide specification (UFGS) or UFC, the DoR must submit a list of the guidelines or requirements being used for the project with sufficient documentation to the Government Project Manager for review and approval prior to completing design.

B-1 WHOLE BUILDING DESIGN GUIDE.

The Whole Building Design Guide provides additional information and discussion on practice and facility design, including a holistic approach to integrated design of facilities.

The WBDG provides access to all Construction Criteria Base (CCB) criteria, standards and codes for the DoD Military Departments, National Aeronautics and Space Administration (NASA), and others. These include, Unified Facilities Criteria (UFC), Unified Facilities Guide Specifications (UFGS), Performance Technical Specifications (PTS), design manuals, and specifications. For approved Government employees, it also provides access to non-government standards.

B-2 CIVIL ENGINEERING RELATED GUIDANCE.

GOVERNMENT PUBLICATIONS

NON-GOVERNMENT PUBLICATIONS

AMERICAN WATER WORKS ASSOCIATION, 6666 W. QUINCY AVENUE, DENVER, CO 80235

AWWA \1\M19, *Emergency Planning for Water Utilities*/1/

Desalination of Seawater and Brackish Water, latest edition

Design and Construction of Small Water Systems, latest edition

Guidelines for the Physical Security of Water Utilities, latest edition

Solar Distillation Practice for Water Desalination Systems, latest edition

Water Treatment in the five part series Principles and Practices of Water Supply Operations, latest edition

NSF INTERNATIONAL, P.O. BOX 130140, 789 N. DIXBORO ROAD, ANN ARBOR, MICHIGAN 48113-0140

NSF Standard 60, *Drinking Water Treatment Chemicals*, latest edition

NSF Standard 61, *Drinking Water System Components,* latest edition

WATER ENVIRONMENT FEDERATION (WEF), 601 WYTHE STREET, ALEXANDRIA, VA 22314-1994

Upgrading and Retrofitting Water and Wastewater Treatment Plants, Manual of Practice (MOP) 28, latest edition

WILEY, \1\JOHN WILEY/1/ & SONS, INC., 111 RIVER STREET MS 4-02, HOBOKEN, NJ, 07030-5774

\1*Handbook of Public Water Systems*, HDR Engineering, Inc., latest edition

MWH's/1/ *Water Treatment: Principles and Design,* latest edition

White's Handbook of Chlorination and Alternative Disinfectants, latest edition

\1\ /1/

UFC 3-230-13
1 March 2023

UNIFIED FACILITIES CRITERIA (UFC)

INDUSTRIAL WATER TREATMENT OPERATION AND MAINTENANCE

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UNIFIED FACILITIES CRITERIA (UFC)

INDUSTRIAL WATER TREATMENT OPERATION AND MAINTENANCE

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

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING SYSTEMS COMMAND (Preparing Activity)

AIR FORCE CIVIL ENGINEER CENTER

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

Change No.	Date	Location

This UFC supersedes UFC 3-240-13FN, dated 25 May 2005.

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FOREWORD

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

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

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

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

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

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CHAPTER 1 INTRODUCTION

1-1 BACKGROUND.

Clearly defining water treatment requirements for industrial water continue to be critical to reduce maintenance cost and increase life expectancy on all equipment.

1-2 REISSUES AND CANCELS.

This UFC supersedes UFC-3-240-13FN Industrial Water Treatment Operation and Maintenance dated 25 May 2005.

1-3 PURPOSE AND SCOPE.

This UFC provides an overview of industrial water treatment operations and maintenance. As used in this UFC, the term “industrial water” refers to the water used in power generation, heating, air conditioning, refrigeration, cooling, processing and all other equipment and systems that require water for operation. This UFC covers Theory of Operation, cause and effect, prevention, and it provides specific performance criteria and minimally acceptable standards for water treatment programs as a whole.

1-4 APPLICABILITY.

This UFC applies to industrial water systems. Industrial water is not the same as potable water. Industrial water is never consumed or used under situations that require a high degree of sanitation. To provide DOD personnel with the most up-to-date information available, the UFC guides the reader to industry standards in the industrial water treatment of heating, cooling and ship to shore equipment.

1-5 GENERAL BUILDING REQUIREMENTS.

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

1-6 CYBERSECURITY.

All control systems (including systems separate from an energy management control system) must be planned, designed, acquired, executed, and maintained in accordance with UFC 4-010-06, and as required by individual Service Implementation Policy.

1-7 GLOSSARY.

Appendix F contains acronyms, abbreviations, and terms.

1-8 REFERENCES.

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

CHAPTER 2 INTRODUCTION TO INDUSTRIAL WATER TREATMENT

2-1 INDUSTRIAL WATER TREATMENT.

Industrial water is not the same as potable water. Industrial water is never consumed or used under situations that require a high degree of sanitation.

Industrial water requires water preparation or chemical treatment, or both, to avoid the problems described in paragraph 2-1.2. Water preparation and chemical treatment requirements are described in Chapters 3 through 6 according to the type of system in question. The shore-to-ship steam purity standards are described in Chapter 4. Examples of industrial water systems and their uses are:

- Steam Boiler Systems. (See Chapter 4.) Steam uses include space and hot water heating, sterilization, humidification, indirect food processing, and power generation.
- Cooling Water Systems. (See Chapter 5.) Cooling water is used in cooling towers, evaporative coolers, evaporative condensers, and once-through systems. Applications are broad, ranging from simple refrigeration to temperature regulation of nuclear reactors.
- Closed Water Systems. (See Chapter 6.) These include closed hot water, closed chilled water, and diesel jacket systems.

2-1.1 Fire Protection and Other Uses.

Fire protection systems such as dedicated fire water distribution systems and building fire sprinkler systems are not considered industrial water systems.

2-1.2 Problems Encountered in Industrial Water Systems.

Problems found in industrial water systems are attributable to reduced or restricted water flow or other changes in operational parameters, and often caused by corrosion, deposits, and biological growth. These problems result in reduced system efficiency (higher operating costs), increased equipment replacement costs, and reduced safety. At times they can be serious enough to cause complete system shutdown. The problems in industrial water systems fall into three main categories:

- Steam boiler water problems (corrosion, deposits, and carryover).
- Cooling water problems (corrosion, deposits, and biological).
- Closed loop problems (corrosion, deposits, and biological).

2-1.2.1 Deposits.

The term “deposits” refers to a broad categorization of residues. Deposits are composed of mineral scale, biological matter, and suspended or insoluble materials (for example, sludge, dirt, or corrosion byproducts). Deposits can be created by the attachment of deposit-forming materials to pipe or equipment surfaces, or by settling and accumulation.

2-1.2.2 Scale.

The term “scale” describes specific types of deposits caused when mineral salts, dissolved in water, are precipitated either because their solubility limits have been exceeded or as a result of reaction to water treatment chemicals. Scale adheres to pipe and equipment surfaces and its formation results in loss of heat transfer and restricted flow of water or steam. Many different types of scale reflect the quality and characteristics of the makeup water and the type of chemical treatment being applied.

2-1.2.3 Biological.

The term “biological” describes both macrobiological organisms (mollusks, clams, fish) and microbiological organisms (algae, fungi, bacteria). Algae are microscopic plants that may grow in various industrial water systems but most commonly appear on the distribution decks of cooling towers. Fungi are living organisms that may cause damage to the wooden parts of cooling towers by causing decay. Slimes are accumulations of these biological contaminants that foul and corrode the cooling water equipment. Macrobiological organisms can cause fouling problems in once-through cooling water systems if untreated (“raw”) water is used.

2-1.2.4 Suspended Solids (SS).

The term “suspended solids” refers to any materials present in the water stream that are not actually dissolved in the water. SS can result from the presence of dirt, silt, and sand in the makeup water or can be introduced into the water from air in a cooling tower system. These solids are caused by feedwater contamination, by internal chemical treatment precipitates, or by exceeding the solubility limits of otherwise soluble salts. Biological matter, both dead and living, can be a form of SS if carried in the water stream. Corrosion products, such as iron oxide, are forms of SS that often originate in the system piping.

2-1.2.5 Corrosion.

The term “corrosion” refers to metal deterioration resulting from a refined metal’s tendency to return to its original state (the ore from which the refined metal was produced). The process of corrosion involves a series of electrochemical reactions. Metals that contact water in any type of water system can corrode if there is no attempt to protect them.

2-1.3 Objectives of Industrial Water Treatment.

Industrial water is treated to achieve the following objectives with respect to the equipment in which it is used: maintaining its efficiency, prolonging its usable “life,” and reducing the frequency of repair or replacement (or both). These objectives can be achieved by treating the water to minimize scale and to control corrosion, fouling, and microbiological growth. To meet these objectives, an adequate and continuous supply of both properly conditioned makeup water and conditioned or chemically treated system water (water within the water-using system) is produced. The source for industrial water is often the installation's potable water distribution system; however, there is a growing trend to use recycled municipal wastewater for makeup to cooling tower systems. When this source of makeup water is used, additional steps can be taken to provide a backup water supply.

2-1.4 Water Conservation.

Make every effort to conserve water used in boilers, cooling towers, and other water-using equipment. This includes identifying and fixing leaks throughout the systems, reducing uncontrolled water losses (drift) from cooling towers, and operating the systems at the highest permissible cycles of concentration (COC) by using proper procedures for blowdown and chemical treatment. Water conservation (using less water) also reduces the amount of treatment chemicals required for the water treatment program. This, in turn, eases operation of wastewater treatment facilities, reduces the requirements for chemical handling, reduces the volume of chemical wastes generated, and reduces the cost of water treatment.

2-1.5 Responsibility for Treatment.

2-1.5.1 Office Responsible.

The office responsible for industrial water treatment exists at the base or facility level. This office is responsible for developing short-term and long-term strategies for acquiring the resources needed to execute an effective water treatment program that incorporates the principles, procedures, and programs provided in this manual.

2-1.5.2 Organizational Assignments.

The development and implementation of efficient and economical procedures for industrial water treatment and water testing processes requires the assignment of specific and appropriate organizational responsibilities. If the person assigned to perform the treatment and testing of industrial water is assigned additional duties, assignment of additional personnel may be required to ensure that adequate and continuous attention is given to industrial water treatment and testing. A system for the regular reporting of trends in test results and for the regular assessment of system performance can be established to keep the assigned personnel appropriately informed.

2-1.6 Unauthorized Non-Chemical Devices.

The military does not currently recognize using non-chemical treatment devices for comprehensive water treatment or trials. These situations are described in detail in Chapter 9.

2-1.7 Health and Safety.

Many of the chemicals used to treat industrial water may be harmful to the health of the system operator and other installation personnel unless they are properly handled and controlled. Handle water treatment chemicals and test reagents with care, following the guidance of Occupational Safety and Health Administration (OSHA) directives, manufacturers’ recommendations, and safety data sheets (SDS). To minimize chemical handling, use automated control and feed equipment. Chapter 8 describes chemical application processes.

2-1.7.1 Protection of Potable Water.

Protecting potable water supplies, as it applies to an industrial water system, involves preventing contamination of the potable water system. Eliminating cross-connections in the water system and using backflow prevention devices or air gaps to provide an interconnection barrier between the water systems are ways to achieve this prevention.

2-1.7.1.1 Cross-connections.

A cross-connection is a physical connection between a potable water supply system and a non-potable water system (such as an industrial water system) through which contaminated water can enter the potable water system.

Cross-connections are eliminated to maintain the safety of potable water supplies. Backflow prevention devices are installed to prevent cross-connections where potable water is supplied to industrial water systems.

2-1.7.1.2 Backflow Prevention Devices.

Class III backflow prevention devices (air gap or reduced pressure principle devices) are required when connecting a potable water supply system to an industrial water system that uses a source of non-potable water. They are also required when connecting a potable water supply system to an industrial water system to which chemicals have been added. Refer to UFC 3-420-01 Plumbing Systems for additional backflow prevention guidance.

2-1.7.1.3 Air Gaps.

If potable makeup water is supplied to a tank or other type of open system, provide an air gap between the water inlet and the maximum overflow level of the tank, device, or system.

2-1.8 Restrictions on Direct Steam Use.

Neutralizing amine chemicals, which are added to the steam to protect the condensate lines from corrosion, make the steam and condensate unfit for consumption or for other uses normally reserved for potable water. Treated steam should not come into direct contact with food and should not be used for heating food trays or for humidification. For these applications, steam-to-steam heat exchangers can be used to provide amine-free steam (see paragraph 4-2.7.6).

2-1.9 Record-Keeping Requirements.

Procedures for industrial water treatment and testing may vary from one installation to another based on differences in the characteristics and quality of the water, as well as on differences in the type and size of the systems. Water system specifications are developed to address local factors such as the installation's mission, geographic location, and climate. The data and information records and logs used to record the results of industrial water treatment and testing can be developed to reflect the minimum documentation requirements needed to verify adequate operation and control of the treatment program. Computer-generated logs require regularly scheduled backup. Chapter 7 provides recommended frequencies for sampling and testing various industrial water systems.

2-1.9.1 Control Charts.

Control charts can be developed to identify the following information: the treatment chemicals used; the chemical levels required to be maintained in the system; other required testing procedures (for example, conductivity, pH); and the information specific to the particular water system (especially for the larger boilers and cooling towers). Water treatment service companies commonly supply these control charts.

2-1.9.2 Operations Logs.

Operations logs can be maintained to establish trends for parameters and items identified in the program control charts. These logs are best maintained as computer-generated spreadsheets and graphs. Hardcopy records are also acceptable.

2-1.9.2.1 Large Boilers.

Maintain water treatment logs on-site in all plants operating above 15 pounds per square inch gauge (103 kilopascal (kpa)) steam or 30 pounds per square inch gauge (207 kpa) hot water, with an output capacity above 100 boiler horsepower or 1 megawatt (3.5 million British thermal units per hour (MMBTUH)). The logs should provide a record of the treatment and test results of boiler water, makeup water, and condensate water. One log can be maintained for each boiler and one for the plant makeup water data.

2-1.9.2.2 Cooling Towers.

Maintain operating logs on-site for all operating cooling towers, and those logs should contain results (including dates) of all chemical tests performed, COC, and the amount of chemicals added.

2-1.9.2.3 Other Systems.

Maintain operating logs on-site for low-pressure steam boilers, high-temperature hot water boilers, medium-temperature hot water boilers, low- temperature water boilers, and closed chilled water systems. These logs should contain results (including dates) of all chemical tests, amount of chemicals added, and the volume of blowdown water, where applicable.

2-1.9.3 Historical Records.

Information pertaining to the maintenance and history of industrial water treatment, other than that which can be entered on the log form or data accumulated for log form entries, can be maintained for each system in a computerized maintenance management system, a separate computer application, or as a hardcopy historical record book. Hardcopy records should be letter size 8.5 inches by 11 inches (216 millimeters x 279 millimeters) or larger, and can be entered into a bound book rather than a loose-leaf binder. Records should contain information (including dates) about system start-up and shut-down, occurrences of corrosion and scale, major maintenance activities performed on the system, replacement of piping and equipment, accidents, outages, changes in method of operation and treatment used, and other pertinent data, including equipment inspection results logs.

2-1.10 Support Available.

2-1.10.1 Boiler and Cooling Water Quality Assurance (QA) and Quality Control (QC) Program.

Submit heating or cooling system water samples to a laboratory for analysis in accordance with an appropriate water QA and QC program. The purpose of QA is to verify that applied treatment chemicals, control limits, and external treatment are appropriate. QA is used to assist operators and managers to achieve accurate in-plant chemical testing and control. The primary purpose for a QA and QC program is to ensure and verify that the in-plant test results represent accurately tested and reported concentrations of water treatment chemicals. If the QA and QC procedures are in error or are not followed, or if the test results are not accurate, the consequences are reduced safety, possible damage to the equipment, and wasted energy, chemicals, and water.

2-1.10.2 Other Support.

Matters pertaining to military policy, requests for technical staff visits to troubleshoot industrial water systems, training of water treatment personnel, and general technical questions can be addressed to the appropriate military office.

U.S. Army Corps of Engineers
441 G. Street, NW Washington,
D.C. 20314-1000

HQ AFCESA/CESM
139 Barnes Drive, Suite 1
Tyndall AFB, FL 32403-5319

Naval Facilities Engineering Service Center
Utilities Systems Branch Code 231
1100 23rd Ave.
Port Hueneme, CA 93043-4370
Commercial (805) 982-3540

2-2 INDUSTRIAL WASTEWATER.

"Industrial wastewater" is a term that refers to any water discharged from an industrial water system. This term applies primarily to cooling tower and steam boiler blowdown; the term also applies to discharge industrial process water (like plating wastes).

2-2.1 Disposal Procedures.

Coordinate the treatment and disposal of liquid and solid (sludge) wastes from industrial systems with the installation environmental engineer.

2-2.1.1 Water Discharge Pretreatment.

Pretreatment of water discharge refers to a treatment procedure that is applied to water before it is discharged to the storm water system, the sanitary sewer system, or the base industrial wastewater treatment system. The installation environmental engineer is usually the individual responsible for determining when pretreatment is required and which methods will be used.

2-2.1.2 Water Discharge Restrictions.

The discharge of industrial water treatment system wastes may be regulated. All requirements can be established by working with the installation environmental engineer. The primary restriction is water quality. In addition to water quality restrictions, the discharge may be controlled in the following ways:

2-2.1.2.1 Discharge Location.

The location of the discharge can be determined by the configuration of both the water treatment system and the available sewers. Normal practice at the installation may include discharge into either the sanitary or industrial wastewater treatment system.

2-2.1.2.2 Discharge Rate.

The maximum rate of discharge to the designated sewer system may be a discharge requirement. Two factors are of importance in setting a maximum rate: the hydraulic capacity of the sewer and the strength (chemical concentration) of the waste.

2-2.1.2.3 Discharge Time Frame.

Discharge from a water treatment system unit may be allowed only at specified times.

2-2.1.2.4 Discharge Responsibilities.

The water treatment system operator is responsible for complying with the procedures and policies established at the installation, including directives on waste disposal that have been issued by the installation environmental engineer. The responsibilities of the installation environmental engineer include compliance of the installation's directives with government environmental regulations.

2-2.1.2.5 Review of Chemicals.

The installation environmental engineer should review the procedures for use of a new water treatment chemical to determine whether or not it can be safely disposed of using the existing procedures, or if new disposal procedures must be developed.

2-2.2 Environmental Regulations.

Numerous environmental regulations established by law may apply at the installation level. Contact the Installation environmental program staff for specific environmental requirements for the project location.

2-2.2.1 The Toxic Substances Control Act.

The Toxic Substances Control Act (TCSA) was amended by the Frank R. Lautenberg Chemical Safety for the 21st Century Act in which the TCSA authorizes the United States Environmental Protection Agency (EPA) to control all new and existing chemical substances that have been determined to pose a potential unreasonable risk to the public health or environment.

2-2.2.2 The Clean Water Act.

The Clean Water Act (CWA) incorporates the Federal Water Pollution Control Act and amendments. The CWA establishes limits for the discharge of pollutants to navigable waters, provides regulation of specific toxic pollutants in wastewater discharges, and provides requirements for the control of oil and hazardous substance discharges.

2-2.2.3 The Safe Drinking Water Act.

The Safe Drinking Water Act provides for protection of underground sources of drinking water and establishes primary and secondary drinking water standards. These standards are available from the installation environmental engineer.

2-2.2.4 The Federal Insecticide, Fungicide and Rodenticide Act.

The Federal Insecticide, Fungicide and Rodenticide Act requires that all pesticides be registered with the EPA. This requirement includes microbiocides used for cooling system treatment.

2-2.2.5 The Resource Conservation and Recovery Act.

The Resource Conservation and Recovery Act (RCRA) addresses the control of solid waste. Hazardous wastes are defined in the RCRA and are controlled by use of a complex manifest system that is designed to track waste from its generation to final disposal.

2-2.2.6 The Occupational Safety and Health Act.

The Occupational Safety and Health Act establishes health and safety requirements for the workplace, including handling and labeling requirements, safety precautions, and exposure limits to workplace contaminants.

2-2.2.7 The Comprehensive Environmental Response, Compensation and Liability Act.

The Comprehensive Environmental Response, Compensation and Liability Act, also commonly referred to as “Superfund,” establishes the responsibilities and procedures for the response to, and control of, existing uncontrolled hazardous waste sites.

2-2.3 Container Management Policy.

The Contractor should use containers that are either reusable or returnable. All containers remain the property of the contractor. All container systems are required to have secondary containment of the contents.

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CHAPTER 3 TECHNICAL REQUIREMENTS MAKEUP WATER

3-1 MAKEUP WATER FOR INDUSTRIAL WATER SYSTEMS.

Industrial water systems at most United States Government installations use fresh water and, often, potable water. Makeup water, often referred to as "makeup," is fresh water that is added to an industrial water system to replace water lost by blowdown, evaporation, wind drift, leaks, steam, humidification, or withdrawal from these systems.

3-1.1 Sources of Makeup Water.

The usual source of makeup water is the installation's potable water supply. This source is water that has been conditioned and is usually of a very uniform quality from day to day. Other sources of makeup water could include groundwater obtained from shallow or deep wells, or surface water from streams or holding ponds. These sources are not treated to the extent that the potable water source is treated. Still another source is reuse water (for example water that is "used" and reclaimed and not rated as potable).

3-1.1.1 Groundwater.

The term "groundwater" refers to subsurface water, such as that obtained from wells or artesian springs. This water contains a high amount of dissolved minerals and is often consistent in quality, although it may vary with the seasons of the year and the conditions of the aquifer from which the water is drawn. Treating groundwater can improve its quality.

3-1.1.2 Surface Water.

The term "surface water" refers to water found in rivers or lakes. Surface water may vary in quality with the seasons of the year or local weather conditions, with higher turbidity and SS possible during rainy weather. Treating these waters prior to use can make the quality more uniform, depending on the type of treatment.

3-1.1.3 Reuse Water.

Reuse water is any water that has been previously used. Reuse water helps conserve the precious limited supply of fresh water since less fresh water is needed for an intended use. Treated municipal wastewater is a type of reuse water and can be a source of makeup. In addition to the natural impurities of a fresh water source, municipal wastewater usually contains ammonia, phosphate, and other byproducts of the waste treatment process. These impurities are factors that affect the usability of reuse water. Other examples of reuse water include cooling tower and boiler blowdown, softener rinse water, plating water effluent, condensate, and reverse osmosis (RO) reject water. Examine each type and source of reuse water and establish its suitability prior to use.

3-1.1.4 Source Selection Factors to Consider.

Industrial water systems will operate more effectively if the source for water is both reliable and (ideally) uniform in quality. A backup water source should be available for use in case of need.

3-1.2 Reasons and Criteria for Treating Makeup Water.

3-1.2.1 Reasons for Treating Makeup Water.

Makeup water is treated to remove or reduce the concentration of any unwanted impurity, including impurities that will cause corrosion, create a deposit or scale in the system, or otherwise interfere with the operation of the industrial water system or limit the use of the original water. The process of treating makeup water often results in water conservation, which minimizes the chemical treatments in terms of frequency and amount of use and the resulting cost.

3-1.2.2 Criteria for Treating Makeup Water.

3-1.2.2.1 Makeup Water for Cooling Tower Systems.

To allow the system to operate at a minimum of three COC, the makeup water needs to be of a minimum standard of quality. Pretreatment of makeup water for cooling towers is not required if the levels of impurities in the water are not excessive. Refer to Chapter 4 for factors limiting COC, including mineral limitations.

3-1.2.2.2 Makeup Water for Steam Boilers.

The quality requirement for makeup water often necessitates using water softeners (zeolite or ion-exchange units) to remove water hardness before use. Dealkalizers can be used to remove alkalinity. High-quality steam applications require demineralization or RO, or both.

3-1.2.2.3 Makeup Water for High-Temperature Hot Water Systems.

The makeup water for high-temperature 350° F (177° C), high-pressure hot water systems should be softened when its total hardness exceeds 10 parts per million (ppm) as calcium carbonate ($CaCO_3$). See Chapter 6 section 6-2 WATER TREATMENT FOR CLOSED SYSTEMS.

3-1.2.2.4 Other Systems.

Soften the makeup water for chilled water systems and for dual-purpose (hot and chilled) systems if its total hardness exceeds 250 ppm (as calcium carbonate [$CaCO_3$]). For hot water boilers, treat makeup water with sodium sulfite and caustic soda, and soften makeup water used for diesel jacket systems if the total hardness of the raw makeup water exceeds 50 ppm (as $CaCO_3$). See Chapter 6 section 6-2 WATER TREATMENT FOR CLOSED SYSTEMS.

3-1.2.3 Measurement of Makeup Water Rates.

Knowing the use rates of makeup water is essential for calculating proper operating data on cooling towers and steam boilers. You may estimate makeup water use rates by recording the time it takes to fill a container of known volume with water obtained from a blowdown line or, preferably, measured with an appropriately sized makeup meter to provide more accurate values. Filling a container is not a recommended method for measuring hot water streams such as boiler blowdown.

3-2 MAKEUP WATER TREATMENT METHODS.

Treatment of industrial makeup water is a process of external water treatment. External treatment involves the treatment, by various processes, of makeup water to remove or reduce hardness, alkalinity, dissolved gases, or other impurities before the water enters the water system (as in steam boiler, cooling tower, closed hot water system or chilled water system). This process of external treatment is often referred to as “pre-treatment.” In contrast, internal treatment involves the treatment of water directly within the water system. Both external and internal treatment methods may be used in a given system.

3-2.1 External Treatment.

External treatment equipment processes and water treatment chemicals reduce or remove impurities contained in the makeup water before the impurities in the water stream enter the internal system. The most effective way to protect the system, reduce boiler problems, and improve operating efficiency is to use a process of removing impurities before they enter a system, particularly a steam boiler. The required treatment methods and equipment are determined by the specific type and amount of impurities that must be reduced or removed from the makeup water. Table 3-1 lists the various external treatment methods that are available to remove the typical impurities found in makeup water. Figure 3-1 illustrates the effects of these treatment methods on raw water.

The treatment process may be applied to only a portion of the makeup water, in which case the treated water is then blended with raw (untreated) water to achieve a specific quality. Treatment involving this type of blending is known as “split-stream” treatment. Split-stream treatment may also involve the blending of two different treated waters to achieve a specific quality. Paragraphs 3-2.2 through 3-2.10 briefly describe external treatment methods. External water treatment is required only for steam boilers and high-temperature hot water systems, but its use may be justified for other industrial water systems as well. Although several types of treatment may be available, government installations most commonly use sodium zeolite softening (ion exchange) for treating makeup water. Table 3-2 provides a guide for selecting external treatment methods/equipment for steam boilers.

Table 3-1 Makeup Water Treatment Methods for Removing Impurities

Impurity	Removal/Reduction Method
Hardness (calcium & magnesium)	Sodium ion exchange Hydrogen ion exchange Lime-soda softening Evaporators RO Electrodialysis
Alkalinity (bicarbonate & carbonate)	Lime-soda softening Hydrogen ion exchange (followed by degasifying) Dealkalization (chloride ion exchange)
SS/turbidity	Filtration/clarification
Dissolved solids	Demineralization (deionization) Evaporators RO Electrodialysis
Dissolved iron	Aeration (converts to precipitated iron), then filtration Sodium ion exchange (iron will foul the resin)
Dissolved gases (carbon dioxide, hydrogen sulfide, methane)	Aeration Degasifying

Figure 3-1 **Effects of Treatment on Raw Water**

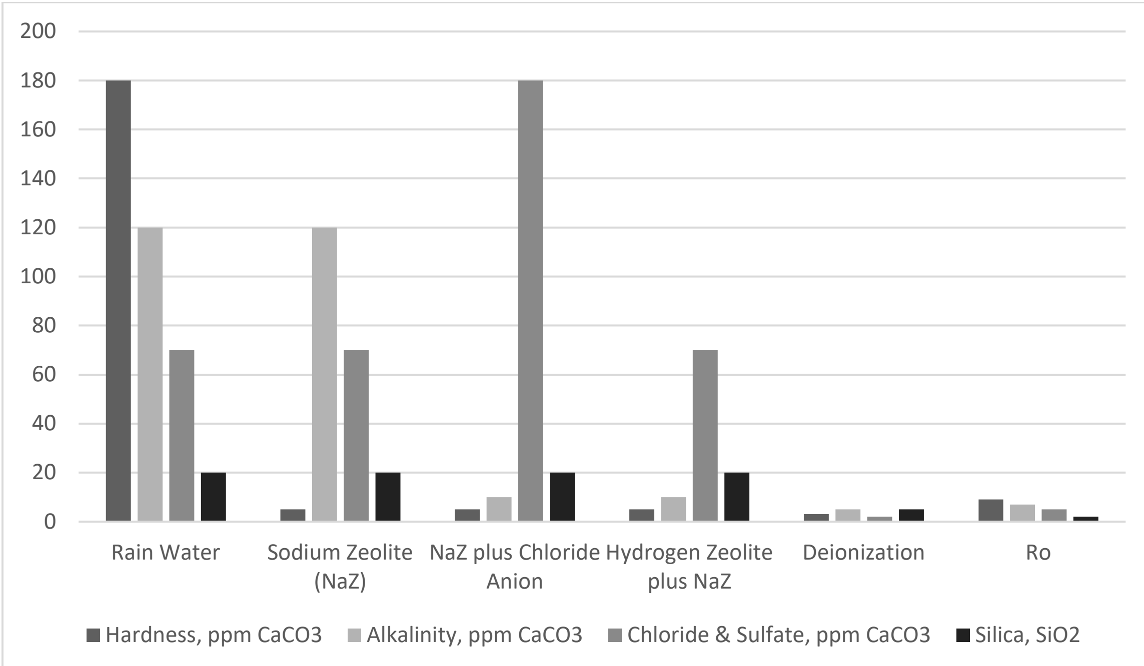


Table 3-2 External Treatment Equipment Selection Guide for Steam Boiler Makeup Water1

Makeup Rate l/sec (gpm)	Steam Pressure KPa (psig)	Alkalinity (ppm $CaCO_3$)	Turbidity	Recommended External Treatment Equipment
All	< 103 (< 15)	All	< 10	Normally internal treatment only
			> 10	Filtration plus internal treatment
< 6.3 (< 100)	103-138 (15-200)	< 75	< 10	Sodium zeolite
			> 10	Filtration plus sodium zeolite
		> 75	< 10	1. Sodium zeolite plus hydrogen zeolite 2. Sodium zeolite plus chloride/anion exchange 3. Hydrogen zeolite
			> 10	1. Filtration plus sodium zeolite plus hydrogen zeolite 2. Hydrogen zeolite
	138-448 (200-650)	< 35	< 10	Sodium zeolite
			> 10	Filtration plus sodium zeolite
		> 35	< 10	1. Sodium zeolite plus hydrogen zeolite 2. Demineralization
			> 10	1. Filtration plus sodium zeolite plus hydrogen zeolite 2. Filtration plus demineralization
> 6.3 (> 100)	103-138 (15-200)	< 75	< 10	Sodium zeolite
			> 10	1. Filtration plus sodium zeolite 2. Hot-lime soda
		> 75	< 10	Sodium zeolite plus hydrogen zeolite
			> 10	1. Filtration plus sodium zeolite plus hydrogen zeolite 2. Filtration plus demineralization Hot-lime hot-sodium zeolite
	138-448 (200-650)	All	< 10	1. Sodium zeolite plus hydrogen zeolite 2. Demineralization
			> 10	3. Filtration plus sodium zeolite plus hydrogen zeolite 4. Filtration plus demineralization Hot-lime hot-sodium zeolite
All	> 448 (> 650) (normally super-heated)	All	< 10	Demineralization
			10-400	Filtration plus demineralization
			> 400	Filtration plus demineralization RO Electrodialysis

1. See notes on following page.

NOTES:

1. Table 3-2 provides only general guidelines. The final choice of treatment system must be based upon complete raw water analysis, feed water requirements, and overall economics, including both external and internal treatment and blowdown. External treatment may be necessary to reach recommended levels of total dissolved solids (TDS) without exceeding other parameter limits for causticity, silica, or SS.
2. Separate deaeration is required for all boilers with pressure over 15 pounds per square inch gauge (0.103 megapascal), except where lime-soda softeners are designed to provide adequate deaeration as well as softening.
3. Degasification is required after hydrogen zeolite treatment.
4. The filtration process may require clarification and aeration.

3-2.2 Aeration.

Well water can contain high levels of dissolved iron (1 to 5 ppm). Although this quantity of dissolved iron may seem small, it can produce excessive precipitates when the iron comes in contact with air. If these precipitates are deposited in system lines, they will restrict flow and heat transfer. Soluble iron can be removed by filtration after contact with air (aeration), a process that causes the soluble iron to be converted by oxidation to insoluble iron, which then precipitates. Aerators are designed to mix air and makeup water in equipment that contains slats or trays to provide thorough mixing (aeration of the water). They are usually of the coke tray or wood slat design. Coke tray aerators consist of a series of coke-filled trays through which the water percolates. A forced-draft fan supplies air for aeration during the percolation process, with the water free falling from one tray to the next. Wood slat aerators are similar to small atmospheric cooling towers with staggered slats to break the free fall of the water and thereby increase the surface contact with air. Wood slat aerators can also be equipped with a forced-draft fan to increase efficiency. In addition to oxidizing iron, aeration can also strip or remove dissolved gases such as carbon dioxide, hydrogen sulfide, and methane. Aerators also contribute to a reduction in dissolved manganese by causing it to be oxidized to an insoluble salt.

3-2.3 Filters and Filtration.

A variety of filters can remove particles in a wide range of sizes, from course to very fine. These solids or particles may include soluble iron that has been precipitated, residual calcium carbonate particles, sand, dirt, debris, and some microbiological organisms.

3-2.3.1 Sand Filters.

3-2.3.1.1 Sand Filter Description.

A sand filter is a bed of sand (or anthracite coal) located below a set of distribution headers and resting on a support layer of coarse rock. The collection header, through which the clarified water is drawn, is situated below the sand filter. Water flows downward through the filter bed, either due to gravity or by applied pressure.

3-2.3.1.2 Method of Action.

The sand or anthracite acts as a support bed for a layer of SS laid down on top of the bed as a result of the filtering process. This layer of deposited solids, formerly SS, does most of the actual removal of solids from the water and is known as the filter cake.

3-2.3.1.3 Filter Cycle.

As the thickness of the filter cake builds up, the water flow decreases and the backpressure increases. When the flow rate becomes too low or the back-pressure too great, the water flow can be reversed, with the filter cake then being backwashed with the wash water to a waste collection point. The filter is then returned to service and the cycle is repeated.

Sand filtration rates are typically 3 gallons per minute per square foot (2 liters per second per square meter). Backwash rates are 12 to 15 gallons per minute per square foot (8.1 to 10.2 liters per second per square meter) for sand filters and 8 to 12 gallons per minute per square foot (5.4 to 8.1 liters per second per square meter) for anthracite filters. A variety of filter types are available.

3-2.3.2 Cartridge and Bag Filters.

Cartridge and bag filters are available in various mesh and pore sizes, which determine the size of the particles removed.

3-2.3.3 Centrifuge Separators.

Centrifuge separators represent still another way to remove suspended materials by passing water through a centrifuge chamber where particles are removed due to density instead of size. Using separators is limited to removing very small particulates. An advantage of separators is that they do not require back flushing or change-outs of filter cartridges or bags.

3-2.4 Lime-Soda Softening.

The lime-soda process is often used for treating large volumes of water 10,000 gallons per day (37,850 liters per day or higher) for potable and industrial uses. The process is used primarily to reduce the levels of hardness and alkalinity, but also to reduce the quantity of silica and SS. The process could be applicable to an entire base or facility; usually this process is not practical for individual small site locations. The process is labor intensive and can produce large amounts of sludge from the precipitated materials.

3-2.4.1 Method of Action.

The process involves adding hydrated lime (calcium hydroxide) and soda ash (sodium carbonate) to the water in an open reaction tank. The calcium and magnesium concentration is reduced by the resulting precipitation of solids. Bicarbonate and carbonate alkalinity is also reduced, as may be some silica. The sludge that is formed is allowed to settle for subsequent removal as a watery sludge. The treated water is filtered prior to use as makeup.

3-2.4.2 Cold and Hot Processes.

Adding lime and soda ash at ambient temperature is referred to as the "cold lime-soda process." When lime and soda ash are reacted with the water at temperatures greater than 212˚ F (100˚ C), the process is called the "hot lime-soda process". The hot process removes a greater amount of the hardness, alkalinity, and silica from the water than the cold process.

3-2.5 Ion Exchange Process.

Several types of ion exchange units are used at military installations. An ion exchange unit is an open or closed vessel containing an ion exchange material, also known as resin, which has been deposited on a gravel support bed. Most ion exchange units operate under pressure, but gravity flow units are also available. Flow rates vary with the type of equipment but are in the range of 6 to 8 gallons per minute per square foot of ion exchange material surface (4 to 5.4 liters per second per square meter). A backup ion exchange unit and a storage tank are typically included to permit an uninterrupted supply of treated water. The manufacturer's recommendations for proper equipment operation should be posted near the softening unit. A typical ion exchange hardness softener unit is illustrated in Figure 3-2. Figure 3-3 shows a typical duplex softener.

Figure 3-2 **Typical Ion Exchange Unit**

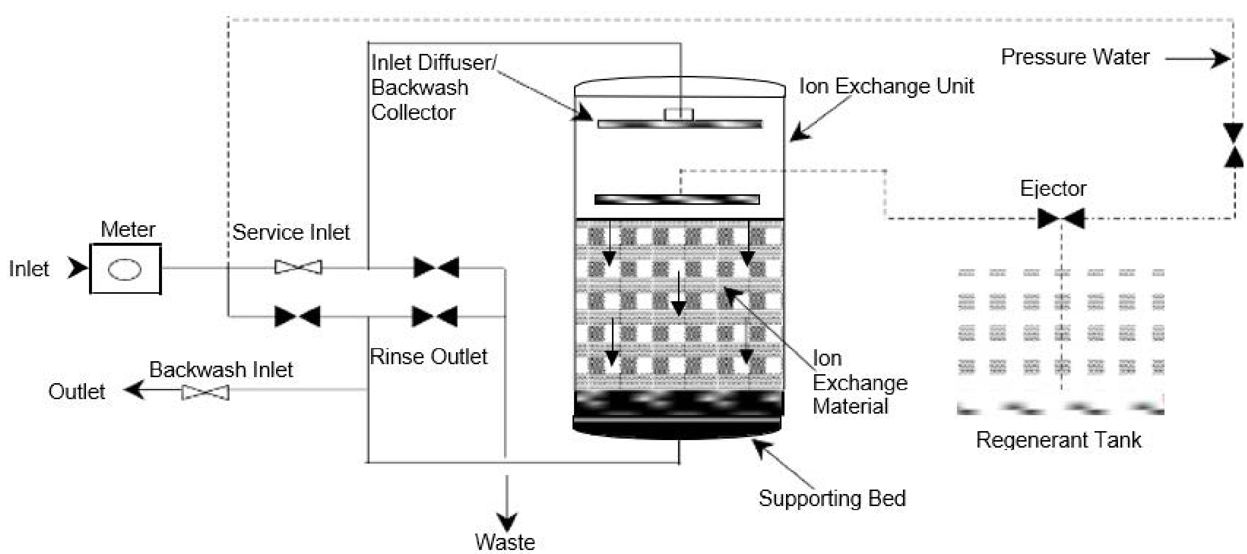
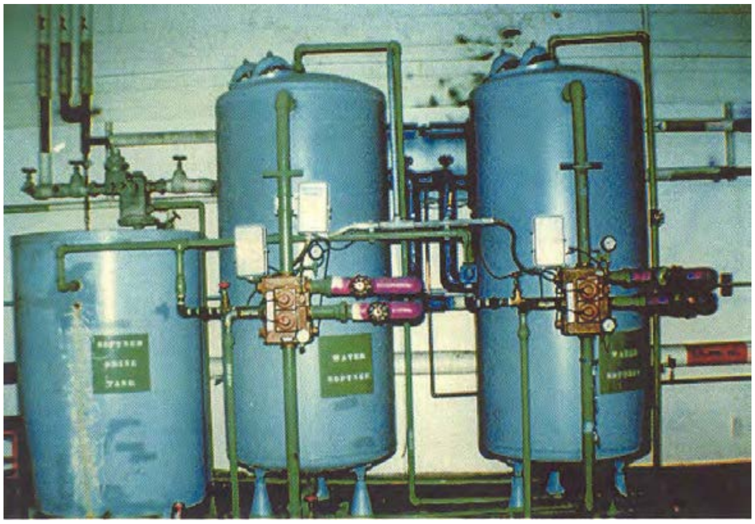


Figure 3-3 **Duplex Softener**



3-2.5.1 Sodium Ion Exchange.

3-2.5.1.1 Service Cycle.

The normal operating cycle during which hardness is removed from the makeup water flowing through the softener is determined by calculating the amount of water that can be softened by a given ion exchange material. The operator must consider several factors:

3-2.5.1.2 Sodium Ion Exchange Process.

The sodium ion exchange process depends upon the exchange of sodium ions in either the zeolite material or synthetic ion exchange resins (whichever is used) for calcium and magnesium ions in the makeup water, as shown below:

Calcium and Magnesium Hardness in Water	+	Sodium Zeolite	→	Calcium/Magnesium Zeolite ion exchange Resin	+	Sodium salts in water

3-2.5.1.3 Water Softener Capacity.

The softening capability or capacity of an ion exchange softener is usually given in units of grains (grams) of total hardness of calcium carbonate ($CaCO_3$). The operator needs to know how much water can be softened before regeneration is necessary. The volume of water that can be softened between regeneration cycles is determined by the softener capacity and the hardness in the water. See the example calculations below.

Equation 3-1. Water Softening

English Units:

The maximum capacity of the ion exchange softener is 2,000,000 grains. The water being treated has 257 ppm total hardness. If the softener regenerations cycle is set for maximum capacity, how many gallons of water can be softened before the softener must be regenerated?

$$Removal = \frac{Capacity, grains\ x\ 17.12}{\text{Total hardness, ppm, in raw water}}$$

$$= \frac{\text{2,000,000 grains x 17.12ppm 1}\ grain\ per\ gallon}{\text{257 ppm}}$$

$$= 133{,}230\ gallons$$

Metric Units:

2,000,000 grains x (1 pound/7,000 grains) x (453.6 grams/1 pound)

= 129,600 grams

$$Removal = \frac{\text{Capacity, grams x 1000 mg/gram}}{\text{Total hardness, ppm}\ (mg\ /\ liter)\text{, in raw water}}$$

$$= \frac{\text{129,600 grams x 1000 mg / gram}}{257\ ppm\ (mg\ /\ liter)}$$

$$= 504{,}280\ liters$$

Thus, for a softener with a rated capacity of 2,000,000 grains (129,600 grams), 133,230 gallons (504,280 liters) of water, with 257 ppm total hardness, can be softened between regeneration cycles.

3-2.5.1.4 Regeneration Cycle.

Regeneration of the ion exchange resin refers to replacement of the calcium/magnesium hardness that has accumulated on the ion exchange resin as a result of the exchange with sodium ions. The regeneration cycle is a process involving a number of steps during which the softener is taken off-line and backwashed. The resin is regenerated by treatment with a strong solution of salt (sodium chloride) and then rinsed.

When the exhausted ion exchange resin material is washed with a strong sodium chloride salt solution (brine), the resin is regenerated by the hardness (calcium and magnesium ions) being exchanged for sodium ions.

Hardness	Sodium	$\rightarrow$	Sodium	Hardness
Zeolite	Chloride		Zeolite	Chloride

The completeness of the regeneration is dependent upon the strength of the salt solution (brine) used and the length of time the solution is in contact with the resin. After the resin is regenerated, it can be used again and again (after regeneration) to continue to remove hardness from water. The following procedure is typical for an ion exchange resin regeneration process.

3-2.5.1.5 Backwash.

Before the exhausted resin bed is regenerated, it must be backwashed by flowing water from bottom to top. The flow rate must be adequate to remove any solids that have been caught on top of the bed. The resin bed volume will also be expanded by about 50 percent due to the backwash flow; the volume of expansion will be dependent upon the flow rate. The backwash flow rate should be controlled so that it will not sweep ion exchange resin out of the softener to the waste collection area. A backwash rate of 4 to 6 gallons per minute per square foot (2.72 to 4.07 liters per second per square meter) of bed surface for about 10 minutes is normal, but the manufacturer's recommendations should be followed.

3-2.5.1.6 Brining.

Next comes the addition of salt, a process known as “brining.” A 10 percent (by saturation) solution of sodium chloride salt brine is slowly added with a down- flow rate of 0.5 to 1 gallon per minute per cubic foot (1.11 to 2.22 liters per second per cubic meter) of bed volume for about 30 minutes. Rock salt is preferred to granulated salt as a brining salt because it is equally as effective, less expensive, and less prone to cake. Some installations may start with a solution of concentrated or saturated brine, which must be diluted before use in the brining step. The salt required and the capacity regenerated is shown for a typical resin in Table 3-3; however, the manufacturer's instructions should be followed, if available.

Table 3-3 Salt Required for Regeneration of a Commonly Used Cation Resin

Salt Use per lb/ft^3 of Ion Exchange Material (kg/m^3)	Capacity of Ion Exchange Material Hardness gr/ft^3 (m^3)
5.0 (80)	19,000 (43,450)
7.5 (120)	24,000 (55,130)
10.0 (160)	27,000 (61,615)
15.0 (240)*	32,000 (73,290)*

* Practical upper limit for exchange capacity. This upper limit and the actual dose per capacity relationship may vary with the resin; the manufacturer's instructions should be followed.

3-2.5.1.7 Slow Rinse.

A slow rinse follows the brining step and is performed at the same rate as the brining step. The rinse is performed with down flow through the softener. One to 3 bed volumes of fresh water are used to remove most of the excess sodium and hardness brine from the bed. The volume of fresh water is equal to 7.5 to 22.5 gallons per cubic foot (1000 to 3000 liters per cubic meter) of bed volume.

3-2.5.1.8 Fast Rinse.

In the last step, a fast rinse is used, also with down flow, to remove any traces of the sodium and hardness brines. This is done at a rate of 1.5 to 2 gallons per minute per cubic foot (200 to 270 liters per minute per cubic meter) of bed volume until the discharge is free of hardness; 35 to 100 gallons per cubic foot (4690 to 13,400 liters per cubic meter) of bed volume is required. The unit is now ready for another service cycle.

3-2.5.1.9 Testing and Record Keeping.

Influent water should be tested for hardness on a weekly basis. The softener effluent water should be tested for hardness on a daily basis, every shift (3 times a day), or as required for systems that require frequent (1 to 3 days) or less frequent regeneration. Accurate records should be kept of these tests, including recording the number of gallons (liters) of water that have been treated during each service cycle, and the amount of salt that was used during each regeneration cycle.

3-2.5.1.10 Operating Problems.

Several common problems are sometimes encountered during softener operation:

3-2.5.1.11 Resin Fouling.

A normal decrease in exchange capacity due to resin fouling is about 5 percent per year. Any decrease greater than this should be determined and corrective action taken.

3-2.5.1.12 Fouling Due to Iron.

A common cause of loss of capacity is resin fouling by iron salts. Soluble iron will exchange for sodium during the service cycle, but sodium will only be incompletely exchanged for iron during the regeneration cycle. There is a simple test to determine iron fouling: a pinch of iron-fouled ion exchange material added to a 10 percent hydrochloric acid solution in a test tube will cause the hydrochloric acid to turn yellow, indicating the presence of iron.

Iron-fouled resin can be returned to design capacity by cleaning with dilute hydrochloric acid, sodium bisulfite, or special resin cleaners. Specific procedures are required.

NOTE: The softener manufacturer's recommendations should be consulted before using this acid cleaning procedure, including those prohibiting acid procedures with a galvanized or unlined steel tank. To use acid procedures, the tank must be constructed of reinforced plastic or rubber, or must be plastic-lined with no breaks in the lining.

3-2.5.1.13 Improper Backwash.

Improper backwash is another common problem. A backwash rate that is too high can result in the ion exchange material being washed out of the unit. The bed depth can be measured by carefully probing to the underdrain support bed. Normal bed depth is usually 30 to 36 inches (0.75 to 1 meter). The bed volume in cubic feet (cubic meters) can be calculated by the following formula:

$$\text{Volume, m}^3 = (\text{Radius, m})^2 \times (\text{Depth, m}) \times 3.14$$

Check the bed depth at 10 points and use the average value. If there is much difference (15 percent or more) in the thickness of different points, channeling may be occurring. Channeling can be caused by too low a backwash rate.

If the calculated bed volume is less than the volume given by the manufacturer, material has been lost during the backwash step. The lost material should be replaced and the backwash rate carefully controlled to ensure material is not being washed out. If the cause of the unit's performance problem or deficiency cannot be determined, the manufacturer's service representative should be consulted.

3-2.5.1.14 Resin Replacement.

The resin in the ion exchanger should be replaced when either the resin capacity or the softening efficiency has decreased by 25 percent and cannot be restored by cleaning and by following the specific procedures recommended by the manufacturer. Based on a normal decrease of 1 to 5 percent per year, the typical ion exchange resin should last from 5 to 25 years. With good operation, the average service life is 8 to 10 years.

3-2.5.2 Hydrogen Ion Exchange.

The hydrogen ion exchange process is essentially the same as the sodium ion exchange process except that the regenerant chemical is an acid (sulfuric or hydrochloric) rather than a salt. The hydrogen ion exchange process will reduce both the amount of the total dissolved solids and the alkalinity of the treated water. During operation of the hydrogen cycle softener, it is necessary to check the outlet (softened) water at regular intervals. The hardness of the outlet water should always be less than 1 ppm. The ion exchange resin must be regenerated if the hardness exceeds 1 ppm. This check can be performed daily, once per shift, or as required depending on unit capacity.

3-2.5.2.1 Exchange Process.

Resins exchange calcium, magnesium, sodium and all cations with hydrogen ions.

Calcium/ Magnesium/ Sodium Salts	+	Hydrogen Zeolite	→	Calcium/ Magnesium/ Sodium Zeolite	+	Hydrogen Salts in Water

The hydrogen salts are acidic and will react with alkalinity to produce carbon dioxide and water. To provide for effective operation, the carbon dioxide must be removed after leaving the vessel by other means.

3-2.5.2.2 Regeneration Method.

The spent ion exchange material is regenerated by contact with dilute acid, such as sulfuric acid or hydrochloric acid.

Hardness and Sodium Salts	+	Sulfuric Acid	→	Hydrogen Zeolite	+	Hardness and Sodium Salt

Adding sulfuric acid in several steps of increasing strength, such as 2, 4, or 6 percent are required for sulfonated styrene resins if fouling of the exchange resin with calcium sulfate is to be avoided.

3-2.5.2.3 Equipment Requirements.

The hydrogen ion exchanger is much the same as the sodium ion exchanger, except that all equipment must be made of, or lined with, acid-resistant material.

3-2.5.2.4 Regeneration Cycle.

The regeneration cycle is much the same as that for the sodium ion exchanger, except that sulfuric acid is used instead of salt. To improve efficiency, regeneration of hydrogen ion exchangers is commonly done counter- currently. During operation of the hydrogen cycle softener, it is necessary to check the outlet (softened) water at regular intervals. The hardness of the outlet water should always be less than 1 ppm. The ion exchange resin must be regenerated if the hardness exceeds 1 ppm. This check can be performed daily, once per shift, or as required depending on unit capacity. Available information on safety and first aid should be reviewed before using sulfuric acid. Chemical handling and safety instructions should be posted near sulfuric acid equipment. Sulfuric acid is corrosive to skin, eyes, clothing, and other materials. Hydrochloric acid should be used with the same precautions. See section 8-4 for chemical safety information.

3-2.5.2.5 Troubleshooting.

Troubleshooting is much the same as for sodium ion exchange, although iron fouling does not occur in hydrogen ion exchangers since the acid removes iron from the resin.

3-2.5.2.6 Effluent Water Properties.

The hydrogen ion exchange effluent water is acidic and cannot be used directly. The water can be mixed with the outlet of a sodium ion exchanger with the result that the acid in the hydrogen ion exchange water will be neutralized to some degree and, at the same time, the degree of alkalinity in the sodium ion exchange water will be lessened. The proportion of the effluent waters to be mixed is dependent upon the analysis of the water being treated, but typically the proportion is approximately one-to-one (half-and-half). The testing of blended water should be done prior to blending to assure that the blended water is satisfactory for use in the boiler or cooling water system. If neutral (pH 7) water is required, a chemical (such as sodium hydroxide) must be added.

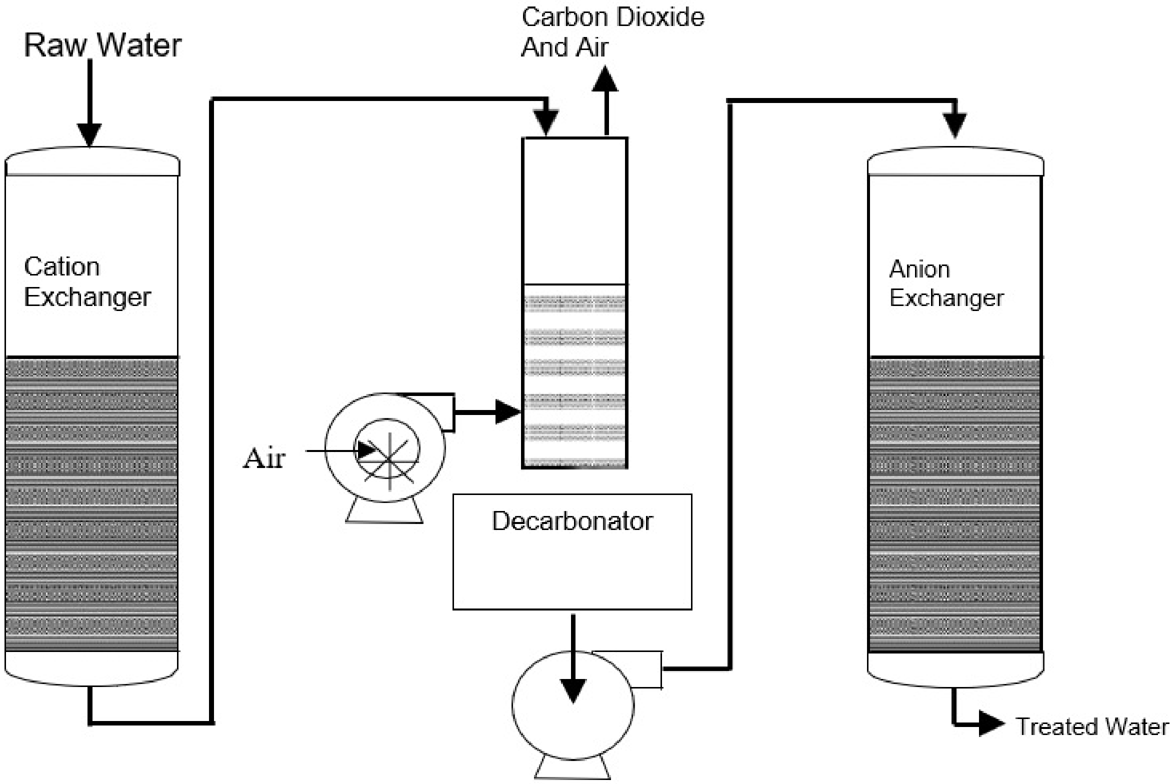
3-2.5.2.7 Carbon Dioxide Production.

Carbon dioxide is produced during the hydrogen ion exchange process and is also produced when the effluent water from hydrogen and sodium ion exchange is mixed. It is removed from the water in a decarbonator (degasifier or deaerator).

3-2.5.3 Demineralization.

Sodium and hydrogen ion exchangers remove only the positively charged ions (cation exchange - like calcium, magnesium, and sodium). Other ion exchange materials have been developed to remove negatively charged ions (anion exchange – such as sulfates, chlorides, and alkalinity). The process of demineralization uses both cation and anion exchange resins to remove all ions from the water, thus producing mineral-free water. A typical deionization (demineralizer) process is illustrated in Figure 3-4. During operation of the demineralizer, it is necessary to check the outlet water at regular intervals. The TDS of the outlet water should always be less than 1 ppm. The ion exchange resin must be regenerated if the TDS exceeds 1 ppm. This check can be performed daily, once per shift, or as required depending on unit capacity.

Figure 3-4 **Demineralization Process**



3-2.5.4 Anion Exchange Process.

The hydrogen ion exchange process is described in paragraph 3-2.5.2. The anion exchange process involves reactions of hydroxyl-regenerated zeolite with the effluent from the hydrogen ion exchanger:

Hydrogen and Anions+	Hydroxyl Zeolite	→	Water +	Sulfate/Chloride Zeolite

3-2.5.5 Anion Ion Exchange Regeneration Method.

The spent anion ion exchange material containing chlorides, sulfates, and other anions is regenerated with sodium hydroxide (caustic).

Sulfate Chloride Zeolite+	Sodium Hydroxide	→	Hydroxyl+	Sodium and Anions Zeolite

3-2.5.5.1 Exchange Process Result.

When the anion exchange process is combined with the hydrogen exchange process, the resulting final water will contain no minerals. It has become deionized (also referred to as demineralized) by exchanging all minerals to hydrogen hydroxide, HOH, commonly referred to as water and written as H_20.

3-2.5.5.2 Exchange Method.

The two reactions can take place in separate vessels (a “two-bed” deionizer), or the two ion exchange materials can be combined in a single vessel (a “mixed-bed” deionizer).

3-2.5.5.3 High Silica Waters.

Removal of silica and magnesium beyond what most demineralizers will provide is accomplished through pre-heating of caustic solution used for regeneration. Optimum temperature is 120 F (49 C) and should not exceed 140 F (60 C), as that temperature can damage the resin; however, few demineralizers are designed for this application.

3-2.5.5.4 Deionization Process Use.

The deionization process is not used at government installations. It is required mainly for high-pressure boilers or high-purity water use. The deionization process may also be used for shore plants providing steam or boiler feedwater to ships.

3-2.5.6 Dealkalization.

3-2.5.6.1 Anion Dealkalization.

It may be necessary to treat water having low hardness and high alkalinity to reduce the alkalinity (bicarbonate and carbonate). The anion exchange process called “anion dealkalization” will remove alkalinity and other anions (like sulfates and nitrates). In most cases, the anion dealkalizer is used following a hardness softener (it is located downline from the softener) because hardness, if not previously removed, can precipitate in the anion resin bed and cause plugging.

Bicarbonate and carbonate (anions) are exchanged for chloride (anion) as illustrated by the following reaction, where “Z” is the zeolite resin material:

NaHCO3 Sodium Bicarbonate	+	ZCl Chloride → Zeolite	NaCl Sodium Chloride	+	ZHCO3 Bicarbonate Zeolite

3-2.5.6.2 System Regeneration.

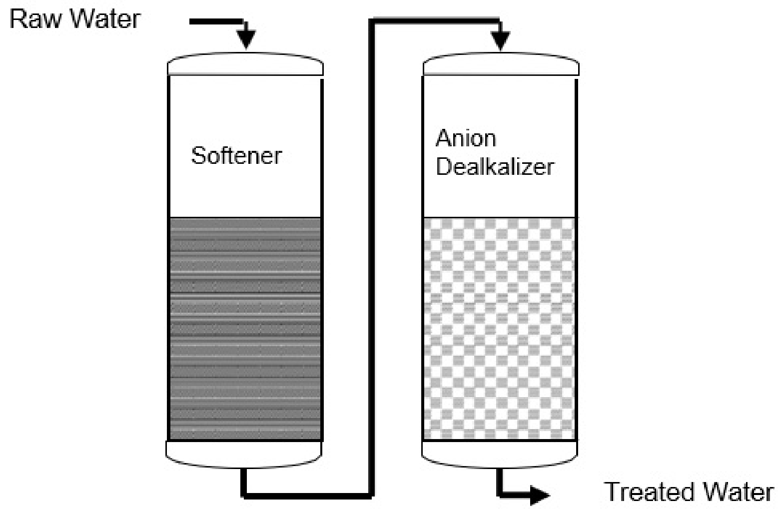
The system is regenerated with sodium chloride (salt) as shown below. The regeneration will be more efficient and effective if the brine used contains about 10 percent of the salt as caustic.

ZHCO3 Bicarbonate Zeolite	+	NaCl Sodium Chloride	→	ZCl Chloride + Zeolite	NaHCO3 Sodium Bicarbonate

3-2.5.6.3 Equipment and Operation.

The equipment and operation of such a system is much the same as for a sodium ion exchange material system described in the paragraph above. This process is illustrated in Figure 3-5.

Figure 3-5 **Anion Dealkalization Process**



3-2.5.6.4 Split-Stream Dealkalization.

In a split-stream dealkalization process, the water is split into two parallel streams with one stream passing through a strong acid cation exchanger (dealkalizer) and the other through a sodium zeolite softener. Blending of the two product streams produces a soft water that is low in alkalinity. The alkalinity reduction is described by the following equation, where "Z" is the zeolite resin material:

Ca(HCO3)2	+	2ZH	$\rightarrow$	Z2Ca	+	2H2CO3
Calcium Bicarbonate		Hydrogen Zeolite		Calcium Zeolite		Carbonic Acid

The carbonic acid dissociates into carbon dioxide (CO_2) and water (H^2O). The water is then passed into a decarbonator (degasifier or deaerator) to remove the CO_2.

3-2.5.6.5 Free Mineral Acid Production.

The strong acid cation exchange resin replaces the sodium, calcium, and magnesium ions with hydrogen ions. Thus, due to the presence of chlorides, sulfates, nitrates, and other anions, free mineral acids (FMA) (like hydrochloric and sulfuric) are produced. Adjustment of the pH level is necessary to balance alkalinity with acidity FMA and form neutral water.

3-2.5.6.6 System Regeneration.

The strong acid cation system is regenerated with sulfuric acid.

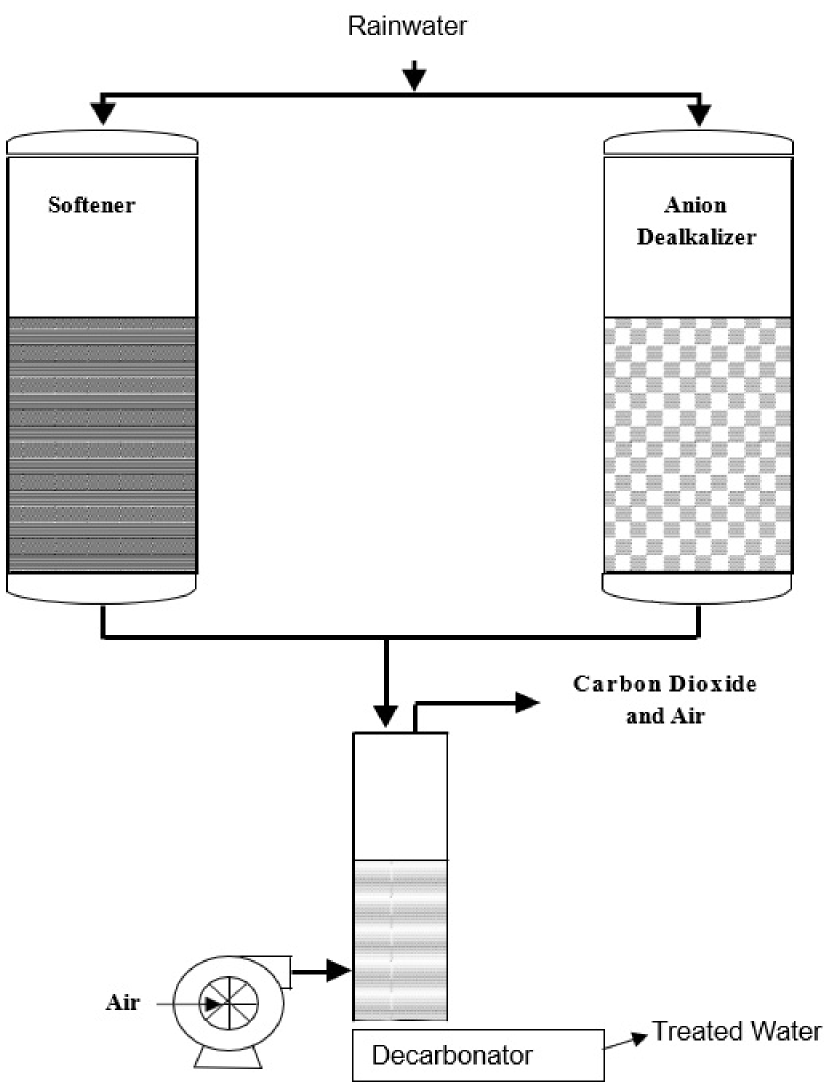
3-2.5.6.7 Equipment Requirements.

The acid exchanger tank must be made of, or lined with, an acid-resistant material.

3-2.5.6.8 Decarbonator Use.

Since blending the two split streams of finished water also produces CO_2, a decarbonator (degasifier or deaerator) is normally used to reduce the CO_2 concentration to 5 to 10 ppm or less. A typical split-stream process is shown in Figure 3-6.

Figure 3-6 **Split-Stream Dealkalizer**



3-2.5.7 Decarbonation.

Carbon dioxide is produced during hydrogen ion exchange and when the effluent waters from strong acid cation ion exchange and the sodium ion exchange are mixed. Carbon dioxide dissolved in water can cause corrosion in water lines, pump impellers, and vessels. As described in Chapter 4, the carbon dioxide concentration must be kept as low as possible in the boiler feed water and in the water entering steam condensate lines.

3-2.5.7.1 Methods of Decarbonation.

Free carbon dioxide is commonly removed in a degasifier or aerator (see paragraph 3-2.2). In steam systems and in high- temperature water systems, removal of CO_2 is usually achieved in the deaerator rather than with a separate degasifier unit, although steam systems can have degasifiers.

3-2.5.7.2 Analysis of Carbon Dioxide Content.

By analyzing the water for the hydrogen ion concentration (pH) and the total (M) alkalinity, the free carbon dioxide content can be calculated (see Table 3-4)

Table 3-4 Carbon Dioxide Content of Water vs. pH

pH	CO_2	pH	CO_2	pH	CO_2
5.4	4.4 M	6.6	0.45 M	7.3	0.099 M
6.0	1.9 M	6.7	0.38 M	7.4	0.079 M
6.1	1.5 M	6.8	0.31 M	7.5	0.062 M
6.2	1.23 M	6.9	0.24 M	7.6	0.050 M
6.3	0.92 M	7.0	0.19 M	7.7	0.040 M
6.4	0.75 M	7.1	0.15 M	7.8	0.033 M
6.5	0.62 M	7.2	0.12 M	7.9	0.026 M

NOTES:

1. At pH levels of 8.0 or higher, the free CO_2 content is negligible.
2. “M” is total alkalinity (as calcium carbonate [$CaCO_3$]).

EXAMPLE:

a. Total alkalinity (M) of an inlet water to a degasifier is 100 ppm and the pH is 6.8. CO_2 content = Value x M = 0.31 x 100 = 31 ppm

b. The outlet pH is 7.9, so the CO_2 content will be (let M = 80, since some alkalinity was removed as CO_2): CO_2 content = 0.026 x 80 = 2.1 ppm

c. The carbon dioxide removal is: 31 - 2.1 = 28.9 ppm

3-2.6 Evaporators.

In the evaporation process used in evaporators, water is heated to produce relatively pure water vapor that is then condensed to liquid water and used for boiler feed. Evaporators are of several different types. The simplest is a tank of water through which steam coils are passed to heat the water to the boiling point. To increase efficiency, the vapor from the first tank may pass through coils in a second tank of water to produce additional heating. Another type of evaporator operates under a partial vacuum, lowering the boiling point of water and enabling evaporation at lower temperatures. Following its production in the evaporator, water vapor is cooled and becomes liquid water that is essentially pure water, without any dissolved solids. Using evaporators may be economical where inexpensive steam is readily available as the source of heat. Evaporators also have an advantage over deionization units when the dissolved solids in the raw water are very high, such as on ocean-going vessels.

3-2.7 Reverse Osmosis (RO).

This process is the opposite of osmosis. It produces very pure water by separating dissolved minerals from the water. Water pressure is used to push water though a membrane. The membrane allows only pure water to pass through. Water thus produced is known as RO product water. All dissolved solids, organics, and gases that do not pass through the membrane are removed in the waste stream of RO reject water. Sufficient care must be taken to protect the membrane from deposits, which reduce efficiency or plug the membrane. This RO process is illustrated in Figure 3-7. An RO unit is shown in Figure 3-8.

Figure 3-7 **RO Schematic**

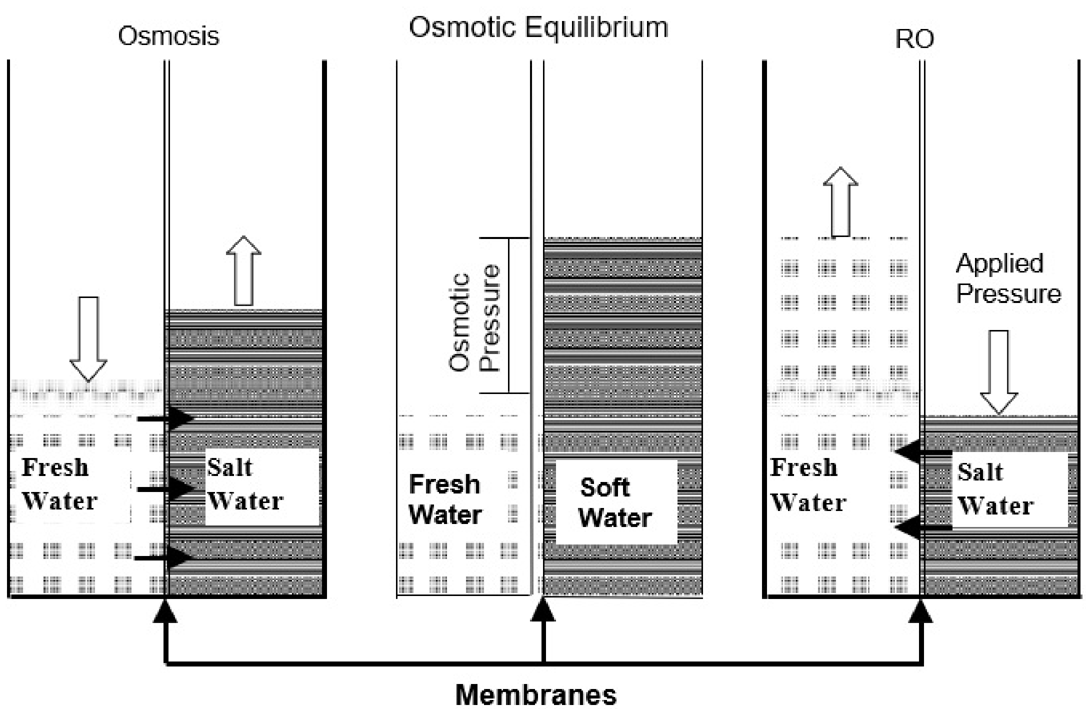


Figure 3-8 **RO Unit**

3-2.7.1 RO Pretreatment.

Material that can potentially foul (or plug) the membrane will interfere with the RO process and must be removed before the water contacts the membrane. Foulants include suspended and colloidal solids, iron, metal oxides, scale, and biological materials. It is important to determine a Silt Density Index (SDI), a measurement of suspended materials in the water, prior to using the water in the RO unit. Only water determined to be within the manufacturer's acceptable SDI range should be used. Pretreatment may be required to achieve an acceptable SDI.

3-2.7.1.1 SS Removal.

SS can be removed by filtration, usually using a sand filter followed by a cartridge filter. The addition of filter aids may be necessary to achieve acceptable filtration. In certain instances, coagulation and clarification may be required before the filtration step.

3-2.7.1.2 Iron Oxide Removal.

Iron oxides are the result of the oxidation of dissolved ferrous salts or corrosion of the equipment. The first process can be controlled by aerating the water prior to its being filtered, the second by threshold treatment with sodium hexametaphosphate before any aeration. For proper operation, these iron oxides must be removed prior to the water contacting the membrane.

3-2.7.1.3 Scale Prevention.

Scale-forming salts are concentrated as a result of the RO process just as they are during an evaporative process. To prevent scale, the water's pH is adjusted by adding either acid to produce a pH of between 5.0 and 6.5, or a scale inhibitor such as sodium hexametaphosphate or any of the phosphonates (PBTC (2-phosphonobutane-1,2,4-

tricarboxylic acid), HEDP (1-hydroxyethylidene 1,1- diphosphonic acid), or AMP (amino-tri (methylene) phosphonic acid)). The solubility of scale-forming salts controls the rejection rate of the water that cannot be processed through the RO unit (the amount of blowdown water produced). Specific guidelines should be obtained from the RO manufacturer.

3-2.7.1.4 Biological Fouling.

Biological fouling is a condition that must be prevented. Potentially, the RO unit membrane may be damaged when chlorine or other oxidants are used. For proper operation, the water must be dechlorinated with a reducing agent or with activated carbon before it contacts the RO membrane.

3-2.7.2 Membrane Configuration.

There are three basic membrane configurations: tubular, spiral-wound or scroll, and hollow fiber.

3-2.7.2.1 Tubular Configuration.

The tubular configuration is simply a porous tube supporting a membrane. Feedwater is introduced into the tube. Product water permeates the membrane going to the outside of the tube. The reject water exits from the far end of the tube.

3-2.7.2.2 Spiral Configuration.

The spiral configuration is a sheet membrane that is supported on each side by a porous material that provides flow distribution and rolled into a spiral or "jelly roll" configuration. The membrane is put in a pressure vessel so pressure can be maintained on its surface. This pressure forces the water through the membrane, separating it from the impurities. The membrane is laminated between porous sheets and sealed on three sides. The laminate is then attached on the fourth side to a porous tube and rolled around the tube into an element. Feed solution is forced into the element at one end, and the permeate works its way through the spiral to the axis tube where it emerges as purified product.

3-2.7.2.3 Hollow Configuration.

The hollow fiber configuration consists of small 3.3-inch (85-millimeter) diameter tubes whose outside wall is semi-permeable. A large number of these tubes are placed in a shell, similar to a heat exchanger. Water, under pressure, on the exterior of the tubes permeates the tubes and is collected from the tube interiors.

3-2.7.3 Sea Water.

RO technology is particularly useful when feedwater is high in dissolved solids or when the source is brackish water or seawater. When used ahead of a deionizer, the chemical requirements for the deionizers are greatly reduced, resin life is extended, and a smaller quantity of chemical regenerants is required.

3-2.8 Ultrafiltration.

The term “ultrafiltration” describes a pressurized membrane process in which particulate, colloidal, and high-molecular-weight dissolved materials are filtered from the water. Ultrafiltration is a process that is similar to RO in that a semi-permeable membrane is used to remove the filterable solids, except that the membrane is more porous, thus allowing some water-dissolved minerals to pass through with the product water. The feedwater flows through the inside of the fibers, permeates through the membrane, and is removed as product from the shell side. The filtered solids are continuously removed from the other end of the fiber in a reject stream that typically contains 5 to 10 percent of the feedwater dissolved solids.

3-2.9 Electrodialysis.

The term “electrodialysis” describes a process that separates all materials and minerals that are ionized from water by attracting the ions dissolved in the water through membranes that are oppositely charged. When the water is high in dissolved minerals, as in brackish water that contains more than 2500 ppm TDS, its use may be more economical than the ion exchange methods. Under some circumstances, it may remove enough minerals to make seawater usable in industrial water systems. This process does not remove un-ionized or poorly ionized materials such as some organics and soluble silica. As with RO, membranes must be kept clean.

3-2.10 Nanofiltration.

This is a process that, in terms of the size of materials removed, is intermediate between ultrafiltration and RO. The molecular weight cut-off properties of nanofiltration membranes are in the range of < 1 x 10-3 m (400 to 800 Daltons or 10 angstroms). Ionic rejections vary widely depending on the valence of the salts. Multivalent salts such as magnesium sulfate ($MgSO_4$) are rejected as much as 99 percent, while monovalent salts such as sodium chloride (NaCl) may have rejections as low as 20 percent.

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CHAPTER 4 STEAM BOILER SYSTEMS

4-1 STEAM BOILER SYSTEM DEFINED.

A steam boiler is an enclosed vessel that holds water and is heated by an external source that converts the water to steam. All steam boilers contain tubes that separate the water from the heat source. Steam boilers are described in this Chapter; hot water boilers are addressed in Chapter 6. Operate boilers in accordance with UFC 3-430-07 and UFC 3-430-11.

4-1.1 Types of Steam Boilers.

Boilers are classified by two criteria*:* 1) operating pressure (the amount of internal pressure generated by the steam that is produced); and 2) the operational design (whether the water [water tube boiler] or the heat source [fire tube boiler]) passes through the inside of the tubes of the boiler vessel.

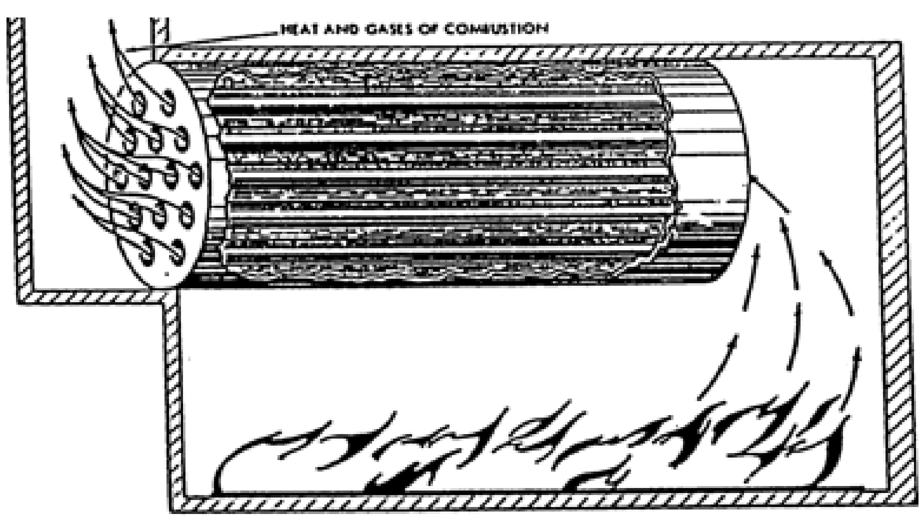
4-1.1.1 Pressure Classification.

A boiler that operates at pressures below 15 pounds per square inch gauge (103 kilopascals) is defined as a low-pressure boiler. A boiler operating pressure greater than 15 pounds per square inch gauge (103 kilopascals) is defined as high pressure. High-pressure boilers can operate at pressures reaching thousands of pounds per square inch gauge (thousands of kilopascals).

4-1.1.2 Fire Tube Boilers.

Fire tube boilers pass fire and hot combustion gas through the interior of the boiler tubes to heat the water that surrounds the tubes (see Figure 4-1). This type of boiler design is commonly used for factory-assembled (package) boilers, which are low pressure.

Figure 4-1 **Fire Tube Boiler**

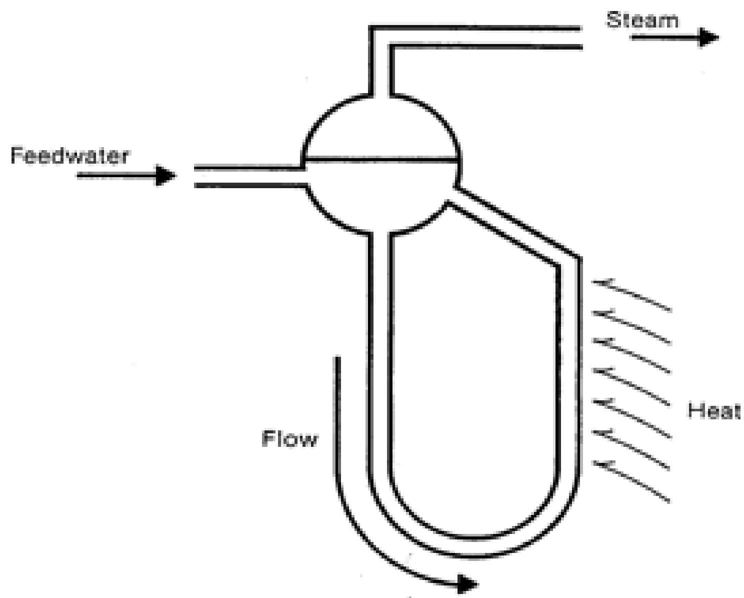


Fire tube boiler. The heat is inside the tubes.

4-1.1.3 Water Tube Boilers.

Water tube boilers pass water through the boiler tubes, with the fire and hot combustion gases contacting the exterior of the tubes (see Figure 4-2). Water tube boilers are used in high-pressure and very-high-pressure applications. Most military installations have a central boiler plant containing water tube boilers in addition to fire tube boilers that are located in, and serve, individual buildings.

Figure 4-2 **Water Tube Boiler**



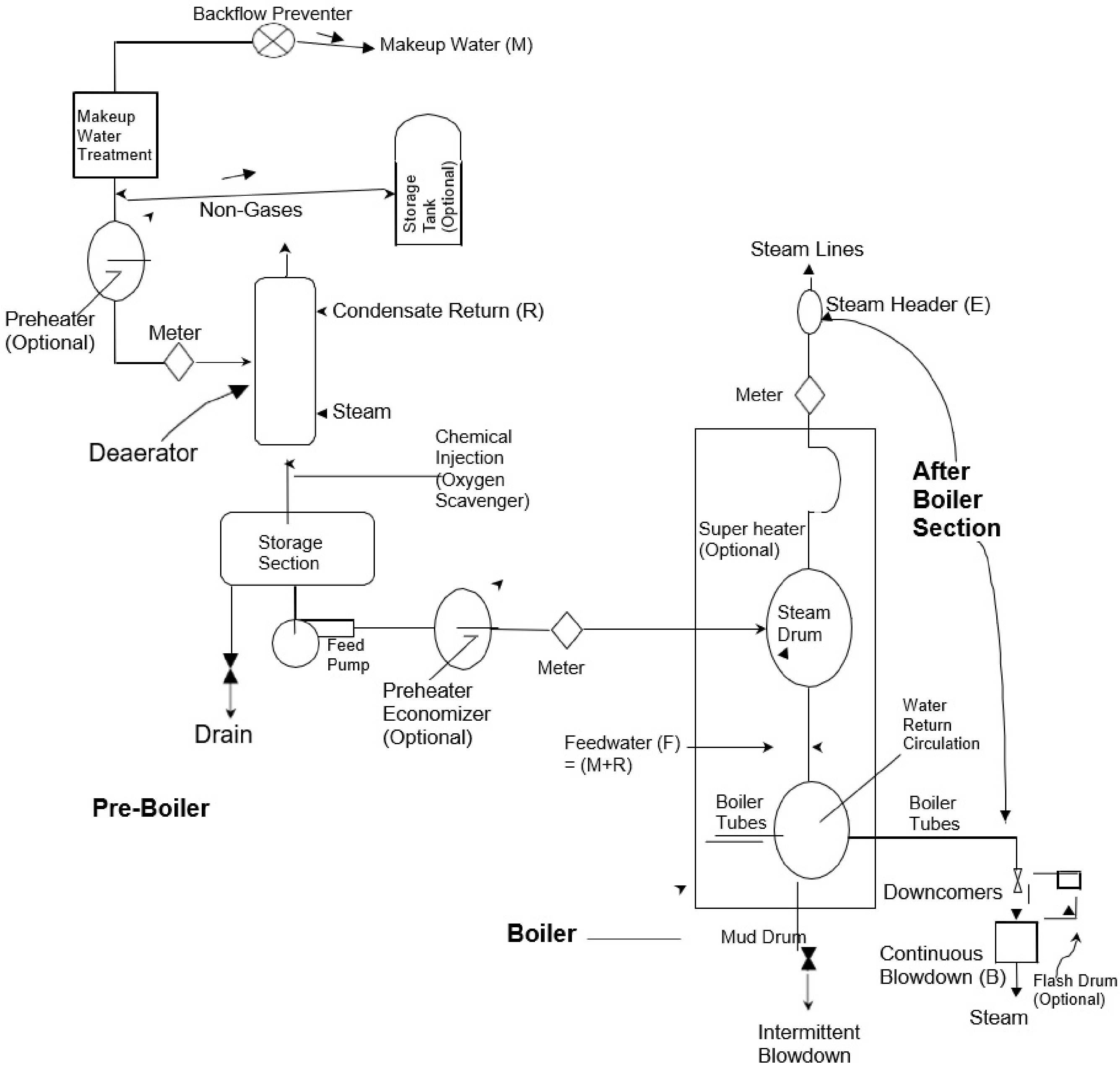
4-1.1.4 Boiler Capacity Rating.

Boiler capacity rating is given as units of either boiler horsepower, kilograms of steam per second (pounds per hour), or kilowatts (British thermal units (BTU) per hour), specifically: 1) one boiler horsepower unit reflects the energy to convert 34.5 pounds (15.7 kilograms) of water to steam from (and at) 100° C at sea level, which is equivalent to 9.812 kilowatts (33,479 BTU per hour); 2) kilogram of steam produced per second (pound of steam produced per hour) represents the number of kilograms of water used each second (pound per hour) to produce the steam; and 3) kilowatts (3,413 BTUs per hour) reflect the energy needed to evaporate the water (produce steam) each hour. The actual quantity of steam produced will vary depending on the boiler efficiency, boiler operating pressure, and altitude with respect to sea level.

4-1.2 Components of a Steam Boiler System.

The functional components of steam boiler systems vary from one system to another based on a variety of design, engineering and service requirements. The typical components that may be included in a specific unit are illustrated in Figure 4-3 and are briefly described in paragraphs 4-1.2.1 through 4-1.2.5.

Figure 4-3 **Components of a Simple Steam Boiler System**



4-1.2.1 Pre-Boiler.

The pre-boiler section of a steam boiler encompasses the boiler system's structural components that hold, move, and treat the water before the water enters the boiler. These pre-boiler system components include the integrated or supplementary water pre-treatment equipment used to process the boiler makeup water, the deaerator used to remove oxygen and other non-condensable gases, and the feed water heaters and pumps. The pre-boiler section may include a storage tank for the treated makeup water. The boiler feed water is usually composed of the makeup water combined with the condensed steam (condensate) that is returned from the distribution system (called the condensate return). The feed water, pre-heated or not, then enters the deaerator, which is used to remove (deaerate) oxygen and other volatile gases. See paragraphs 4-2.6.1 and 4-2.6.1.1 for more information on deaerators.

4-1.2.2 After-Boiler.

The after-boiler, or post-boiler, section of the boiler system encompasses all structural components of the boiler system that hold, move, and process the steam and water downstream from the actual boiler. The after-boiler includes steam piping, heat exchangers, steam traps, condensate piping, turbines, process equipment, and super heaters.

4-1.2.3 Boiler Components.

A fire tube boiler passes the hot combustion gases through the tubes, which are surrounded by the water to be converted to steam. A water tube boiler passes the hot combustion gases around the tubes, which contain the water to be converted to steam. In either type of boiler, the steam passes into a steam drum and then into the steam lines. The circulation of water in the water tube boiler may be accomplished by heating only, through a process of "natural circulation," which requires no external force or pumping. Alternatively, the water can be pumped through the heating circuit of the boiler by a process referred to as "forced circulation." Usually, a mud drum is provided at the lowest point in the water circulation section to allow the removal of any water-formed sludge. There will be at least two locations for the removal of boiler water blowdown*:* 1) for surface blowdown, sometimes referred to as a skimmer, located just below the operating water level of the steam drum; and 2) one or more bottom blowdown locations at the mud drum.

4-1.2.4 Steam Drum.

The feed water is added to the steam drum, where a mixture of steam and water is produced and where the steam is separated from the water. This separation process usually includes using mechanical devices to assist in removing any entrained boiler water from the steam. Chemicals used for internal boiler water treatment may be added (fed) to the water in the steam drum. A process of either continuous or intermittent surface blowdown is used to maintain the TDS of the boiler water and achieve the optimal operating conditions in the boiler. In some boiler systems, the blowdown water will be discharged to a flash tank, where a lower pressure steam is produced (possibly for use in the deaerator). Also, water from continuous blowdown may be used to preheat the makeup water by means of a heat exchanger. Steam from the drum may be discharged directly to the steam header or, in some boilers, heated further in a super heater to generate superheated steam.

4-1.2.5 Steam Header.

The steam generated by the boiler is discharged from the steam drum to a header. The steam header feeds the steam to the steam distribution system. The steam is consumed by process equipment, lost through leaks, lost from valves, fittings, or steam traps, or condensed for return to the deaerator and subsequently reused for additional steam production.

4-1.3 Measuring Equipment.

To develop an appropriate water treatment program for a steam boiler system, as well as to monitor the effectiveness of the on- going program, measure the quantities of steam, feed water, blowdown, makeup, and condensate into and from the system. As a minimum, install a flow meter in the makeup water line. Installing flow meters on the feed water line and in the steam header is also advisable, but due to cost considerations this practice is usually limited to large steam boilers. The rates and volumes for production of condensate and blowdown water can be calculated using the method described in paragraphs 4-1.5 and 4-1.6.

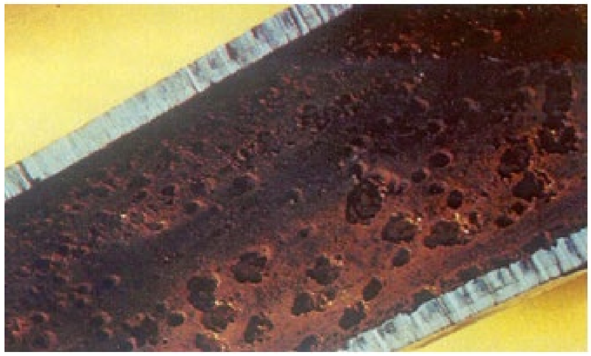
4-1.4 Common Boiler Problems.

Common water-related problems inside the entire boiler system are corrosion, deposition, and carryover.

4-1.4.1 Corrosion Problems.

Corrosion problems are the result of the action of oxygen and the effect of low or high pH on metal components, including the boiler tubes and drum, which are constructed of carbon steel. Corrosion can also occur from excessive alkalinity of excessive pH of the boiler water. This caustic attack is most likely to occur under scale or deposits, where very high local concentrations of hydroxide can build or in zones where insufficient cooling flows fails to sufficiently remove the heat input, leading to boiling, and thus steam blanketing occurs.” Corrosion can occur in the boiler, as well as in the pre-boiler and after-boiler sections, which can also be constructed of carbon steel. Corrosion can result in loss of metal volume or in a reduction of the integrity of the metal, situations that can lead to structural failure, particularly when metal loss is localized (see Figure 4-4). Corrosion is therefore also a safety concern. Corrosion in the steam lines, condensate lines located in the after-boiler section, and in the carbon steel piping can result in the production of system leaks leading to the loss of condensate, a situation which increases demands for energy, water, and chemicals.

Figure 4-4 **Boiler Tube Oxygen Pitting**



4-1.4.2 Deposition Problems.

Deposition problems result from the precipitation of minerals dissolved in the feed water, causing the formation of one or more types of scale on boiler system components. Deposition can occur by other mechanisms when corrosion products (rust) enter the boiler after being created in either the after-boiler or pre-boiler sections. These corrosion products can form iron-based scales. Using certain water treatment chemicals can also result in the formation of scale when the chemicals are not properly applied. All scales provide insulation to the transfer of heat between the water and the heated metal tubes (see Figure 4-5). Scale can occur in any section of the boiler system, resulting in a reduced capacity for heat transfer. Due to the resulting reduced heat transfer from the fireside of the tube to the water, the metal tubes operate at a higher temperature than if the scale were not providing insulation. Consequently, steam is produced inefficiently due to greater fuel demands, and fuel costs are increased. The greater the thickness of scale, the greater the insulating effect, and the higher the temperature of the tubes (see Figure 4-6). At sufficiently high metal temperatures, the tube can lose its tensile strength and rupture (see Figures 4-7, 4- 8, and 4-9).

Figure 4-5 **Scaled Boiler Tube**

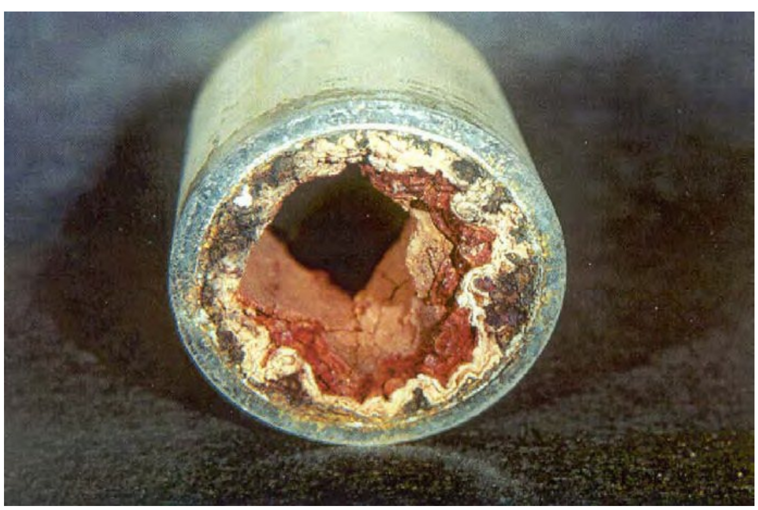


Figure 4-6 **Impact of Scale on Heat Transfer**

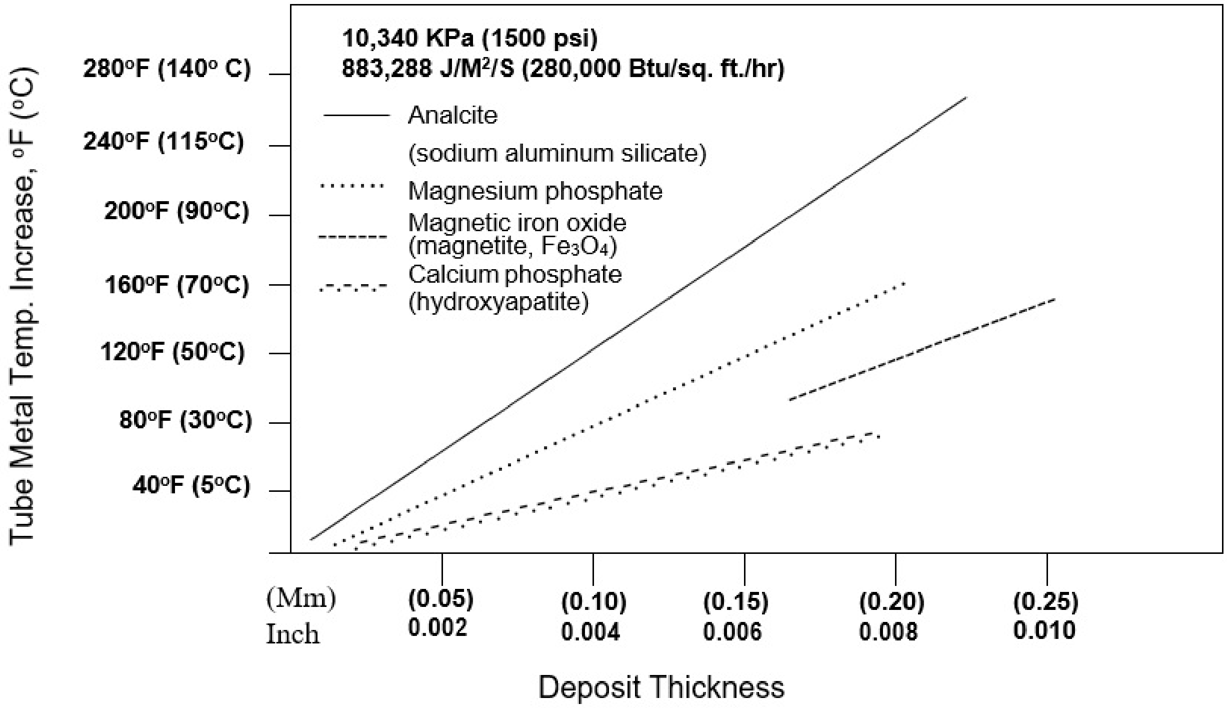


Figure 4-7 **Effect of Boiler Deposits on Boiler Tube**

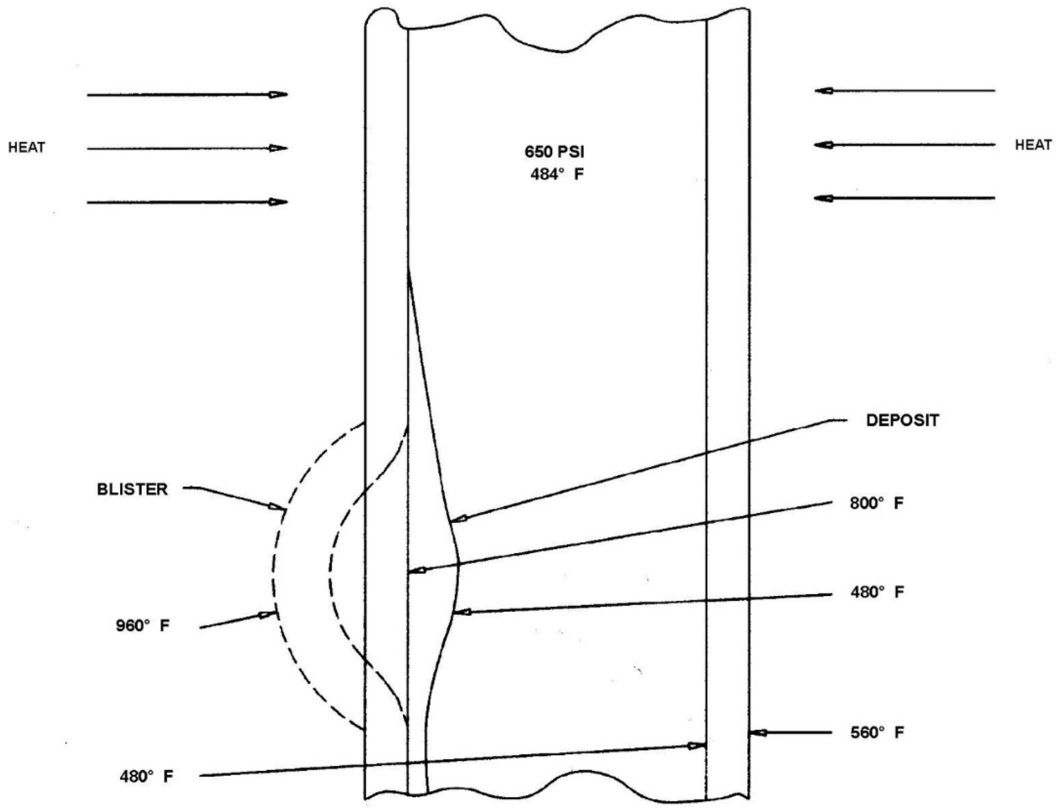
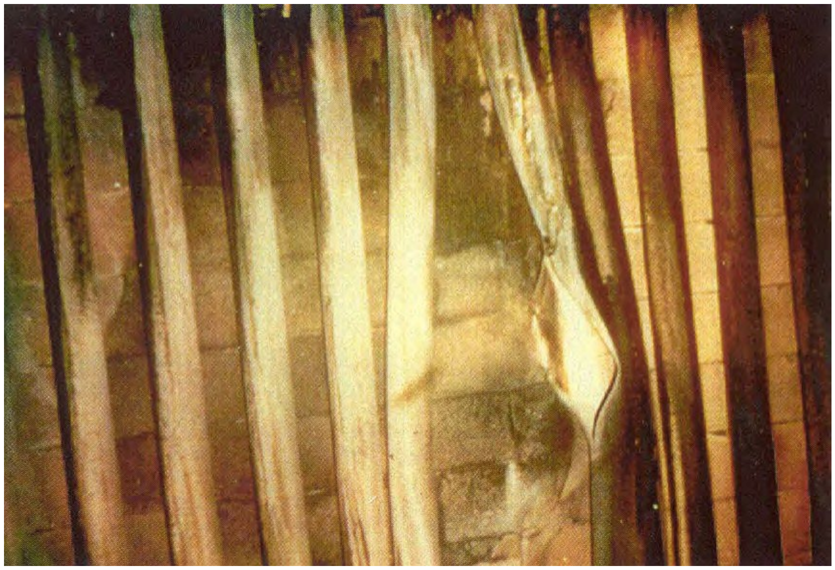


Figure 4-8 **Metal Fatigue on Boiler Tube**

Figure 4-9 **Failed Boiler Tube**



4-1.4.3 Carryover Problems.

Carryover problems are caused by misting, foaming, priming, and silica carryover (see paragraph 4-2.8). Carryover is a process that results in impure steam quality. Dissolved solids contained in the carryover material can contribute to corrosion and deposition problems.

4-1.5 Calculations.

To understand and produce efficient boiler operations, boiler calculations are performed and the results applied correctly. Boiler calculations are the means for providing information used to determine optimal blowdown rates and to assess condensate return. The greatest efficiency of boiler operations can be achieved by optimizing the COC by adjusting the amount of blowdown to give the proper volume of water. Efficient boiler operations recover and return as much condensate as possible. The material balance or mass balance of an operating boiler system can be calculated from the results of water tests and the known (measured) value of a single boiler operational parameter such as steam production, makeup water usage, feed water usage, or blowdown. Steam table data can be used with mass balance information to calculate energy input and energy output for the boiler system. Chemical feed rates can be used with mass balance information to develop an estimation tool for the annual consumption of water treatment chemicals. Familiarity with these calculation procedures and their application to boiler system operations assessment is required of any base or facility engineer or section supervisor. This knowledge is also useful for boiler operators. Examples of boiler calculations are provided in paragraphs 4-1.5.3 through 4-1.6.3.

4-1.5.1 Cycles of Concentration (COC).

COC in a steam boiler is a term that refers to the number of times the minerals in the feed water have been concentrated in the boiler by its operation. As boiler water evaporates and steam is produced, minerals that were dissolved in the boiler water remain behind, increasing the mineral content of the remaining water. As steam is produced, additional mineral-laden feed water enters the boiler, resulting in additional minerals being introduced into the boiler and increasing the amount present in the boiler. Mineral content in an operating boiler water system can be limited only by blowdown.

4-1.5.2 Blowdown.

Blowdown consists of draining some of the boiler water with its accumulated solids, and replacing it with treated feed water before harmful levels of solids are reached. Dissolved solids tend to concentrate near the water surface in the steam drum. Therefore, surface blowdown is most effective in reducing the concentration of dissolved solids. Bottom blowdown is used to remove precipitated sludge from the boiler mud drum. However, blowdown results in the loss of heated water and treatment chemicals. Economical operation requires careful control of blowdown to maintain safe solids levels, while minimizing both heat and chemical additive losses.

4-1.5.3 Water Balance for Feed water, Evaporation, and Blowdown.

The total volume of the water (feed water) that is added to the boiler must equal the total volume of the water (steam plus boiler water blowdown) that is removed from the boiler. By convention, these water quantities are commonly expressed in kilograms per second (pounds per hour) in this equation for water balance:

Equation 4-1. Feedwater

$$F = E + B$$

Where:

F = feed water, lb/hr (kg/s)

E = steam generated, lb/hr (kg/s)

B = blowdown, lb/hr (kg/s)

4-1.5.4 Calculation of Feed water and Blowdown Water.

The feed water or blowdown water (or both) can be calculated in relation to the COC using these equations:

Equation 4-2. Calculation of feedwater & blowdown water

$$\mathrm{COC} = \mathrm{F} \div \mathrm{B} \text{ or } \mathrm{F} = \mathrm{B} \times \mathrm{COC} \text{ or } \mathrm{B} = \mathrm{F} \div \mathrm{COC}$$

Where:

COC= cycles of concentration, no units

F= feed water, lb/hr (kg/s)

B= blowdown, lb/hr (kg/s)

It is common to express blowdown as a percentage:

B = 100/COC

4-1.5.5 Relationship Between Feed water, Blowdown, Steam Generation, and COC.

Using the terms defined in paragraphs 4-1.5.3 and 4-1.5.4, the relationship between feed water, blowdown, steam generation, and COC is represented as:

a. F = B x COC, from COC, Equation 4-2 above

b. F = E + B, from COC, Equation 4-1 above

c. B x COC = E + B, replacing F in Equation 4-2 with Equation 4-1

d. B x COC - B = E, rearranging Equation c. above

e. B x (COC-1) = E, rearranging Equation d. above

f. B = E ÷ (COC-1), rearranging Equation a. above

4-1.5.6 Calculating Blowdown Rates.

The blowdown water volume is rarely measured by a meter. As shown below, it can be calculated if any two of the following parameters are known: 1) feed water; 2) COC; or 3) steam generation (E). Steam volume is usually measured in units of meters on large boilers. The COC can be calculated by measuring the conductivity or TDS in both the boiler water and the feed water. Note that the conductivity and quantity of TDS is the same for the boiler water and the blowdown water.

Equation 4-3. Calculating blowdown rates

$$COC = B_{TDS} / F_{TDS} \text{ or } B_{\mu mhos} / F_{\mu mhos3}$$

Where:

COC= cycles of concentration, no units B_{TDS}= blowdown TDS, ppm

F_{TD}= feed water TDS, ppm

$B_{\mu mhos}$= blowdown conductivity, micromhos $F_{\mu mhos}$= feed water conductivity, micromhos

4-1.5.7 Determining Feed water and Blowdown Rates.

The blowdown calculations in paragraph 4-1.5.6 can be used to determine the feed water rate in pounds per hour (units of kilograms per hour). Note that the term “feed water” refers to water that is fed to the boiler and includes the makeup water plus the condensate return and steam from the deaerator.

EXAMPLE:

a. 250-pound-per-square-inch-gauge (1720-kilopascal) boiler operates at a conductivity level of 5000 µmhos. The boiler feed water has a conductivity of 250 µmhos. The COC calculation is:

   COC = Bµmhos / Fµmhos or 5000 µmhos / 250 µmhos = 20 COC

b. The percent blowdown is:

   percent B = 100/COC or 100/20 = 5 percent

c. If the boiler is producing 40,000 pounds per hour (5 kilograms per second of steam), the blowdown must be:

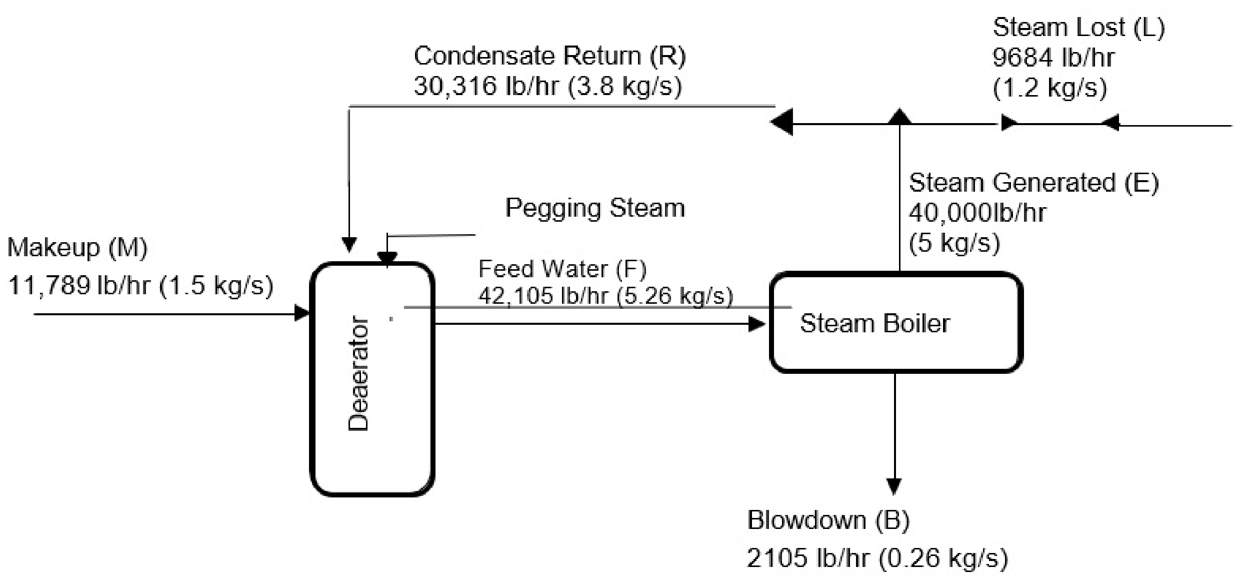
   B = E ÷ (COC - 1) = 5.0 ÷ (20 - 1) = 2105 lb/hr (0.26 kg/s)

d. The feed water is calculated to be:

   F = E + B = 5.0 + 0.26 = 42,105 lb/hr (5.26 kg/s)

This is equivalent to 5054 gallons per hour at 8.33 pounds per gallon (5.3 liters per second). This example is illustrated in Figure 4-10.

Figure 4-10 **Simplified Boiler System Water Balance**



4-1.5.8 Determining Makeup Water and Condensate Return Rates.

Makeup is the water from the external water treatment system added to the boiler system upstream of the deaerator. The amount, expressed as either volume or percentage, of makeup water required in a boiler is affected by blowdown, steam leaks, consumption of steam in process equipment, and loss of condensate by boiler system leakage. In a "tight" boiler system, where steam is not lost in process equipment, about 5 to 10 percent makeup is expected. Water balance is affected by condensate return; however, boilers that lose considerable condensate due to losses of steam or condensate can approach a requirement for 100 percent makeup, which is a very inefficient and costly condition. The calculations below can be used for determining makeup water needs and condensate return rates.

4-1.5.9 Makeup Water Rate.

Makeup is the difference between the volume of condensate return and the volume of feed water.

Equation 4-4. Makeup Water Rate

$$M = F - R$$

Where:

M = makeup, lb/hr (kg/s)

F = feedwater, lb/hr (kg/s)

R = condensate return, lb/hr (kg/s)

4-1.5.10 Condensate Return Rate.

Since the returned condensate usually does not contain any appreciable level of dissolved solids or conductivity, determination of percent makeup is calculated using the equation:

Equation 4-5. Condensate Return Rate

$$percent\ M = \left(1 - \frac{F\mu mho}{M\mu mho}\right) \times 100\ percent$$

Where:

percent M= percent makeup

Fµmho= feedwater conductivity, micromhos

Mµmho= makeup conductivity, micromhos

EXAMPLE 4-2:

a. Makeup water conductivity is 900 µmhos for the boiler water in this example. The percent makeup is calculated:

$$percent\ of\ M = \left(1 - \frac{F\mu mho}{M\mu mho}\right) \times 100\ percent\ or\ \left(1 - \frac{250}{900}\right) \times 100\ percent\ percent\ of\ M = 72\ percent$$

b. This means that the makeup water is 28 percent of the feedwater. The condensate return percent is calculated:

$$percent\ of\ R = 100 - percent\ of\ M = 100 - 28 = 72\ percent$$

c. The quantity of makeup water is calculated:

M = (percent of M/100) x F

or (28/100) X 42,105 lb/hr (5.3 kg/s)

M = 11,789 lb/hr (1.5 kg/s)

d. The quantity of condensate return is calculated:

R = F - M = 5.3 – 1.5 = 30,316 lb/hr (3.8 kg/s)

4-1.5.11 Difference Between Amount of Steam Produced and Amount of Condensate.

The difference between amount of steam produced and the amount of condensate returned represents the combined loss from the system of both steam and condensate. These losses may result from leakage of steam, consumption of steam by the process equipment, leakage of condensate, or deliberate discharge of contaminated condensate. The total water loss can be calculated:

Equation 4-6. Total Water Loss

$$L = E - R$$

Where:

L = total steam and condensate losses, lb/hr (kg/s)

E = steam generated, lb/hr (kg/s)

R = condensate return, lb/hr (kg/s)

EXAMPLE 4-3:

a. The steam losses from the boiler described in Examples 4-1 and 4-2can be calculated:

$L = E - R = 5.0 - 3.8 =$ 9684lb/hr (1.2kg/s)

b. This relationship and the information from the previous examples are presented in Figure 4-9.

4-1.5.12 Basis for Evaluating Boiler System Efficiency.

A good basis for evaluating boiler system efficiency can be developed by monitoring the system's water conductivity values, measuring the quantity of steam generated, and performing the required calculations after a regularly scheduled interval of time. An increase in steam loss may indicate a new leak, a size increase in existing leaks, a new consumption of steam, or condensate losses. Additionally, calculations of boiler system efficiency can provide a good basis for estimating savings in steam cost resulting from maintenance efforts to reduce steam and condensate losses.

4-2 BOILER WATER TREATMENT AND CONTROL.

References to boiler water treatment in the late nineteenth century relate that the process of removing the scale from a boiler required much less effort and time if the boiler operator had forgotten to remove cooked potatoes from the boiler water. It was determined that the starch in potatoes causes a soft sludge, rather than a hard scale, to be formed, and this sludge was easier to remove than hard scale. Other natural organics, including lignin and tannins from wood, plant matter, plant extracts, and even manure and coffee grounds, produced similar results. It was determined that addition of phosphate by itself produces a manageable sludge, although starch, lignins, and tannins have been used to supplement the phosphate. Phosphate is still very commonly combined with other water treatment chemicals. Early use of alkaline materials included lime, soda ash, and caustic soda. Oxygen scavengers, such as sodium sulfite, were found to be effective for preventing oxygen corrosion. Many of these materials are still used today. The wide range of water treatment chemicals that is currently available allows for development of a comprehensive approach to industrial boiler water treatment, including using specialty chemicals such as chelants, polymers, and amines.

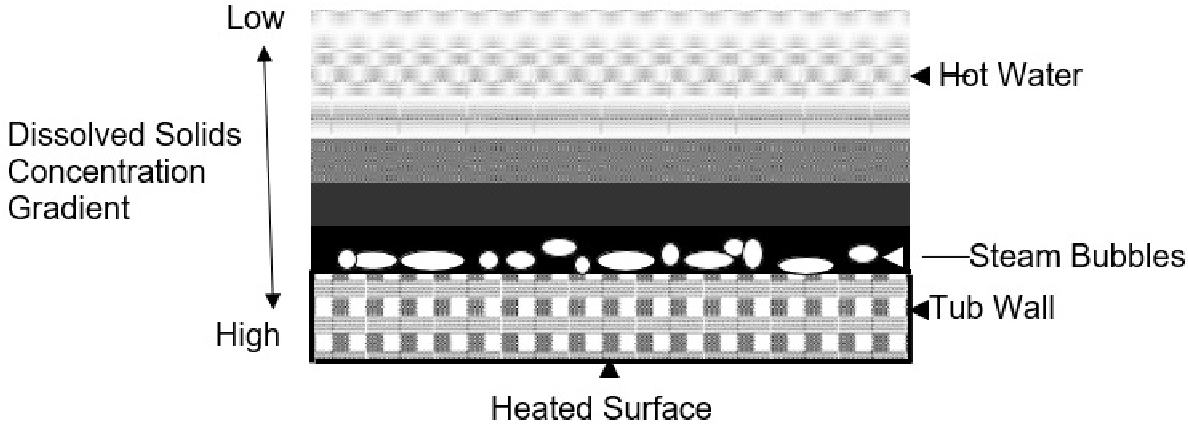
4-2.1 Boiler Deposit Formation.

Dissolved solids in boiler feed water become more concentrated in the boiler water as steam is generated. Some of the dissolved solids can come out of solution (precipitate) and form scale in the boiler tubes. Some dissolved solids can form sludge (mud) in the boiler and form adherent deposits on boiler tubes. These deposits reduce heat transfer.

4-2.1.1 Scale.

Scale can occur in isolated spots due to water evaporation, as illustrated in Figure 4-10. When a steam bubble forms on a heated surface, a thin film of water situated between the bubble and the tube wall becomes more concentrated with the dissolved materials. This thin layer can be as much as 30˚ F (17˚ C) hotter than the average boiler water temperature. These local conditions can cause precipitation of the dissolved solids and local formation of scale. See Figure 4-11.

Figure 4-11 **Localized Scale Formation Process**



4-2.1.2 Sludge Deposits.

Sludge deposits can form when the precipitated materials in the boiler water stick to the boiler tubes due to their hot surfaces as a result of the same phenomenon described in paragraph 4-2.1.1. Scale and sludge often form together.

4-2.1.3 Dissolved Solid Materials.

Some dissolved solid materials become less soluble as the water temperature increases. This situation occurs with most of the salts that constitute calcium and magnesium hardness ($CaCO_3$, $CaSO_4$, $MgCO_3$, $Mg[OH]_2$). As a result of this property, these materials tend to form scale in the hotter areas of the boiler because they remain soluble in the cooler areas of the boiler. By using an appropriate form of water treatment, these scaling agents can be removed from the boiler system water either before they enter the boiler (external treatment) or after (internal treatment), although it is often best to remove the dissolved magnesium and calcium minerals (hardness) before they enter the boiler (see paragraph 4-2). With the proper chemical treatment, they can be effectively controlled and treated internally in the boiler.

4-2.2 Common Scale Found in Boilers.

The most common scale materials consist of calcium and magnesium salts and iron oxide. Calcium and magnesium salt deposits are white or off-white. Iron oxide scales are red or black deposits. The type of scale can be identified accurately by deposit analysis. It is common to have more than one type of scale in boiler deposits.

4-2.2.1 Calcium Carbonate.

Calcium carbonate scale is white or off-white in color and is formed by the breakdown of calcium bicarbonate with heat. Calcium carbonate scale is formed in both untreated boilers and improperly treated boilers. A drop of a dilute acid solution on the deposit will cause bubbling on the calcium carbonate scale area as a result of the release of carbon dioxide. This procedure can be used to identify this type of scale. Calcium carbonate scale can result when there is calcium hardness in the boiler feed water due to improper softener operation and when there is an inadequate level of sludge or scale conditioner or dispersant.

4-2.2.2 Calcium Sulfate.

Calcium sulfate (gypsum) is off-white or tan in color and is formed in boilers that are using water of high hardness and low alkalinity without proper treatment. Addition of a strong acid will dissolve the calcium sulfate scale with no gas bubble formation or release of carbon dioxide. Calcium sulfate is much less common than calcium carbonate, but it can form when there is calcium hardness in the boiler feed water due to improper softener operation and when there is an inadequate level of sludge or scale conditioner or dispersant.

4-2.2.3 Calcium Phosphate.

Calcium phosphate is formed when the dissolved calcium in the feedwater reacts with phosphate treatment chemicals added to the boiler water. With proper treatment controls, calcium phosphate forms a sludge that will be removed in the blowdown. However, calcium phosphate can deposit as scale if the pH of the boiler water is below 11.0 and if a sludge conditioner is not used. Addition of a strong acid will dissolve this scale fairly easily with no gas bubble formation.

4-2.2.4 Magnesium Phosphate.

Magnesium phosphate scale is an off-white deposit formed by the reaction of magnesium salts from the feedwater with the phosphate used in the boiler water treatment. It will form only if both the hydroxide content and silica content of the boiler water are low. Addition of a strong acid will dissolve this scale fairly readily with no gas bubble formation.

4-2.2.5 Magnesium Silicate.

Magnesium silicate scale, an off-white deposit, is formed from the magnesium and silica in the feedwater when the pH is above 11.0 and the silica level is more than half that of the phosphate level in the boiler water. Normally, it forms as a sludge that will be removed in the blowdown, but it may form scale deposits on tubes if a sludge conditioner is not present. Most acids will not remove this deposit. Caustic or special chemicals are needed to remove the magnesium sulfate scale.

4-2.2.6 Iron Oxide and Iron Hydroxide.

Iron oxide scales and iron hydroxide scales are red/black deposits that are formed when the iron salts dissolved in the feedwater react with hydroxide found in the boiler water. Usually, the dissolved iron is introduced into the system from the condensate return due to corrosion. Iron oxide can be deposited as a scale on the boiler tubes if the proper type of sludge conditioner is not present. With proper water treatment, this deposit should form as sludge, rather than scale, and can be removed by blowdown. The presence of iron oxide on the internal boiler surfaces can be caused by oxygen corrosion of the boiler metal.

4-2.3 External Boiler Water Treatment.

Specific technologies for external treatment or pre-treatment are described in Chapter 3. The strategy for external treatment is to remove unwanted impurities in the makeup water before they can enter the boiler. Proper external treatment can eliminate, or at least minimize, scale- and corrosion-forming conditions and minimize the internal water treatment required to protect the boiler system components.

4-2.3.1 External Water Treatment for High-Pressure Boilers.

The higher the pressure of the boiler, the greater the need for high-purity feedwater. A 40,000-pound-per-hour (5-kilogram-per- second) water tube boiler operating at 900 pounds per square inch gauge (6205 kilopascals) requires deionized feedwater. External treatment options include RO followed by demineralization. Guidelines for feedwater purity are described in paragraph 4-3.4.

4-2.3.2 External Treatment for Low-Pressure Boilers.

Low-pressure boilers can operate with simple external treatment or sometimes no external treatment at all. A 3450-pound-per-hour (0.44-kilogram-per-second) (100 horsepower) fire tube boiler operating at less than 15 pounds per square inch gauge (103 kilopascals) may require using only a sodium zeolite softener for water treatment. A small heating boiler that is returning over 99 percent of the condensate may not require any external treatment, particularly if the makeup water is low in hardness and the condensate is not contaminated.

4-2.4 Internal Treatment of Boiler Water.

Internal treatment of boiler water is a process of adding chemicals to the boiler to control deposition and corrosion. Internal water treatment, together with proper blowdown control, controls the water impurities that have not been removed or reduced through external treatment.

4-2.4.1 Preventing Scale Formation.

Internal boiler water treatment for scale prevention can be performed using either a solubilizing chemical treatment program or a precipitating chemical treatment program. The solubilizing treatment program uses chemicals designed to keep scale-causing materials with hardness (mineral ions) in solution, whereas the precipitating treatment program uses chemicals designed to react with hardness-causing materials and precipitate them as a sludge that will not adhere to tube surfaces. Both the solubilizing approach and the precipitating approach require good blowdown control to keep hardness and sludge levels within chemical performance capabilities.

4-2.4.1.1 Low-Pressure Boilers.

Low-pressure steam boiler systems 15 pounds per square inch gauge (103 kilopascals and less) that use little or no makeup or blowdown are usually not chemically treated for scale control because, due to low makeup water demands, there is no continuous addition of scaling agents (present in the makeup water) to the boiler. If there are high makeup requirements (over 1 percent per month) or if the makeup water is over 300 ppm total hardness, a treatment program is required to protect the boiler system.

4-2.4.1.2 High-Pressure Boilers.

High-pressure boilers 15 to 900 pounds per square inch gauge (103 to 6205 kilopascals) must use either a precipitating-type water treatment chemical program or a solubilizing-type chemical treatment program.

4-2.4.1.3 Precipitating Water Treatment Programs.

A precipitating program often uses phosphate, which will react with calcium to form a calcium phosphate sludge called “hydroxyapatite” ($3Ca_3(PO4)_2 \bullet Ca(OH)_2$), and act as both as a sludge conditioner or dispersant. Magnesium reacts with hydroxide and silica to form a magnesium silicate sludge called “serpentine” ($2MgSiO_3 \bullet Mg(OH)_2 \bullet H_20$). Sufficient hydroxyl alkalinity (causticity) is required to allow the formation of the proper types of sludge. Sludge that is properly formed and conditioned is fluid enough to be removed through bottom blowdown of the boiler. Sodium hydroxide may be required to maintain the appropriate hydroxyl alkalinity (causticity). Phosphate precipitating agents are prepared as either orthophosphate (“ortho” means single phosphate) or as one of several forms of polyphosphate (“poly” means multiple phosphate molecules bonded together). Sodium hexametaphosphate, sodium tripolyphosphate, and sodium pyrophosphate are examples of polyphosphates. In the boiler, polyphosphate breaks down to the orthophosphate form due to the higher temperature. Polyphosphates can be added either to the feedwater or directly to the steam drum. Orthophosphate should only be fed into the steam drum, not to the feedwater, since it can react with the hardness (mineral ions) to form scale in the feedwater lines.

4-2.4.1.4 Solubilizing Water Treatment Programs.

A solubilizing program uses one or more of the following chemicals to keep scale-forming materials in solution: phosphonates (also known as organic phosphate), chelants, or polymers. Solubilizing agents, such as phosphonates (not to be confused with phosphate), chelants, and polymers are common chemicals used in boiler water treatment formulations. Chelants, such as ethylene diamine tetra-acetic acid (EDTA) or nitrilo-triacetic acid (NTA), bind (chelate) calcium, magnesium, and iron. Using phosphonates and chelants requires special injection systems and excellent feed control. Excess (free) phosphonate or chelant can attack metal surfaces, causing corrosion, although phosphonates are less aggressive than chelants. Water-treating polymers are long-chain, water-soluble compounds containing electrochemically active side branches that perform various functions such as solubilization, dispersion, agglomeration, and crystal distortion to prevent boiler deposits. Polymers do not attack metal surfaces and can be fed into the feedwater line or directly into the boiler steam drum with proper injection equipment.

4-2.4.1.5 Boiler-Specific Treatment Programs.

High-pressure boilers over 900 pounds per square inch gauge (6205 kilopascals) use high-quality feedwater that is produced by extensive external treatment; thus, scale-forming materials are not normally present in the water and cannot form scale in the boiler. These boilers often use water treatment programs designed specifically for that particular boiler. These programs require excellent control of water chemistry and involve applying coordinated phosphate, congruent phosphate, equilibrium phosphate, and all volatile treatment. Boiler pressures of this level are usually found in operations used to drive turbines for the generation of electrical power.

4-2.4.2 Determining Chemical Treatment Feed Rates.

Development of a chemical treatment program involves selecting the type of chemical to be used, selecting appropriate concentration levels for each chemical (when used in combination with other chemicals), and selecting the required chemical treatment (addition) scheme to ensure proper water treatment. Selection factors are described in paragraph 4-3. Blowdown discharge rates can be used to calculate the rate of chemical addition and the amount of chemical required to replace that lost in the blowdown and to meet the treatment objectives. In practice, chemical feed equipment is set up to deliver the chemicals on a “proportional-feed-on-demand” basis. The operator must keep treatment levels within prescribed control ranges by adjusting pumps and timers while controlling COC within the system. Selection of the type and quantity of required chemical treatment is an issue that involves both technical concerns and ancillary issues pertaining to institutional concerns in the areas of procurement, contracts, and budgets. This situation is described in Chapter 11.

Example illustrates phosphate demand. Similar approaches could be used for other treatment technologies. In the case of sulfite, the treatment requirement must first satisfy the demand due to oxygen in the feedwater. Additional sulfite is fed to attain a residual or excess amount in the boiler water to ensure adequate protection. The second part of Example 3-4 takes into account that the treatment chemical formulation is not composed of 100 percent active ingredients. Formulations are most often less than 50 percent active and can be as little as 10 percent active chemical, with the balance of the formulation usually being water.

EXAMPLE:

a. The boiler in Examples 4-1, 4-2, and 4-3 will be operated with a phosphate level of 60 ppm (as PO_4) in the boiler water. The blowdown has been determined to be 2105 pounds per hour (0.26 kilogram per second). The required phosphate addition on a daily basis must equal the phosphate that is discharged with the blowdown water, plus that used up in precipitating calcium phosphate. The amount of phosphate required to replace that lost in blowdown is calculated by this method:

Phosphate loss

= (B)(treatment ppm residual)/1,000,000

= 0.26 60 ppm (kg/s) x/1,000,000

= 0.13 lb/hr (0.000016 kg/s) or 1.38 kg/day

b. The treatment chemical selected is sodium hexametaphosphate (HMP) containing 90.5 percent phosphate as PO_4. This means there is 0.905 pound (0.905 kilogram) of phosphate (PO_4) per pound (kilogram) of chemical:

Chemical required

= phosphate loss ÷ 0.905

= 1.38 ÷ 0.905

= 3.35 lb/day (1.52 kg/day)

NOTE: This calculation does not incorporate any phosphate reaction and precipitation with hardness (see paragraph 4-2.4.3), so the practical amount of HMP needed would be slightly higher.

4-2.4.3 Preventing Sludge Deposits.

In either low-pressure or high-pressure boilers, the feedwater hardness (dissolved minerals) can precipitate in the boiler. To prevent the formation of adherent sludge deposits, natural or synthetic (or both) water- soluble organic chemicals are added to the boiler water. Organic chemicals help to create sludge by distorting the crystal structure of scale-forming compounds and preventing the formation of scale. Properly formed and conditioned sludge is fluid enough to be removed through bottom blowdown of the boiler mud drum. A typical natural organic compound, quebracho tannin, has been used traditionally with satisfactory results in military boilers, but its use is diminishing in favor of the new synthetic, water-soluble polymers. Tannin is effective for the control and minimization of sludge and contributes to corrosion control since it absorbs a small amount of dissolved oxygen and helps to form a protective film on mild steel surfaces. To be effective, tannin levels should be maintained at several hundred ppm (of active component) in the boiler water. Polymer materials are typically maintained between 5 to 20 ppm (of active component). The most recently developed synthetic water-soluble polymers have been shown to be more cost-effective than tannins. For example, polyacrylates or copolymers of methacrylate and sulfonated styrene are dispersants, sludge and scale inhibitors commonly used for minimizing the formation of deposits in boilers. Polymer treatments are commonly found in water treatment formulations available from vendors.

4-2.5 Corrosion in the Boiler.

Corrosion within the boiler results from an improper pH level (below 10.3), a situation that contributes to general (overall) corrosion, and from oxygen not being removed from the feedwater, a situation that causes pitting of the mild steel tubes and drums.

4-2.5.1 General Corrosion.

"General corrosion" is a term that refers to an overall uniform corrosion of metal surfaces. Adequate prevention of general corrosion is achieved by maintaining a proper pH, thus allowing the formation of a protective iron oxide coating known as magnetite. Magnetite is a self-limiting form of corrosion that forms in the outermost surface layers of, and that adheres to, the mild steel tube surfaces. Magnetite is composed of an iron oxide complex of $Fe_3O_4 + FeO + Fe_2O_3$.

4-2.5.1.1 Proper pH for Boilers up to 6205 Kilopascals.

The proper pH range for boilers up to 900 pounds per square inch gauge (6205 kilopascals) is between 10.3 and 12.0. Adjustment of the boiler water to within this pH range is achieved through cycling up the natural alkalinity contained in the feedwater and, if necessary, adding a chemical alkalinity agent such as sodium hydroxide (caustic soda), sodium carbonate (soda ash), or an alkaline phosphate treatment.

4-2.5.1.2 Proper pH for Boilers Over 6205 Kilopascals.

Proper pH adjustment for boilers over 900 pounds per square inch gauge (6205 kilopascals) is achieved by using water treatment chemicals, which are added because the demineralized feedwater is essentially unbuffered. The chemical treatment programs include coordinated phosphate, congruent phosphate, equilibrium phosphate, and all volatile treatment. Phosphate programs of this type are not used as conventional precipitating agents for hardness-causing materials but instead are used as buffering agents for pH control (see Table 4-1).

Table 4-1 Summary of Phosphate Treatment Programs

Program	PO_4	OH	Na:PO_4Ratio	pH
Conventional	30-60	20-350	N/A	11-12
Coordinated	5-25	Trace	2.85:1 to 3:1	9-10.5
Congruent	2-5	Zero	2.3 to 2.6:1	8.8-9.4
Equilibrium	<2.4	<1.0	N/A	9.3-9.6

4-2.5.2 Pitting Corrosion.

Pitting corrosion is a term that refers to a deep, localized corrosion usually caused by oxygen molecules on the metal surfaces in the boiler water. This process results in the formation of corrosion pits that can extend into the interior metal layers of metal boiler components. Corrosion pitting can be severe enough to lead to perforations of tube surfaces (see Figure 4-4).

4-2.5.3 Other Types of Corrosion.

Other types of corrosion can occur in high- pressure boilers over 900 pounds per square inch gauge (6205 kilopascals) for which the water treatment program includes coordinated, congruent, or equilibrium phosphate- type chemical treatment (not to be confused with standard phosphate precipitating programs). These other corrosion mechanisms include caustic attack, hydrogen embrittlement, and phosphate hideout.

4-2.6 Removing Oxygen from Feedwater.

A very corrosive liquid results when oxygen is dissolved in water. Oxygenated water is particularly corrosive to mild steel, which is almost always used to construct the main components of the boiler system. The corrosivity rate of oxygenated water doubles with every 18° F (10° C) increase in temperature. Oxygen corrosion can be recognized by the presence of pits found typically in the top of, or at the waterline of, the steam drum. Oxygen can be removed from feedwater by mechanical or chemical methods, or both; a combination of these methods is used commonly.

4-2.6.1 Mechanical Oxygen Removal.

Mechanical removal of oxygen from feedwater requires a deaerating heater in which both the makeup water and condensate return are in contact with live steam and mixed using trays, sprays, or both. This heating process literally strips most of the oxygen and other non-condensable gases out of the feedwater. The oxygen and other gases, along with a small amount of steam, are vented from the deaerator to the atmosphere.

4-2.6.1.1 Deaerator Operation.

Two key parameters associated with deaerator operation are controlled to maintain maximum oxygen removal. First, the deaerator vent is checked to verify that a plume of steam is always flowing out of the vent. Second, both the pressure within the deaerator and the temperature of the outlet water are controlled. Deaerators should operate at a pressure of 3 pounds per square inch gauge (20.68 kilopascals) or more. At any given pressure, the deaerator water outlet temperature should be within 2° F (1° C) of the water temperatures shown in Table 4-2, adjusted for the altitude of the installation. If the deaerator is operating with low or no steam flow or at a low water temperature, the deaerator is not being operated efficiently and is not removing the maximum amount of oxygen. Schematic diagrams of mechanical deaerators are shown in Figures 4-12 and 4-13.

Table 4-2 Deaerator Water Outlet Temperature for Boiler Systems at Various Sea Level Pressures

Deaerator Pressure psig (kPa)	Deaerator Water Outlet Temperature F (C)	Deaerator Pressure psig (kPa)	Deaerator Water Outlet Temperature F (C)
0 (0.00)	212.0 (100)	11 (75.84)	241.6 (116.4)
1 (6.89)	215.3 (101.8)	12 (82.74)	244.4 (118)
2 (13.79)	218.5 (103.6)	13 (89.63)	246.4 (119.1)
3 (20.68)	221.5 (105.3)	14 (96.53)	248.4 (120.2)
4 (27.58)	224.4 (106.9)	15 (103.42)	250.3 (121.3)
5 (34.47)	227.1 (108.4)	16 (110.32)	252.2 (122.3)
6 (41.37)	229.8 (109.9)	17 (117.21)	254.1 (123.4)
7 (48.26)	232.2 (111.2)	18 (124.11)	255.3 (124.1)
8 (55.16)	234.8 (112.7)	19 (131)	257.0 (125)
9 (62.05)	237.1 (113.9)	20 (137.90)	258.8 (126)
10 (68.95)	239.4 (115.2)	--	--

NOTE: For every 500 feet (152 meters) in elevation from sea level, subtract 1 F (0.5 C) from the listed temperature. A mechanical deaerator that is operating efficiently can reduce the oxygen content of feedwater from the saturation level to a fraction of a ppm. However, even a trace amount of oxygen can cause corrosion pitting in the boiler. The complete removal of oxygen requires the addition of a chemical agent called an "oxygen scavenger."

Figure 4-12 **Mechanical Deaerator Schematic (Spray Type)**

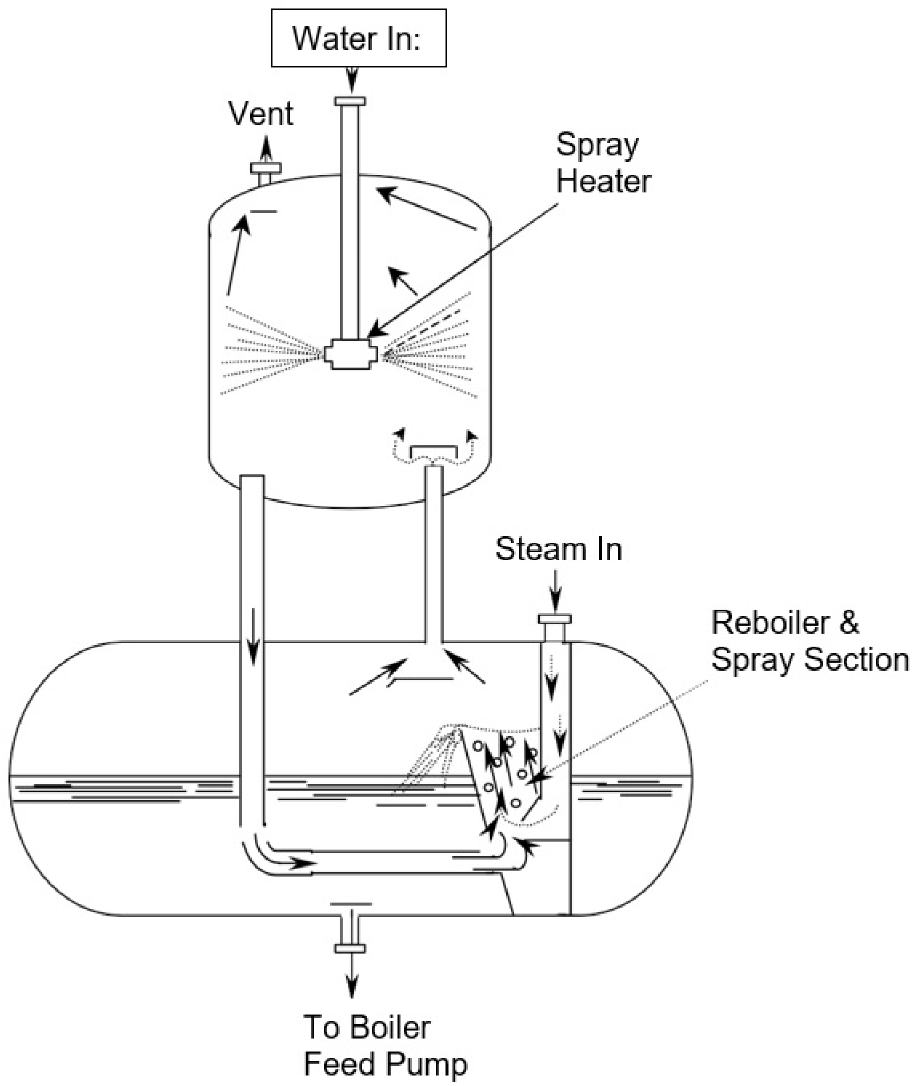
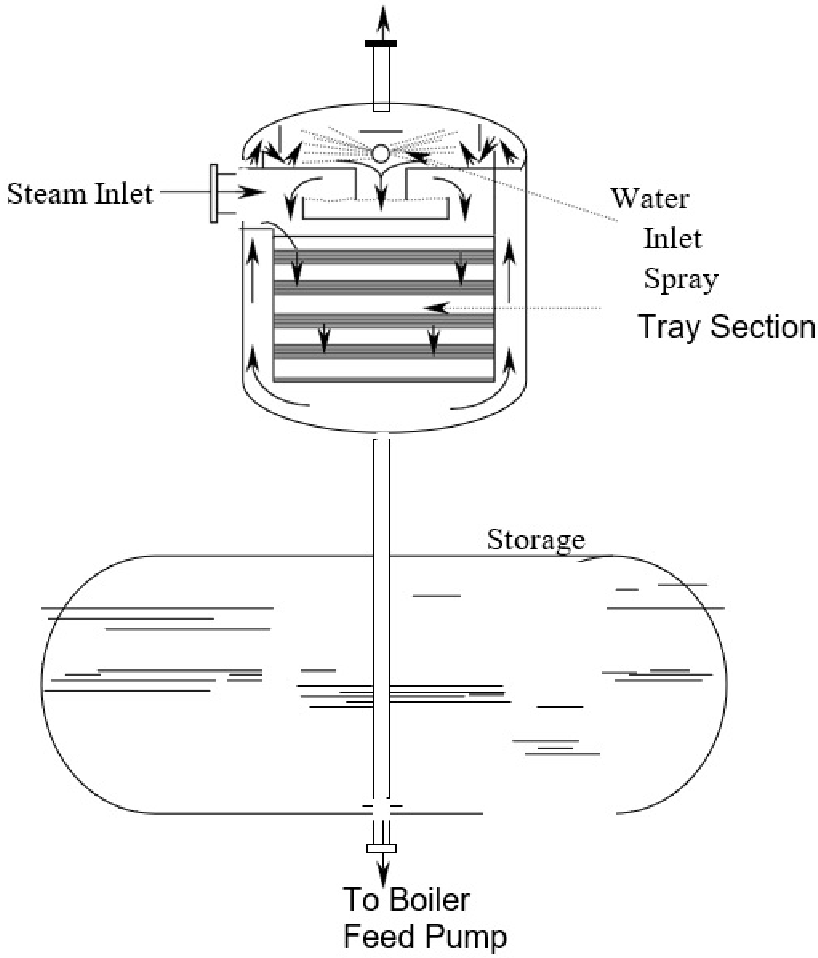


Figure 4-13 **Mechanical Deaerator Schematic (Tray Type)**



4-2.6.2 Chemical Removal of Free Oxygen.

Oxygen scavengers are chemicals that react with oxygen. Oxygen scavengers remove the oxygen from the boiler feedwater so it will not cause pitting corrosion.

4-2.6.2.1 Oxygen Scavengers for Boilers up to 6205 Kilopascals.

Oxygen scavengers for boilers up to 900 pounds per square inch gauge (6205 kilopascals) include catalyzed sodium sulfite and uncatalyzed sodium sulfite, both of which are oxygen scavengers and sources of sulfite. When a deaerator is used, any uncatalyzed oxygen scavenger will suffice and can be fed into the storage area of the deaerator. Use catalyzed sodium sulfite in systems without a deaerator. A cobalt sulfate salt, which is present in the catalyzed sodium sulfite material, is used as the catalyst. Catalyzed sulfite reacts more quickly with oxygen than does uncatalyzed sulfite. Both the sodium sulfite and the catalyst must be fed into the feedwater upstream from the boiler so oxygen can be scavenged before the feedwater enters the boiler. This addition scheme also serves to protect feedwater piping from corrosion. A sufficient amount of the oxygen scavenger must be fed to meet the demand for the oxygen initially present and provide an excess residual (reserve amount) for occasions when the oxygen level may increase unexpectedly, so that water testing will always indicate that an excess amount is present. (See Table 4-3 for typical sulfite levels in the boiler water.)

Table 4-3 Levels of Sulfite to be Carried in Boiler Water

Boiler Pressure psig (KPa)	Sulfite Residual (as ppm SO2)
0-15 (0-103)	20-40
16-149 (110-1020)	20-40
150-299 (1030-2060)	20-40
300-449 (2070-3100)	20-40
450-599 (3100-4130)	20-40
600-749 (4140-5160)	15-30
>750 (>5170)	15-30

4-2.6.2.2 Oxygen Scavengers for Boilers Over 900 PSI.

For boilers over 900 pounds per square inch gauge (6205 kilopascals), the list of oxygen scavengers includes specialty volatile treatments such as hydroxylamine, hydroquinone, carbohydrazide, hydrazine sulfate, and erythorbic acid. Hydrazine can no longer be used because it is a suspected carcinogen. Like hydrazine, these specialty volatile treatments not only scavenge oxygen but also passivate metal surfaces. These chemicals are normally maintained in the boiler water in the parts-per-billion (ppb) range. Sulfite-type oxygen scavengers are not used in boilers over 900 pounds per square inch gauge (6205 kilopascals) because of the potential for thermal decomposition producing sulfur dioxide and hydrogen sulfide, both of which can cause corrosion. The thermal decomposition reactions are:

Equation 4-7. Thermal Decomposition Reactions

$$\mathbf{Na2SO3 + H20 + Heat \rightarrow 2NaOH + SO2\uparrow}$$

$$\mathbf{or}$$

$$\mathbf{4Na2SO3 + 2H2O + Heat \rightarrow 3Na2SO4 + 2NaOH + H2S\uparrow}$$

These reactions have been shown to occur at boiler pressures as low as 600 pounds per square inch gauge (4140 kilopascals), although they do not usually create a serious problem until pressures exceed 900 pounds per square inch gauge (6205 kilopascals).

4-2.7 Condensate Corrosion and Control.

4-2.7.1 Causes of Condensate Corrosion.

Oxygen and carbon dioxide are common steam condensate impurities that promote condensate corrosion. Less common are process contaminants, each of which has corrosive properties dependent upon the nature of the contaminant and on the materials that may be corroded. The piping found in steam condensate systems is commonly constructed of mild steel, whereas heat exchangers are usually copper or mild steel.

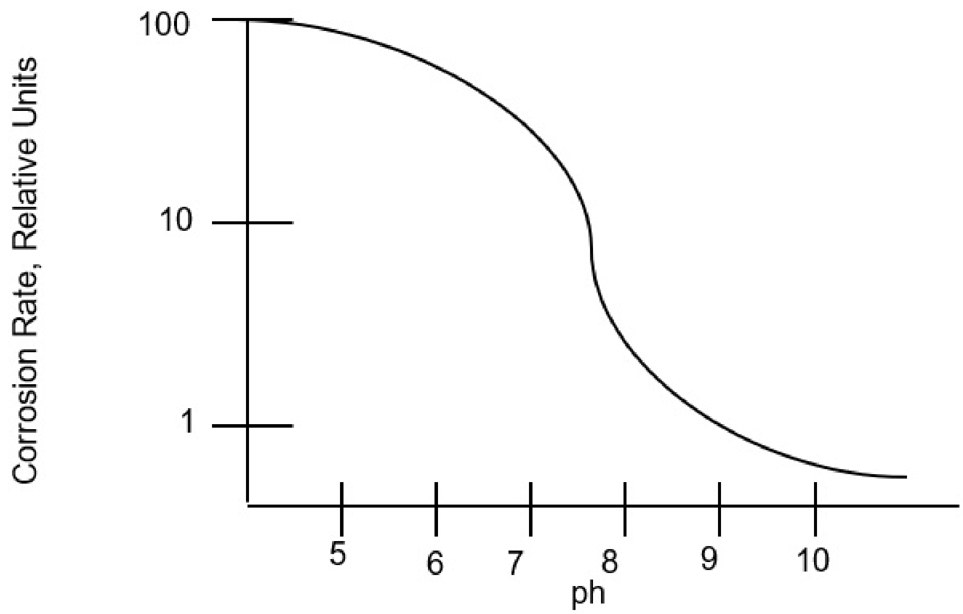
4-2.7.1.1 Air.

Air is the source of oxygen in a condensate system. Condensate lines that are used intermittently are particularly susceptible to condensate corrosion because the cooling of a heated condensate line creates a vacuum that can draw air into the system piping through valve seals or condensate sumps. Additionally, any dissolved oxygen in the feedwater that is not completely removed, either chemically or mechanically, can enter the boiler and pass with the steam into the condensate lines where it is consumed in a pitting corrosion attack on the metal surfaces. Oxygen corrosion in a condensate system is evidenced by pitting and by the presence of corrosion product deposits called "tubercles."

4-2.7.1.2 Carbon Dioxide.

Carbon dioxide (CO_2) can enter the boiler system if it is dissolved in the feedwater. However, CO_2 can be removed effectively through the deaerator. The most common source of carbon dioxide in steam condensate is the carbonate (CO^{2-}) and bicarbonate (HCO^{-}) ions (alkalinity) in the feedwater. Under the influence of heat and pressure in the boiler, the carbonate (CO^{2-}) and bicarbonate (HCO^{-}) ions (alkalinity) break down into hydroxyl (OH^-) ions (alkalinity) and CO gas. This free CO_2 is volatile and leaves the boiler with the steam. When the steam subsequently condenses, the CO_2 dissolves in the condensate and forms carbonic acid (H_2CO_3), which lowers the pH of the condensate and is corrosive to most metals, particularly to mild steel (see Figure 4-14). You can recognize carbon dioxide corrosion by the thinning of condensate line walls, particularly at the condensate liquid level within the pipe and at pipe threads where the condensate flows. Prevent corrosion in steam boiler systems by neutralizing the CO_2 with volatile amines.

Figure 4-14 **Effect of pH on Mild Steel and Copper Corrosion**



4-2.7.2 Estimating Carbon Dioxide in Steam.

Corrosion engineers find it useful to know the amount of carbon dioxide (CO_2) in steam when assessing the return on investment (cost savings from removing the CO_2 versus the cost for use of internal chemical treatment to remove the CO_2). Engineers and water treatment service companies need to estimate the amount of CO_2 to properly estimate the amount of neutralizing amine water treatment chemical that must be used. Example illustrates this estimation:

CO_2 levels in the steam can be estimated from the amount of bicarbonate and the carbonate alkalinity present in the feedwater as follows, where the “P” and “M” alkalinity measure these compounds. (See paragraph 7-6.1 for test methods.)

Equation 4-8. Estimating Carbon Dioxide in Steam

$$\mathbf{CO^2} = [\mathbf{bicarbonate\ x\ 0.79}] + [\mathbf{carbonate\ x\ 0.35}](\mathbf{18})\mathbf{CO^2} = [(\mathbf{M} - \mathbf{2P})\mathbf{x\ 0.79}] + [\mathbf{2P\ x\ 0.35}]$$

Where:

CO_2 = carbon dioxide estimate, ppm as CO_2

M = total (methyl orange) alkalinity, ppm as $CaCO_3$

P = phenolphthalein alkalinity, ppm as $CaCO_3$

EXAMPLE

a. Measured P = 2 ppm, M = 60 ppm

b. Bicarbonate CO_2 contribution (60 - (2 x 2)) x 0.79 = 44.2

c. Carbonate CO_2 contribution (2 x 2) x 0.35 = 1.4

d. Carbon dioxide estimate CO_2 = 44.2 + 1.4 = 45.6 ppm CO_2 in the steam

NOTE: This is a significant amount of CO_2 in steam due to the amounts of P and M alkalinity in the feedwater. There is some requirement to reduce alkalinity in this quality of feedwater.

4-2.7.3 Control of Carbon Dioxide by Neutralizing Amines.

Amines are organic compounds containing a nitrogen group similar to ammonia. They are referred to as “neutralizing amines” in boiler applications because they neutralize acidic (carbonic acid) conditions by raising the pH of the condensate. These amine compounds are volatile and escape the boiler with the steam and eventually dissolve in the steam condensate.

4-2.7.3.1 Control Limits.

Amines are added to maintain the pH between 7.5 to 9.0, ideally 7.5 to 8.5, in all parts of the condensate return system. The condensate pH level should not be allowed to fall below 7.5 anywhere within the entire condensate return system or corrosion will occur. For shore-to-ship steam, the requirement is 8.0 to 9.5 pH. (see Table 4-17). These amines are fed separately from other chemicals and are fed directly into the boiler steam drum where they vaporize and travel with the steam into the steam lines. Use continuous amine feed to maintain a constant, effective pH in the steam condensate.

4-2.7.3.2 Vapor-Liquid Distribution Ratios.

Morpholine, diethylamino-ethanol (DEAE), and cyclohexylamine are the three neutralizing amines approved for use in military boilers. Limitations of their use are described in paragraph 4-2.7.6. Physical and chemical properties of these amines are shown in Table 4-4. When steam condenses in a condensate return system that services multiple heat exchangers in different locations along the steam distribution system, some amines tend to “fall out” into condensate in legs close to the boiler while some amines tend to stay in the steam and come out in condensate toward the end of the steam distribution system. The degree to which this occurs is called the “vapor-liquid distribution ratio” and is expressed:

$$\text{Vapor-Liquid Distribution Ratio} = \frac{\text{Amine in steam phase}}{\text{Amine in condensate phase}}$$

Table 4-4 Physical and Chemical Properties of Neutralizing Amines

Property	Morpholine	DEAE	Cyclohexylamine
Boiling Point (100 percent amine)	264 F (129 C)	325 F (163 C)	273 F (134 C)
Boiling Point (amines/water azeotrope)	--	210 F (99 C)	205 F (96 C)
Decomposition temperature	644 F (340 C)	794 F (423 C)	205 F (96 C)
Vapor-Liquid Distribution Temperature	0.4	1.7	4.7
Specific Gravity (100 percent amine)	1.002	0.88	0.86
pH, 100 ppm solution	9.7	10.3	10.7
Amount of amine required to maintain pH of 8.0 in water	37 ppm	22 ppm	15 ppm

Amines have different vapor-liquid distribution ratios and will not work equally well in all systems. Depending on the particular amine, it can be effective in short-, medium-, or long-distance condensate lines. In complex condensate return systems, optimum results are obtained by choosing the appropriate amine or combination of amines on a system-by-system basis. A neutralizing amine selection chart is provided in Table 4-5. Often blends of different amines are used.

Table 4-5 Neutralizing Amine Selection Chart

Amine	Low Pressure (below 15 psig (103 KPa))	High Pressure Systems (above 15 psig (103 KPa))		
		Short System < 800 ft (<243 m)(2)	Medium System < 1 mile (<1.61 km)(2)	Long System > 1 mile (> 1.61 km)(2)
Morpholine		X		
DEAE	X		X	X
Cyclohexylamine	X			
Cyclohexylamine / morpholine mixture			X	X

NOTES:

1. Cyclohexylamine is not for use in systems having a feedwater alkalinity more than 75 ppm.
2. These system lengths are for classification only and are not absolute. For example, a medium-length system may have more of the characteristics of a long system if lines are poorly insulated or because of poor design. The characteristics of a condensate return system are best determined by a condensate pH survey.

4-2.7.3.3 Morpholine.

Morpholine has a low vapor-liquid distribution ratio and will drop out of steam quickly, making it suitable for protecting condensate return systems of short to moderate length. Morpholine is best suited for use in high-pressure systems (15 to 900 pounds per square inch gauge (103 to 6205 kilopascals)) because of its high boiling point. Very little morpholine is lost in deaerators from returning condensate.

4-2.7.3.4 DEAE.

DEAE has a vapor-liquid distribution ratio between that of morpholine and cyclohexylamine. This makes DEAE a good choice for protecting systems of moderate length where either morpholine or cyclohexylamine, if used separately, would not provide complete protection. The low boiling point of a mixture of DEAE and water makes DEAE suitable for use in both low-pressure boilers and high- pressure boilers.

4-2.7.3.5 Cyclohexylamine.

Cyclohexylamine has a high vapor-liquid distribution ratio and consequently is best suited for protecting extremely long systems. Cyclohexylamine can also be used in low-pressure systems. Cyclohexylamine is not used in systems when the feedwater alkalinity exceeds 75 ppm because of the low solubility of cyclohexylamine bicarbonate, which can be produced and form deposits. The likely areas for formation of these deposits are low-flow areas at the far end of the condensate return system. This deposition problem can be avoided by reducing feedwater alkalinity or by using DEAE. It is also necessary to treat long systems with morpholine to protect the early part of the system where steam is first condensed.

4-2.7.3.6 Amine Blends.

A mixture of morpholine, DEAE, or cyclohexylamine can be used to provide full protection in medium and large systems. The optimum blend of these amines is determined by measuring the actual pH of the condensate at various locations in the condensate return system. If samples from far sections have a lower pH than other samples, the cyclohexylamine in the mixture can be increased and vice versa. Another pH survey should be done when the blending ratio is changed. An initial blend of 1 part cyclohexylamine and 3 parts morpholine is a good starting point.

4-2.7.4 Control of Carbon Dioxide and Oxygen by Filming Amines.

Carbon dioxide corrosion can be controlled with 0.7 to 1.0 ppm of a filming amine such as octadecylamine. This chemical will coat the condensate pipe and prevent the carbon dioxide in the water from coming into contact with the pipe wall. Filming amines may also be appropriate for use if there is a high degree of air leakage (oxygen) because they coat the metal; however, you should not use them in condensate systems that have had corrosion problems in the past. Excess adsorption of the filming amine on the rust will occur and the amine can dislodge the rust and cause it to be returned to the deaerator or to the boiler. Adding filming amines continuously during operation and directly into the steam header through a quill, instead of into the steam drum, is essential. Addition of inadequate dosages can result in accelerated pitting-type corrosion due to incomplete surface coverage. You may need written authorization from the appropriate source before using filming amines in military boilers.

4-2.7.5 Control of Carbon Dioxide and Oxygen by Specialty Volatile Amines.

Some of the specialty oxygen scavengers described in paragraph 4-2.6.2.2 for boilers over 900 pounds per square inch gauge (6205 kilopascals) can be used for the purpose of control of both carbon dioxide and oxygen. The specialty volatile amines include hydroxylamine, hydroquinone, carbohydrazide, hydrazine sulfate, and erythorbic acid. They work by both raising the pH of condensate and by scavenging oxygen. They also passivate metal surfaces. Their use may not be appropriate and is restricted by the Food and Drug Administration (FDA). Note that these chemicals may not be needed for good operation of military boiler plants.

4-2.7.6 Amine Limitations and Indoor Air and Steam Quality Issues.

21 CFR Part 173.310 restricts using common neutralizing amines and filming amines to the limitations summarized in Table 4-6. Note that the limits shown in Table 4-6 are maximum allowable concentrations. Using amines may not always be advisable. If amine addition is not continuous, or if the boiler operation is cyclic (for instance shutting down the boiler for several hours each day), the maximum amine concentration may vary widely and exceed limits, even though the average concentration is within the limits.

Table 4-6 Amine Limits

Amine	Limitation
Cyclohexylamine	Not to be exceed 10 ppm in steam, and excluding steam in contact with milk and milk products.
DEAE	Not to exceed 15 ppm in steam, and excluding steam in contact with milk and milk products.
Hydrazine	Zero in steam.
Morpholine	Not to be exceed 10 ppm in steam, and excluding steam in contact with milk and milk products.
Octadecylamine	Not to be exceed 3 ppm in steam, and excluding steam in contact with milk and milk products.

4-2.7.6.2 Steam Used for Sterilization.

Some facilities, hospitals in particular, use steam in autoclaves for the purpose of sterilizing equipment such as surgical instruments. There is often concern that neutralizing amines may leave an amine contaminant on the equipment. Installing a dealkalizer to process the makeup water and thereby reduce the levels of bicarbonate and carbonate alkalinity is an alternative to using neutralizing amines. Using a dealkalizer effectively reduces, and may even eliminate, the need for neutralizing amines to reduce carbon dioxide corrosion. Steam- to-steam heat exchangers may be used to raise sterile steam.

4-2.7.6.3 Food Preparation.

The use of neutralizing amines or filming amines is prohibited if the steam contacts milk or milk products. In addition, to provide a margin of safety, the military prohibits any amines in steam used directly for cooking. This may be a sufficient reason to prevent using building steam in food preparation kitchens. In some cases, kitchens use steam to heat jacketed kettles in which food is heated. This application of steam as a heat source does not involve direct contact of the steam with foodstuffs. In other cases, direct contact between the steam and the foodstuffs is the method used to provide heating. There may be concerns that the amines will impart an amine taste or odor to the food. To alleviate this concern, use package steam generators to provide a source of steam that is independent of the building steam system. Another alternative is to use a steam-to-steam heat exchanger.

4-2.7.6.4 Humidification.

Steam is often used to humidify the air in buildings. The use of amines may raise a concern of contamination of the air in the building. To provide a margin of safety, the military prohibits using amines in steam that is used directly for humidification. Normally, the quantity of an amine in the air of a steam- humidified building is quite small, usually in the low ppb range; however, packaged steam generators can eliminate this concern.

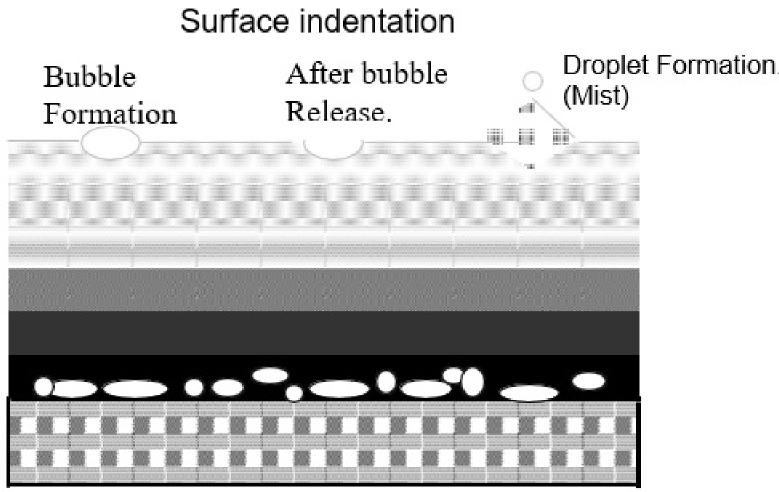
4-2.8 Water Carryover in Steam.

The steam that is produced from boiler water should not contain any liquid water. Common causes of water droplets or impurities being carried into the steam are misting, foaming, priming, and silica carryover.

4-2.8.1 Mist Carryover.

The term "misting" refers to a process in which a fine mist is produced as water boils. This 3-stage process is illustrated in Figure 4-15. In stage 1, a bubble of steam vapor reaches the water surface. In stage 2, the bubble bursts, leaving a dent in the water. In stage 3, the water rises to fill the dent. The center of the dent fills at a faster rate than the edges resulting in a small droplet of boiler water that is thrown off as a fine mist. Most, if not all, of the mist is removed in the mist eliminator section of the steam drum; however, any mist that is not removed will be entrained in the steam. These fine droplets will have the same level of dissolved solids as the boiler water and will contaminate the steam and the condensate.

Figure 4-15 **Water Boiler Mist Formation**



4-2.8.2 Foaming Carryover.

The term “foaming carryover” refers to boiler water foam and the carryover of foam into the steam. A variety of conditions can cause foam. Excessive levels of alkalinity, TDS, SS, and at times water treatment chemicals can interact to create foam in the boiler. Normally, maintaining the total alkalinity at less than 20 percent of the TDS and the total suspended solids (TSS) at less than 8 percent of the TDS can control foaming to a reasonable level. In addition, adding antifoam agents to the boiler water can control foaming. Polyamides and polyglycols are examples of antifoam agents.

4-2.8.3 Priming Carryover.

The term “priming” refers to boiler water in the steam when, due to liquid level variations and surges in the steam drum, water is mixed with the steam and is subsequently carried into the steam header. A mechanical problem or mechanical properties, such as oversensitive feedwater controls, large steam demands, or incorrect blowdown procedures, always cause priming. There is no chemical control method available, although the addition of antifoam chemicals may help reduce the extent of this occurrence. Boiler operations should be reviewed and modified if priming carryover is occurring.

4-2.8.4 Silica Carryover.

The term “silica carryover” refers to a situation that occurs when silica in the boiler water volatilizes and enters the steam independently of water carryover. The silica can then form a deposit in the condensate lines and in process equipment when the silica condenses from the steam. When steam turbines are used, silica deposition can be very serious, resulting in unbalancing of the steam turbine blades. Maintaining a low silica level in the boiler water can control silica carryover. The acceptable level is dependent upon the boiler operating pressure; Table 4-7 shows suggested limits.

Table 4-7 Silica Levels Allowed in Boiler Water

Boiler Pressure psig (KPa)	Allowable Silica ppm (as SiO_2)
0-15 (0-103)	150
16-149 (110-1027)	150
150-299 (1034-2062)	150
300-449 (2068-3096)	90
450-599 (3103-4130)	40
600-749 (4137-5164)	30
750 (5171)	20

4-2.8.5 Determining Water Carryover in Steam.

The best way to determine if any water carryover is occurring is to measure the conductivity of the steam or of the steam condensate. If you detect less than 25 micromhos conductivity in the condensate, then carryover is probably insignificant. If conductivity is greater than 25 micromhos, you should investigate to identify the cause.

4-2.8.5.1 Conductivity Measurement Implications.

A conductivity measurement above 25 micromhos in the steam condensate indicates that there is either carryover or leakage into the steam or condensate system. Accordingly, a test for hardness in the condensate must also be performed. If you find hardness, contamination of the condensate is likely due to raw water or leakage into the condensate system rather than boiler water carryover. If boiler water is at a very low hardness, then raw water may be the cause.

4-2.8.5.2 Deposit Analysis.

Any deposits found in the steam or condensate systems should be analyzed to determine the source. Deposits that are mostly magnetic iron oxide are due to corrosion of mild steel in the condensate system. Using neutralizing amines (as described in paragraphs 4-2.7.3 and 4-2.7.4) can control these deposits. If the deposits are mostly silica, increasing the blowdown or removing silica from the makeup water can reduce them. If the deposits are mostly sodium salts (sodium hydroxide, sodium carbonate, sodium chloride, sodium sulfate, and sodium phosphate), the cause is probably boiler water carryover from misting, priming, or foaming.

4-3 DEVELOPING A STEAM BOILER SYSTEM WATER TREATMENT PROGRAM.

A complete boiler water treatment program takes into account industry- developed guidelines for feedwater quality limits and boiler water quality limits. The water treatment industry recognizes the suggested water limits developed by the American Society of Mechanical Engineers (ASME), the American Boiler Manufacturers Association (ABMA), and USACE. The limits developed by these three organizations are not always identical; furthermore, the limits are actually only guidelines. In some cases these limits have been exceeded by boiler operations without unacceptable impacts; however, these limits should be considered as prudent, safe, and practical guidelines (see Tables 4-8 through 4-20).

4-3.1 Organizing a Treatment Program.

Once you have defined water treatment requirements, organize personnel to implement the program. The organization process consists of identifying a staff, training them to execute the program, and integrating the program into overall installation management.

4-3.2 Operator Training.

Operator training is essential to a water treatment program. Operators should understand the operation of their specific plant and reasons for specified procedures, including requirements of CFR Title 29, Part 1910.1200, *Hazard Communication*. An understanding of reasons for, and results of, chemical treatment is essential. Knowledge of thermodynamic and mechanical interactions of plant equipment is important. The operator should be particularly aware of safe operating procedures. Since internal chemical treatment of boiler water is a significant factor in achieving reliable and efficient plant operation, operators should have an understanding of the subject. Training should include the specifics of water treatment and related costs.

4-3.2.1 Pretreatment Training.

Pretreatment is necessary to ensure the quality of the water to be treated for industrial use and to prevent or reduce associated problems such as deposits and corrosion. Training might address these methods of pretreatment (depending on the type of plant):

- Chemical addition.
- Ion exchange.
- RO.
- Distillation.

4-3.2.2 Treatment Training.

Steam boilers, high-temperature water systems, and cooling water systems all require treatment of feed water to prevent or reduce deposits, scale, corrosion, and microorganisms.

4-3.2.2.1 Boiler Water Treatment.

The training related to boiler water treatment should address:

- Necessity for internal boiler water treatment.
- Deaeration and oxygen scavenging.
- Maintenance of concentration levels.
- Causes and effects of deposits, scale, and corrosion.
- Chemical treatment programs, such as phosphate, polymers, sulfite, hydrazine, and others.
- Where to feed chemicals.
- Effects of carryover and silica on steam purity.
- Prevailing ASME and internal standards.
- Corrosion in condensate returns from oxides of iron and copper.
- Effects of filming and neutralizing amines and hydrazine.
- Boiler layup procedures.
- Recognition of abnormal boiler water chemistry conditions.
- Taking prompt and effective corrective action for abnormal boiler water conditions.

4-3.2.2.2 Cooling Systems Treatment.

Training for treatment of cooling systems feedwater should address:

- Once-through cooling water systems.
- Recirculating cooling water systems.
- Need for and means of maintaining clean condensers.
- Chemicals and methods of treatment.
- COC.

4-3.2.2.3 Blowdown.

Blowdown is used in both cooling and steam systems to regulate COC of solids through dilution with makeup water. Training associated with blowdown procedures should include:

- Surface versus bottom.
- Internal provisions.
- Estimating blowdown.
- Continuous and intermittent.

- Controllers and COC.
- Heat recovery through flash tanks and heat exchangers for boilers.

4-3.2.3 Program Content.

Training should be provided in steps that are geared to operators' capabilities. Weekly sessions, with handouts, periodic reviews, and testing should be planned to assess trainees' retention and understanding of material and effectiveness of teaching methods. Training should include the following topics:

- Basic water chemistry.
- Chemistry concepts.
- Water chemistry fundamentals.
- Elementary water treatment.
- Water chemistry applications.
- Water treatment equipment.
- Boiler water treatment.
- Raw water treatment.
- Ion exchange.
- Cooling water treatment.

4-3.3 Equipment and Procedures.

Chapter 8 contains a description of water quality instrumentation and treatment equipment for various applications. Paragraph 8-3 describes procedures. The subject is also covered in Appendix D.

4-3.4 Feed water Quality Limits.

Tables 4-8 through 4-12 show feed water limits. The limits are specific for the type of boiler, operating pressure, and steam application. Since feed water is the combination of makeup water and condensate return, recovering as much uncontaminated condensate as possible is advisable, considering the cost of boiler water treatment and the benefits derived from both energy and water conservation. The high purity of uncontaminated condensate minimizes the requirement for treatment of makeup water and boiler water. The feed water parameters shown in Tables 4-8 through 4-12 do not specify levels for alkalinity and silica because it is assumed that these levels in the boiler water will be limited through blowdown. In higher pressure boilers using demineralized makeup water, alkalinity and silica will be very low or even absent. Although not specified, it can make sense to reduce feed water alkalinity and silica in boilers less than 900 pounds per square inch gauge (6205 kilopascals) to allow for an increase in COC and, consequently, to reduce chemical demand. The tables show limits for hardness, iron, and copper. Hardness and iron can be removed by softening the makeup water. Iron and copper may still be present in the feed water if they are present in the condensate due to corrosion. In many instances, these limits cannot be met for small heating boilers (such as oxygen content in feed water for boilers that lack a deaerator, or hardness levels in feed water for boilers that lack softeners). The only alternative is to chemically treat boiler water and control COC, as required.

Table 4-8 Suggested Feed water Limits for Industrial Water Tube Boiler 0–300 psig (0–2068 KPa)

Feedwater Property	ASME	ABMA	USACE
Dissolved oxygen ppm O_2 before chemical oxygen scavenger addition	< 0.007	Note 6	NS
Total iron ppm Fe (as Fe)	< 0.1	Note 6	NS
Total copper ppm Cu (as Cu)	< 0.05	Note 6	NS
Total hardness ppm (as $CaCO_3$)	< 0.5	Note 6	Softened
pH at 77 F (25 C)	8.3-10.5	Note 6	NS
Non-volatile TOC ppm (as O_2)	< 1	Note 6	NS
Oily matter ppm	< 1	Note 6	NS

NOTES:

1. Makeup water percentage: Up to 100 percent of feedwater.
2. Assumes existence of deaerator.
3. Conditions: no super heater, turbine drives, or process restriction on steam purity.
4. Steam purity: 1.0 ppm TDS maximum.
5. NS = not specified.
6. See ABMA Standard – Boiler 401

Table 4-9 Suggested Feedwater Limits for Industrial Water Tube Boiler 301-600 psig (2075-4137 KPa)

Feedwater Property	A SME	ABMA	USACE
Dissolved oxygen ppm O2 before chemical oxygen scavenger addition	<0.007	Note 6	NS
Total iron ppm Fe (as Fe)	<0.05	Note 6	NS
Total copper ppm Cu (as Cu)	<0.025	Note 6	NS
Total Hardness ppm (as CaCO3)	<0.3	Note 6	NS
pH at 77 F (25 C)	8.3-10.5	Note 6	NS
Non-volatile TOC ppm (as O2)	< 1	Note 6	NS
Oily Matter ppm	< 1	Note 6	NS

NOTES:

1. Makeup water percentage: Up to 100 percent of feedwater.
2. Assumes existence of deaerator.
3. Conditions: no super heater, turbine drives, or process restriction on steam purity.
4. Steam purity: 1.0 ppm TDS maximum.
5. NS = not specified.
6. See ABMA Standard – Boiler 401

Table 4-10 Suggested Feedwater Limits for Industrial Fire Tube Boiler 0–300 psig (0-2068 KPa)

Feedwater Property	Limit
Dissolved oxygen (ppm O2) before chemical oxygen scavenger addition	< 0.007
Total iron ppm Fe (as Fe)	< 0.1
Total copper ppm Cu (as Cu)	< 0.05
Total Hardness ppm (as $CaCO_3$)	< 1.0
Ph at 77 F (25 C)	8.3-10.5
Non-volatile TOC ppm (as O_2)	< 10
Oily matter ppm	< 1

NOTES:

1. Makeup water percentage: up to 100 percent of feedwater.
2. Assumes existence of deaerator.
3. Conditions: no super heater, turbine drives, or process restriction on steam purity.
4. Steam purity: 1.0 ppm TDS maximum

Table 4-11 ASME Feedwater Limits for Industrial Water Tube Boilers

Feedwater Property	0 - 300 psig (0 - 2068 KPa)	301-450 psig (2075-3103 KPa)	451 - 600 psig (3110 - 4137 KPa)	601 - 750 psig (4144 - 5171 KPa)	751 - 900 psig (5178 - 6205 KPa)	901 - 1000 psig (6212 - 6895 KPa)	1001 - 1500 psig (6902-10,342 KPa)	1501 - 2000 psig (10,349-13,790 KPa)
Dissolved oxygen (ppm O2) before adding chemical oxygen scavenger	< 0.007	< 0.007	< 0.007	< 0.007	< 0.007	< 0.007	< 0.007	< 0.007
Total iron ppm Fe (as Fe)	≤ 0.1	≤ 0.05	≤ 0.03	≤ 0.025	≤ 0.02	≤ 0.02	≤ 0.01	≤ 0.01
Total Copper ppm Cu (as Cu)	≤ 0.05	≤ 0.025	≤ 0.02	≤ 0.02	≤ 0.015	≤ 0.01	≤ 0.001	≤ 0.001
Total hardness ppm (as $CaCO_3$)	≤ 0.03	≤ 0.03	≤ 0.02	≤ 0.02	≤ 0.1	≤ 0.05	ND	ND
pH at 77 F (25 C)	8.3-10.0	8.3-10.0	8.3-10.0	8.3-10.0	8.3-10.0	8.3-9.6	8.3-9.6	8.3-9.6
Chemicals for pre-boiler system	NS	NS	NS	NS	NS	VAM	VAM	VAM
Non-volatile TOC ppm (as O_2)	< 1	< 1	< 0.5	< 0.5	< 0.5	< 0.2	< 0.2	< 0.2
Oily Matter ppm	< 1	< 1	< 0.5	< 0.5	< 0.5	< 0.2	< 0.2	< 0.2

NOTES:

1. Makeup water percentage: Up to 100 percent of feedwater.
2. Assumes existence of deaerator.
3. Conditions: Includes super heater, turbine drives, or process restriction on steam purity.
4. Saturated steam purity target as shown.
5. NS = not specified.
6. ND = not detectable.
7. VAM = Use only volatile alkaline materials upstream of a temporary water source.

Table 4-12 ASME Suggested Feedwater Limits for Marine Propulsion Water Tube Boiler

Feedwater Property	450-850 psig (3103-5861 KPa)	851-1250 psig (5867-8618 KPa)
Dissolved oxygen (ppm O_2) before chemical oxygen scavenger addition	< 0.007	< 0.007
Total iron ppm Fe (as Fe)	< 0.02	< 0.01
Total copper ppm Cu (as Cu)	< 0.01	< 0.005
Total hardness ppm (as $CaCO_3$)	< 0.1	< 0.05
pH at 77° F (25° C)	8.3–9.0	8.3–9.0
Chemicals for pre-boiler system	VAM	VAM
Oily matter ppm	< 0.05	< 0.05

NOTES:

1. Makeup water percentage: Up to 5 percent of feedwater.
2. External treatment: at sea, evaporator condensate; in port, evaporator condensate or water from shore facilities meeting feedwater quality guidelines.
3. Assumes existence of deaerator.
4. Saturated steam purity: 30 ppb TDS maximum, 10 ppb Na maximum, 20 ppb SiO2 maximum.
5. VAM = Use only volatile alkaline materials.

4-3.5 Boiler Water Chemistry Limits.

Tables 4-13 through 4-16 show boiler water chemistry limits. The limits are specific for the type of boiler, operating pressure, and steam application. There are two types of limits to recognize. The first comes from the presence of natural constituents in the feedwater (such as TDS or conductivity, silica, and alkalinity). These constituents can be the controlling factor for COC. Blowdown is ultimately required to keep their levels within limits. SS is the result of precipitation of minerals. These are kept within limits through bottom blowdown. The second type is treatment limits for chemicals added into the boiler (see Tables 4-17 and 4-18)

Table 4-13 ASME Suggested Boiler Water Limits for Industrial Water Tube Boiler

Boiler Water Property	0-300 psig (0-2068 KPa)	301-600 psig (2075-4137 KPa)
Silica (ppm SiO_2)	< 150	< 90
Total alkalinity	< 1000	< 850
Free OH alkalinity	NS	NS
Specific conductance (μmhos/cm) without neutralization	< 7000	< 5500

NOTES:

1. Makeup water percentage: Up to 100 percent of feedwater.
2. Assumes existence of deaerator.
3. Conditions: no super heater, turbine drives, or process restriction on steam purity.
4. Steam purity: 1.0 ppm TDS maximum.
5. NS = not specified.

Table 4-14 ASME Boiler Water Limits for Industrial Water Tube Boilers

Boiler Water Property	0 - 300 psig (0 - 2068 KPa)	301 - 450 psig (2075 - 3103 KPa)	451 - 600 psig (3110 - 4137 KPa)	601 - 750 psig (4144 - 5171 KPa)	751 - 900 psig (5178 - 6205 KPa)	901 - 1000 psig (6212 - 6895 KPa)	1001 - 1500 psig (6902 - 10342 KPa)	1501 - 2000 psig (10349 - 13790 KPa)
Silica (ppm SiO_2)	≤ 150	≤ 90	≤ 40	≤ 30	≤ 20	≤ 8	≤ 2	≤ 1
Total alkalinity	< 350	< 300	< 250	< 200	< 150	< 100	NS	NS
Free OH alkalinity	NS	NS	NS	NS	NS	NS	ND	ND
Specific conductance (μmhos/cm) without neutralization	5400-1100	4600-900	3800-800	1500-300	1200 -200	1000-200	≤150	≤80
TDS (maximum) ppm	1.0-0.2	1.0-0.2	1.0-0.2	0.5-0.1	0.5-0.1	0.5-0.1	0.1	0.1

NOTES:

1. Makeup water percentage: Up to 100 percent of feedwater.
2. Assumes existence of deaerator.
3. Conditions: Includes super heater, turbine drives, or process restriction on steam purity.
4. Saturated steam purity target as shown.
5. NS = Not specified.
6. ND = Not detectable

Table 4-15 ASME Boiler Water Limits for Industrial Fire Tube Boilers 0–300 psig (0-2068 KPa)

Boiler Water Property	Limit
Silica (ppm SiO_2)	< 150
Total alkalinity	< 700
Free OH alkalinity	NS
Specific conductance (μmhos/cm) without neutralization	< 7000

NOTES:

1. Makeup water percentage: Up to 100 percent of feedwater.
2. Assumes existence of deaerator.
3. Conditions: no super heater, turbine drives, or process restriction on steam purity.
4. Steam purity: 1.0 ppm TDS maximum.
5. NS = not specified

Table 4-16 ASME Suggested Boiler Water Limits for Marine Propulsion Water Tube Boiler

Boiler Water Property	450-850 psig (3103-5861 KPa)	851-1250 psig (5867-8618 KPa)
Silica (ppm SiO_2)	< 30	< 5
Total alkalinity	NS	NS
Free OH alkalinity	< 200	ND
Specific conductance (μmhos/cm) without neutralization	< 700	< 150

NOTES:

1. Makeup water percentage: Up to 5 percent of feedwater.
2. External treatment: at sea, evaporator condensate. In port, evaporator condensate or water from shore facilities meeting feedwater quality guidelines.
3. Assumes existence of deaerator.
4. Saturated steam purity: 30 ppb TDS maximum, 10 ppb Na maximum, 20 ppb SiO2 maximum.
5. NS = not specified.

6. ND = non detectable.
7. VAM = Use only volatile alkaline materials.

4-3.6 Shore-to-Ship Steam Quality.

Shore-to-ship steam purity is specified in NAVSEA S9086-GX-STM-020, Section 220, Volume 2, Boiler Water/Feedwater Test and Treatment.

Table 4-17 NAVSEASYSCOM Shore-To-Ship Steam Purity Requirements

Constituent Property	Requirement
pH	8.0 to 9.5
Conductivity	25µmho/cm max
Dissolved Silica	0.2 ppm max
Hardness	0.10 epm max
Total Suspended Solids	0.10 ppm max

4-3.7 Treatment Guidelines for Low-Pressure Steam.

Treatment guidelines for boilers operating at less than 15 pounds per square inch gauge (103 kilopascals) are determined by size and type, as described in Table 4-18. Cast iron boilers and boilers less than 334 watts (10 horsepower) are not treated. Boilers with greater than 95 percent condensate return can either be treated the same as a closed hot water boiler (see Chapter 6), or treated the same as boilers with less than 95 percent condensate return. The latter uses external treatment, usually softening, and internal chemical treatment that includes a scale inhibitor (precipitating type – phosphate) or solubilizing type (phosphonates and polymers) sulfite to control pitting due to oxygen, and a neutralizing amine to control pH in the condensate system. Sometimes raising pH in the boiler water requires a supplemental source of alkalinity. Usually this supplemental source is caustic soda, but it can also be sodium carbonate (soda ash).

Table 4-18 Treatment Guidelines for Low-Pressure Steam

Boiler	Guidelines
Cast iron	Not treated
Less than 334 W (10 hp)	Not treated
Boiler with 95 percent condensate return	1. External treatment: softening. 2. Internal treatment: precipitating or solubilizing scale inhibitor, sulfite, tannin derivatives, filming surfactant, caustic supplement if necessary, neutralizing amine. 3. See Tables 4-19 through 4-20. Or Treat same as closed hot water (see Chapter 6).
Boilers with less than 95 percent condensate return	1. External treatment: softening. 2. Internal treatment: precipitating or solubilizing scale inhibitor, sulfite, tannin derivatives, filming surfactant, caustic supplement if necessary, neutralizing amine. See Tables 4-19 and 4-20.

4-3.8 Treatment Guidelines for Medium- and High-Pressure Steam.

Treatment of medium- 16 to 299 pounds per square inch gauge (110 to 2062 kilopascals) and high-pressure 300 to 900 pounds per square inch gauge (2068 to 6205 kilopascals) boilers is similar and is described in Table 4-19. Treatment can include either a precipitating (phosphate) or a solubilizing (phosphonate or polymers) approach to scale control. Sulfite is used to control pitting due to oxygen, and a neutralizing amine is used to control pH in the condensate system. Sometimes raising pH in the boiler water requires a supplemental source of alkalinity. Usually this source is caustic soda, but it can also be sodium carbonate (soda ash). Boilers operating between 600 to 900 pounds per square inch gauge (4137 to 6205 kilopascals) will sometimes use erythorbic acid or specialty volatile oxygen scavengers or amines (such as hydrazine, DEHA, carbohydrazide, hydroquinone or methylethylketoxime) as oxygen scavengers in boiler water. The volatile compounds can also scavenge oxygen in a condensate system. Refer to paragraph 4-2.7 for a description of condensate corrosion control.

Table 4-19 Treatment Guidelines for Medium- and High-Pressure Steam

Parameter	Boiler Water Treatment Control
COC	Maximum of 100, per ASME
General corrosion	Maximum total alkalinity, per ASME guidelines, pH of 10.3–12.0. May require alkalinity builder.
Pitting corrosion	20-40 ppm sulfite for boilers up to 900 psig (6205 KPa). Specialty volatile oxygen scavengers optional for boilers 600-900 psig (4137-6205 KPa). Also, tannin derivatives and other organic-based oxygen scavengers
Condensate corrosion	Maintain pH of 7.5-9.3 using neutralizing amines or follow guidelines for filming surfactant chemistry. Specialty volatile oxygen scavengers optional.
Deposition control	1. Precipitating program using phosphate or carbonate with a polymer sludge conditioner. Or 2. Solubilizing program using chelants, phosphonates, or polymers. Or Tannin and lignin derivatives and phosphonates and/or polymers (including acrylate-styrenesulfonate co-polymers and polymethacrylates)
Carryover control due to foaming	Limit total alkalinity, per ASME guidelines, and treat with antifoam as required.

4-3.9 Condensate Corrosion and Control.

Oxygen and carbon dioxide are common steam condensate impurities that promote condensate corrosion. Less common are process contaminants, each of which has corrosive properties dependent upon the nature of the contaminant and the materials that may be corroded. The piping found in steam condensate systems is most commonly constructed of mild steel, whereas heat exchangers are usually copper or mild steel. (For more information, see paragraph 4-2.7.)

4-3.10 Treatment Guidelines for Very-High-Pressure Steam.

Treatment of very-high-pressure 900 pounds per square inch gauge (greater than 6205 kilopascals) boilers is different than for those of lower pressure. Because temperatures and pressures are much more extreme, the boilers can tolerate little in the way of boiler water impurities. Table 4-20 provides treatment guidelines.

Table 4-20 Treatment Guidelines for Very-High-Pressure Steam

Parameter	Boiler Water Treatment Control
COC	Maximum of 100, per ASME.
General corrosion control	Maintain pH, per ASME guidelines, using coordinated, congruent, or equilibrium phosphate, or with all volatile treatment.
Pitting corrosion control	Volatile hydrazine substitutes: hydroxylamine, hydroquinone, carbohydrazide, hydrazine sulfate, tannin derivatives, or erythorbic acid.
Condensate corrosion control	Maintain pH of 7.5-9.3 using specialty volatile oxygen scavengers listed for pitting control above.
Deposition control	External treatment to remove scaling agents. Example: RO with demineralization
Carryover control due to foaming	External treatment to remove alkalinity and other minerals. Example: RO with demineralization

4-3.11 Boiler Operator Duties.

Operators should keep feedwater quality, COC, and treatment levels within program control limits at all times. Operators must perform recordkeeping and assess trends in the results of system performance tests routinely (see paragraph 2-1.8). When changes in feedwater quality, TDS, or chemical treatment levels occur, the operator must investigate and resolve the reasons for these changes. Report to supervisor any unresolved abnormalities. Boiler operators need to understand their equipment and how it operates. Does it operate seasonally? Does it operate intermittently? Does the amount of condensate return vary? These conditions may require adjustments in chemical treatment.

Paragraphs 4-4 and 4-5 present some common problems.

4-4 CHEMICAL REQUIREMENTS FOR BOILER START-UP.

Start-up of a new or repaired boiler requires special water treatment procedures. The start-up of a boiler after a wet or dry layup period also requires special water treatment procedures.

4-4.1 Common Problems during Start-up of New Boilers.

A common problem that can occur during start-up of new boilers is corrosion of the boiler tubes due to improper initial conditioning of the water and boiler metal. Carryover of boiler water due to improper start-up can also occur, particularly with new boilers.

4-4.2 Start-up of New Boilers and Condensate Systems or Repaired Boilers.

As a result of the fabrication process, a new or repaired boiler that is erected in the field or shipped as a package unit will likely contain oils and greasy films, and perhaps rust, on the metal surfaces. The oils, grease, and rust can contribute to carryover and contaminate the steam and initiate corrosion of the boiler components. A pre-operational alkaline boil-out procedure is required to remove these materials. This pre-operational process is usually part of a new construction project and therefore may not be in the direct control of boiler operations personnel. Often, the contracting officer involved with the project can provide verification of the completion of this important step.

The following example of an alkaline boil-out procedure consists of four steps:

1. Inspect the inside of the boiler and remove all debris.
2. Add an alkaline boil-out chemical formulation to the boiler water. This should be roughly equivalent to the following formulation: 24 pounds (10.4 kilograms) of caustic soda, 24 pounds (10.4 kilograms) of disodium phosphate, 8 pounds (3.5 kilograms) of sodium nitrate, 0.5 pound (0.2 kilogram) non-ionic wetting agent (a low-foaming detergent) per each 1000 gallons (3785 liters) of boiler capacity.
3. Fill the boiler to the steam header and maintain at low fire for 1 to 2 days. For condensate systems, this formulation should be circulated for 3 to 4 days, drained completely, and the system dried completely by purging with dry air.
4. Drain and flush. Proceed immediately to operational treatment levels or to a layup status. Untreated water should never be allowed to remain in the boiler.

Table 4-21 Troubleshooting Boiler System Water

Problem	Recommended Solution/Possible Cause
Hardness in feedwater	1. Check softener Possible leak into condensate system
Change in overall treatment levels	1. Change in amount of condensate return 2. Change in blowdown control Change in overall chemical feed rate
Loss of alkalinity	1. Hardness incursion 2. Loss of caustic feed Excessive blowdown
Loss of scale prohibitor	1. Hardness incursion 2. Loss of chemical feed Excessive blowdown
Loss of sulfite	1. Loss of sulfite feed 2. Poor deaerator operation or influx of oxygen Excessive makeup and loss of condensate
High conductivity (>25 mhos) in steam	Carryover due to misting, foaming, or priming
Foaming carryover	Excessively high TDS, alkalinity, or chemical treatment
Priming carryover	Operational problem with excessive load demands, feedwater and level control problem, uneven firing patterns
Misting carryover	Defective mist eliminators

4-4.2.1 Start-up of Boiler from Wet Layup.

Boilers that have been properly laid up wet will already have adequate excess levels of sulfite and alkalinity (see paragraph 4-5.4). Upon adjusting the water level and firing up the boiler, feed all chemical treatments as normally added, except for sulfite and alkalinity supplement. There is no need to feed these treatments until blowdown results in reducing their levels. Then add chemicals in the amounts required to reach normal maintenance levels.

4-4.2.2 Start-up of Boiler from Dry Layup.

Boilers that have been properly laid up dry (see paragraph 4-5.3) can be filled with feedwater to their normal operating boiler water level. The start-up dosage of sulfite and alkalinity supplement (caustic or soda ash) can be fed along with the standard chemical treatment feed rates to obtain normal levels of water treatment chemicals. It is necessary to achieve proper sulfite and alkalinity levels in the boiler water to control corrosion while the COC is increased to normal operating levels. The sulfite concentration should be at least 20 ppm (SO_3), and the alkalinity level should result in a pH of about 11.0.

4-5 CHEMICAL REQUIREMENTS FOR BOILER LAYUP.

Boiler layup also requires special water treatment. Boilers that will be out of service for more than four calendar days require special water treatment to prevent internal corrosion. Boiler layup can be either dry or wet. The advantages of wet layup are that it often provides better corrosion protection and the boiler can be brought on-line much faster than when dry layup procedures are used.

4-5.1 Operational Considerations.

Operational considerations are important to consider when determining the proper boiler status. The terms “lead” and “lag” are used commonly for boilers that need to meet varying load demands. The lead boiler satisfies the base steam load. The lag boiler meets any extra steam demand that might be needed during hours of the evening or mornings or when (additional) process loads are required. Lag status does not apply to a cold boiler that is not required for duty for a few days. Such a boiler should be considered in layup condition and should be prepared accordingly.

4-5.2 Common Problems that Occur During Layup.

Common problems that occur during layup are: oxygen pitting of tubes and condensate piping, sometimes to the point of failure; general corrosion of tubes and condensate piping; and corrosion product contaminating feed water via the condensate system.

4-5.3 Dry Layup of Boilers.

Boilers with manholes may be laid up in one of two ways, depending on the length of storage and conditions in the boiler room: open dry layup, or moisture-absorbing material such as silica gel or lime, quicklime or silica gel layup.

4-5.3.1 Open Dry Layup Method.

The open dry layup method is recommended for short-term storage (30 to 150 days) where the boiler room is dry, has low humidity, and is well ventilated. It is important to keep the boiler dry. The recommended procedure consists of six basic steps:

1. Take the boiler out of service and drain it completely while still warm. Make sure the water walls and gauge columns are not overlooked.
2. Lock and tag out boiler in accordance with written procedures.
3. Break the feedwater and steam connections to the boiler and blank off connections if other boilers in the plant are operating.
4. The boiler may be opened and the inside washed of all loose scale and sediment by flushing with high-pressure water.
5. Use a stiff brush to clean all internal surfaces that can be reached.
6. Leave boiler open to the atmosphere. Should a humid atmosphere exist, the boiler must be closed up and the procedure specified in paragraph 4-5.3.2 used.

4-5.3.2 Quicklime or Silica Gel Layup Method.

This procedure is recommended for storage over 150 days or for less than 150 days when the boiler room and atmosphere is quite humid and not well ventilated. The recommended procedure consists of eight basic steps:

1. Take the boiler out of service and drain completely while still warm. Make sure that water walls and gauge columns are not overlooked.
2. Lock and tag out the boiler in accordance with written procedures.
3. Break the feedwater and steam connections to the boiler and blank off connections if other boilers in the plant are operating.
4. The boiler may be opened and the water-contacted inside surface washed to remove all loose scale and sediment by flushing thoroughly with high-pressure water.
5. Use a stiff brush to clean all internal surfaces that can be reached.
6. Place quicklime (not hydrated lime) or new, unused silica gel in one or more metal or fiber trays in the boiler. Place the trays on wood blocks so air can circulate under them. The amount of lime or silica gel required is about 50 pounds (22 kilograms) per 3000 pounds per hour (0.36 kilogram of steam per second) boiler capacity.
7. Seal the boiler to prevent any moist air from entering the boiler.
8. Open and inspect the boiler every 2 months. Replace any moist quicklime or silica gel with new material.
9. Carefully reseal immediately after the inspection and after the addition of new chemicals.

4-5.4 Wet Layup of Boilers.

This method means that the boiler is kept completely full of treated water. This method is easier to check and the boiler can be put back in service more quickly. This method should not be used if the boiler is subject to freezing temperatures.

4-5.4.1 Wet Layup without Draining (Operational Boilers).

This method is used most commonly when a boiler is to be shut down for 4 to 30 calendar days. Often the boiler must be maintained in a standby condition. Corrosion will most likely occur in the boiler unless both the water level in the steam drum and the chemicals in the boiler are increased. These procedures are recommended for wet layup of a boiler without draining or cleaning:

1. Approximately 4 hours before the boiler is to be shut down, add sufficient sodium hydroxide (caustic) to increase the hydroxyl alkalinity (causticity) to 10 to 20 percent higher than the upper limit given in Tables 4-19 and 4-20 for the pressure of the boiler to be laid up.

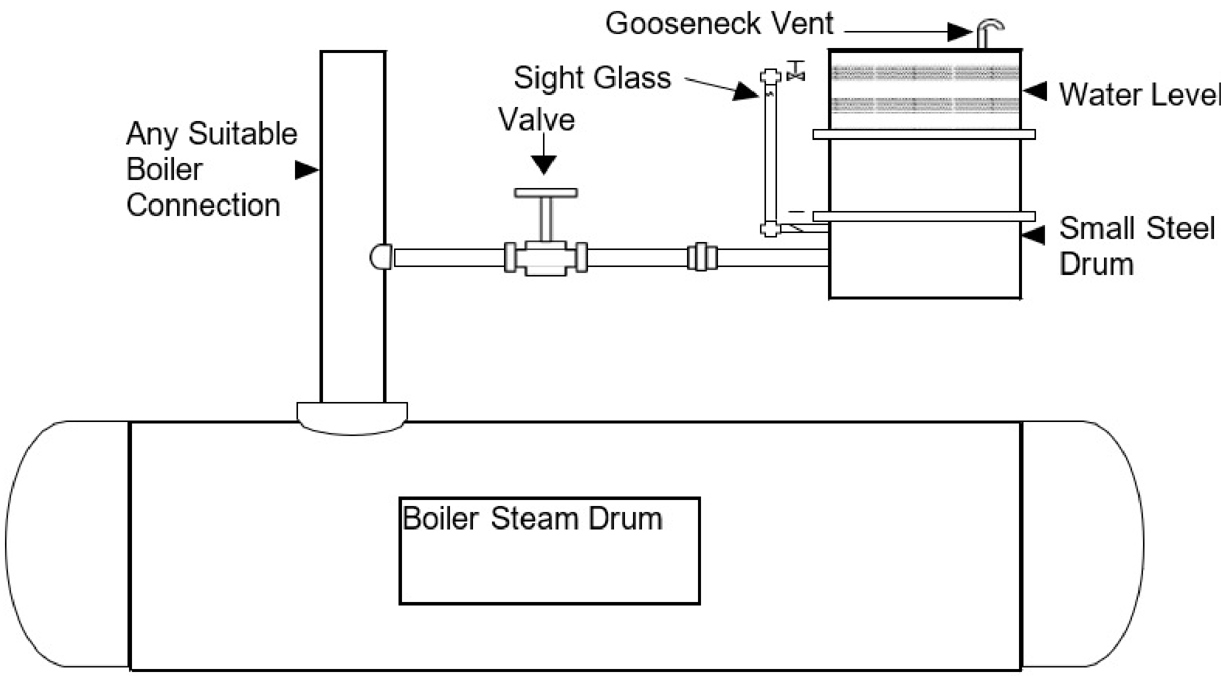
2. Add sufficient sodium sulfite to increase the sulfite residual to 200 ppm (as SO3).
3. Extinguish the fire to the boiler.
4. Add water to completely fill the entire boiler until the water runs out of the vent (safety) valve or air cock.
5. When the boiler is completely cool, add more water to ensure it is full.
6. Maintain a pressure of 5 to 10 pounds per square inch gauge (35 to 69 kilopascals) during layup and maintain the levels of alkalinity and sulfite.
7. Check the boiler frequently to make sure no water has leaked out.
8. Analyze the boiler water at least once per month to make sure the chemical residuals are being maintained.

4-5.4.2 Wet Layup of Drained Boilers.

These procedures are recommended for boilers that have been emptied for cleaning or repair before wet layup:

1. Drain the boiler completely and remove scale or deposits.
2. Remove connections to other active boilers, feedwater, and steam systems.
3. Fill the boiler with water (deaerated water if available) and add enough sodium hydroxide (caustic) to give a hydroxyl level of about 200 ppm (as OH).
4. Add sodium sulfite to give a sulfite residual of 200 ppm (as SO3).
5. Circulate chemicals in the boiler by careful boiling for 2 hours. Be sure to fill the boiler to replace any losses during this treatment.
6. Extinguish the fire to the boiler.
7. Add water to completely fill the entire boiler until the water runs out of the vent (safety) valve or air cock.
8. When the boiler is completely cool, add more water to ensure it is full. Maintain a pressure of 35 to 69 kilopascals during layup and maintain the levels of alkalinity and sulfite.
9. Inspect the boiler weekly and replace any water losses. To facilitate inspections, a small steel tank equipped with a gauge glass can be installed above the top of the boiler, as shown in Figure 4-16. Fill the tank with treated water and connect to a steam takeoff tap, vent, or safety valve connection. A glance at the water level in the small drum will quickly tell whether or not the boiler is completely filled.

Figure 4-16 **Inspection Gauge for Wet Boiler Layup**



4-5.5 Layup of Condensate Systems.

Layup of condensate systems is much more difficult than layup of boilers. As the system cools, oxygen will be drawn in, resulting in a situation that leads to corrosion. Purging the system with dry, inert gas can be effective, but the logistics can be nearly impossible and the hazards include the potential for suffocating people if the system is located in an unvented area. Application of a high dosage of a filming amine prior to shut down can be effective, but its use is restricted for many applications and is prohibited in military operations. Application of a high dosage of neutralizing amines (see paragraph 4-2.7.3) or of a specialty volatile oxygen scavenger (see paragraph 4-2.7.5) can be helpful. The application of any amine or specialty volatile oxygen scavenger can be limited where steam purity or FDA restrictions exist.

4-6 COMMONLY ASKED QUESTIONS AND ANSWERS ON BOILER WATER TREATMENT

Q1. What is meant by neutralized conductivity?

A1. Boiler water most often contains hydroxyl (OH^-) alkalinity. The OH^- contribution to conductivity is disproportionately large compared to other ion species. Furthermore, the OH^- contribution towards conductivity is not used in calculating TDS. The OH^- conductivity is therefore neutralized using an organic acid (gallic acid). Organic acids are used because they do not contribute to conductivity.

Q2. What is the relationship between conductivity and TDS?

A2. Conductivity is a measurement of electrical conductance of ionized species dissolved in water and is reported in units of micromhos or microsiemens per centimeter. TDS is the actual amount of mineral in solution measured in ppm. In boiler water, neutralized conductivity times 0.7 yields a good approximation to TDS. When tannin is used as a dispersant, the factor increases proportionally to the amount of tannin present.

Q3. Why are there different types of alkalinity to be concerned with?

A3. Alkalinity can exist as bicarbonate (HCO_3^-), a carbonate (CO_3^{2-}), or as hydroxyl (OH^-). Natural waters usually contain bicarbonate or carbonate alkalinity. Hydroxyl alkalinity is required in steam boilers below 900 pounds per square inch gauge (6205 kilopascals) and is either provided by addition of caustic or by the breakdown of bicarbonate and carbonate alkalinity in the boiler. The breakdown of bicarbonate and carbonate alkalinity also produces carbon dioxide, which forms carbonic acid in the condensate system.

Q4. How often should bottom blowdown be done?

A4. There is no absolute rule for frequency of bottom blowdown. It can vary between once per shift to once or twice a week. The required frequency depends on the boiler, the feed water quality and the type of chemical treatment program. A precipitating treatment program reacts with hardness in the feed water to form a sludge that must be removed through bottom blowdown. A solubilizing treatment program keeps hardness in solution and creates little in the way of sludge.

Q5. Where is the best location to feed sulfite?

A5. Sulfite, like any oxygen scavenger, should be fed into the storage section of a deaerator. This ensures the removal of oxygen before the feed water enters the boiler.

Q6. What is the difference between makeup water and feed water?

A6. Makeup water is water that comes from a source outside of the boiler system. Feed water is a combination of makeup water and condensate return.

Q7. How does one balance chemical treatment levels and COC?

A7. COC is controlled through blowdown. Blowdown is often measured by maintaining conductivity or TDS within a specific control range. Chemical treatment levels are controlled by the chemical feed rate into the boiler and by blowdown. It is best to maintain consistent control of COC first, followed by proper adjustment of chemical feed rates. If there is a sudden change in chemical treatment levels without any changes in blowdown or chemical feed rates, then there is likely to be a change in feedwater quality (change in condensate return rate, hardness excursion, poor deaerator operation).

Q8. Are boiler water treatment chemicals safe to work with?

A8. Yes, provided the directions on the SDS sheets are followed. The highest hazard is due to chemical burns from highly caustic substances.

Q9. Why is it impossible to get all the parameters (for example alkalinity, TDS) in the control range?

A9. It is not impossible as long as the control ranges are proper for a given boiler operation. The first parameter to control is COC. Maximum cycles are limited by some parameter (such as alkalinity, TDS, silica, carryover). Any one of these can be the limiting factor for COC. Once proper cycles are established, chemical treatment feed rates should be adjusted to keep levels within control ranges.

Q10. The softeners need to be regenerated more often than before. What could be the problem?

A10. The problem could be one of many things. It usually is due to higher demands for makeup water. It could, however, be due to an increase in makeup water hardness levels or a deficiency in regeneration. Deficiencies in regeneration can be due to insufficient brine strength, insufficient brine time, inadequate backwash resulting in channeling, lost or cracked resin, and heavily fouled resin due to iron.

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CHAPTER 5 COOLING WATER SYSTEMS

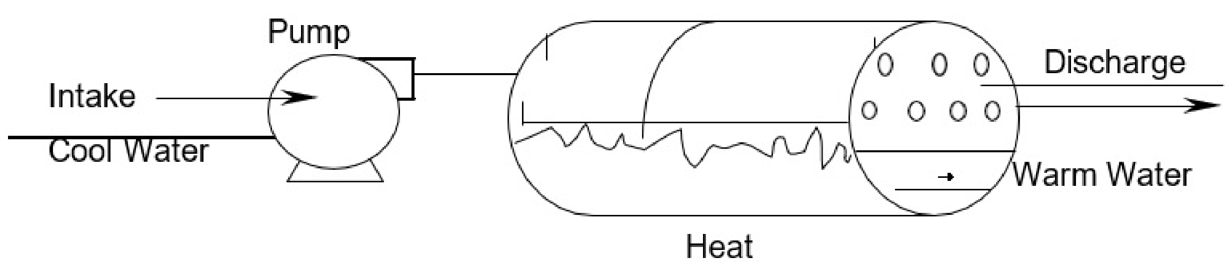
5-1 TYPES OF COOLING WATER SYSTEMS.

Cooling water systems remove heat generated from a variety of industrial processes. There are three basic types of cooling water systems: once-through, open recirculating, and closed recirculating cooling water systems. This Chapter describes once-through and open recirculating systems. Chapter 6 describes the closed recirculating system.

5-1.1 Once-Through Cooling Water Systems.

Once-through cooling water systems use cool water that circulates only once through the entire system before being discharged. This type of system is commonly found along rivers or coastlines where abundant water is available for use. The system contains heat exchange equipment and transfer piping, as shown in Figure 5-1. Power utility services often use this type of system.

Figure 5-1 **Once-Through Cooling Water System Diagram**



5-1.2 Open Recirculating Cooling Water Systems.

Open recirculating cooling water systems are open to the atmosphere and continuously recycle and reuse the cooling water. These systems are composed of an evaporator unit, a cooling tower, or an evaporative condenser. These units mix air and water and allow some of the water to evaporate, cooling the balance of the water volume. The cooled water is then circulated to heat exchangers or chillers, where heat is added to the cooling water thereby removing heat from the process flow stream. The warmed water is then circulated to the cooling tower, where the cycle is repeated. Water is lost from the system primarily through evaporation; however, a portion of the cooling water must be discharged as waste (blowdown) to maintain a suitable water quality within the system. All water lost from the system is replaced by makeup water. Recirculating cooling water systems are found in most air conditioning chiller operations, as well as many heat exchange operations. Evaporative fluid coolers and evaporative condensers are terms defining open recirculating cooling water systems that use evaporators, which are slightly different than a cooling tower and do not send the cooled water out of the evaporative unit itself. An evaporative cooler cools a circulating fluid that does not change phase (does not condense from a gas to a liquid). An evaporative condenser cools a circulating fluid from a gas into a liquid, such as a refrigerant. The hot fluid that is to be cooled is brought to the unit. Figure 5-2 shows a typical evaporative cooler and evaporative condenser diagram; Figure 5-3 shows a typical open recirculating cooling water system; and Figure 5-4 shows a typical cooling tower system.

Figure 5-2 **Evaporative Fluid Cooler and Evaporative Condenser Diagram**

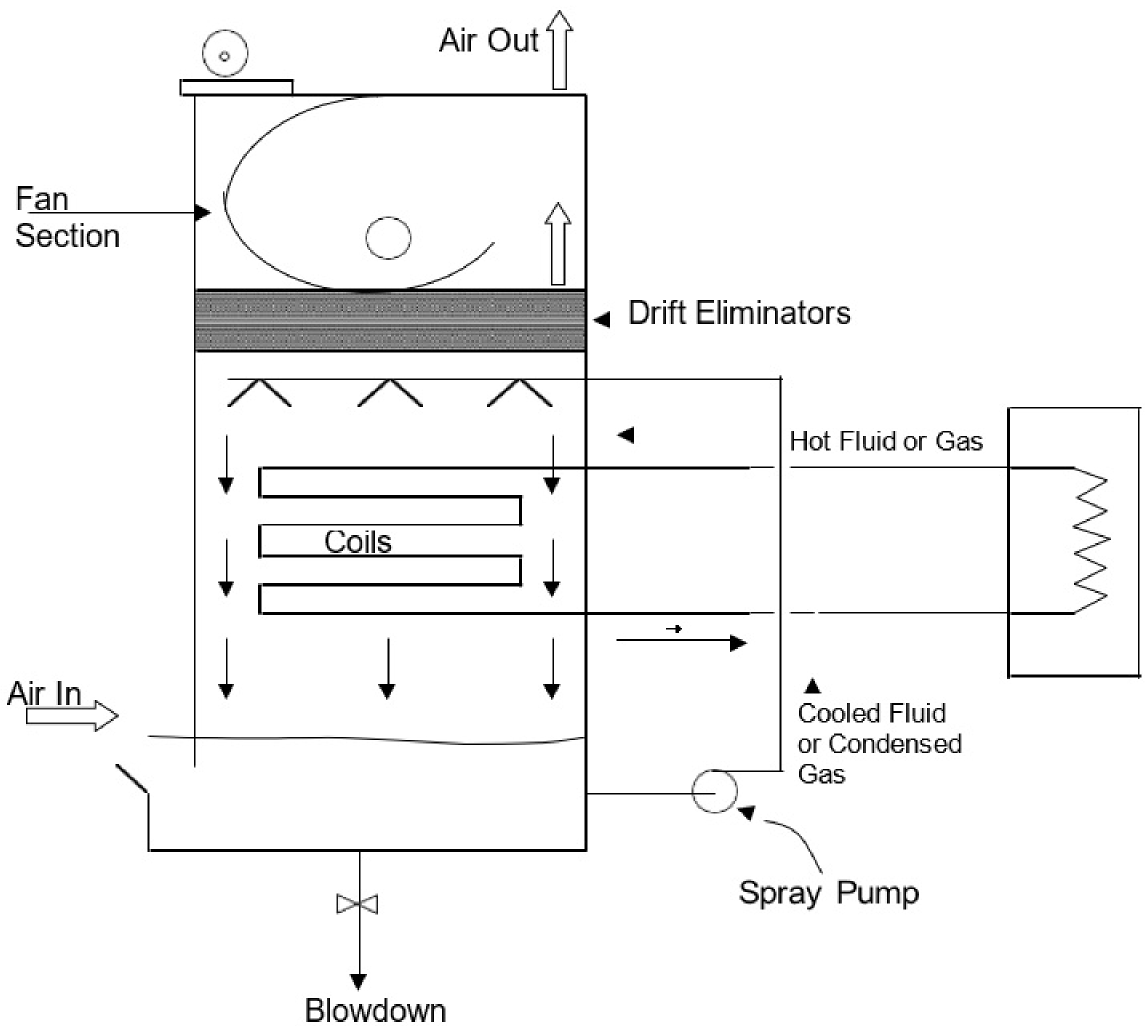


Figure 5-3 **Open Recirculating Cooling Tower Water System Diagram**

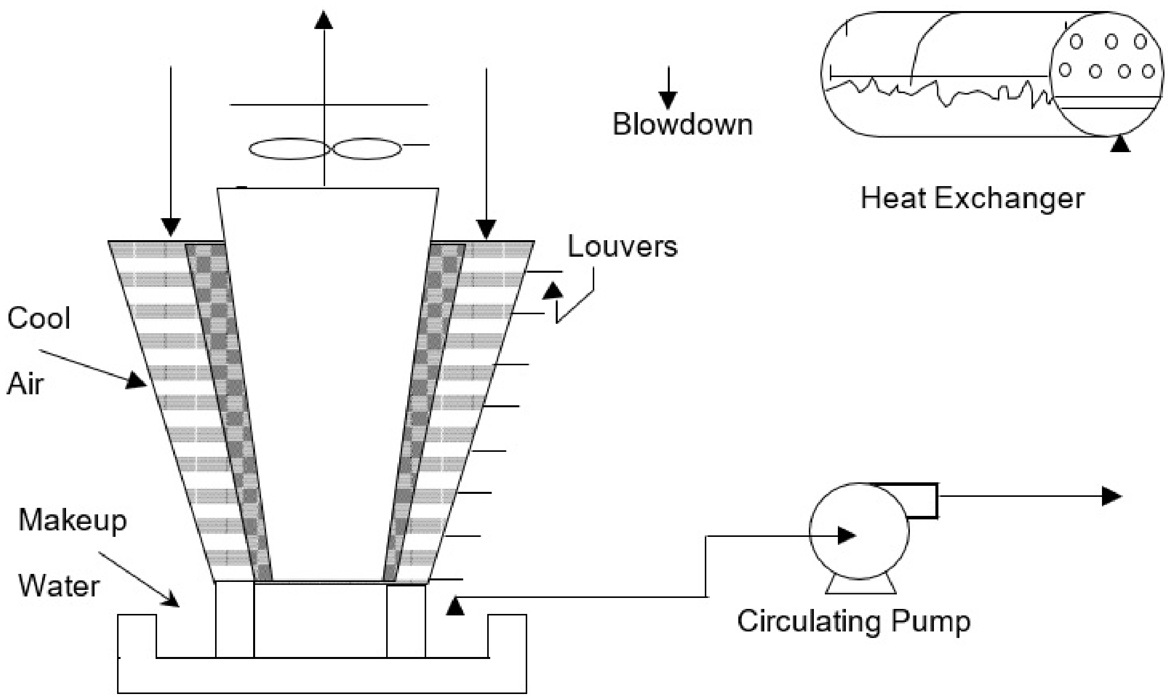
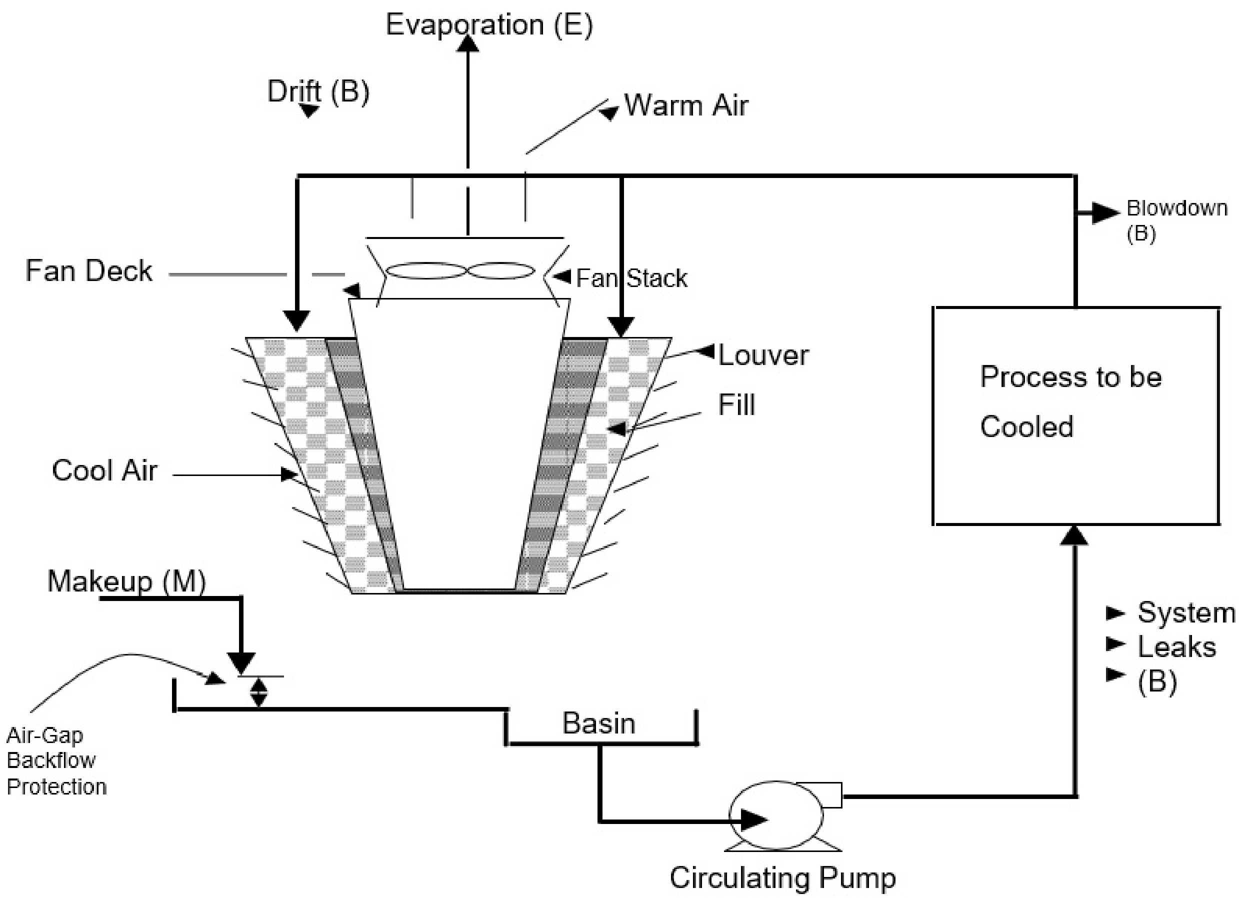


Figure 5-4 **Cooling Tower Water System**



5-1.3 Types of Cooling Towers.

Types of cooling towers include natural draft, induced draft, and forced draft.

5-1.3.1 Natural-Draft Towers.

In natural-draft towers, airflow through the tower is achieved naturally (for example without any mechanical means such as fans). Air flows across the falling water and up through the cooling tower as a result of the differential density between the lighter, heated and humidified, air within the tower and the cooler and dryer outside air. Fitting the tower with spray nozzles, which create more mixing of air and water droplets and improve the evaporation efficiency, produces increased water- cooling rates. Large utility power plants use these large natural-draft cooling towers, which are called hyperbolic cooling towers due to their hyperbolic shape (see Figure 5- 5).

Figure 5-5 **Hyperbolic Natural-Draft Cooling Towers**

5-1.3.2 Forced-Draft Towers.

The term “forced draft” denotes that air is forced or blown by fans into the cooling tower and up through the flow of falling water in the cooling tower. Drift eliminators are installed to prevent water entrained in the air from leaving the system.

5-1.3.3 Induced-Draft Towers.

The term “induced draft” denotes that air is drawn by fans through the flow of falling water and up and out of the cooling tower. The airflow can be drawn either cross-flow or counter-flow with respect to the orientation of the falling water, resulting in either a cross-flow tower or a counter-flow tower. Drift eliminators are also present. (See Figures 5-6, 5-7, 5-8, and 5-9 for diagrams and photos of cross-flow and counter-flow cooling towers.)

Figure 5-6 **Cross-Flow Cooling Tower**

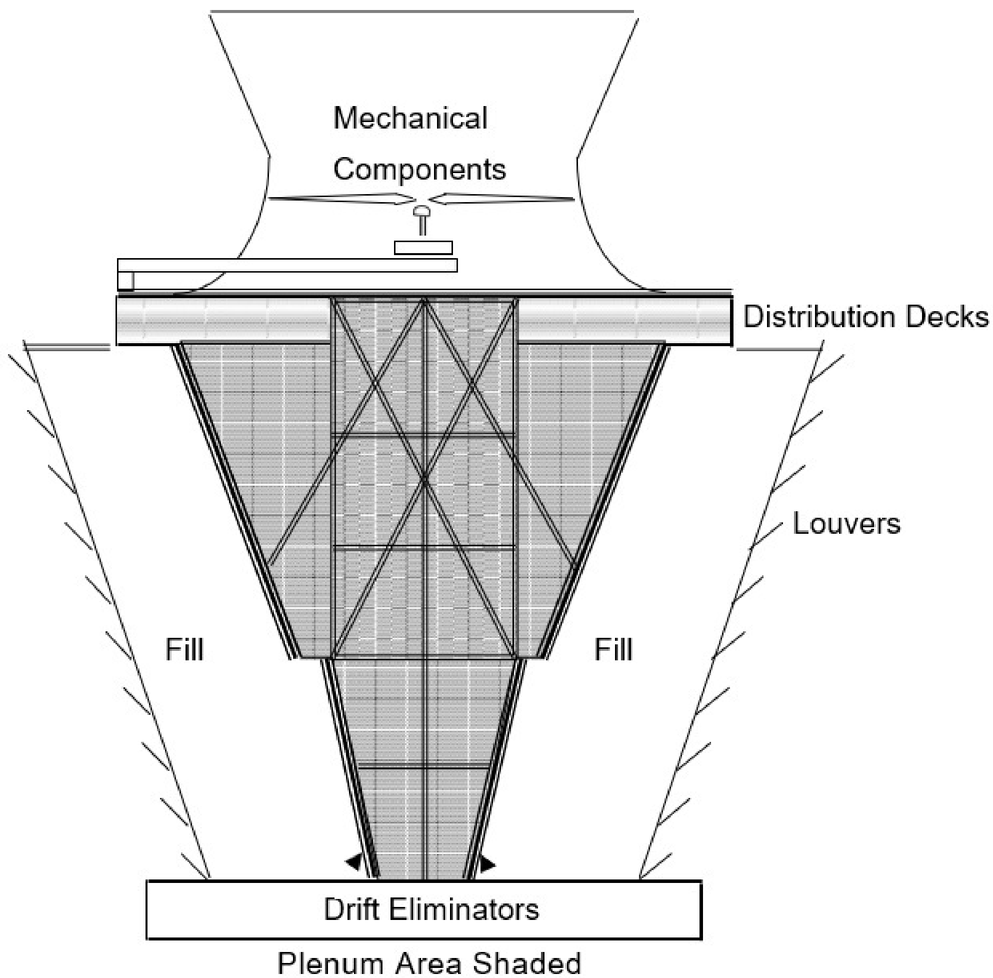


Figure 5-7 **Cross-Flow Cooling Tower**

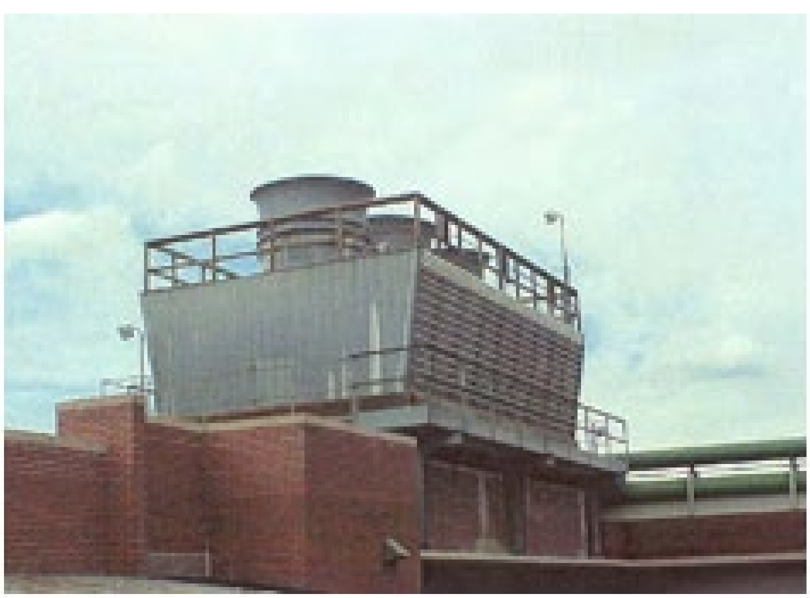


Figure 5-8 **Counter-Flow Cooling Tower Diagram**

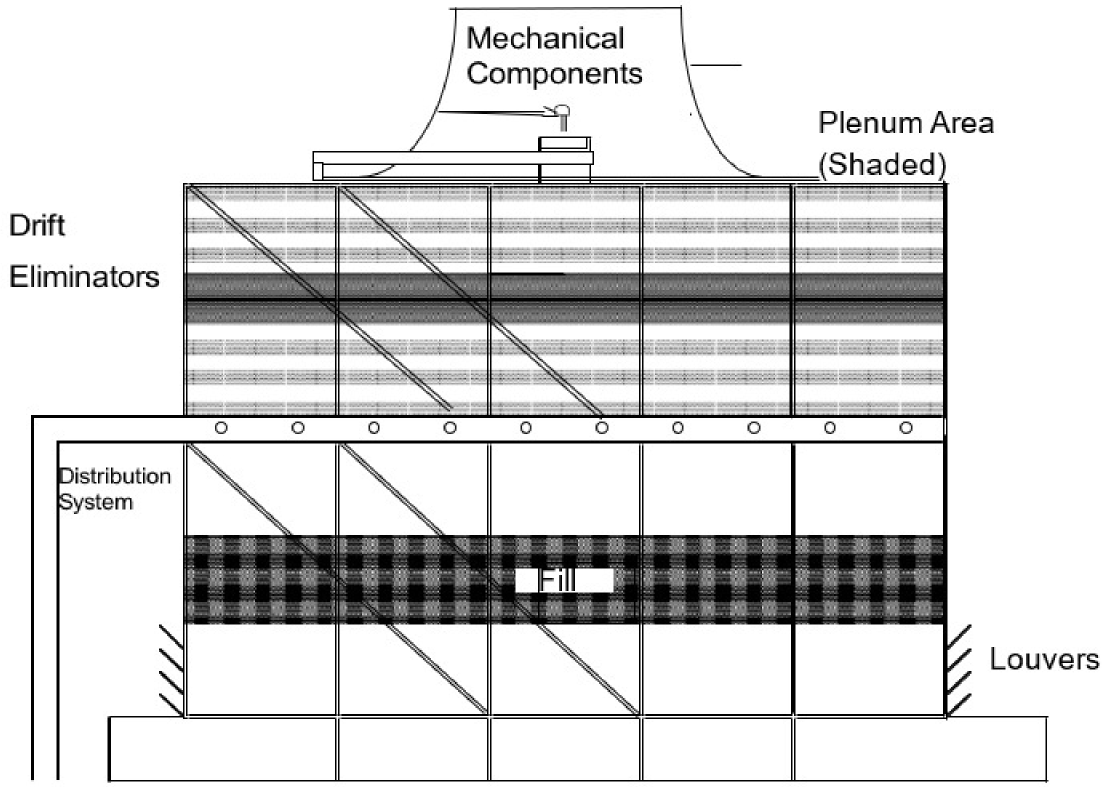
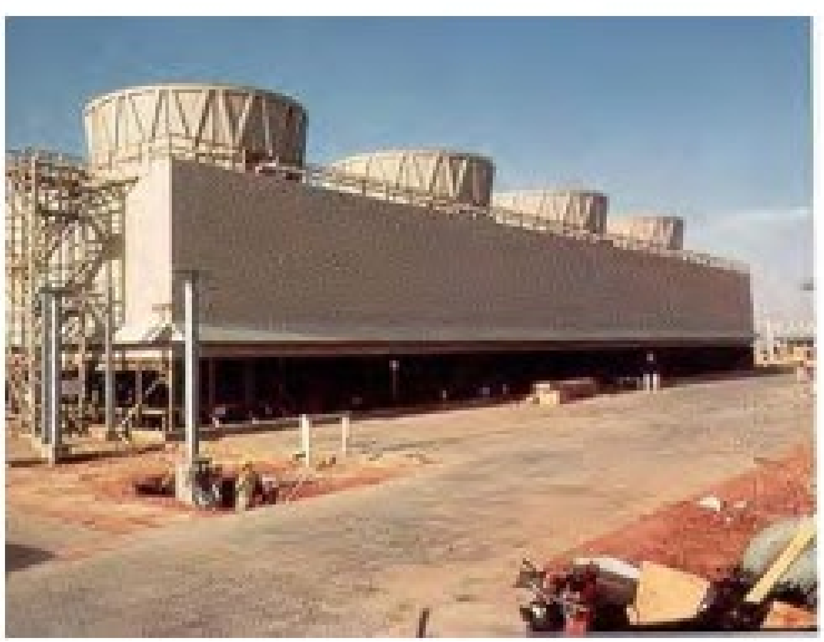


Figure 5-9 **Counter-Flow Cooling Tower**



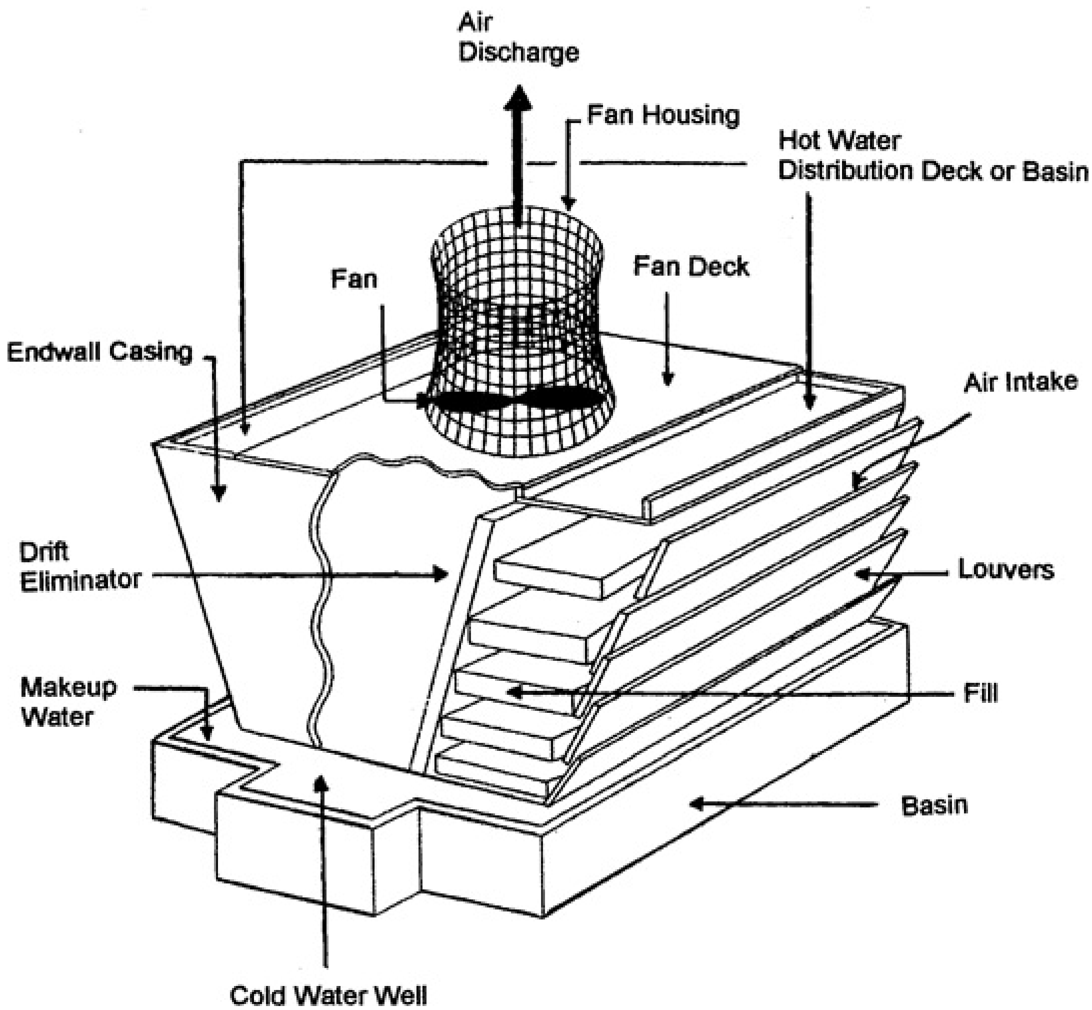
5-1.3.4 Typical Cooling Towers at Government Installations.

Cooling towers at military installations are commonly of the induced-draft, cross-flow variety, although counter-flow and forced-draft cooling towers are also represented. The cooling tower range in size from small to large capacity.

5-1.4 Components of a Cooling Tower.

Figure 5-10 shows a simple diagram of a 1-fan, induced-draft, cross-flow cooling tower. The major parts of the tower include the basin and cold well, louvers, fill, water distribution (and fan) deck, drift eliminators, fan and fan discharge, and the end wall casings.

Figure 5-10 **Induced-Draft Cross-Flow Cooling Tower Components**



5-1.4.1 Basin and Cold Well.

The basin is that portion of the cooling tower structure located under the tower that is used for collecting cooled water and which can be used as a location for adding makeup water. The cold well is a deepened portion of the basin that contains submerged water circulation pumps. The basin may be constructed of concrete, wood, metal, or fiberglass.

5-1.4.2 Louvers.

Louvers are flat or corrugated members constructed of wood, plastic, cement board, or fiberglass, and installed across (horizontally) the open side of a tower. The main function of louvers is to prevent water from splashing out of the cooling tower through the openings where air enters the tower. Louvers are usually set at an angle to the direction of airflow.

5-1.4.3 Fill.

Fill is the internal part of a tower where air and water are mixed. The fill intercepts the downward fall of water. The water is mixed with the air contained in the fill material and water is evaporated and cooled. There are two types of fill: splash fill and film fill. The falling water hits the splash fill, splashes, and breaks up into smaller water droplets, resulting in an increased rate of evaporation. The splash fill is made of wooden slats or bars, plastic, or ceramic tile. Film fill is a compact plastic material, similar to a honeycomb that causes water to flow over the fill material, creating a large wet surface that maximizes evaporation as air travels past the film surface (see Figure 5-11).

Figure 5-11 **High-Efficiency Cooling Tower Film Fill**

5-1.4.4 Drift Eliminators.

The drift eliminators efficiently remove water droplets from the air and return the recovered water to the cooling tower, thereby minimizing the loss of cooling tower water. They are located in areas that are situated after the fill and water sprays and just before the area where the air exits the cooling tower (see Figures 5-6 and 5-8). Drift eliminators are also known as “mist eliminators.”

5-1.4.5 Water Distribution and Fan Deck.

In a cross-flow cooling tower, the hot water basin is used to distribute the warm return water flow uniformly over the tower fill (see Figure 5-6). In a counter-flow cooling tower, water sprays are used to distribute the warm water (see Figure 5-8). The fan deck supports the motor and fan of the water spray system. The stack is the structure (typically a cylinder) that encloses the fan and directs warm, humid discharge air upward and out of the cooling tower.

5-1.4.6 Cell.

This is the smallest subdivision of a large cooling tower in which the fan can operate as an independent unit. A mid-wall casing must separate each end of the cell from the adjacent cells to ensure all air flow induced by the cell fan is drawn only through the cell fill and mist eliminator air path. Figure 5-7 illustrates a typical three-cell cross-flow cooling tower. Figure 5-9 illustrates a typical four-cell counter-flow cooling tower.

5-1.5 Common Cooling Water System Problems.

Water-related problems can cause system downtime, loss of equipment efficiency, the need for capital replacement of equipment, and can increase the risk of disease from pathogenic microorganisms. An open recirculating cooling tower system has a greater potential for these problems than does a once-through cooling water system, due to the air- and water-mixing design of the open recirculating system. These problems are associated with water-caused deposits, corrosion, or microbiological organisms, and occur for various reasons:

- The cooling tower is essentially a huge air scrubber that can introduce materials such as microorganisms, gases, dust, and dirt into the circulating water, which provides an excellent growth environment for pathogenic microorganisms. These materials can contribute to the formation of deposits and cause corrosion.
- If the water is not properly treated and its quality maintained, corrosion and scale and solids deposition can occur. The potential for these problems results from the nature of the cooling system design and the operating conditions, including water evaporation, mineral concentration, and water temperatures of up to 130° F (54° C).
- The constant addition of makeup water results in increased quantities of mineral constituents that can form scale, deposits, and corrosion.

Blowdown control and proper water treatment can minimize these problems.

- The film fill contains small water and air passages that can become plugged, thereby causing a reduction in cooling tower operational efficiency due to reduced water evaporation (see paragraph 5-1.4.3).
- Current designs for heat exchangers and cooling towers provide for more efficient operation than in the past, but unexpected water problems may occur. Some of the more prevalent potential problems are described in paragraphs 5-1.5.1 through 5-1.5.4.

5-1.5.1 Enhanced and Super-Enhanced Chiller Condenser Tubing.

Recent air conditioning chiller equipment designs incorporate enhanced and super-enhanced chiller condenser tubes. Previous designs have used smooth-bored waterside condenser tubing. The enhanced tube is machined with rifled grooves that provide an increased surface area and a resultant increase in heat transfer; however, the rifled grooves and ridges tend to entrap SS (such as dirt, silt, sand, and old corrosion products), which are deposited from the cooling water as it passes through the tube. This deposition of material on metal surfaces can create a type of localized corrosion called “under-deposit corrosion.” This situation has resulted in numerous cases of tube failure. The super-enhanced chiller tubes have even finer grooves and ridges, making this type of tubing even more susceptible to under-deposit corrosion. (See Figures 5-12 and 5- 13, which show photos of super-enhanced copper tubes.)

Figure 5-12 **Close-Up of Corrosion Pitting on Super-Enhanced Copper Tube**

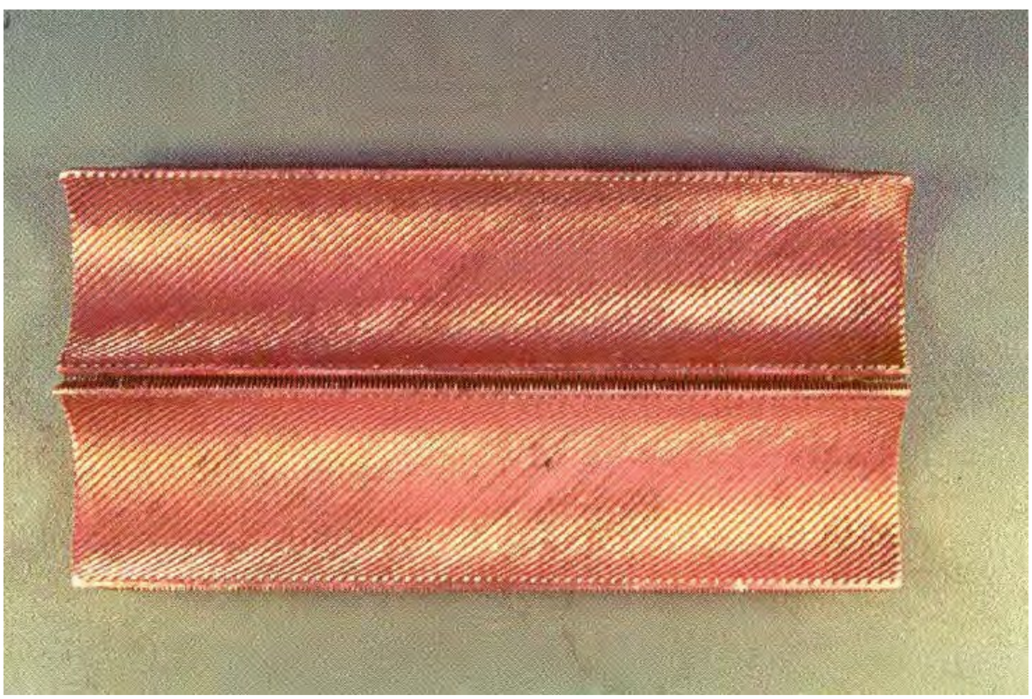
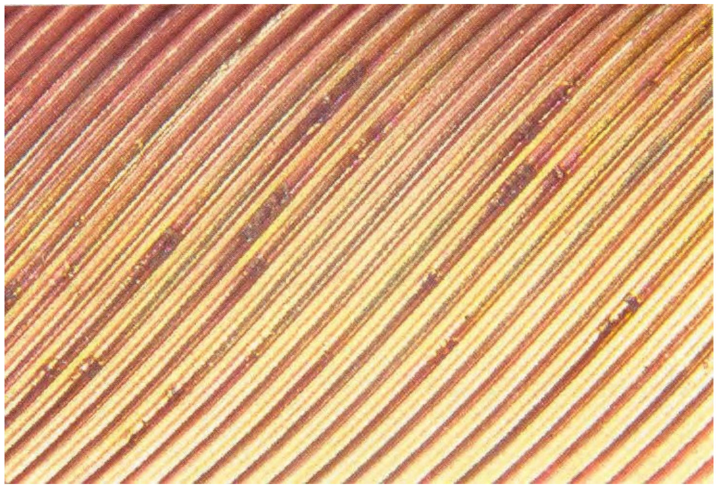


Figure 5-13 **Close-Up of Corrosion Pitting on Super-Enhanced Copper Tube**



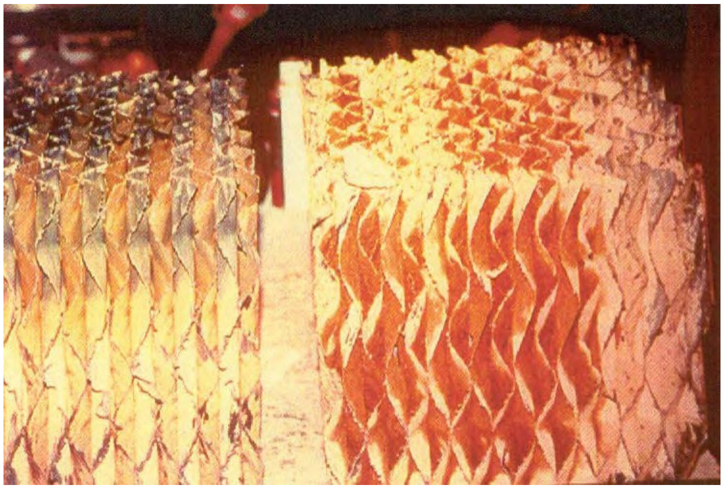
5-1.5.2 White Rust.

Some cooling towers are constructed with galvanized steel components and must not be exposed to conditions of high pH (high alkalinity). The galvanizing process deposits a protective zinc coating on a mild steel metal surface, resulting in increased resistance to corrosion. Failure to avoid such exposure can result in production of “white rust” due to the corrosion of the galvanizing coating. Eventually, this corrosion process exposes the mild steel underneath, which then starts to corrode. White rust failures have been a common occurrence throughout the country, mainly with newer cooling towers. Proper protection of the galvanizing material is necessary both during startup of a new cooling tower and during normal operations. Specific water treatment chemicals are needed to provide this protection. Examples include pretreatment with a high level of orthophosphate.

5-1.5.3 Cooling Tower Film Fill.

Small- and medium-sized cooling towers use film fill, which is a tightly packed media as compared to the splash-type fill used prevalently in the past (see paragraph 5-1.4.3 and Figure 5-11). Film fill has a higher potential for fouling (plugging) due to adherence and entrapment of biomass and of SS (such as dirt, silt, and sand). The cooling capacity of a cooling tower can be reduced if the film fill is extensively fouled (see Figure 5-14). Instances of severe fouling have resulted in the collapse of fill into the cooling tower basin. In addition, fouling deposits in the fill can harbor pathogenic microbiological organisms such as Legionnaires’ disease.

Figure 5-14 **Heavily Fouled Cooling Tower Film Fill**



5-1.5.4 Legionella Bacteria.

This type of bacteria is the cause of Legionnaires' disease. It can grow in cooling water systems even when a proper microbiological control program has been maintained. This bacterium can be discharged in the drift produced from all types of cooling tower systems. If a susceptible person inhales the bacteria, the disease could possibly develop. A number of outbreaks of Legionnaires' disease are reported throughout the country. See paragraph 5-4.7 for information on controlling Legionella.

5-2 COOLING TOWER WATER CALCULATIONS

5-2.1 Principles of Cooling Tower System Operations.

The function of a cooling tower is to dissipate heat from water-cooled refrigeration, air-conditioning and industrial process systems. Water is typically the heat transfer medium used to dissipate the heat. A cooling tower uses a combination of heat and mass transfer (evaporation) to cool the water flowing through the tower. Conductive heat transfer accounts for 20 to 30 percent of the total heat dissipated. The remaining 70 to 80 percent of total cooling is the result of evaporative cooling of about 1 to 2 percent of the recirculating water, depending on the decrease in temperature across the tower. It takes approximately 2,326,000 joules to evaporate 1000 BTU per 1 pound of water (1 kilogram of water). If this amount of heat is extracted from 1000 pounds (454 kilograms) of water, approximately 1 pound (0.45 kilogram) of water will be evaporated and the temperature will drop 1˚ F (0.55˚ C). If 10 pounds (4.5 kilograms) of water are evaporated, the water temperature will drop 10˚ F (5.5˚ C). The water lost by evaporation is replaced with makeup water. Water is also added to replace water lost through tower drift (loss of water from the tower as a fine mist), leaks in the system (unintentional blowdown), and water discharged as intentional blowdown. Water that is added to the cooling tower to replace all of these losses is known as cooling tower makeup water.

5-2.1.1 Relationship between Evaporation, Blowdown, and Makeup.

The operation of cooling towers can be described by the relationship between evaporation, blowdown, and makeup. Makeup water must equal blowdown water plus water evaporation to maintain a constant operating water level in the system:

Equation 5-1. Operation of Cooling Towers

$$M = B + E$$

Where:

M = makeup water, gpm (liters/sec)

B = blowdown, gpm (liters/sec) (all sources)

E = evaporation, gpm (liters/sec)

NOTE: Blowdown (B) includes discharge to sewer, drift loss, and any leaks from the system.

EXAMPLE:

M = 100 gpm (6.3 liters/sec)

B = 10 gpm (0.63 liters/sec)

E = 90 gpm (5.67 liters/sec)

5-2.1.2 Cycles of Concentration (COC).

One of the common terms used in describing the water use efficiency of cooling tower water systems is COC. COC represents the relationship between the makeup water quantity and blowdown quantity. COC is a measure of the total amount of minerals that is concentrated in the cooling tower water relative to the amount of minerals in the makeup water or to the volume of each type of water. The higher the COC, the greater the water use efficiency. Most cooling tower systems operate with a COC of 3 to 10, where 3 represents acceptable efficiency and 10 represents very good efficiency. It has been found that the range of 5 to 7 COC represents the most cost-effective situation.

5-2.1.2.1 Calculating COC by Volume.

If both makeup and blowdown water volumes are known, COC by volume can be calculated. The term is defined as:

Equation 5-2. COC by Volume

$$C = M \div B$$

Where:

C = COC, no units

M = makeup water, gpm (kg/hr)

B = blowdown losses, gpm (kg/hr)

EXAMPLE:

M = 100 gpm (6.3 liters/sec)

B = 10 gpm (0.63 liters/sec) C = M ÷ B = 10

5-2.1.2.2 Determining COC by Water Analyses.

To determine COC, you must know the mineral content of both makeup and blowdown water. For example, you must determine both the conductivity of the recirculating cooling tower water and the conductivity of the makeup water. (Note that the blowdown water will have the same conductivity as the recirculating water.) Conductivity is commonly measured in micromhos (μmhos). You can also estimate COC by using other water quality parameters such as chlorides, silica, or sulfates. The relationship is represented by this equation:

Equation 5-3. Determining COC by Water Analyses

$$c = \frac{\mathrm{B\mu mhos}}{\mathrm{M\mu mhos}} \; or \; \frac{\mathrm{B_{Cs}}}{\mathrm{M_C}}$$

Where:

C = COC, no units

Bμmhos = conductivity of blowdown (recirculating water), microμmhos (μmhos)

Mμmhos = conductivity of makeup water, μmhos Cl = chlorides in blowdown, ppm

Cl = chlorides in makeup water, ppm

EXAMPLE:

The measured conductivity of the blowdown (recirculating water) is 800 micromhos and the makeup is 300 micromhos.

The COC is:

$$c = \frac{\mu\text{mhos}}{\mu\text{mhos}}$$

$$\mathrm{C} = 800 \div 300 = 2.67$$

NOTE: The parameters of conductivity or chloride concentration are used commonly for such measurements. Other water quality parameters can be used, but sometimes with inaccurate results (calcium, magnesium, alkalinity, and silica can form deposits, meaning they drop out of solution). COC based on these parameters could be considerably less than that based on conductivity or chlorides. Similarly, chemical additions of sulfuric acid can yield higher sulfate levels than those species cycled up naturally.

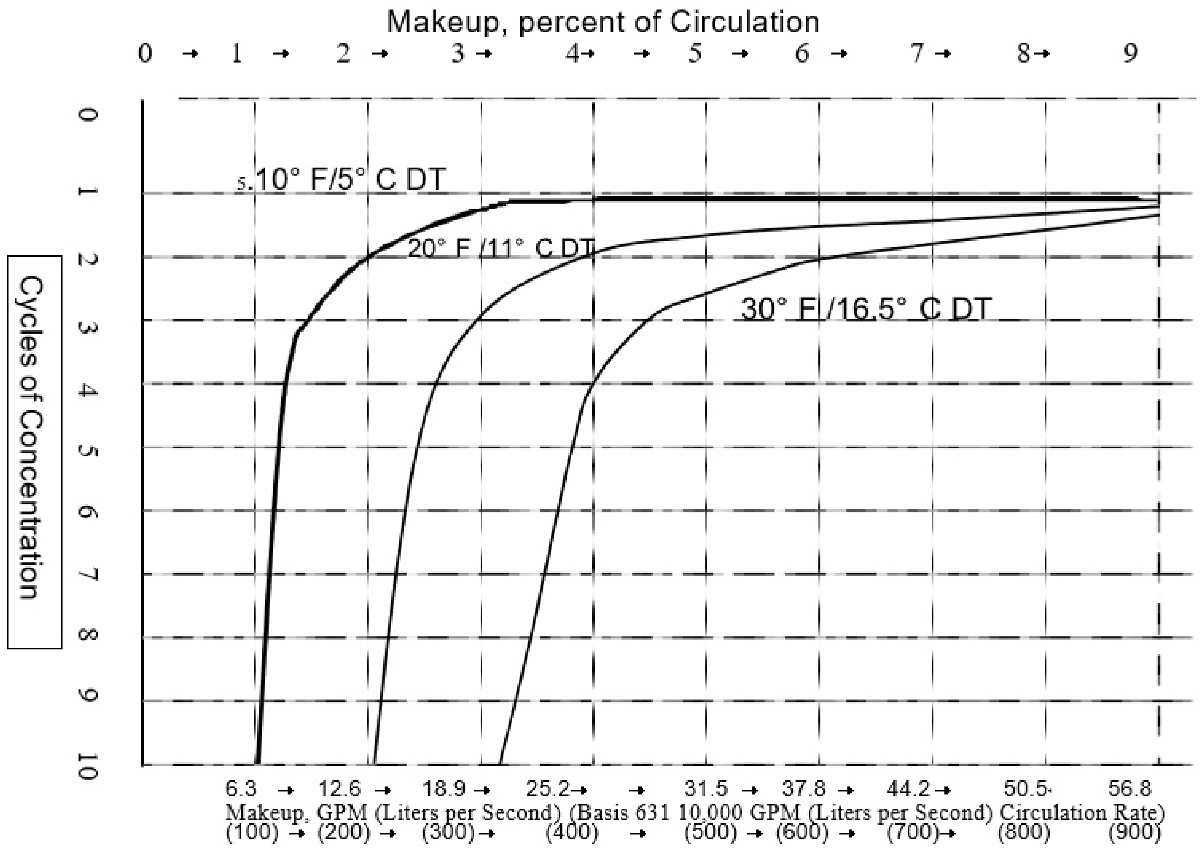
5-2.1.2.3 Controlling COC.

A simple, sometimes overlooked rule: To increase COC, decrease blowdown; to decrease COC, increase blowdown.

5-2.1.2.4 Relationship between COC and Makeup.

COC and makeup requirements are related to the temperature drop across a cooling tower and to the recirculating rate of the tower. As shown in Figure 5-15, for a recirculating tower with water temperature drops of 10° F (5.5° C), 20° F (11° C), and 30° F (16.5° C), the makeup water requirement decreases rapidly as COC is increased to about 4 or 5, with lower incremental reductions at higher COC; therefore, COC can be adjusted (increased) to allow for reductions in water use (water conservation) and for reductions in the amount of water treatment chemicals used.

Figure 5-15 **Effect of COC on Makeup Requirement**



5-2.1.3 Relationship between Blowdown, Evaporation, and COC.

You can use the cooling water evaporation loss to calculate the blowdown rate that must be maintained to operate at a selected COC. The relationship between blowdown, evaporation, and COC is represented with this equation:

Equation 5-4. **Relationship Between Blowdown, Evaporation, and COC**

$$\mathbf{B} = \mathbf{E} \div (\mathbf{C} - \mathbf{1})$$

Where:

B = blowdown, liters per day or liters per second (gpd or gpm)

E = evaporation, liters per day or liters per second (gpd or gpm)

C = COC, no units

EXAMPLE: A cooling tower evaporates 600 gallons per minute (37.8 liters per second) and operates at 4 COC:

$$\mathbf{B} = \mathbf{37.8\ l/sec\ (600\ gpm)} \div (\mathbf{4} - \mathbf{1}) = \mathbf{12.6\ l/sec\ (200\ gpm)}$$

a. This formula is derived using data from previously presented equations:

1. $M = B + E$ from paragraph 4-2.1.1
2. $C = M \div B$ from paragraph 4-2.1.2.1
3. $C = (B + E) \div B$ from equation (2) and (1) above
4. $C = 1 + (E \div B)$ rearranging equation
5. $(C - 1) = E \div B$ rearranging equation
6. $B = E \div (C - 1)$ rearranging equation

b. If you know the quantity of evaporation, you can calculate the blowdown required for a given value of COC. You can estimate the evaporation using simple "rule of thumb" estimates:

c. For a typical recirculating cooling tower water system, approximately 1 percent of the recirculating rate (R) of the cooling water is evaporated for every 10 F (5.5 C) temperature drop in the cooling water as it passes through the tower; therefore, you may calculate the evaporation rate (E) this way:

$$\mathbf{E(l/sec) = 0.01\ x\ R(l/sec)\ x\ \Delta T\ drop\ in}\ ℃ \div \mathbf{5.5}\ ℃$$

Since 0.01 ÷ 5.5 = 0.0018, this can be condensed to:

$$\mathbf{E = R\ x\ \Delta T\ x\ 0.0018}$$

or

$$\mathbf{E = R\ x\ \Delta T \div 550}$$

NOTE: Newer cooling towers can have 0.75 percent of the recirculation rate evaporated for every 10 F (5.5 C) drop.

EXAMPLE 4-2:

A cooling system operates at 5000 gallons per minute (315 liters per second). The temperature drop through the tower is 14 F (7.8 C). The evaporation estimate is represented by this equation:

$$\mathbf{E = 0.01\ x\ 315\frac{l}{sec}(5000\ gpm)x\ 14\ \ F(7.8\ \ C) \div 10\ \ F(5.5\ \ C) = 4.5\ l/sec\ (70\ gpm)}$$

or

$$\mathbf{E = 315\ x\ 7.8 \div 550 = 4.5\ l/sec\ (70\ gpm)}$$

d. For a cooling tower system serving air conditioner and chiller operations, the evaporation rate used depends on the type of chiller:

- Approximately 1.5 gallons per hour per ton (20 liters per hour per kilowatt) for centrifugal, reciprocating, and screw-type chillers.
- Approximately 3 gallons per hour per ton (40 liters per hour per kilowatt) for absorption-type chillers.

5-3 OBJECTIVES OF COOLING WATER TREATMENT.

The primary objectives of cooling water treatment are to maintain the operating efficiency of the cooling water system and to protect the equipment that contacts the cooling water. These objectives are accomplished by controlling or minimizing deposition, corrosion, and microbiological growth on the cooling water equipment. Treatment programs must also address requirements for environmental compliance, safety, water conservation, and limitation of chemical costs. This paragraph reviews the requirements for, and elements of, a water treatment program for cooling water systems.

5-3.1 Deposit Formation and Control.

Deposits that occur in cooling water systems are usually divided into two categories: scale and fouling. The presence of either type of deposit in the heat exchangers or in the film fill can interfere with heat transfer, thereby reducing the efficiency of operation. Deposits can also promote under- deposit corrosion. Scale and non-biological fouling are described in this paragraph. Biological fouling is described in paragraph 5-4.

5-3.2 Scale.

Scale is formed from minerals, formerly dissolved in water, that were deposited from the water onto heat transfer surfaces or in-flow water lines. As water is evaporated in a cooling tower, the concentration of dissolved solids becomes greater until the solubility of a particular scale-causing mineral salt is exceeded. When this situation occurs in an untreated cooling water system, the scale will form on any surface in contact with the water, especially on heat transfer surfaces. The most common scaling minerals are calcium carbonate, calcium phosphate, calcium sulfate, and silica, usually in that order. Formation of magnesium silicate scale is also possible under certain conditions. Most other salts, including silica, are more soluble in hot water than in cold water; however, most calcium and magnesium salts, including calcium phosphate and calcium carbonate, are more soluble in cold water than in hot water. This is called “reverse solubility.” The water temperature will increase as recirculating water passes through the cooling system. As a result, calcium and magnesium scales may form anywhere in the system, but most likely on heated surfaces such as heat exchangers or surface condensers. Silica will form in areas having the lowest water temperature, such as in the cooling tower fill.

5-3.2.1 Determining Scaling Potential.

The maximum solubility limit for specific dissolved minerals will determine the types of scale that can form under a given set of conditions. To minimize water blowdown, the amount of dissolved materials in the cooling water should be maintained as close as possible to the maximum solubility level. This water quality parameter, TDS, is controlled by maintaining COC in the system at a level that is equal to the lowest COC allowable for whichever salt has the lowest solubility. The salt of concern is often calcium carbonate or calcium phosphate, but it may be silica. The operating COC can be increased substantially with use of the cooling water treatment chemicals described in this paragraph.

5-3.2.2 Calcium Carbonate Scale.

Calcium carbonate scale results from the breakdown of calcium bicarbonate, a naturally occurring salt. The degree of scaling depends primarily on the calcium levels, bicarbonate alkalinity levels, and water temperature in the cooling water system. The most accurate prediction of scale can be developed using the Practical (Puckorius) Scaling Index (PSI) (see paragraph 5-3.4.2). A rough prediction of calcium carbonate scale potential can be developed using this formula:

Equation 5-5. Prediction of Calcium Carbonate Scale Potential

$$C = \sqrt{\frac{110000}{TA \ x \ M_{ca}}}$$

Where:

C = COC

TA = total (M) alkalinity (as $CaCO_3$) in makeup, ppm

M_{Ca} = calcium hardness (as $CaCO_3$) in makeup, ppm

5-3.2.3 Calcium Phosphate Scale.

Calcium phosphate scale results when calcium hardness reacts with phosphate. This will occur when more than 10 ppm of orthophosphate are present in the circulating water and when the calcium hardness is sufficiently high. The following formula can provide a very rough prediction of the potential for calcium phosphate scale:

Equation 5-6. Potential for Calcium Phosphate Scale

$$C = \frac{(105) \ x \ (9.8 - B_{pH})}{M_{ca}}$$

Where:

C = COC, no units

BpH = measured pH in blowdown, pH units

MCa = calcium hardness (as CaCO3) in makeup water, ppm

5-3.2.4 Calcium Sulfate Scale.

Calcium sulfate scale results when the calcium hardness reacts with the sulfate. The potential for calcium sulfate scale can be predicted using this formula:

Equation 5-7. Potential for Calcium Sulfate Scale

$$c = \sqrt{\frac{125000}{M_{ca} \, x \, M_{su}}}$$

Where:

C = COC, no units

M_{Ca} = calcium hardness (as $CaCO_3$) in makeup, ppm

M_{Su} = sulfate (as SO_4) in makeup, ppm

5-3.2.5 Silica Scale.

Silica scale can occur when the concentration of silica exceeds its maximum solubility limit in water. A safe, very conservative value to assume for the solubility limit is 150 ppm (as SiO_2); thus, the maximum COC can be calculated with this formula. However, silica solubility depends on pH and temperature and is in the range of approximately 150 to 180 ppm (as SiO_2) at the temperature range encountered in most cooling towers 80° F to 130° F (26° C to 54° C). As the pH increases in the cooling tower water, silica becomes more soluble; thus, if cooling tower water pH is 9.0, approximately 250 ppm silica (as SiO_2) is the maximum. Using 150 ppm as the upper limit, the allowable COC is represented by this equation:

Equation 5-8. Allowable COC

$$c = \frac{150}{M_{si}}$$

Where:

C = COC, no units

150 = assumed maximum solubility of silica, ppm

M_{Si} = silica (as SiO_2) in the makeup, ppm

5-3.3 Determining COC to Control Operations.

In cooling water systems, the lowest calculated COC allowable, as determined by the relationships for these salts, is the controlling factor for operations. This is because as the system operates, the material that has the lowest calculated COC will be the first to come out of solution (precipitate) and the most likely to form a scale deposit in the system. To prevent these materials from forming a deposit on cooling water equipment, you must keep the COC in the system at a level that is lower than the lowest COC calculated for calcium carbonate, calcium phosphate, calcium sulfate, and silica. Using appropriate water treatment chemicals will allow higher COC, depending on which chemical is used.

EXAMPLE 5-3:

a. A cooling tower makeup has the following composition:

Calcium hardness	100	ppm as $CaCO_3$
Total (M) alkalinity	60	ppm as $CaCO_3$
Phosphate	3	ppm as PO_4
Sulfate	60	ppm as SO_4
Silica	14	ppm as SiO_2
pH	7.2	

At what COC can the system operate scale free without water treatment? (Assume that the estimated pH in the blowdown water is 8.5.)

b. Based on calcium carbonate:

$$\boldsymbol{c = \sqrt{\frac{110000}{60 \times 100}} = 4.3}$$

c. Based on calcium sulfate:

$$\boldsymbol{c = \sqrt{\frac{125000}{100 \times 60}} = 14.4}$$

d. Based on silica:

$$\boldsymbol{coc = 150 \div 14 = 10.7}$$

The COC determined for calcium carbonate is lowest at 4.3, and this controls the system operation. If the system is operated without water treatment, scaling should not occur if the system is operated at less than 4.3 COC. Use of scale control treatment will allow the number of allowable COC (for calcium carbonate) to be increased; you can then determine the COC and blowdown by using a calculated scaling index.

5-3.4 Calcium Carbonate Scaling Indices.

The scale found most commonly in cooling tower water systems is calcium carbonate, present in the form of calcite ($CaCO_3$) (for example limestone). The solubility of calcium carbonate, which decreases with an increase in temperature, is a complex function of temperature, TDS, calcium hardness, total alkalinity, and pH. To predict if scale would form in the hotter sections of a cooling water system, researchers have developed several scaling indices. Paragraphs 5-3.4.1 and 5-3.4.2 describe the predictive indexes that are used most commonly for cooling water.

5-3.4.1 Langelier and Ryznar Indices.

W.F. Langelier derived a method to calculate the calcium carbonate scale-forming and scale-dissolving tendencies of drinking water. The method is based on determining the saturation pH (pH_s) at which calcium carbonate scale will start to precipitate out of solution. If the measured pH (pH_{actual}) of the water is greater than its pH_s, thus a positive value, the water has a scale-forming tendency. If the measured pH (pH_{actual}) of the water is less than its pH_s, thus a negative value, the water will have a scale-dissolving tendency. The pH_{actual} minus pH_s is known as the Langelier Index or Langelier Saturation Index (LSI) ($LSI = pH_{actual} – pH_s$). This index was originally designed to predict calcium carbonate scale in potable water. There are serious deficiencies in the accuracy of this index; consequently, it has lost its practical application for cooling water systems.

J.W. Ryznar later devised a more sensitive formula for predicting calcium carbonate scale. This formula is known as the Ryznar Index or Ryznar Stability Index (RSI). The formula is: $2pH_s – pH_{actual}$. A value of 6 indicates “stable” water, a value less than 6 indicates a scale-forming tendency, and a value greater than 6 indicates a scale-dissolving tendency. The indices have also been used to try to estimate the degree to which calcium carbonate scale will form in drinking water and in cooling water. The more positive the LSI value, the greater the scale formation; however, for the RSI, the smaller the index, the greater the scale formation. The LSI and RSI can give conflicting predictions based on the same water quality information.

5-3.4.2 Practical (Puckorius) Scaling Index (PSI).

Paul R. Puckorius and J. Maxey Brooke developed a modified version of the RSI that gives a more accurate and consistent indication of the calcium carbonate scaling potential of cooling water. Known as the Practical Scaling Index (PSI), and also known as the Puckorius Scaling Index, it takes into consideration the effect of the type of total alkalinity of the cooling water on the measured pH (pHactual) value. The measured pH does not always relate correctly to bicarbonate alkalinity because of the buffering effect of other ions. Rather than using the measured pH in calculating the PSI, an adjusted or equilibrium pH (pHeq) is used: PSI = 2pHs - pHeq. As with the RSI, a PSI value of 6 indicates stable water and a value lower than 6 indicates a scale-forming tendency. Without scale-control treatment, a cooling tower with a PSI of 6 to 7 should operate scale free. However, a PSI of greater than 6 indicates that scaling may occur. Information on calculating the PSI is provided in Appendix B. Use of the PSI is most applicable when cooling water pH is above 7.5.

5-3.5 Scale-Control Methods.

Three basic methods are used to prevent the formation of scale in cooling water systems:

a. Remove the water scaling ingredients from the water before use. This includes softening, RO, and other technologies described in Chapter 3.

b. Keep the scale-forming ingredients in solution. This is the most common scale-control method used for cooling water, and it can be achieved by use of either or both of the following two methods: adding acid, which lowers the pH of the recirculating water, or adding a scale inhibitor (phosphonate or specific polymer), which allows higher COC to be maintained without scaling. Acid neutralizes (destroys) mineral alkalinity, one of the constituents forming calcium carbonate scale; however, because of the hazards associated with handling strong acids and the potential damage from an acid spill, the use of acid in cooling towers is not recommended.

c. Allow the water-scaling ingredient to precipitate as sludge. Modern chemical treatment can distort or modify scale crystals such that they cannot adhere to each other to form a hard deposit; instead, they become a sludge that can be removed through filtration or blowdown. All three methods are authorized for use on military installations and can be used in combination with one another.

5-3.5.1 Calcium Carbonate Scale Control Using Solubilizing Chemicals.

Acids and phosphonates are chemicals that keep scale from forming. The use of acid in cooling towers may not be appropriate for use at military installations due to the associated risk of corrosion.

5-3.5.1.1 Acids.

The acid most commonly used is sulfuric acid used as a diluted solution (40 percent sulfuric acid in water). The use of acids requires adequate pH control.

5-3.5.1.2 Phosphonates.

The phosphonates used most frequently for calcium carbonate scale control in recirculating cooling water systems are AMP (amino-tri [methylene] phosphonic acid); HEDP (1-hydroxyethylidene 1,1-diphosphonic acid); and PBTC (2-phosphonobutane-1,2,4-tricarboxylic acid).

The chemical reaction of all phosphonates is similar; however, their stability varies greatly. The presence of chlorine or other oxidants in treated cooling water favors the use of PBTC, which is very resistant to decomposition, followed by HEDP, and finally AMP. An active dosage of 3 to 5 ppm of either AMP or HEDP, or 1.5 to 2.5 ppm PBTC, will increase the solubility of calcium carbonate by a factor of 3 or more relative to using no chemical treatment. Rather than operating at a PSI of 6.0 (stable water, no scale) in an untreated system, the cooling tower water can be used at a PSI of 4.0 without the occurrence of scale (see paragraph 5-3.4.2 and Appendix A); however, in the absence of calcium scaling conditions, phosphonates can increase the corrosion of both mild steel and copper.

5-3.5.2 Calcium Carbonate Scale Control Using Solubilizing Polymers.

Many different polymers are used in water treatment. For the most part, they have multi-faceted performance capability; they can inhibit various types of scale formation as well as disperse SS. Often water treatment products will include more than one type of polymer in the product formulation. For control of calcium carbonate, homopolymers such as polyacrylate, polymethacrylate, and polymaleate are used to keep calcium carbonate in solution. Dosages of 3 to 5 ppm of active polymer in the cooling tower water can control calcium carbonate scale formation to a PSI value as low as 4.5.

5-3.5.3 Calcium Carbonate Scale Control Using Sludge-Forming Polymers.

Certain homopolymers and copolymers act as crystal modifiers by distorting calcium carbonate crystals such that they do not attach themselves to heat exchange surfaces, but instead the crystals become SS that can be removed through filtration or blowdown. Usually dosages of 1 to 3 ppm of active polymer in the cooling tower water will control calcium carbonate scale. Due to formation of sludge, rather than the stabilization of carbonate in solution, the PSI is not meaningful under these conditions.

5-3.5.4 Calcium Phosphate Scale Control Using Solubilizing Inhibitors.

Often calcium phosphate scale is formed in cooling water systems treated with a phosphate- based corrosion inhibitor program or when phosphate is present in the makeup water (like potable or recycled water). Calcium phosphate is much less soluble in water than is calcium carbonate. If the calcium hardness is 500 ppm and the pH is above 7.0, without any polymer treatment calcium phosphate scale will likely form, even at the low level of 10 ppm phosphate (as PO_4) in the cooling water (see paragraph 5-3.3). Calcium phosphate solubility can be increased by a factor of a little less than 3 by the addition of 4-ppm phosphonate (HEDP/PBTC) or by the use of 6 to 8 ppm of a copolymer or terpolymer specific for calcium phosphate inhibition.

5-3.5.5 Calcium Sulfate Scale Control Using Solubilizing Polymers.

Calcium sulfate formation can result from high concentrations of calcium ions and sulfate ions in the recirculating water; however, calcium sulfate is the most soluble of the scale-forming calcium salts found in cooling tower waters having pH levels of greater than 8.0. This means that calcium sulfate scale will not form unless some calcium ions (hardness) remain in solution after the calcium reacts with all the carbonate and phosphate in the water. Calcium sulfate scale may occur when the recirculating water contains calcium hardness in the range of 500 to 700 ppm as $CaCO_3$ and sulfate in the range of 500 to 700 ppm SO_4. (See the predictive index in paragraph 5-3.4) The addition of 3 to 5 ppm of a copolymer of acrylate and acrylamide will allow calcium sulfate to remain in solution at a level almost 3 times the level allowed when using no treatment. Calcium sulfate scale rarely forms at pH levels above 8.0 in the cooling water.

5-3.5.6 Magnesium Silicate Scale Control.

Formation of magnesium silicate is possible in cooling systems, but only under certain rare conditions. Magnesium ions (hardness) first react with hydroxyl ions (OH-) to form magnesium hydroxide, which then reacts with (absorbs) dissolved or colloidal silica. A deposit analysis often reports this material as magnesium silicate. Since magnesium hydroxide solubility decreases at pH levels above 9.0, this scale will usually occur only at a pH level above 9.0 and when the magnesium hardness concentration is greater than 100 ppm.

5-3.5.7 Silica Scale Control.

Silica solubility is dependent upon temperature and pH. At pH levels greater than 8.5, silica remains soluble (no scale) at a concentration of 250 ppm as SiO2. At pH levels of 7.5 or below, maximum silica solubility is 150 ppm as SiO2. At maximum silica levels, silica will first deposit on the cooling tower slats rather than in the heat exchanger because silica is more soluble in hot water than in cold water. The slats will become coated with a white, sometimes sparkling, deposit. If this occurs, blowdown should be increased to decrease COC by at least 1 unit. This procedure should stop additional scale formation. If the concentration of silica in the makeup water is above 30 ppm, it will usually be the parameter that controls the adjustment of cooling water system COC. If the silica concentration is high, external treatment can reduce the level of silica in the makeup water (see Chapter 3). The introduction of water treatment chemicals based on new polymer technology may allow the solubility of silica to be increased above the old recognized limit of 150 ppm.

Table 5-1 Summary of Scale Control Methods

Scale	Control Method
Calcium carbonate	1. Solubilize using phophonates. 2. Solubilize using polymers (polyacrylate, polymethacrylate, polymaleate). 3. Form sludge using specialty polymers.
Calcium phosphate	1. Solubilize using phosphonates. 2. Solubilize using specialty copolymers or terpolymers.
Calcium sulfate	Solubilize using copolymers of acrylate and acrylamide.
Magnesium silicate	Maintain water chemistry of: pH < 9.0, magnesium hardness < 500 ppm, and silica < 100 ppm.
Silica	1. Maintain water chemistry with silica < 150 ppm. 2. Solubilize with silica-specific polymer.

5-3.6 Cooling Water Fouling.

The term “fouling” refers to the deposition of materials that are normally held in suspension in the cooling water: mud, silt, and other SS brought into the system with the makeup water; dust, dirt, and debris scrubbed out of the air passing through the tower; product leakage such as oils; corrosion products from the system; and biological organisms, both living and dead. Combinations of any or all of these materials can be present in the cooling water.

5-3.7 Fouling Control.

Fouling from mud, dirt, and corrosion products can be controlled by the addition of a water-soluble polymer dispersant, such as a polyacrylate. The addition of about 4 to 5 ppm of active polymer, together with sufficient water velocity (3.28 feet per second (1 meter per second)), can keep foulants in suspension and prevent them from being deposited on heat transfer surfaces. Higher dosages (5 to 20 ppm) of active polymer can be required for heavily fouled systems. It is best to reduce the loading of SS by mechanically removing them from the system through blowdown, filtration, and physical sump cleaning. Removing oil or oily materials requires a non-foaming surfactant. Paragraph 5-4 describes prevention of fouling by biological organisms. Table 5-2 summarizes foulant control methods.

Table 5-2 Summary of Foulant Control Methods

Foulant	Control Method
Mud, dirt, corrosion products	1. Disperse using polymers and maintain adequate flow. 2. Form sludge using specialty polymers.
Oily matter	Disperse using a non-foaming surfactant.

5-4 MICROBIOLOGICAL DEPOSITS AND CONTROL.

Microbiological organisms are composed of three classes: algae, bacteria, and fungus. Large biological organisms such as clams, snails, mussels, or similar species are referred to as macrobiological organisms. The presence of any biological growth can be detrimental to cooling tower operations. Problems include fouling, corrosion, and loss of efficiency.

These problems can lead to downtime, higher operating cost, and even premature replacement of equipment. Additionally, some bacteria are pathogenic and can pose a risk to human life.

5-4.1 Algae.

The term “algae” refers to algal, microbiological, tiny, stringy blue and blue-green plants, which are usually found growing in masses on top of and on sides of cooling towers.

Algae grow only in sunlit areas. They will slough off and become part of the suspended matter in the circulating water, a situation which may cause fouling and plugging of water sprays. Algae also provide a breeding place, and are a nutrient, for bacteria.

5-4.2 Bacteria.

The term “bacteria” refers to a large group of one-celled microorganisms. Bacteria can grow in either the absence or presence of sunlight. There are several ways to classify bacteria, including “aerobic,” meaning those living in the presence of oxygen, and “anaerobic,” meaning those living in the absence of oxygen. In a cooling water system, one can categorize bacteria as either “planktonic” or “sessile,” which are terms that describe whether the bacteria are, respectively, either free floating or found growing on surfaces (stickers). Categories of bacteria are described below. Table 5-3 shows types of bacteria and their growth conditions.

5-4.2.1 Planktonic Bacteria.

Planktonic bacteria are suspended in the water, sometimes referred to as “free floaters” or “swimmers,” and are aerobic bacteria that thrive in an oxygenated environment. They are not harmful to the cooling system since they do not cause deposits or corrosion, but they can provide nutrients for other microorganisms; in addition, some planktonic bacteria such as *Legionella Pneumophila* are pathogenic and can present a significant human health risk.

5-4.2.2 Sessile Bacteria.

Sessile bacteria are stickers, or non-swimming bacteria, and can cause deposits and corrosion. Sessile bacteria types include slime-formers and anaerobic (corrosive) bacteria. Slime-formers can grow and form gelatinous deposits on almost any surface in contact with the cooling water. These deposits can grow so large that they restrict water flow and interfere with heat transfer; they also may promote under-deposit corrosion. Feeling the sides of the cooling tower basin just below the water level is one way to detect the presence of slime-formers. Usually if there are slime formers in the system, you can feel deposits. Anaerobic bacteria thrive in oxygen- deprived environments and often establish colonies beneath slime deposits or under other types of deposits. One type of anaerobe is sulfate-reducing bacteria (SRB), which produce hydrogen sulfide, a chemical that is very corrosive to metals. This type of corrosion attack is much localized and can result in pipe and tube failures. The presence of SRB should be suspected in a water system if the underside of a slime layer is black or if you detect the odor of rotten eggs. Any type of microbiological corrosion is referred to as microbiologically influenced corrosion (MIC). Bacteria cause most of the MIC found in cooling water systems. Use surface microbiological measurements to monitor sessile bacteria.

Table 5-3 Bacterial Types and Problems Created

Bacteria Type	Technical Names and Examples	Conditions for Growth		Problems Created
		Temperature	pH	
Aerobic - capsulated	• Aerobacter aerogenes Flavobacterium • Proteus vulgaris • Pseudomonas aeruginosa • Serratia • Alcaligenes	68-104º F (20-40º C)	4-8 (7.4 optimum)	Aerobic - capsulated
Aerobic - spore forming	• Bacillus myocoides • Bacillus subtilis	68-104º F (20-40º C)	5-8	Aerobic - spore forming
Aerobic - sulfur	• Thiobacillus • thiooxidans	68-104º F (20-40º C)	0.6-6	Aerobic -sulfur
Anaerobic – sulfate reducing	• Desulfovibrio desulfuricans • Clostridium	68-104º F (20-40º C)	4-8	Anaerobic –sulfate reducing
Iron depositing	• Crenothrix • Leptothrix • Gallionella	68-104º F (20-40º C)	7.4-9.5	Iron depositing

5-4.3 Fungi.

The term “fungi” refers to classes of organisms made up of molds and yeasts, some of which attack and cause wood decay in cooling towers. The control of fungi requires special preservative treatment of wood. Fungi also produce deposits in cooling water equipment.

5-4.4 Microbiological Control.

The term “microbiological control” refers to techniques used to minimize the presence of microbiological organisms in cooling water. Chemical biocide treatment is the method used on government installations for microbiological control in cooling water. Biocides that are used to control microbiological growth fall into one of two broad categories: oxidizing and non-oxidizing microbiocides. A cost-effective approach for control involves the regular use of oxidizers as a primary biocide, augmented by selective use of non-oxidizing biocides. Important factors for the effectiveness of any biocide include using a proper dosage and allowing adequate contact time with the microbiological organisms. All microbiocides are toxic and must be handled safely and with caution; use the SDS for safety instructions.

5-4.4.1 Oxidizing Biocides.

“Oxidizing biocides” is a term describing microbiocides that oxidize or irreversibly “burn up” the bio-organisms. Oxidizing biocides also destroy nutrients that the microorganisms require for growth. Avoid addition of excess amounts (over-feeding) of oxidizing biocides because they are corrosive to metal and wood in the cooling system and have the potential to destroy some scale and corrosion inhibitors. The various oxidizing biocides are described below. Table 5-6 provides guidelines for selecting oxidizing microbiocides.

5-4.4.1.1 Chlorine and Chlorine Release Agents.

Chlorine (Cl2) compounds are the most effective industrial oxidizing biocides and the most widely used. Chlorine is available as a chlorine gas, dry calcium hypochlorite (HTH), liquid sodium hypochlorite (bleach), plus several other dry products that release chlorine. When chlorine is introduced into water, it hydrolyzes to form hypochlorite ion (OCl-) and hypochlorous acid (HOCl); it is the latter chemical that is the stronger oxidizing biocide. The presence of hypochlorous acid is greater, proportionate to hypochlorite ion, at low pH levels. At a pH of 5.0, hypochlorous acid exists almost exclusively. At a pH of 7.5, there are approximately equal amounts of hypochlorous acid and hypochlorite ion. Figure 5-16 shows this relationship. Chlorine is effective, but to a lesser degree, as a biocide at a pH of 7.5 or greater because the hypochlorite ion has about one-tenth the biocidal efficacy of hypochlorous acid. A pH range of 6.5 to 7.5 is considered optimal for chlorine or chlorine-based microbiological control programs. Above pH 7.5, relatively higher levels of chlorine are required to be effective. Military installations seldom use gaseous chlorine for treating cooling towers because of safety concerns, difficulty with controlling the feed of the gas, and increasing concern for the environmental effects of escaping residual chlorine gas. The most commonly used chlorine-based products are bleach and HTH.

Figure 5-16 **Halogen Species vs. pH in Water**

HOCl = hypochlorous acid
OCl^- = hypochlorite ion
HOBr = hydrobromous acid
Obr = hypobromite ion
Cl_2 = chlorine
Br_2 = bromine

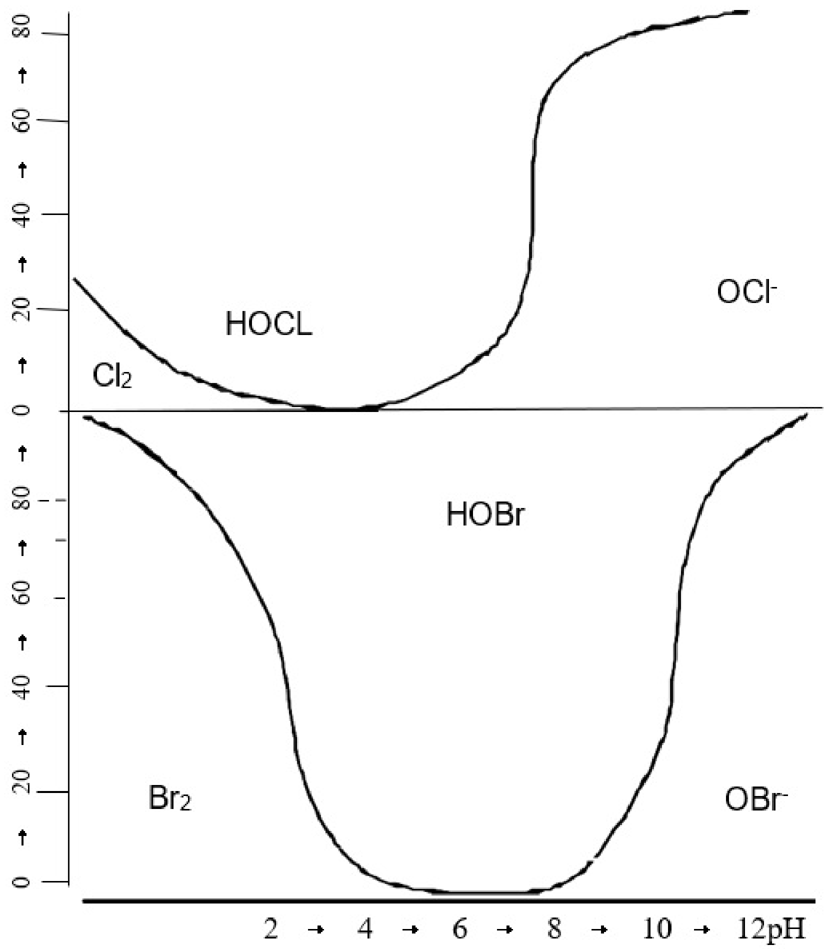


Table 5-4 Chlorine Release Agents

Release Agents	Comments
Sodium Hypochlorite 12 percent	Concentrated Liquid Bleach
Calcium Hypochlorite (HTH)	Dry product, releases chlorine
Chlorine Gas	Gaseous chlorine
Cloloisocyanurates	Dry organic chlorine compound, releases chlorine and cyanuric acid

5-4.4.1.2 Bromine Release Agents.

Bromine (Br2) compounds are very similar to chlorine compounds. Although more expensive than chlorine compounds, their main advantage is that bromine is more effective at higher pH ranges (7.5 or greater) than chlorine. Bromine has a lower vapor pressure than chlorine and is 6 times as soluble in water, making it less subject to vaporization loss from a cooling tower. When bromine is introduced to water, it hydrolyzes to form hypobromite ion (OBr-) and hypobromous acid (HOBr); Figure 5-16 shows this relationship. A pH range of 7.5 to 10.0 is considered optimal for the use of bromine. Bromine release agents include dry chemicals called hydantoins and bromine salts, such as sodium bromide. When a salt solution is mixed with an oxidizing agent, such as bleach, and a reaction occurs, bromine is produced. In water, bromine degrades more rapidly than chlorine. Recent developments in bromine chemistry have resulted in the production of a bromine solution (liquid). Table 5-5 shows examples of some bromine release agents. The most popular sources of bromine are the dry bromine release products.

Table 5-5 Bromine Release Agents

Release Agent	Comments
Bromo-chloro-dimethyl hydantoin	Dry product – releases bromine
Bromo-chloro-methyl-ethyl hydantoin	Dry product – releases bromine
Isocyanuric acid plus sodium bromide	Dry product – releases bromine
Chlorine plus sodium bromide	Produces bromine liquid
Peroxide plus sodium bromide	Produces bromine liquid
Ozone plus sodium bromide	Produces bromine liquid
Stabilized bromine	Hydrobromite liquid

5-4.4.1.3 Ozone.

Ozone (O_3) is a gas produced by passing dry air either through a strong electric field or near an ultraviolet light. If ozone is dissolved in water, the resulting solution can be added to cooling water. Ozone is a very strong oxidizing biocide that, if properly applied, can provide effective control of microorganisms in cooling tower systems; however, because of safety and operational problems associated with its manufacture and use, and the resulting high capital and operating costs, it is neither the most economical method nor the preferred method for microbiological control in cooling towers under normal operations. Ozone can increase metal corrosion and does not prevent scale (see paragraph 9-2.9.1).

5-4.4.1.4 Chlorine Dioxide.

Chlorine dioxide (ClO_2) is a gas generated by mixing several chemicals. The chlorine dioxide gas produced in this manner is subsequently dissolved in water, with the water containing the chlorine dioxide then added to the cooling water. Chlorine dioxide must be produced in close proximity to the point of use. It is not recommended for use on military installations due to the complexity of its production and safety concerns associated with its production and handling.

5-4.4.1.5 Hydrogen Peroxide.

Hydrogen peroxide (H_2O_2) is a liquid that is usually used at a concentration of 30 percent in water. Hydrogen peroxide is considered one of the most environmentally friendly oxidizing biocides because it degrades to water; however, concentrated hydrogen peroxide will react in a violent manner when it comes into contact with organic chemicals and materials.

Table 5-6 Guidelines for Oxidizing Microbiocide Effectiveness.

Microbiocide	Bacteria Types				Fungi	Algae	Comments
	Slime Forming		Iron Depositing	Corrosive			
	Spore Formers	Non-Spore Formers					
Chlorine	P	E	E	N	P	F	Dangerous to handle; corrosive to metal; available as dry, gas, or liquid; less effective higher pH (> 7.5)
Bromine	F	E	E	N	P	F	Can be produced from bromides; very effective at pH 6.0-10.0; very effective with ammonia; less volatile than chlorine
Ozone	E	E	E	F	G	P	Very volatile; can attack wood, PVC, copper, and gaskets
Chlorine dioxide	G	E	E	N	P	F	Must be produced onsite; very volatile; not sensitive to pH; does not react with ammonia and many organics
Chlorine	P	E	E	N	P	F	Dangerous to handle; corrosive to metal; available as dry, gas, or liquid; less effective higher pH (> 7.5)

E = Excellent G = Good F = Fair P = Poor N = Not effective

5-4.4.2 Non-Oxidizing Biocides.

Non-oxidizing biocides are microbiocides that act as “poisons;” they disrupt the metabolic or reproductive processes of micro- and macro-organisms and are therefore toxic. Non-oxidizing biocides are organic compounds that are very toxic to organisms, including human beings and animals. They are usually liquids, but some are available as dry products (such as pellets, solids). A major consideration for their use is their persistence with respect to the discharge limitations for water (effluent) containing these toxic substances. Also, when choosing and applying a non-oxidizing biocide, you must consider the cooling tower system’s operating parameters, such as pH and retention time. The applied dosages of microbiocides should never exceed EPA maximum limits, which are always printed on the container labels. The labels will also identify the active microbiocide ingredient, the percentage of each chemical that is present in the formulation, and the EPA registration number. Control programs often combine both oxidizing and non-oxidizing biocides. The most important aspect of bio-fouling control is to match the non-oxidizing biocide to the problem organism. Table 5-7 provides guidelines for non-oxidizing biocide effectiveness.

Table 5-7 Guidelines for Non-Oxidizing Microbiocide Selection.

Microbiocide	Bacteria Types				Fungi	Algae	Comments
	Slime Forming		Iron Depositing	Corrosive			
	Spore Formers	Non-spore Formers					
Quaternary ammonium salts	E	E	E	G	P	G	Effective pH 6.5-9.2; foaming potential; reacts with anionics
Organo tin plus quaternaries	E	E	E	G	P	G	Effective pH 6.5-9.2; foaming potential; reacts with anionics; tin compounds often restricted
Dibromo-nitrilo-propionamide	E	E	E	G	N	P	Effective pH 6.5-7.5; degrades quickly; uses glycol solvent
Methylene bis thiocynate	E	E	G	E	P	P	Effective pH < 7.5; deactivated with high pH
Isothiazolone	E	E	G	G	G	G	Effective pH 4.5-9.3; dangerous to humans
Dodecylguanidine	E	E	G	G	G	G	Effective pH 6.5-9.5
Glutaraldehyde	E	E	G	E	G	G	Effective pH 6-10
Terbutylazine	N	N	N	N	N	E	Very effective algaecide; blocks photosynthesis
Carbamates	E	E	G	G	G	F	Eff. pH 7-9; corrodes copper

E = Excellent G = Good F = Fair P = Poor N = Not effective

5-4.5 Algae Control.

Algae can be controlled by two techniques: chemical methods and physical methods. Since algae require sunlight to survive and grow, covering the upper hot water decks of cooling towers with plywood can often control algae deposits. Chemical methods consist of using oxidizing and non-oxidizing biocides, which can control algae to various degrees (see Tables 5-6 and 5-7). The effectiveness of oxidizers is considered only fair while that of several non-oxidizers is in the range of very good to excellent. One of the more effective biocides for algae is terbutylazine, a triazine product (see Table 5-7).

5-4.6 Bacterial Control.

Accepted industry practice for bacterial control is the use of oxidizing and non-oxidizing biocides that are specific for the type of bacteria. The most cost-effective microbiocide programs for medium and large cooling towers use an oxidizer as a primary biocide and one or more non-oxidizers selectively as a secondary biocide (see Tables 5-6 and 5-7). Smaller cooling systems often use one or more non- oxidizing biocides, although dry oxidizing biocides are also used commonly. The most overlooked aspect of bacterial control is maintaining a system kept clean of deposits and SS (such as dirt, silt, sand, corrosion products) through the use of filters and periodic wash-down procedures. Clean systems reduce the demand for chemical and microbiological control. Table 5-8 shows accepted industry guidelines for a bacterial control program with the use of a test kit.

Table 5-8 Guidelines for Bacterial Control in Cooling Towers.

Bacterium Type	Colony-Forming Units/ml
Total aerobic bacteria	$< 10^4$
Sulfate-reducing bacteria	Undetectable
Surface microbiological	$< 10^6$ – Undetectable

5-4.6.1 Bacterial Control with Oxidizing Biocides.

Bacterial control with oxidizing biocides can be accomplished by either continuous feed or slug feed of the oxidant. A continuous-feed process typically maintains 0.1 to 0.3 ppm of free halogen in the return water to the cooling tower. A typical slug-feed process adds treatment chemicals periodically to give 0.5 to 1.0 ppm of free halogen in the return water to the cooling tower for a period of 2 to 4 hours, 3 times per week. Halogen refers to the group of elements including chlorine and bromine. “Free” halogen refers to the measured residual of halogen available for disinfection. Stabilized Halogen technology is generally controlled on a total halogen residual. For continuous feed, control at 0.5 to 1 ppm total, and for slug feed control at 2.4 ppm for a period 2-4 hours, 3 times per week.

5-4.6.2 Bacterial Control with Non-Oxidizing Biocides.

Bacterial control with non-oxidizing biocides uses one or more biocides as shown in Table 5-7. Usually different non-oxidizers are added on an alternating schedule; they are slug-fed every other week for optimum effectiveness. Each time you use a non-oxidizing biocide, it is important to maintain an adequate dosage for 24 hours to enable sufficient contact time for maximum effectiveness.

5-4.7 Legionnaires’ disease.

Legionnaires’ disease (Legionellosis) is a respiratory disease (atypical pneumonia) that is caused by infection of susceptible individuals who have inhaled a fine water mist containing the bacterium known as *Legionella Pneumophila*. Water in a cooling tower can become infected with the bacterium if an inadequate microbiological control situation occurs. The presence and density of *Legionella Pneumophila* bacteria cannot be detected by standard microbiological testing methodologies. Instead, cooling water samples must be sent to a laboratory that has been certified to conduct the required tests. If the presence of the bacteria in cooling water is established, proper disinfection steps are required. A procedure known as the Wisconsin Protocol, developed by the

Wisconsin State Health Department, has proven effective. This protocol requires the addition of high dosages of chlorine (10 ppm free residual) at a pH of less than 7.5 for 24 hours, flushing the system, then repeating. Additional testing for Legionella is required to determine the effectiveness of the procedure. Maintaining a clean, microbiologically free cooling water system and using effective water treatment is preferable to dealing with remedial efforts. The Cooling Technology Institute (CTI) and the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) have published position papers on the prevention of Legionella; these can be downloaded from their respective websites: https://www.cti.org/ and https://www.ashrae.org/. Refer to UFC 3-420-01 Plumbing Systems for additional guidance about Legionella.

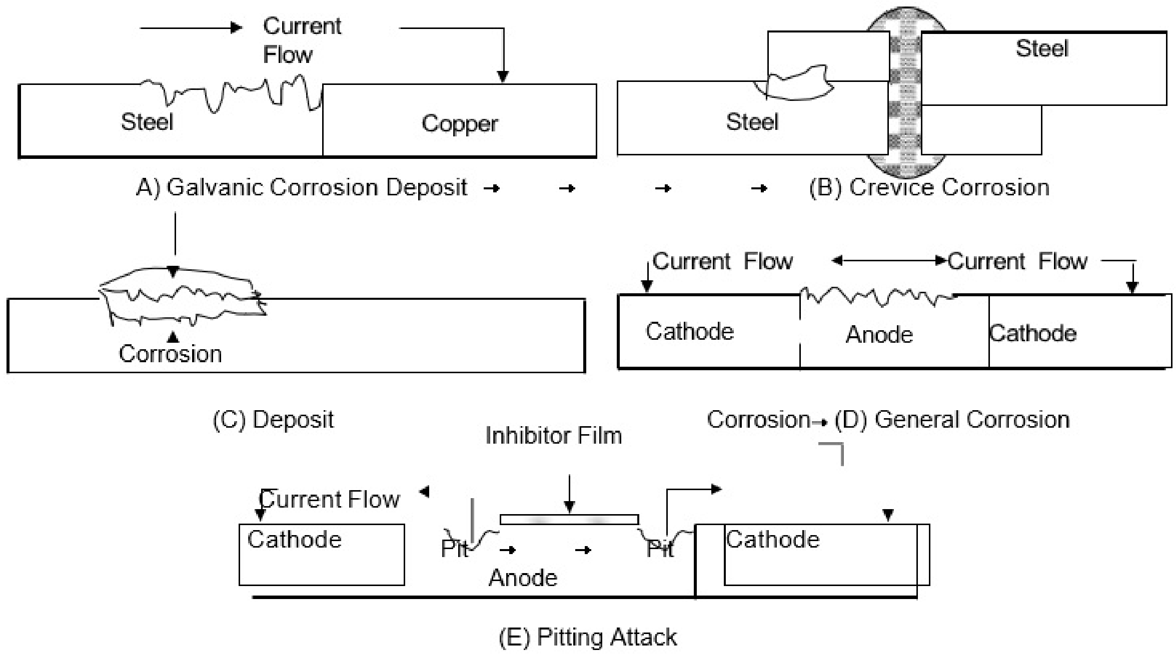
5-4.8 Macrobiological Control.

The term "macrobiological control" refers to control of larger biological organisms such as mussels, clams, and snails. They can exist in cooling systems that use seawater or river water as makeup. The first line of defense is using mechanical prevention with strainers and filters on the intake water to prevent infiltration into the cooling water system. Control methods within the cooling system include thermal shock and chemical treatment with oxidizing and non-oxidizing biocides.

5-5 CORROSION IN COOLING SYSTEMS.

The term "corrosion" (in a cooling water system) is defined as the electrochemical deterioration of a metal that is in contact with cooling water. Corrosion occurs when an electric current flows from one part of the metal (anode) through the water (electrolyte) to another part of the metal (cathode). Corrosion takes place at the anode only. The cathode is the driving force of the corrosion action. Forms of corrosion associated with industrial water systems are illustrated in Figure 5-17.

Figure 5-17 **Forms of Corrosion.**



5-5.1 Galvanic Corrosion.

See Figure 5-17 (A). This term refers to corrosion that occurs when two different metals are coupled together. The metal with the least resistance becomes the anode and will corrode due to the electrochemical reaction produced. One of the most common instances of galvanic corrosion occurring in cooling water systems results when mild steel and copper alloy metals are brought into contact with one another (like copper tubing attached to a mild steel tube sheet or brass valves connected to mild steel or galvanized piping). As a result of the electrochemical reaction, the copper is dissolved in the water and corrosion of copper alloy results. The copper can also plate out (stick) on mild steel surfaces, setting up additional galvanic cells. Another example is the electrochemical reaction that occurs when mild steel and zinc (galvanizing) are coupled together at temperatures normally found in cooling tower systems. The zinc becomes the anode and is corroded. Figure 5-18 shows the galvanic series. Any coupling of a metal that is higher in the galvanic series with a metal or alloy that is lower in the galvanic series results in electrochemical reaction in which the “higher” metal functions as the anode or active metal.

Figure 5-18 **Galvanic Series of Common Metals and Alloys Found in Cooling Water Systems.**

Active End

Magnesium
Magnesium alloys
Zinc
Galvanized steel
Aluminum 1100
Aluminum 6053
Alclad
Cadmium
Aluminum 2024 (4,5 Cu 1.5 Mg, 0.6 Mn)
Mild steel
Wrought iron
Cast iron
13 percent Chromium stainless steel Type 410 (active)
18-8 Stainless steel Type 304 (active)
18-12-3 Stainless steel Type 316 (active)
Lead-tin solders
Lead
Tin
Muntz metal
Manganese bronze
Naval brass
Nickel (active)
76 Ni – 16 Cr – 7 Fe alloy (active)
60 Ni – 30 Mo – 6 Fe – 1 Mn
Yellow brass
Admiralty brass
Aluminum brass
Red brass
Copper
Silicon brass
70-30 Cupro nickel
G-Bronze
M-Bronze
Silver solder
Nickel (passive)
76 Ni-15 Cr – 7 Fe alloy (passive)
67-Ni-33 Cu alloy (Monel)
13 percent Chromium stainless steel Type 410 (passive)
Titanium
18-8 Stainless steel Type 304 (passive)
18-12-3 Stainless steel Type 316 (passive)
Silver
Graphite
Gold
Platinum

Noble or Passive End

5-5.2 General Corrosion.

See Figure 5-17 (D). The term "general corrosion" refers to uniform corrosion of metal surfaces. A single piece of metal will have cathodic and anodic areas due to differences in impurities and stresses. These areas will change periodically, causing the metal to corrode over the entire surface at a more or less uniform rate.

5-5.3 Concentration Cell Corrosion.

When two pieces of the same metal are in a solution capable of acting as an electrolyte, and the electrolyte contains different substances or the same substance in different amounts, such as a salt or a mixture of salts, or oxygen, an electrical potential difference will develop between them.

5-5.3.1 Crevice Corrosion.

See Figure 5-17 (B). The term "crevice corrosion" refers to corrosion that occurs in a slight separation between two pieces of metal, such as at the contact point of two mild or stainless steel plates that have been bolted together. Water flow is restricted in a crevice and, as a result, oxygen is consumed faster than it can be replenished. The metal in the crevice functions as an anode and corrodes. This is a form of concentration cell corrosion, also called "differential oxygen cell" corrosion. Stainless steel is particularly susceptible to this type of corrosion, which results in localized or pitting attack.

5-5.3.2 Under-Deposit Corrosion.

See Figure 5-17 (C). The term "under-deposit corrosion" refers to corrosion occurring under any type of deposit. The underside of a deposit that has been caused by fouling, bacterial slime, or debris acts in much the same way as the inside of a crevice. The metal under the deposit becomes anodic and corrodes. This process is considered another form of concentration cell corrosion because oxygen cannot easily get under the deposit. All metals are susceptible to this type of corrosion, which results in localized or pitting attack.

5-5.3.2.1 Microbiologically Influenced Corrosion (MIC).

See Figure 5-17 (E). This term refers to metal corrosion associated with microbiological organisms whose presence contributes to the creation of, or maintenance of, a corrosive environment. MIC can be either eliminated or prevented to a large degree by the proper use of biocides.

5-5.4 Corrosion Rate.

The term "corrosion rate" refers to the rate at which the corrosion action proceeds. The rate is measured in units of mils per year (mpy). A mil is one-thousandth of an inch (0.0254 millimeter). The rate measurement is performed using corrosion coupons that have been exposed to cooling water for a short period of time (30 to 90 days). The weight of the coupon is measured before and after exposure to the water. The thickness of the metal lost due to corrosion over the testing period is then calculated using a measurement of the weight loss. This weight loss is extrapolated to give a rate for 1 year and a calculation of the thickness loss is then performed and the value is reported. Alternatively, this measurement can be taken using specialized instruments that rapidly measure corrosion rates. Table 5-9 shows the corrosion rates for corrosion coupons of different metals. Paragraph 7-5.2 provides detailed information on corrosion testing.

Table 5-9 Assessing Corrosion Rates in Cooling Water Systems: 90-Day Corrosion Coupon Test.

Metal	mpy	Comment
Mild steel piping	< 1	Excellent
	> 1 to 3	Good
	> 3 to 5	Fair
	> 5 to 10	Poor
	> 10	Unacceptable
Mild steel Hx tubing	< 0.2	Excellent
	> 0.2 to 0.5	Good
	> 0.5 to 1.0	Fair
	> 1.0 to 1.5	Poor
	> 1.5	Unacceptable
Copper and copper alloys	< 0.1	Excellent
	> 0.1 to 0.2	Good
	> 0.2 to 0.3	Fair
	> 0.3 to 0.5	Poor
	> 0.5	Unacceptable
Galvanized steel	< 2	Excellent
	> 2 to 4	Good
	> 4 to 8	Fair
	> 8 to 10	Poor
	> 10	Unacceptable
Stainless Steel	< 0.1	Acceptable
	> 0.1	Unacceptable

NOTE: Determine pitting on coupons by visual observation; any pitting is unacceptable.

5-5.5 Corrosion Control Methods.

In cooling water systems, two basic techniques are used to provide corrosion protection to the metals that the water contacts: use of chemical corrosion inhibitors, and raising the pH of the cooling water. Figure 5-19 illustrates the effect of pH on the corrosion rate of mild steel. Most military cooling water systems contain components fabricated primarily of copper alloy and mild steel. Galvanized steel is present in galvanized cooling towers and stainless steel may be present in piping. As the cooling water pH is increased (ideally to within the range of 8.0 to 9.5), copper and mild steel corrosion rates will decrease as shown in Figure 5-19, although very high pH levels are corrosive to copper. The increase in pH alone cannot always protect metals adequately, especially since cooling water is highly aerated (oxygen saturated). Chemical corrosion inhibitors are used to provide protection from corrosion of the metal components of cooling water systems. Table 5-10 shows criteria for the selection of corrosion inhibitors. The principal strategy for a cooling system corrosion protection program is to ensure protection of the metal in the heat exchanger (metal that is the thinnest metal in the system). The secondary goal is to provide protection from corrosion of the mild steel piping. When galvanized steel cooling towers are part of the cooling system, specialized corrosion inhibitors are the best control method. Galvanized steel is corroded at pH levels above 9.0 and below 6.0.

Figure 5-19 **Effect of pH on Corrosion Rate of Unprotected Mild Steel in Water.**

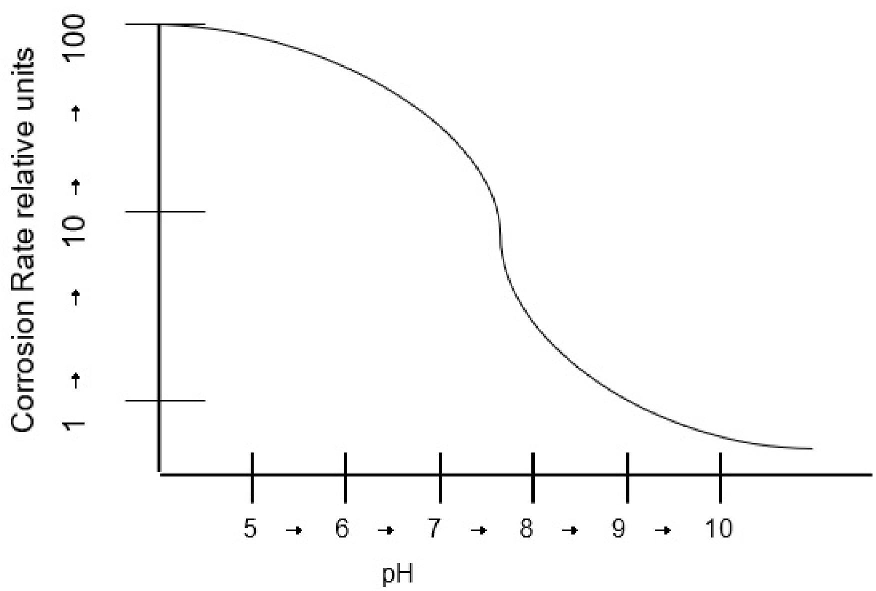


Table 5-10 Criteria for Corrosion Inhibitor Selection.

Corrosion Inhibitor	Metal			pH Range (ideal)
	Steel	Copper	Aluminum	
Cathodic Inhibitor				
Polyphosphate[1]	Excellent	Attacks	Attacks	6.5-8.5
Zinc salts[2]	Excellent	None	None	6.5-8.5
Polysilicate[3]	Excellent	Excellent	Excellent	7.5-10.0
Molybdate	Good	Fair	Fair	7.5-10.0
Anodic Inhibitor				
Orthophosphate[1]	Good	Attacks	Attacks	6.5-8.5
Orthosilicate[3]	Good	Good	Good	7.5-10.0
Copper Corrosion Inhibitor				
Azoles	Fair	Excellent	Fair	6.0-10.0

NOTES:

1. May require polymeric calcium phosphate dispersant.
2. Rarely used alone. Requires zinc solubilizer above pH 7.8.
3. Do not use if natural silica is 150 ppm or greater.

5-5.5.1 Effective Corrosion Control.

Effective corrosion control requires maintaining appropriate pH levels, plus adding maintenance dosages of chemical corrosion inhibitors. Chemical corrosion inhibitors form a protective film or barrier on the cooling system metal surfaces that have been cleaned prior to adding an initial high dosage of inhibitor. The initial high dosage of inhibitor passivates (protects) the metal. The appropriate dosage of corrosion inhibitor must be maintained continuously in the cooling water to ensure continuing protection. Table 5-11 shows examples of various passivation and maintenance dosage levels of corrosion inhibitors. Corrosion inhibitors are divided into three classes: cathodic, anodic, and general filmers. Corrosion inhibitors form a protective film on either the anode, the cathode, or over the entire metal surface. The types of corrosion inhibitors are described below.

5-5.5.1.1 Anodic Inhibitors.

Anodic inhibitors form a protective film coating on the anodic metal (where the metal is lost) and thus directly control corrosion by preventing the reaction that results in corrosion. Any unprotected areas will corrode at a much faster rate than the protected areas, a factor that could result in pitting or localized attack of the unprotected areas. Examples of anodic inhibitors include orthophosphate, nitrite, and orthosilicates. Under certain conditions, molybdate can function as an anodic inhibitor.

5-5.5.1.2 Cathodic Inhibitors.

Cathodic inhibitors form a protective film coating of the cathodic metal (where metal is not lost) and thus indirectly prevent corrosion by interfering with the current flow required for the electrochemical reaction to proceed between the cathodic and anodic metals. The corrosion reaction rate is governed by the size and type of the cathode relative to the anode. Even when cathodic areas are not completely covered by the protective film, corrosion will occur, but usually more slowly and uniformly than when using anodic inhibitors alone. The occurrence of localized corrosion or pitting attack is greatly reduced. Examples of cathodic inhibitors include zinc salts, polyphosphates, and polysilicates. Under most conditions, molybdate will function as a cathodic inhibitor.

5-5.5.1.3 General Inhibitors.

General inhibitors produce a protective film on the surfaces of all metals. These corrosion inhibitors are organic compounds, such as certain phosphonates, amines, and other nitrogen chemicals. They may be used in cooling water systems.

5-5.5.1.4 Corrosion Inhibitors for Specific Metals.

Some corrosion inhibitors provide corrosion control for specific metals. The protection of copper and copper alloys requires the use of azoles, such as tolyltriazole (TTA), benzotriazole (BZT), and butylbenzo-thiazole, which can be added to the system separately from, or as part of a blend of, other treatment chemicals.

5-5.5.1.5 Galvanic or Crevice Corrosion.

Control of galvanic or crevice corrosion is achieved primarily by engineering and mechanical design. These types of corrosion can also be partially controlled by physical and chemical considerations. A dielectric coupling (insulator), used to separate two different metallurgies, can help to prevent galvanic corrosion. From a chemical perspective, adjusting pH and using proper corrosion inhibitors will reduce corrosion.

5-5.5.1.6 Deposit Corrosion.

Control of deposit corrosion requires maintaining deposit-free metal surfaces. This applies to any form of deposit, such as scale, biomass, corrosion products, or foulants. The occurrence of most types of deposits is prevented by dispersants, scale inhibitors, or biocides, along with the maintenance of adequate flow velocities. Routine, adequate cleaning of filters and tower sumps will help reduce deposits.

5-5.5.1.7 MIC.

MIC is best prevented by stopping conditions that foster biological growth and by using an effective microbiological control program. A MIC prevention program includes adequate control (prevention) of deposits and fouling, avoidance of low-flow and dead-leg conditions, and implementation of a consistently effective microbiological program (see paragraph 5-4.4).

Table 5-11 Guidelines for Passive Film Formation and Subsequent Maintenance

Corrosion Inhibitor	Dosage (ppm)		Film-Formation Time (Days)
	Initial	Maintenance	
Cathodic Inhibitor			
Polyphosphate[1]	40-60 as PO_4	10-20 as PO_4	5-6
Zinc salts[2]	10-20 as Zn	3-5 as Zn	5-6
Polysilicate[3]	40-60 as SiO_2	10-20 as SiO_2	10-12
Molybdate	40-60 as Mo	5-20 as Mo	10-12
Anodic Inhibitor			
Orthophosphate[1]	40-60 as PO_4	15-20 as PO_4	5-6
Orthosilicate[3]	40-60 as SiO_2	10-15 as SiO_2	10-12
Copper Corrosion Inhibitor			
Tolyltriazole	10-20 as TTA	1-2 as TTA	5-6

Note: General: Maintenance dosage shifts to lower part of range as pH rises.

1. May require polymeric calcium phosphate dispersant.
2. Rarely used alone. Requires zinc solubilizer above pH 7.8.
3. Do not use if natural silica is 150 ppm or greater.

5-6 DEVELOPING AN EFFECTIVE COOLING WATER TREATMENT PROGRAM.

An effective and complete cooling water treatment program addresses many factors, including those associated with compliance and safety, protection of equipment, and cost. Compliance and safety considerations are mandatory components of the program. Achieving or exceeding minimally acceptable equipment protection at the lowest possible cost is an advisable outcome for a well-designed program. The overall cost of the treatment program includes not only the cost of chemical treatment, but also the costs of water, disposal, manpower, and equipment. Development of an appropriate cooling water treatment program is dependent upon knowledge of both the specific equipment to be protected and the quality of the water to be used (source water and system water).

5-6.1 Equipment.

Corrosion inhibitors are selected based on the metallurgy of individual pieces of cooling system equipment. Typical systems include equipment components of different metals. For example, systems may include smooth and enhanced copper tube bundles, mild steel transfer piping, and galvanized cooling tower components; therefore, to select the proper corrosion inhibitor, it is important to identify all metals contacted by the cooling water. (See Table 5-10 for corrosion inhibitor selection criteria.)

5-6.2 Operational Features and Parameters.

Operational features and parameters of the cooling water system must be known to select the proper scale and deposit inhibitors. This requirement refers to operational parameters such as maximum temperature, minimum velocities, usage patterns, and whether or not layup periods occur. The best chemical treatment programs cannot overcome the stresses of poorly operated systems. A good example of system stress is intermittent chiller operation that allows for SS accumulation (deposits) in chiller tube surfaces due to low flow or lack of flow. This situation creates a strong potential for under-deposit corrosion and for MIC that the chemical treatment may not be able to overcome completely. Stagnant water can also cause deposits and corrosion. High water temperatures can cause scale. The maximum water temperature should be known so that the proper scale-control method can be used.

5-6.3 Water Quality.

Water quality within the cooling water system is a critical consideration. The source may be potable or reuse or recycled water. The various water constituents must be known so appropriate water treatment chemicals can be selected for controlling specific water quality parameters.

5-6.4 Cooling Water Treatment Programs.

5-6.4.1 Categories.

For the purpose of developing a water treatment program, cooling tower recirculating water systems can be divided into three basic categories:

- Small-sized towers – capacity less than 25 tons (88 kilowatts)
- Medium-sized towers – 25 to 100 tons (88 to 352 kilowatts)
- Large-sized towers - greater than 100 tons (352 kilowatts)

The water treatment program selected for cooling tower systems will vary depending on the size of the tower (among other factors). Treatment program considerations are described in paragraphs 5-6.5 and 5-6.6 for small-, medium-, and large-sized towers, respectively.

5-6.4.2 Cycles of Concentration (COC).

The COC of small, medium, and large cooling towers may be controlled by blowdown, either automatic or manual, to avoid the high levels of silica and calcium salts that can lead to scale. If the cooling tower is not chemically treated, the COC should be adjusted to be slightly less than the lowest allowable COC value based on all scale-forming water ingredients (see paragraph 5- 3.3). The use of chemical treatment permits a higher

COC, which is usually limited by either the chemical effectiveness or the water treatment control.

EXAMPLE: An untreated cooling tower system can operate at 10 COC based on the level of silica without scale forming, but can operate at only 2 COC based on the level of calcium carbonate. Accordingly, the tower system should be operated at a maximum of 2 COC. The system can likely be operated at 5 to 6 COC when an effective chemical treatment is applied and maintained to control calcium carbonate.

5-6.5 Treatment Program for Small Cooling Towers.

Typically a small cooling tower will have a rating of less than 25 tons (88 kilowatts). The treatment program used for small towers should be designed to be simple to control and easy to apply, with very little operator attention required. This does not mean that no attention is required, only less than that required for medium-sized systems. The treatment program for small systems is shown in Table 5-12.

Table 5-12 Small Cooling Tower Treatment Program

Parameter	Method
COC	Do not exceed COC limits for untreated water
Scale and corrosion program	Dry, slowly soluble, phosphate compound
Microbiological program	Dry, slowly soluble, oxidizing biocide
SS	Filtration and periodic wash downs, as required

5-6.5.1 Treatment.

Small systems can be treated with a low dosage (5 to 10 ppm) of a slowly soluble phosphate chemical (sodium/calcium polyphosphate) by placing a nylon mesh bag containing the product into the cooling tower. The product, if applied in this manner, will usually provide adequate scale and corrosion control. Microbiological control can be obtained by use of a dry, pelletized, oxidizing biocide, such as bromo- chlorohydantoin or isocyanuric acid plus sodium bromide (see paragraph 5-4.4.1).

Either of these biocides can be fed continuously via a feeder or suspended in a mesh bag in the cooling tower water. The cooling tower sump should be kept clean of SS and other debris by use of a filter and periodic wash downs.

5-6.6 Treatment Program for Medium and Large Cooling Towers.

The chemical treatment program for these cooling tower systems (typically greater than 25 tons [88 kilowatts]) requires sufficient, regular testing as well as water and chemical control to protect the equipment in contact with the cooling water. Usually treatment includes control of scale, fouling, microbiological growth, and corrosion. The composition of an optimum chemical treatment program for cooling towers on a military installation depends on the quality of water available, the operating conditions of the cooling system, and the environmental constraints placed on treatment chemicals in the blowdown water (effluent discharge limitations). Conditions at a particular installation may require variation of the quantity or mix of the chemicals suggested in Table 5-13.

Table 5-13 Treatment Programs for Medium and Large Cooling Towers.

Parameter	Approach
COC	Target a minimum of 3 COC (ideally 5 COC) that the chemical treatment will allow.
Corrosion control	1. Use of cathodic corrosion, possibly supplemented with anodic inhibitors for mild steel. If a galvanized cooling tower is present, use a polysilicate or low-level phosphate while keeping pH in the range of 8 to 9. 2. Copper corrosion inhibitor should be used for all copper tubes and especially for enhanced and super-enhanced copper tubing.
Scale control	Phosphonate/polymer program, augmented by a phosphate dispersant if phosphate corrosion inhibitor is used.
SS	Polymer dispersant coupled with adequate flow. Avoid no- flow conditions in heat exchangers as much as possible. Mechanical filtration and routine physical sump cleaning recommended.
Microbiological control	1. Primary biocide: oxidizing biocide using continuous feed or slug feed as an alternate. 2. Secondary biocide: non-oxidizing biocide using slug feed, as required.

5-6.6.1 Treatment.

Medium and large cooling towers are usually, but not always, treated with a liquid formulation containing both scale inhibitors and corrosion inhibitors. These are often simply referred to as an "inhibitor.” Inhibitor products are usually fed on a continuous basis using automated control and feed equipment. The concentration of these formulated products varies greatly from vendor to vendor. Biocides are usually, but not always, liquid products. It is common to use an oxidizing biocide as a primary biocide and a non-oxidizing biocide as a secondary biocide, used as needed to control bacteria and other biological growth. Oxidizing biocides can either be fed continuously at a low level or dosed periodically at a higher level. Non-oxidizers are dosed as needed and only when oxidizing biocides are either ineffective or not used at all.

5-6.6.2 Testing.

Testing should be done regularly to insure that COC, chemical levels, and bacteria levels are within the targeted control range. This requirement could demand a testing frequency of three times per week, or even daily.

5-6.7 Cooling Tower Operator Duties.

If detected early, problems associated with scaling, corrosion and fouling in a cooling tower system can be minimized by corrective action. Some of the things the operator should look for when on-site are described below.

5-6.7.1 Cooling Tower Distribution Deck.

It is important to look for the presence of algae, debris, or anything that has plugged water distribution holes causing an uneven water flow through the tower, thus lowering tower efficiency. Clean plugged holes and replace damaged water distribution spray nozzles. In addition, look for the presence of algae deposits. If algae deposits are present, increase the level or frequency of biocide or algaecide treatment, and cover the deck if uncovered.

5-6.7.2 Cooling Tower Fill, Air Intake Slats, and Basin.

5-6.7.2.1 Scale Deposits on Cooling Tower Fill.

The presence of deposits, particularly on cooling tower fill, can be established by removing some fill to determine if partial plugging has occurred. Scale can range in color from white to gray or reddish depending on the scale composition. Scale formation on the cooling tower fill usually indicates a severe scaling situation. If possible, obtain a sample of the scale for analysis and, based on the result, select a scale inhibitor for that specific scale.

5-6.7.2.2 Scale Deposits on Air Intake Slats.

Scale can form on the air intake slats of a cooling tower. This buildup is due mostly to water splashing and evaporating, causing deposition of soluble salts or minerals. This situation does not indicate a serious problem. These deposits can be, and should be, washed off periodically, but ideally not into the cooling tower basin. Chemical treatment can provide some reduction in the occurrence deposits.

5-6.7.2.3 Slime Deposits.

Slime deposits (microbiological) can sometimes be detected by feeling below the water level on the distribution deck and on the walls of the cooling tower basin. Most microbiological growth will have a slimy feel. If slime deposits are present, increase biocide frequency or increase the dosage.

5-6.7.2.4 Suspended Solids.

The purpose of a dispersant is to keep particulate solids in suspension and to prevent them from settling or from adhering to heat transfer surfaces. Adequate water flow is required to prevent them from settling. Particulate solids in suspension are removed with the blowdown water. The tower water should be turbid if the dispersant is doing its job. Keep the cooling tower sump clean of SS by cleaning periodically and using a filter.

5-6.7.3 Corrosion Test Coupons.

When removing corrosion coupons, always note and record the visual appearance with regard to the presence of scale, rust, or biomass. Take photographs of the corrosion coupons. Submit (or evaluate) coupons for corrosion rate and for the type of corrosion that is occurring.

5-6.7.4 Inside Surface of Heat Exchanger Tubes.

To effectively examine the inside (water-contacted) surfaces of heat exchanger tubes, a boroscope is needed because only a few inches of the interior can be seen visually using a flashlight. Scale deposits, typically hard and tightly adhered to the tube surface, range in color from white to gray or reddish, depending on the composition of the scale. No scale should be present. It is important to inspect heat exchanger tubes at least once per year.

Fouling-type deposits may look similar to scale deposits. Unlike scale, these deposits usually adhere loosely to the tube surface. Biomass will appear slimy and feel slippery, and will usually adhere loosely.

5-6.7.5 Chiller Performance.

Degradation of chiller performance or chiller efficiency may be a strong indication of scale or fouling problems in the chiller. If a reduction in chiller capacity occurs while cooling water is being cooled efficiently and within design parameters, then the chiller condenser section should be opened and examined. The chiller evaporator section may not contain water material scale but may be fouled with corrosion products. You should open and examine the chiller evaporator if chilled water could possibly be inadequately treated.

5-6.7.6 Cooling Tower Surfaces.

Cooling towers made of galvanized steel should be examined for white rust or possible rusty surfaces that may indicate that the galvanizing is no longer present on the metal surfaces and the steel is rusting. Cooling towers constructed of wood should be examined for wood deterioration or decay.

5-7 COOLING WATER SYSTEM START-UP AND LAYUP REQUIREMENTS.

The startup of a new cooling water system requires special consideration. Proper cooling water system layup is also important, especially for chiller tube bundles or other heat exchange equipment. For a new cooling tower system, it is important to make sure that the equipment that contacts the cooling water is clean and properly protected from initial corrosion. Also, disinfection is needed to eliminate the presence of microbiological organisms that can cause corrosion, deposits, and growth of pathogenic organisms such as Legionella bacteria. Implementation of a proper layup process is critical to prevent corrosion and microbiological growth during stagnant water conditions.

5-7.1 Stand-by Conditions.

The term “stand-by” is often applied to a chiller that is in rotation with other chillers on-line. This stand-by period could be of varying duration, from a few days to a few weeks. Rotating chillers frequently is important for minimizing stagnant conditions that lead to under-deposit and MIC corrosion. It is good practice to run the recirculation pumps through a stand-by chiller for at least 15 minutes each day to minimize corrosion. A chiller that must be left on stand-by for an extended period of weeks without recirculation should be laid up wet or dry according to procedures described in paragraph 5-7.4.

5-7.2 Common Problems during Layup or Due to Improper Initial Start-up.

Common problems that occur during layup or due to improper initial start-up include corrosion of tubes and transfer piping (sometimes to the point of failure), micro-biological growth with potential for MIC corrosion, and growth of pathogenic microorganisms.

5-7.3 Start-up of New Cooling Water Tower Systems.

5-7.3.1 Initial Cleaning.

A new cooling water tower system will contain dirt, oils, greasy films, and rust located on the metal surfaces as a result of system fabrication. A pre-operational alkaline cleaning process is required to remove the dirt, oil, grease, and rust, and to prepare metal surfaces for initial corrosion control. When galvanized steel is involved, special care must be taken so that the pH does not exceed 8.5 during the cleaning and passivation process to avoid conditions that promote white rust. The cleaning and passivating procedure for a new cooling tower system is usually part of a new system construction project and, as such, is not in the direct control of the cooling system operations personnel. Verification of the completion of these important steps is obtained from the contracting officer involved with the project. A cleaning and passivation procedure for cooling tower systems with galvanized steel is provided below. The procedure is similar for systems that do not contain galvanized steel, except that the pH restriction does not apply.

5-7.3.2 Cleaning and Passivation Procedures.

In the startup of new cooling tower systems containing complex metallurgies that include galvanized steel, follow the cleaning and passivation procedures for cooling tower systems containing galvanized steel, stainless steel, mild steel, or copper. These procedures should not be used for cleaning and passivating aluminum. Conventional chemical cleaners and typical heating, ventilation, and air conditioning (HVAC) water treatment programs use highly alkaline, high-pH water, which can initiate white rust formation on galvanized surfaces and copper tubes. Galvanized steel can simply be passivated by exposure to highly aerated water and a phosphate or polysilicate treatment. This treatment forms a zinc corrosion inhibition layer, which is a natural, dense, adherent, and protective corrosion product film. High pH (above 8.5) produces unwanted white rust that is fragile and not protective against corrosion. The following procedures are recommended.

5-7.3.2.1 Hydrostatic Testing.

Perform hydrostatic testing:

a. Inspect and remove all debris.
b. Fill the system with treated water and circulate. This should include orthophosphate or hexametaphosphate (as PO_4) at 40 to 60 ppm, and tolyltriazole (active) at 10 to 20 ppm.

5-7.3.2.2 Pre-operational Cleaning Procedure.

If the system passes hydrostatic testing, proceed immediately to this pre-operational cleaning and passivation procedure. Do not allow untreated water to be added to the system.

a. Drain and flush any debris from hydrostatic testing.
b. Dose and circulate (for 24 hours) a sufficient amount of a cleaning formula based on the volume of the system. A formulation is provided below.
c. Drain and flush the system, and clean all strainers.
d. Fill the system with makeup water and circulate for 30 minutes.
e. Take a sample of system water while it is circulating. The sample should match the makeup water supply for clarity and SS; conductivity ±10 percent; and pH ±0.3 pH units from 7.5 to 8.5.

If necessary, repeat steps a) through e) until the system water matches this description. The system should now be clean and passivated.

5-7.3.2.3 Chemical Cleaning and Passivation Formulation.

Apply this chemical cleaning and passivation formulation when the water system pH is 7.5 to 8.5; adjust pH as required. Formulation limitations may require adding separate components to keep things in solution. Other formulations may be used.

- Orthophosphate (or) hexametaphosphate (as PO4): 60 ppm
- Polyacrylate (active): 20 ppm
- Tolyltriazole (active): 10 ppm
- Sodium gluconate: 50 ppm
- Pluronic L-61 (active) (non-ionic surfactant with antifoam): 400 ppm
- Phosphate scale inhibitor: 50 ppm

5-7.3.2.4 Passivation of the System.

Supplemental corrosion inhibitors may be used in conjunction with the phosphate but are not required. Maintain and circulate the levels for the time required. After passivation, proceed to operational readiness or layup as required. Tables 5-14 and 5-15 show chemical technology used for passivation.

5-7.3.2.5 Operational Readiness.

If system operation is not required for a period of a week or more, proceed to layup. For normal operation, allow corrosion inhibitor levels to subside to maintenance levels through normal blowdown. Proceed to maintenance water treatment program.

Table 5-14 Required Chemical Technology

Inhibitor	Dosage	pH	Film Formation
Polyphosphate	40-60 ppm as PO_4	6.5-7.9	14-21 days
Orthophosphate	20-30 days as PO_4	6.5-7.9	14-21 days
Tolytriazole	10-20 days as TTA	6.5-7.9	14-21 days

Table 5-15 Supplemental Chemical Technology

Inhibitor	Dosage	pH	Film Formation
Zinc	10-20 ppm as Zn	6.5-7.5	14-21 days
Polysilicate	40-50 ppm as SiO_2	7.5-8.5	14-21 days
Molybdate	40-60 ppm as Mo	7.5-8.5	14-21 days

5-7.4 Layup of Cooling Tower Systems.

5-7.4.1 Wet Layup of Cooling Water Systems and Equipment.

Systems and system equipment such as heat exchangers, chiller tube bundles and the like can be laid up wet, but first they require a physical cleaning to remove all suspended materials. Apply corrosion inhibitors at increased dosages, usually at a level of about 4 to 5 times the normal maintenance dosage. Apply an increased dosage (within EPA limits) of a non-oxidizing biocide that has a long half-life, such as glutaraldehyde or isothiazolone.

5-7.4.2 Dry Layup of Cooling Water Systems and Equipment.

Systems and equipment can be laid up dry, although dry layup is more appropriate for a single piece of equipment, such as a chiller's condenser tube bundle or other heat exchanger. All metal surfaces must be completely dry; residual moisture is not acceptable. In humid climates you should use a desiccant such as a quicklime gel or an equivalent. Place the desiccant in as many locations as necessary and replace as required.

CHAPTER 6 CLOSED INDUSTRIAL WATER SYSTEMS

6-1 DEFINITION.

The term “closed water system” refers to a water system that is used to provide heating, cooling, or both for industrial processes or facilities. The system is sealed (closed), sometimes under pressure, and is not open to the atmosphere. No evaporation takes place and, with good operation, water is lost only minimally from the system. In general, water treatment for closed systems is much easier than for open systems. Makeup water is needed only to replace seal leakage and other incidental leakage. Because of the small makeup water requirements of these systems, they require little chemical treatment, which can be added intermittently as needed. Once properly treated, the system water does not form scale and has little or no corrosion potential. Two main types of closed water systems are used at military installations: hot water closed heating systems and chilled water closed cooling systems.

6-1.1 Hot Water Heating Systems.

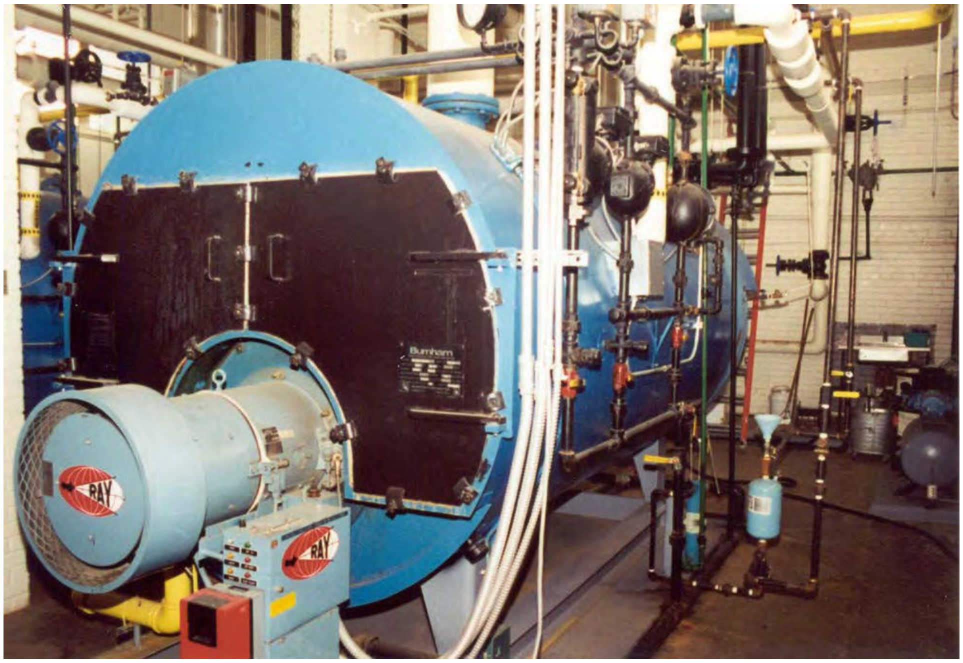
Hot water heating systems are designed to produce hot water, and although they are often referred to as hot water boilers, they are actually hot water heaters rather than boilers. For new construction, hot water heating systems are preferred over steam systems. Hot water heating systems, also known as hydronic heating systems, recirculate water to distribute heat in facilities. They operate at three temperature ranges:

- High-temperature water systems (pressurized systems with water temperatures higher than 350 F (177 C)) – no steam, only very hot water.
- Medium-temperature water systems (pressurized systems with water temperatures from 250 to 350 F (121 to 177 C)) – no steam, only quite hot water.
- Low-temperature water systems (water temperatures lower than 250 F (121 C))– no steam, only hot water.

6-1.1.1 Hot Water Boilers.

Hot water boilers can be either direct-fired (heated by combustion of gas, oil, or coal) or unfired (heat supplied by steam from a steam boiler, heated by hot water from a higher-temperature hot water system, or heated by a solar energy system). For many applications, hot water boilers are preferred over steam boilers because there are essentially no makeup water requirements and chemical treatment programs are less complex and easier to maintain. They require less manpower for operation, less maintenance, and have fewer water-related problems than steam boiler systems. Figure 6-1 shows a hot water boiler. Operate hot water boilers in accordance with UFC 3-430-07 and UFC 3-430-11.

Figure 6-1 **Hot Water Boiler**



6-1.1.2 Description of Hot Water Systems.

A typical hot water (hydronic) heating system is similar in composition to the closed cooling water system shown in Figure 6-2, except that a fired or non-fired heat exchanger is used rather than a chiller. Hot water boilers (fired and unfired) differ from steam boilers described in Chapter 4 because hot water boilers:

- Provide heated water but do not generate steam.
- Do not have deaerating heaters. (These are not required because there is essentially no makeup water requirement and thus very little air enters the system.)
- Require recirculating pumps to distribute the heated water to the processing equipment.
- Require expansion tanks that contain a cushion of steam or nitrogen.
- Do not contain a condensate return because there is no steam generated, but there is a return system.
- Do not require blowdown.
- Are fabricated with mild steel components, but also may contain copper heat exchanger tubes, particularly in unfired systems.

6-1.2 Closed Chilled Water Systems, Brine Systems, and Glycol Systems.

Closed chilled water systems, brine systems, and glycol systems supply cold or chilled water for cooling processes and air conditioning. They are water systems designed for minimal loss of water. These systems contain mild steel piping, copper heat exchangers and, in some systems, aluminum piping, stainless steel piping, cold rolled steel piping, and potentially other metals.

6-1.2.1 Closed Chilled Water Systems.

Closed chilled water systems circulate water that is cooled by refrigeration equipment. Water temperature ranges typically vary between 40 to 55° F (4 to 13° C). A typical chilled water system is depicted in Figure 6-2. Chilled water systems can have large storage capacity (1,000,000 gallons (3785 cubic meters) or higher). Chillers are shown in Figure 6-3.

Figure 6-2 **Typical Closed Chilled Water System Schematic**

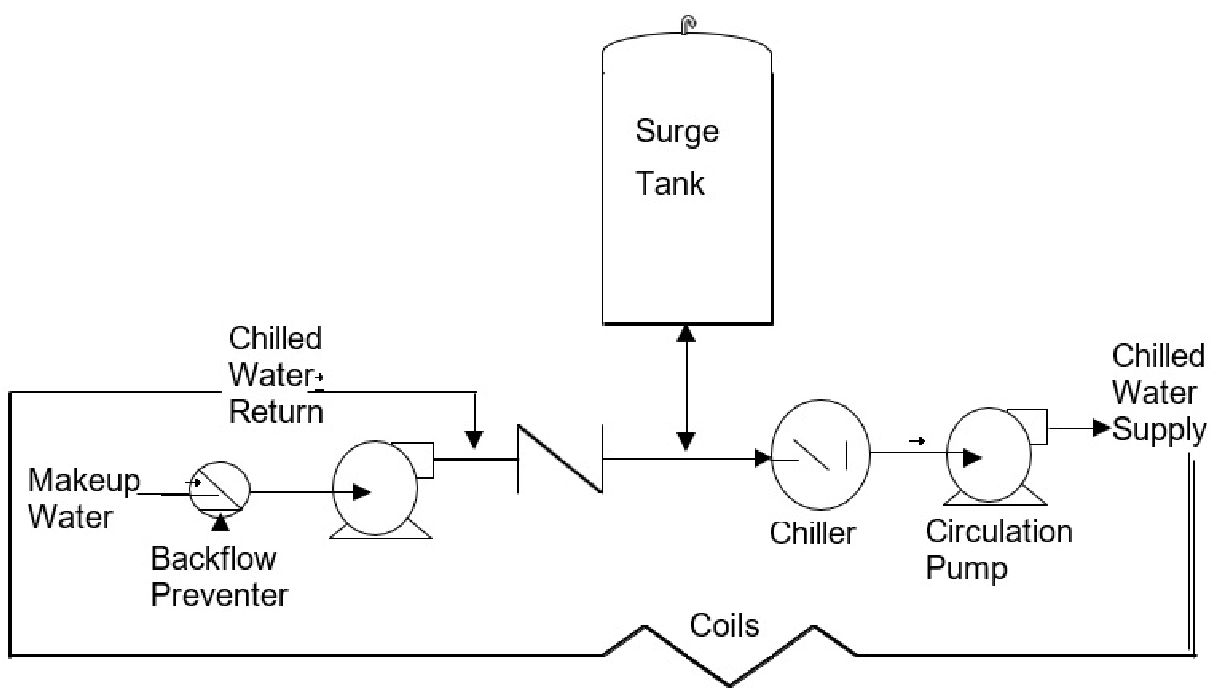


Figure 6-3 **Chillers**

6-1.2.2 Closed Brine Systems.

Closed brine systems are chilled water systems in which calcium chloride, sodium chloride, or a mixture of sodium chloride and calcium chloride has been added to the water to lower its freezing point sufficiently to maintain it as a liquid (ice-free) at temperatures of 30 to 50° F (-1 to 10° C). Brine systems have been largely replaced by glycol systems.

6-1.2.3 Closed Glycol Systems.

Closed glycol systems are chilled water systems that contain a mixture of water and glycol (ethylene or propylene) that will not freeze at the system operating temperature of 20 to 35° F (-7 to 2° C).

6-1.3 Combined Hot and Chilled Water Systems.

Some closed systems serve the dual purpose of producing circulating hot water during the cold season and chilled water during the hot season.

6-1.4 Diesel Engine Jacket Cooling Systems.

Diesel engine cooling systems are considered closed systems, even when surge tanks are open to the atmosphere.

The heat transfer from the circulating water is usually accomplished using a heat exchanger, not by evaporation. These systems have low water losses. Several of the metals used in these systems require good corrosion control. The three basic types of diesel engine cooling systems are described below.

6-1.4.1 Air-Cooled Diesel Cooling Systems.

Air-cooled diesel cooling systems are used on most small engines as well as some large engines. The jacket water is circulated through an air-cooled radiator. Antifreeze must be used in these systems when radiators are exposed to low-temperature atmospheric air or when the water temperature exceeds the boiling point (212° F (100° C))

6-1.4.2 Water-Cooled Diesel Engine Cooling Systems.

Water-cooled diesel engine cooling systems are used mainly on large engines. The jacket cooling water passes through a heat exchanger, rather than a radiator, where a separate cooling water loop removes the heat from the jacket cooling water. These systems commonly use antifreeze.

6-1.4.3 Vapor-Phase Diesel Engine Cooling Systems.

Vapor-phase diesel engine cooling systems, also called ebullient systems, use water that is heated to a temperature at the boiling point or above the boiling point for pressurized systems. Steam is formed from the cooling water as it removes heat from the system. The steam produced in this way can be recovered and used for space heating. This type of system requires significant amounts of makeup water and chemical treatment.

6-2 WATER TREATMENT FOR CLOSED SYSTEMS.

Water treatment programs for both closed hot water and closed chilled water systems are developed primarily to control corrosion, although the programs may also control deposition and microbiological organisms. If needed, scale deposition can be prevented by external treatment (as with ion exchange softening) or can be controlled with inhibitors as described in Chapter 4. Corrosion must be completely controlled by water treatment programs. If corrosion occurs, corrosion products will eventually plug the system, resulting in decreased operational efficiency and the need for cleaning. Microbiological growth is not a concern in hot water systems, but can occur in chilled water systems and should be controlled (see paragraph 6-2.3).

6-2.1 Makeup Water Requirements.

Makeup water requirements for closed systems are very small unless there are leaks in the system (see paragraph 6-2.4). Closed systems should not be drained or purged unless there is evidence that indicates the need to remove dirty water or sludge. For proper operation, makeup water in high- temperature and medium-temperature water systems is deaerated (de-oxygenated) using both mechanical and chemical methods and is also softened. Oxygen can be removed from low-temperature water systems either chemically or mechanically to prevent oxygen-induced corrosion. Chilled water systems can require partial softening if the makeup water exceeds 250 ppm total hardness (as $CaCO3$). The makeup water requirements are monitored carefully in systems of all types (see Table 6-1). If there is an increase in the quantity of makeup water required, the leak should be found and repaired quickly. After the repair, water treatment chemicals should be replenished immediately.

Table 6-1 Makeup Water Requirements for Closed Systems

System Type	Requirement
High-temperature hot water	Softened and deaerated
Medium-temperature hot water	Softened and deaerated
Low-temperature hot water	Less than 100 ppm total hardness as $CaCO_3$
Chilled, brine, glycol	Less than 250 ppm total hardness as $CaCO_3$
Diesel engine jacket	Less than 50 ppm hardness as $CaCO_3$ Demineralization when brackish water is used

6-2.2 Corrosion Control Programs.

Five basic water treatment programs are used in closed systems:

- Sulfite-caustic soda.
- Nitrite-azole.
- Molybdate-azole.
- Nitrite-molybdate-azole blend.
- Polysilicate-azole.

The choice of which chemical treatment system to use should be based primarily on the water temperature and the metals in the system as well as the relative cost of the treatment program at the specific installation. The various water treatment programs are listed in Table 6-2 for each type of closed water system. Table 6-3 provides microbiological control monitoring guidelines for closed water systems.

Table 6-2 Selection Guidelines for Closed System Treatment

System Type	Treatment Program
High-temperature hot water	Sulfite-caustic (1)
Medium-temperature hot water	Sulfite-caustic (1)
Low-temperature hot water	Sulfite-caustic (1) Nitrite-azole Molybdate-azole Nitrite-molybdate-azole
Chilled, brine, glycol	Nitrite-azole Molybdate-azole Nitrite-molybdate-azole
Diesel engine jacket	Polysilicate-azole

NOTES: (1) Or other oxygen scavenger-caustic.

Table 6-3 Microbiological Control Guidelines for Closed Water Systems

Bacterium Type	Colony-Forming Units/ml
Total aerobic bacteria	$< 10^3$
Sulfate-reducing bacteria	Undetectable
Surface microbiological	$< 10^6$ - Undetectable

6-2.2.1 Sulfite-Caustic (or other Oxygen Scavenger-Caustic) Treatment Program.

This program is required for high- and medium-temperature closed hot water systems. It is optional for low-temperature water systems. The water is treated with sodium hydroxide (caustic soda) and with sodium sulfite. This program is suitable for water systems having temperatures up to 550 F (288 C). This chemical program is not compatible with ethylene glycol nor propylene glycol. A recommended procedure for maintenance is described below.

1. Soften makeup water unless the total hardness in the makeup water supply is less than 10 ppm. The makeup water should be dealkalized if the makeup's total alkalinity is more than 200 ppm, as CaCO3.
2. Add sodium sulfite to maintain 50 to 100 ppm sulfite (as SO3).

Add the appropriate chemical to maintain a pH of 9.0 to 10.0. A pH lower than 9.0 can be raised by adding sodium hydroxide (caustic soda). A pH higher than 10.0 can be lowered by adding sodium bisulfite.

1. Test daily to maintain pH and sulfite levels within range.
2. Deaerator can be used to help reduce incoming oxygen in high make-up systems.

6-2.2.2 Nitrite-Azole Treatment Program.

This program is not recommended for systems having water temperatures exceeding 250 F (121 C), or for (CL + SO4) concentrations>800ppm. Also, avoid nitrate-based programs if (CL + SO4) concentrations is > 800ppm. It can be used in low-temperature water and chilled water systems. Water is treated with a nitrite-borax compound to a nitrite level of 1000 ppm (as NO2). This level will require about 1.7 to 1.8 pounds (0.77 to 0.81 kilogram) nitrite- borax per 100 gallons (0.38 cubic meters) of water in the system. Most water treatment service companies offer this treatment as a formulated product. There is also a generic nitrite-borax compound product that is a premixed blend containing approximately 68 percent sodium nitrite, 10 percent borax, 17 percent sodium carbonate (soda ash) and 5 percent copper corrosion inhibitor. Adjust to a pH of 9.0 to 9.5 with sodium carbonate (soda ash), if necessary. This chemical treatment program is compatible with ethylene glycol water mixtures used for freeze protection. A recommended procedure for maintenance is described below.

1. Soften makeup water if the hardness is over 250 ppm as $CaCO_3$.

2. Add sodium nitrite-borax-azole blend to maintain a nitrite level of 600 to 1000 ppm (as NO_2) in the system.
3. Add sodium carbonate, if necessary, to maintain a pH range of 8.5 to 9.5.
4. If copper is present, maintain a minimum of 10 ppm of tolyltriazole.
5. Test after chemical addition and then monthly for pH and nitrite levels.

6-2.2.3 Molybdate-Azole Treatment Program.

This program is not recommended for systems where water temperatures exceed 250 F (121 C). Most water treatment service companies offer this as a formulated product. There is also a generic molybdate-azole compound product that is a pre-mixed liquid containing approximately 10 percent sodium molybdate, 3 percent caustic soda, and 3 percent azole (copper corrosion inhibitor). Maintain a molybdate level of 125 ppm (as Mo) and adjust pH to the range of 8.5 to 9.5 with sodium hydroxide (caustic soda). NOTE: Some restrictions may pertain to discharge of water containing molybdate. This chemical treatment program is compatible with ethylene glycol or propylene glycol. A recommended procedure for maintenance of the system consists of five steps:

1. Soften makeup water if hardness is over 250 ppm as CaCO3 (calcium carbonate).
2. Control the molybdate-azole compound to maintain a molybdate level of 100 to 125 ppm (as Mo).
3. Add sodium hydroxide (caustic soda) to maintain a pH of 8.5 to 9.5. It is likely that a buffer will be needed for pH control in this range.
4. If copper is present, maintain a minimum of 10 ppm of tolyltriazole.
5. Test monthly for proper pH and molybdate levels.

6-2.2.4 Molybdate-Nitrite-Azole Treatment Program.

This program is not recommended for use in systems in which water temperatures exceed 250 F (121 C). An effective approach for corrosion control in these systems involves a program that combines elements of the molybdate program and the nitrite program. The targeted maintenance level for the combined addition of molybdate and nitrite is about half of what either would be for individual addition. Most water treatment service companies offer this chemical combination as a formulated product. This chemical treatment program is also compatible with ethylene glycol or propylene glycol. A recommended procedure for maintenance of the system consists of five steps:

1. Soften makeup water if hardness is over 250 ppm as $CaCO_3$ (calcium carbonate).
2. Control the nitrite-molybdate-azole compound to maintain a nitrite level of 300 to 400 ppm (as NO_2), a molybdate level of 50 to 75 ppm (as Mo). Avoid this program if (CL + S O_4) concentration exceeds [(NO_2 + MO)-100]ppm.

3. Add sodium hydroxide (caustic soda) to maintain a pH of 8.5 to 9.5. It is likely that a buffer will be needed for pH control in this range.
4. If copper is present, maintain a minimum of 10 ppm of tolyltriazole.
5. Test monthly for proper pH and treatment levels.

6-2.2.5 Polysilicate-Azole Treatment Program.

This program is not recommended for systems where water temperatures exceed 250 F (121 C). This program is especially beneficial when aluminum metal is present. Aluminum is rarely found in comfort heating and cooling systems, but is sometimes found in closed process cooling water loops or diesel engine jacket systems. Aluminum will corrode at high pH, so the pH of the system water must be closely monitored if aluminum is present. This chemical treatment program is also compatible with ethylene glycol or propylene glycol. A recommended procedure for maintenance of the system consists of five steps:

1. Soften makeup water if hardness is over 250 ppm as CaCO3 (calcium carbonate).
2. Control the treatment to maintain a polysilicate level of 80 to 100 ppm (as SiO2).Maintain a pH of 7.5 to 8.9. Adjust with dilute hydrochloric or caustic as necessary.
3. If copper is present, maintain a minimum of 10 ppm of tolyltriazole.
4. Test monthly for proper pH and treatment levels.

6-2.3 Treatment and Control of Microbiological Growth.

Treatment and control of microbiological growth is a concern in chilled or closed cooling water systems. It is a particular concern if a nitrite-based corrosion inhibitor is used. Nitrite can serve as a nutrient for some bacteria. Microbiocide selection must be compatible with the corrosion inhibitor program and the pH levels in the system water. Glutaraldehyde and isothiazolone are commonly used in chilled water systems. Oxidizing biocides should not be used since they are not compatible with nitrite water treatment.

6-2.4 Identifying Water Leaks.

The best way to check for leaks in a closed water system is to periodically read and record the water usage displayed by a totalizing water meter installed in the makeup water line or to use an inert, fluorescent material indicate a leak. The florescent material can also be used to help pinpoint leaks or do leak studies. If the system does not have a water meter, the existence of leaks can be checked by testing the inhibitor concentration in the circulating water. The inhibitor concentration should be measured once per month using molybdate, polysilicate, or azole, but not nitrite. Do not depend upon the nitrite test; nitrite can be lost due to bacteria action. If nitrite is measured and its concentration has decreased while the conductivity has remained constant, biological contamination is present. If the measured values for both parameters decrease, there is a leak in the system. Borate concentration would be the best indicator of leak detection.

When the inhibitor concentration has dropped to 98 percent of the original value, about 2 percent of the system water will have been lost. If the lapsed time for this 2 percent loss is less than 4 months, the system's loss of water is excessive and any leaks should be found and eliminated. Another convenient indication of water loss is the measurement over time of a drop in conductivity. If the system water conductivity equals that of the makeup, the treatment chemical is totally absent. Inert florescent material can be added to the system and used to help pinpoint leaks, or do leak studies. Loss of the fluorescent material can be monitored in real time; such loss indicates a leak.

NOTE: A 2 percent loss over 4 months equals 0.5 percent loss per month. The accuracy of this test is limited, so if the loss for any month exceeds 1 percent, the test should be repeated. If retesting confirms the water loss, the leaks should be found and eliminated.

EXAMPLE:

a. The initial recommended molybdate concentration in chilled water systems is 125 ppm. After 4 months, the concentration is 123 ppm. Is the water loss excessive?

$$\mathbf{Loss} = \left(\frac{[\mathbf{initial - final}]}{\mathbf{initial}}\right)\mathbf{x\ 100} = \left(\frac{[\mathbf{125 - 123}]}{\mathbf{125}}\right)\mathbf{x\ 100} = \mathbf{1.6\ percent\ after\ 4\ months}$$

b. The monthly loss based on the 4-month result is calculated:

$$\mathbf{1.6\ percent\ over\ 4\ months} = \mathbf{0.4\ percent\ per\ month}$$

This loss is less than 1 percent per month and not excessive.

c. If the concentration had dropped to 123 ppm after 1 month, the loss would be:

$$\mathbf{Loss} = \left(\frac{[\mathbf{125 - 123}]}{\mathbf{125}}\right)\mathbf{x\ 100} = \mathbf{1.6\ percent\ after\ 1\ month}$$

d. The monthly loss is calculated:

$$\mathbf{1.6\ percent\ over\ 1\ month} = \mathbf{1.6\ percent\ per\ month}$$

This loss is greater than 1 percent per month, and the system should be inspected for leaks.

6-2.5 Procedures for Layup of Hot and Chilled Water Systems.

Follow the procedure for wet layup of operational boilers described in paragraph 4-5.4. Note these additional recommendations:

- For hot water systems, completely fill the hot water generator and expansion tank. Where nitrogen pressurization is used for the system, the expansion tank should not be filled.

- For all steel systems using the sulfite-caustic soda program, increase the pH to 11.7 with sodium hydroxide (caustic soda). Add sodium sulfite to a level of 100 ppm (as SO3).
- Treat chilled water systems using the nitrite-borax or molybdate-caustic soda treatments with appropriate chemicals to maintain levels required for normal operation.

Test monthly for treatment chemicals and check water levels.

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CHAPTER 7 WATER SAMPLING AND TESTING OF WATER SYSTEMS

7-1 WATER SAMPLING AND TESTING.

Water sampling and testing procedures provide information that can be used for the following purposes: to ensure the protection of the water system equipment; to prevent unexpected system failure; to provide information used to control water quality; and to verify that water treatment chemicals are maintained at the proper concentration within the system or, if not, to allow for adjustment of their concentration. Adequate chemical treatment of water systems requires that specific levels of specific chemicals be maintained in the water to provide the system with protection from corrosion and deposits. This requirement applies to both cooling and boiler water systems. The purpose of a sampling and analysis program for industrial water is to ensure and verify that the required levels of treatment chemicals are being maintained and that the water quality parameters are within the specified control ranges. The sampling and analysis program incorporates two levels of testing: in-plant routine testing used for operational purposes, and periodic independent (third-party) QA testing used for verification and oversight. When an analytical test indicates that the concentration of a given chemical is not within the limits required, the testing process must be evaluated to determine that the sampling and testing were performed properly and that the test result is valid. As part of an adequate QA/QC program, test methods, including the chemical reagents, must be checked on a yearly basis. A properly applied industrial water treatment program incorporates procedures that ensure that representative samples, which are samples that are representative of actual water system conditions, have been collected and analyzed. Safety considerations must be a priority when sampling any industrial water system (particularly boilers) and when conducting laboratory tests.

7-1.1 In-Plant Testing.

In-plant testing is used by water system operators to monitor and ensure both the proper operation of system equipment and the proper quality of the water in the equipment. Routine, appropriate, in-plant operational testing of the system waters is an essential component of a water treatment program. Routine testing of specific operational parameters and water quality criteria allows the operator to verify the adequacy of the water treatment program and to make necessary adjustments to avoid and prevent operational problems. When an analytical test indicates that the concentration of a given chemical is not within the limits required, the testing process must be evaluated to determine that the sampling and testing were performed properly and that the test result is valid. If testing data for the water quality analyses are inconsistent with that expected for the treatment method being used, the reasons must be determined. This determination can involve reanalysis and checking of the test reagents, as well as checking the accuracy of the in-plant testing results through independent QA analysis. Military installations are required to obtain water testing chemicals and equipment from commercial sources. Test procedures will be furnished with the test kits.

7-1.2 Independent QA Analysis.

To verify the accuracy of the in-plant testing, as well as to provide supplemental or additional analyses, independent (third-party) QA analytical services are incorporated as part of the plant's QA program. These services can be more complete than routine in-plant testing and can provide a more detailed analysis of the system conditions. Independent QA analysis is a useful tool for plant managers and operators to verify that their systems are being maintained properly, and is an especially important tool for government managers at sites where plant operations have been contracted out (outsourced).

7-2 COOLING TOWER WATER SAMPLING AND TESTING.

7-2.1 Cooling Water Testing Requirements.

Water samples from the recirculating cooling water systems should be tested for pH, conductivity, and inhibitor content. Calcium hardness and methyl orange (M) alkalinity may also be tested. In addition, follow the water testing requirements established by the supplier of the water treatment chemicals where appropriate. Testing parameters for the makeup water include, as a minimum, M alkalinity, conductivity, and calcium hardness. Appropriate water testing requirements and sampling frequency are summarized in Table 7-1. Periodic testing for chlorides in the recirculating water and makeup water may be required to calculate the most accurate COC in an operating system.

Table 7-1 Recommended Water Sample Frequency and Testing Requirements for Cooling Tower Systems

Water Tested	pH	M Alkalinity	Conductivity (or TDS)	Calcium Hardness	Inhibitor
Makeup water	--	1/W	1/W	1/W	--
Small CT < 25 tons (88 kW) water*	1/W	1/W	1/W	1/W	1/W
Medium CT 25-100 tons (88-352 kW) water*	2/W	2/W	2/W	2/W	2/W
Large CT > 100 tons (352 kW) water	1/D	1/D	1/D	1/D	1/D

NOTES:

C = Cooling tower.

W = Week (for example, 1/W = once per week).

D = Day (for example, 1/D = once per day).

* = Slowly soluble polyphosphate chemicals used in treatment of small and medium cooling towers should be checked at least weekly and replaced as necessary.

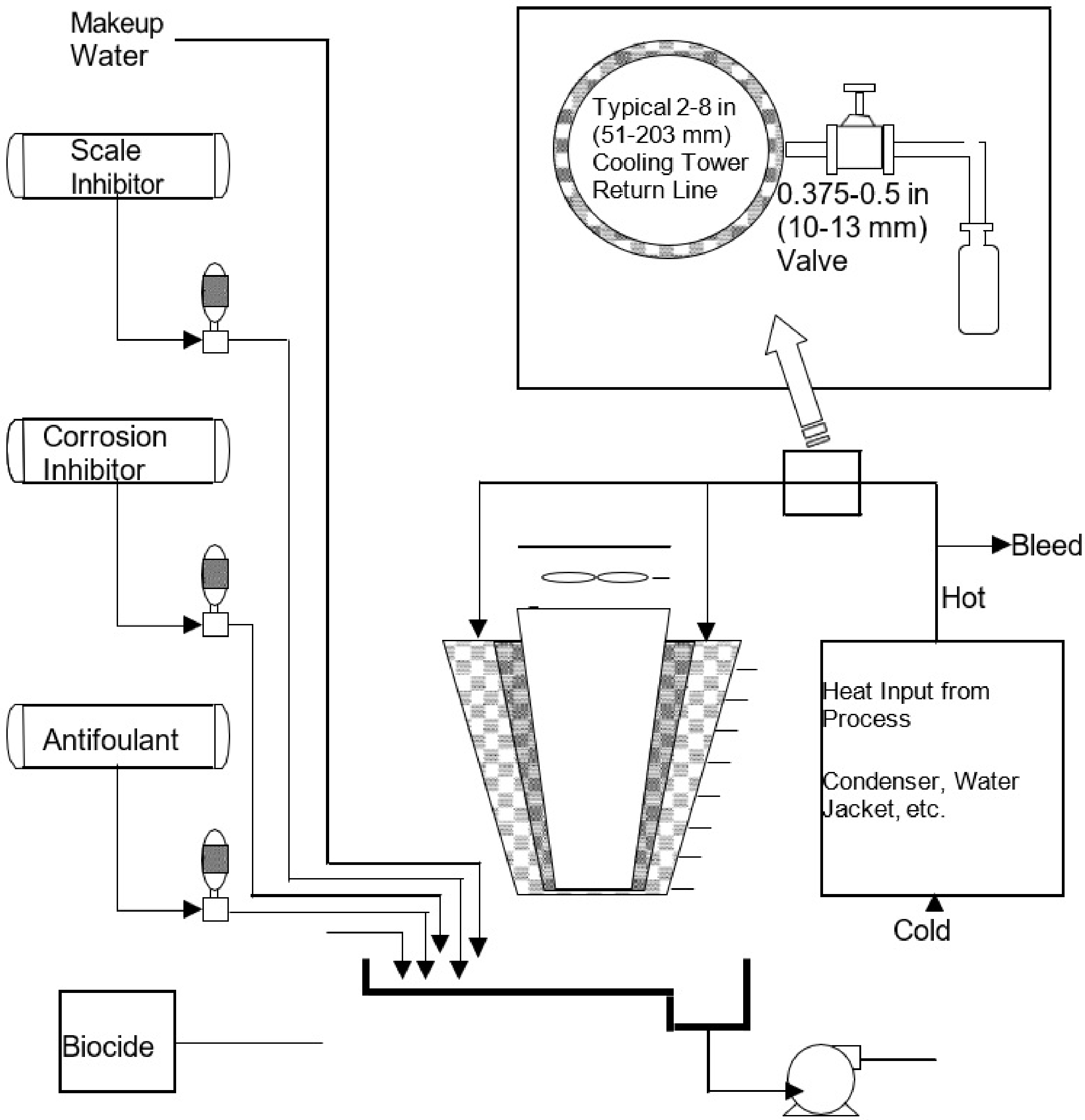
7-2.2 Frequency of Cooling Water Sampling and Testing.

Water samples of the recirculating water in small towers (less than 25 tons [88 kilowatts]) be sampled and tested at least once per week, those of medium-sized towers (88 to 25 to 100 tons (352 kilowatts)) at least 2 times per week, and those of large towers (more than 100 tons (352 kilowatts)) daily. You can establish a routine schedule that is designed to meet these goals for sampling and testing. For many cooling towers, the makeup water quality is quite consistent over time. Collection and analysis of 1 sample per week of the makeup source is usually an adequate frequency. If makeup water quality varies, increase the frequency to allow for sampling of makeup water at the same time as cooling water sampling. Always flush the water sample line prior to sampling.

7-2.3 Cooling Water Sampling.

Cooling tower water samples are collected in clean, 1-quart (1-liter) glass or plastic bottles. The bottle is capped (sealed) immediately and tested without delay (within 1 hour since some water quality will gradually change). The sample is not collected immediately after the addition of treatment chemicals but is collected after the chemicals have been allowed to mix thoroughly with the system water. Samples of the recirculating cooling water can be collected by dipping from the cold well, or can be collected from the recirculating pump discharge after the line has been flushed for 10 seconds or until no sediment remains. If these locations are inaccessible, another location may be used. Typical sampling points for an open recirculating system are shown in Figure 7-1. It is best to always collect the sample for each system in the same manner and from the same location for consistent results.

Figure 7-1 **Typical Water Sampling Points for an Open Recirculating Cooling Water System**



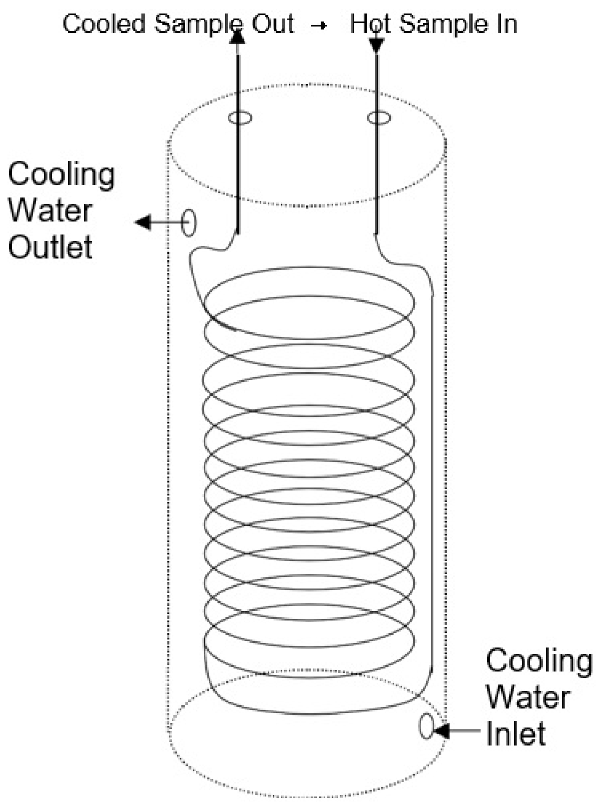
7-3 ROUTINE BOILER WATER SAMPLING AND TESTING.

Boiler water is very hot and under pressure. Caution should be exercised and appropriate safety procedures followed when collecting samples. If the boiler water is not cooled as it is sampled, part of the water will flash off as steam during the sampling process and the remaining sample will not be truly representative of the boiler water. The sample could contain a lower level of oxygen or carbon dioxide than the actual levels in the boiler water. Values of other sample constituents would be higher because less water would be present in the test sample due to the release of the steam. Use of the sample cooler described in paragraph 7-3.1 will greatly reduce the chance of the operator getting burned, and will allow a representative boiler water sample to be collected.

7-3.1 Boiler Water Sampling Cooler.

A commercially available boiler water sample cooler can be used when collecting a boiler water sample. If one is not available, then a 15 to 20 foot (4.6 to 6.1 meter) long coil of copper or stainless steel tubing 0.25 inch (76 millimeters) may be used to cool the sample. The coil can be immersed in a permanent cooling jacket as shown in Figure 7-2, or it may be immersed in a bucket of cold water, if this does not interfere with operation of the system or create a hazard. The flow of the boiler water sample through the coil must be slow enough so that the cooled boiler water sample is no more than just warm to the hand approximately 100° F (38° C).

Figure 7-2 **Boiler or Condensate Water Sample Cooling Coil.**



7-3.2 Boiler Water Sampling Procedures.

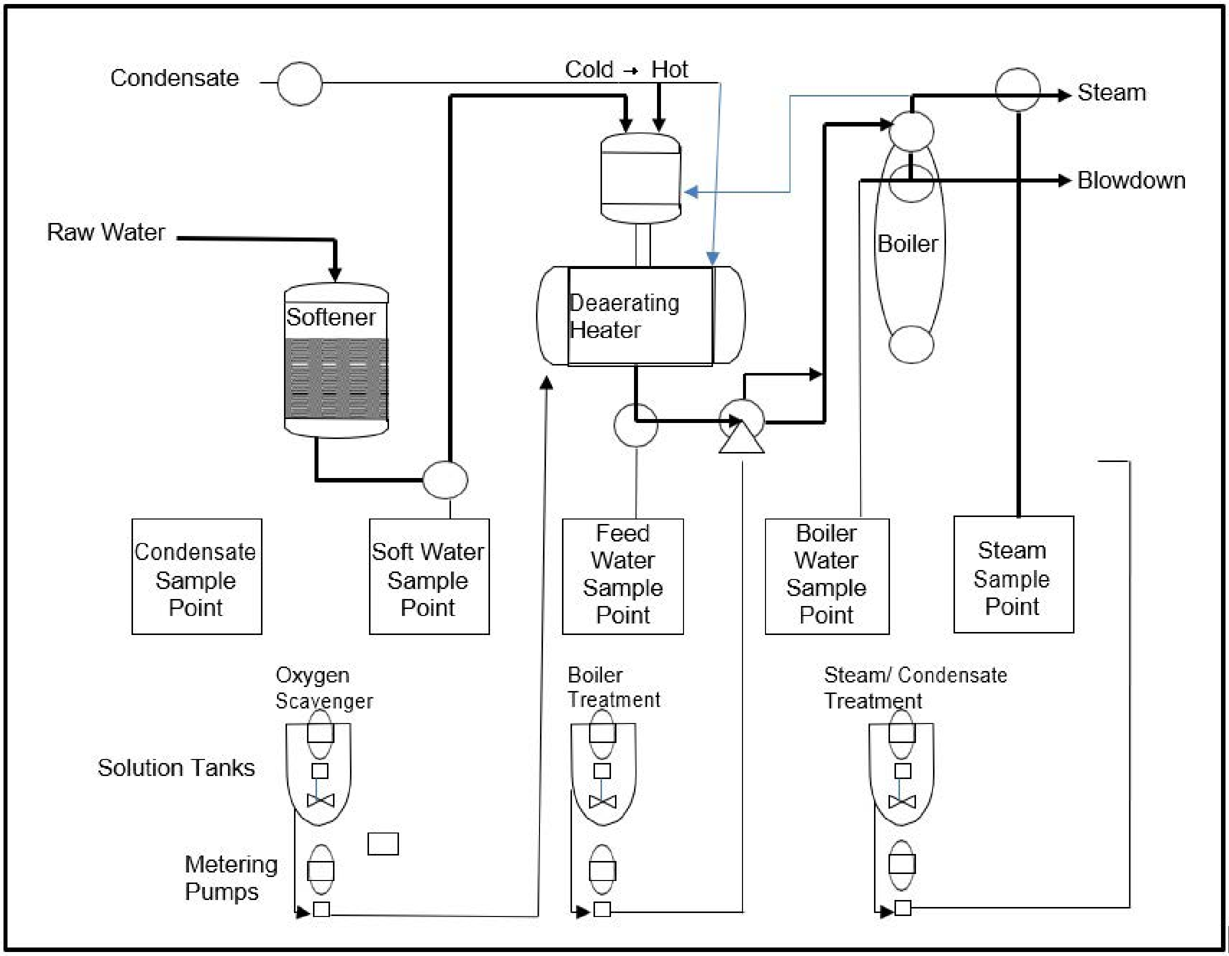
The cooling water to the jacket cooling coil is turned on before taking the boiler water sample and turned off after the sample has been collected. The coil with boiler water is flushed with several times its volume before collecting the sample to be tested. The cooled end of the boiler water sample coil is then extended to the bottom of the sample bottle and at least 1 volume of the bottle is allowed to overflow the container during the collection process. The sample collection bottle can be plastic or glass. Glass bottles are not used if the boiler is silica limited or if high silica is suspected.

7-3.3 Sampling Locations.

Typical locations for water sampling points in a steam boiler system are shown in Figure 7-3. Each sampling point has a separate cooling coil. Two or more sampling points are not connected by a single manifold to the same cooling coil because it is almost impossible to determine if one of the valves has a leak that might contaminate the sample being taken. Guidelines for sample collection are provided below.

- The makeup water sample does not have to be cooled. The sample location typically will be the output of an ion exchange unit or some other water-softening unit.
- The boiler feedwater sample is a combination of makeup and condensate return. An appropriate location for sample collection is from the discharge of the boiler feed pump. This will be a hot sample, so a cooling coil is used. Alternatively, sample collection for feedwater can be from the low-pressure deaerator outlet.
- The boiler water is very hot. Collect this sample from the continuous blowdown line between the boiler and the regulating valve if possible. You may collect it from a gauge-glass connection, if necessary. Use of a cooling coil is recommended.
- The steam condensate is hot. For small systems, collect this sample from a line that enters the deaerating heater if possible. For medium and large systems, you may need to collect condensate samples at two or more locations in the system to obtain sufficient data for calculation of the proper treatment level. When attempting to find a leak, you may need to collect condensate samples from various locations in the system. Use of a cooling coil is recommended.
- Steam is collected regularly for systems with high-quality steam requirements like those with turbines and those meeting NAVSEA steam quality requirements. Otherwise, steam samples are rarely collected. Refer to the ASME Performance Test Code (ASME PTC 19.11, Steam and Water Sampling, Conditioning and Analysis in the Power Cycle, for sampling procedures.

Figure 7-3 **Typical Locations for Water Sampling in a Steam Boiler Water System**



7-3.4 Frequency of Sampling and Testing.

The recommended sampling and testing frequency for steam boiler systems is summarized in Table 7-2.

Table 7-2 Water Sampling Frequency and Testing Requirements for Boiler Water Systems

Source of Sample	pH	Total Alkalinity* (M)	Hydroxyl Alkalinity (Causticity)	Calcium Hardness	TDS	Copper and Iron	Ortho-phosphate	Sulfite
Makeup water	--	1/W	--	1/W	1/W	--	--	--
Feedwater, small boilers (<25 hp [245 kW])	--	1/W	--	1/W	1/W	--	--	--
Feedwater, medium boilers (25-150 hp [245–1470 kW])	--	2/W	--	2/W	2/W	--	--	--
Feedwater, large boilers (>150 hp [1470 kW])	--	1/D	--	1/D	1/D	--	--	--
Boiler water, small boilers	1/W	--	1/W	--	1/W	--	1/W	1/W
Boiler water, medium boilers	2/W	--	2/W	--	2/W	--	2/W	2/W
Boiler water, large boilers	1/D	--	1/D	--	1/D	--	1/D	1/D
Condensate return (small boilers)	1/W	--	--	As needed	1/W	1/Q	--	--
Condensate return (medium boilers)	2/W	--	--	As needed	2/W	1/Q	--	--
Condensate return (large boilers)	1/D	--	--	As needed	1/D	1/Q	--	--

NOTES:

W = Week (for example, 1/W = once per week)

D = Day (for example, 1/D = once per day)

Q = Quarter (for example, 1/Q - once per 3 months)

* = Feedwater alkalinity only for boilers that use dealkalizers.

7-3.5 Boiler Feedwater Sample.

Boiler feedwater samples should be collected once per week for small boilers (less than 25 horsepower/245 kilowatts), at least 2 times per week for medium boilers (25 to 150 horsepower/1470 kilowatts), and daily for large boilers (greater than 150 horsepower/1470 kilowatts). The samples should be tested for M alkalinity, conductivity, and calcium hardness.

7-3.6 Condensate Water Sample.

Condensate water samples should be collected once per week for small boilers (less than 25 horsepower/245 kilowatts), at least 2 times a week for medium boilers (25 to 150 horsepower/1470 kilowatts), and daily for large boilers (greater than 150 horsepower/1470 kilowatts). The samples should be tested for pH and conductivity. If the conductivity is greater than 35 micromhos, the sample should be tested for calcium hardness. If applicable based on the metallurgy of the system, the condensate samples should be tested for iron and copper on a quarterly basis.

7-3.7 Boiler Blowdown Water Sample.

Boiler blowdown water samples should be collected for small boilers (less than 25 horsepower/245 kilowatts) once per week, for medium boilers (25 to 150 horsepower/1470 kilowatts) at least 2 times per week, and for large boilers (greater than 150 horsepower/1470 kilowatts) daily. The samples should be tested for hydroxyl (OH) alkalinity (causticity), neutralized conductivity, scale treatment chemicals (for example orthophosphate), and sulfite.

7-3.8 Boiler Water QA Analysis.

The components of a boiler water QA program are described in paragraph 2-1.10.1. Appropriate boiler water sampling requirements are described below.

- Each operating boiler plant equipped with hot water or steam boilers and having one or more boilers of 3.3 million BTU per hour or 100 horsepower (980 kilowatts) or greater capacity may submit a boiler water sample for QA once per month to an independent QA laboratory or to the contractor providing the service to the military. These QA contractors are independent experts in the field of boiler and cooling water treatment and interpretation of sample analysis data.
- Each operating boiler plant equipped with hot water or steam boilers of less than 100 horsepower (980 kilowatts) capacity submits a boiler water sample for QA once every 3 months to an independent QA laboratory or to the contractor providing the service to the military.
- For all high-pressure (greater than 15 pounds per square inch gauge (103 kilopascals)) boilers and for low- pressure boilers treated with caustic, phosphate, tannin, and sodium sulfite, the boiler water sample size is a 1-liter plastic bottle, or as required by the QA laboratory.
- For low-pressure boilers (less than 15 pounds per square inch gauge (103 kilopascals)) treated only with caustic, the boiler water sample size is a 0.12-liter (4-ounce) plastic bottle, although a 1-liter plastic bottle may be used.
- For hot water boilers, the boiler water sample size is a 1-liter plastic bottle, or as required by the contract laboratory.

- Boiler water sample shipping containers and bottles used for submitting boiler water check samples can be obtained by request to the contract laboratory. Shipping containers for high-pressure boiler water samples are designed for shipping a 1-liter plastic bottle. Shipping containers for water samples from low-pressure boilers treated with caustic soda are designed for shipping a 0.12-liter plastic bottle. Pack the bottle carefully so it will not leak during shipping. A completed information data sheet must be enclosed in each sample shipping container shipped to the laboratory.

7-4 WATER SAMPLING AND TESTING FOR CLOSED HOT AND CHILLED CIRCULATING WATER SYSTEMS.

The recommended testing frequency for these systems is summarized in Table 7-3, with additional information provided below.

Table 7-3 Water Sampling and Testing Requirements for Closed Hot and Chilled Circulating Water Systems

System	pH	Sulfite	Nitrite	Molybdate	Total Hardness	Total Alkalinity
HTW with caustic-sulfite treatment	1/day	1/day	--	--	--	--
Closed MTW & LTW hot water w/nitrite-borax treatment	1/mo	--	1/mo	--	--	--
Closed MTW & LTW hot water w/molybdate treatment	1/mo	--	--	1/mo	--	--
Chilled water & brine; w/molybdate treatment	1/mo	--	--	1/mo	--	--
Chilled water & brine w/nitrite-borax treatment	1/mo	--	1/mo	--	--	--
Diesel jackets w/molybdate treatment	1/mo	--	--	1/mo	--	--
Diesel jackets nitrite- borax	1/mo	--	1/mo	--	--	--
Ion exchange feedwater	--	--	--	--	1/week	--
Ion exchange outlet	--	--	--	--	3x/day	--
Dealkalizer feedwater	--	--	--	--	--	1/week
Dealkalizer outlet	--	--	--	--	--	3x/day

7-4.1 Sampling and Testing of Makeup Water.

The makeup water for boiler systems, chilled water systems, and diesel engine jacket water systems usually comes from an ion exchange unit or a dealkalizer.

The recirculating water from high-temperature water systems and from systems that use the sulfite-caustic soda treatment program is tested once per day for pH and sulfite (see paragraph 7-2.2.1).

Recirculating chilled water and hot water treated with the nitrite-borax or molybdate programs is tested once per month for either molybdate or nitrite, depending upon the chemical in use (see paragraph 7-2.2.2, 7-2.2.3 and 7-2.2.4). The system pH is tested once per month and on the day following chemical additions.

7-4.2 Ion Exchangers and Dealkalizer Water.

The recommended water testing frequencies for these systems are summarized in Table 7-3, with additional information provided below.

7-4.2.1 Influent Water Testing.

Ion exchange influent water is tested once per week for total hardness. Dealkalizer influent water is tested once per week for total (M) alkalinity.

7-4.2.2 Effluent Water Testing.

Effluent water from these systems is tested for total hardness either once per day or once per shift (3 times a day) depending on the frequency of regeneration; more frequently if the frequency of regeneration is excessive. The appropriate frequency (cycle length) will depend upon feedwater hardness, bed size, resin type, strength of regenerant, and flow rate.

7-4.2.3 Sampling Location.

The location of the water sample point is an important consideration for ensuring that a representative water sample is obtained. Care must be taken to avoid collecting a sample that is a mixture of influent and effluent water on ion exchange units that use automatic regeneration and multi-port valves.

7-4.2.4 Brine Testing.

The brine used for regeneration is sampled periodically and tested with a hydrometer to measure its strength. The sodium chloride brine should be as near 100 percent saturation as possible (approximately 28 percent by weight) for efficient softener regeneration.

7-5 WATER TESTING.

Routine and appropriate testing of the system water is an essential component of a water treatment program. Water testing provides information that can be used: to ensure the protection of the water system equipment; to prevent unexpected system failure; to provide information used to control water quality; and to verify that water treatment chemicals are maintained at the proper concentrations within the system or, if not, to allow for adjustment of their concentrations. An adequate testing program requires proper recordkeeping of the data that are used for assessing the effectiveness of the water treatment program. If testing data for the water quality analyses are inconsistent with that expected for the treatment method being used, determine the reasons. This determination can involve reanalysis and checking of the test reagents. If the test results are correct, the water quality and water treatment program must be re-evaluated and modified, if necessary. Paragraph 7-6 describes interpretation of water test results.

7-5.1 Water Sample Testing Methods.

Water tests are usually performed with test kits obtained from commercial sources. Test kits can be used to test for: alkalinity- phenolphthalein (P); alkalinity-methyl orange (M or total); alkalinity-hydroxyl (OH) or “causticity”; conductivity; tannin; pH; hardness (total and calcium, magnesium by difference); phosphate (ortho and total); sulfite; nitrite; chloride; molybdate; phosphonate; chlorine or bromine (total and free); total iron; and total copper.

7-5.2 Corrosion Testing.

Corrosion test specimens or corrosion testing instruments can be used to monitor the rate of corrosion. Corrosion test information can also be used to evaluate how well equipment is being protected from corrosion by the water treatment program. The degree of corrosion (if any) that is occurring in large or critical heating and cooling systems should be determined at all military installations.

Consider the following information when developing a program of corrosion testing:

7-5.2.1 Corrosion Test Coupons.

Corrosion test coupons are usually used as corrosion test specimens for open and closed cooling systems, closed hot water systems, and domestic water systems (see Appendix C).

7-5.2.2 Corrosion Pipe Inserts.

Corrosion pipe inserts are often used as corrosion test specimens in steam condensate return systems (see Appendix D).

7-5.2.3 Commercial Resources for Testing.

Corrosion test coupons and testing analysis services can be obtained from commercial sources. Corrosion pipe insert assemblies for steam condensate systems and analytical evaluation of the test inserts should be obtained from a QA laboratory or contractor under contract with the military. Guidance for corrosion testing is provided in Appendices C and D.

7-5.2.4 Corrosion Test Results.

Corrosion test results are usually determined as a rate of corrosion penetration into the metal and reported in mils metal loss per year (mpy). A one-thousandth [0.001] of an inch (mil is 2.5-thousandths of a centimeter); thus, the corrosion rate of 10 mpy means that the thickness of a piece of metal is reduced by 10 x 0.0025 = 0.025 centimeter per year (0.01 inch per year). If the metal coupon being studied is 0.1588 centimeter (0.0625 inch) thick, this means that it will be completely dissolved or corroded in just over 6 years. Corrosion rates may also be expressed in millimeters per year (mmpy) corrosion. The relationship between mpy and mmpy is: 1 mpy = 0.0254 mmpy; 1 mmpy = 39.4 mpy. Corrosion also may be given as a weight loss in milligrams per square decimeter per day (mdd). For mild steel, the relationship is: 1 mdd = 0.2 mpy or 1 mpy = 5 mdd.

7-5.2.5 Testing Instruments.

A variety of electronic instruments are available to monitor and record corrosion rates. These instruments are installed and maintained by individuals who have been adequately trained for these activities. The most commonly used instrument of this type is a linear polarization corrosion instrument that provides instantaneous corrosion measurement and is often used for troubleshooting.

7-5.2.6 Heat Transfer Corrosion Test Equipment.

Heat transfer corrosion test equipment is used to determine the corrosion rate under heat transfer conditions. This type of equipment can more accurately determine corrosion in chillers.

7-6 INTERPRETATION OF RESULTS FROM WATER TESTS.

Adequate chemical treatment of water systems requires that specific levels of specific chemicals be maintained in the water to provide the system with protection from corrosion and deposits. This requirement applies to both cooling and boiler water systems. When an analytical test indicates that the concentration of a given chemical is not within the required limits, the testing process must be evaluated to determine whether sampling and testing were performed properly and the test result is valid. As part of an adequate QA/QC program, test methods, including the chemical reagents, must be checked on a routine basis. Consider these guidelines when evaluating test results:

- When the (valid) test results indicate a treatment level that is too low, the chemical addition program should be evaluated and the appropriate adjustment made; this normally means increasing the chemical feed rate by 10 percent or less. If adjustments to the treatment program do not correct the situation, then the entire water system may need to be evaluated to determine the nature of the problem. You can obtain assistance through the military offices suggested in paragraph 2-1.10.2.

- When the (valid) test results indicate that a given level of treatment chemical is too high, the chemical addition program should be evaluated. Exercise caution when reducing chemical feed rates to adjust the level of a treatment chemical that exceeds the required limits. The chemical feed rate should not be reduced more than 5 to 10 percent at any one time.
- When the test results indicate that the level of hardness in the water is higher than the required level, the makeup water treatment system should be investigated and problems identified, including other possible incoming sources of water hardness into the system.

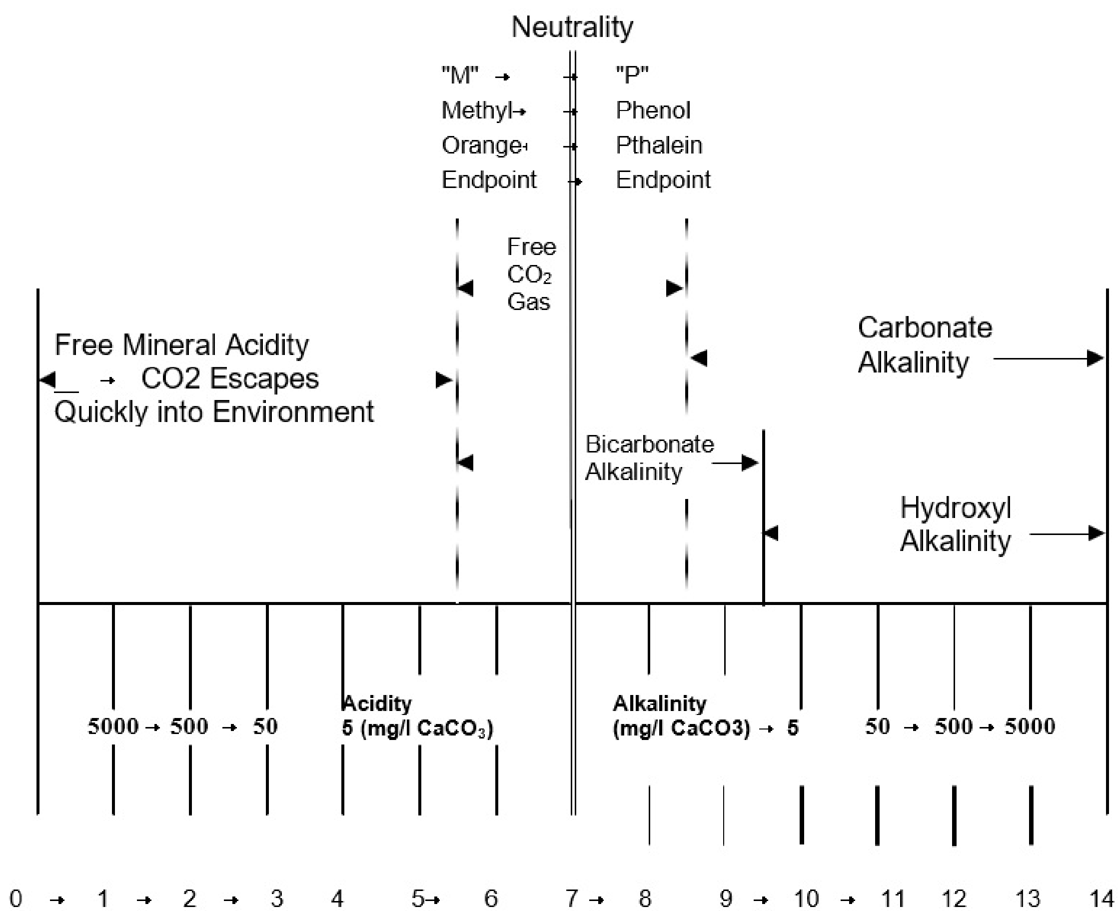
7-6.1 Alkalinity Test Relationships.

7-6.1.1 Sources of Alkalinity.

The three basic sources of alkalinity in water result from the bicarbonate ion (HCO $^{-}$), the carbonate ion (CO $^{-}$), and the hydroxyl ion (OH^{-}).

The amount of each of these ions in water can be determined by titration with an acid to specific pH levels (end points) using phenolphthalein (P alkalinity) or methyl orange (M alkalinity) indicators to their particular titration end-points. The relationship between pH and the various types of alkalinity is shown in Figure 7-4.

Figure 7-4 **Acidity, Alkalinity, and pH Ranges.**



7-6.1.2 Relationship of P, M, and OH Alkalinities.

Test procedures for determining P and M alkalinities are included in commercially available test kits. The OH^- alkalinity can be determined by a specific test or it can be estimated by knowing the P and M alkalinity values. The OH^- alkalinity is contributed by the hydroxyl ions (OH^-) in the water, and is also known as "caustic alkalinity" or "causticity." The relationship between the measured P and M alkalinity values and the level of hydroxyl, carbonate, and bicarbonate forms of alkalinity are shown in Table 7-4 and described below.

Table 7-4 Alkalinity Relationship Based on P and M Tests

Situation	Hydroxyl	Level of Alkalinity Contributed by Carbonate	Bicarbonate
P = M	M	0	0
P > ½M	2P – M	2 (M - P)	0
P = ½M	0	M	0
P < ½M	0	2P	M - 2P
P = 0	0	0	M

EXAMPLE:

If P = 86 ppm as CaCO3, and if M = 118 ppm as CaCO3 Then, situation 2 (from Table 7-4) exists (P > ½M)

or P is greater than ½ of M);

Hydroxyl = 2P - M = (2 x 86) - 118 = 54 ppm as CaCO3 Causticity = hydroxyl alkalinity as CaCO3 ÷ 3

= 54 ÷ 3 = 18 ppm as OH^-

Carbonate = 2(M – P) = 2 X (118 - 86)

= 64 ppm as CaCO3 Bicarbonate = 0 ppm as CaCO3

Check: Total = 54 + 64 + 0 =118 ppm M alkalinity as CaCO3

Review of each situation in Table 7-4 provides this information, with situation:

1. The tests for P alkalinity and M alkalinity are equal. This means that all of the alkalinity is due to hydroxyl ions. There is no carbonate or bicarbonate present. (This is rare but occurs when a caustic solution is not exposed to air.
2. The P alkalinity is greater than one-half of the M alkalinity. This indicates that there is hydroxyl and carbonate alkalinity, but no bicarbonate alkalinity.

3. The P alkalinity is equal to one-half of the M alkalinity. This indicates that all the alkalinity is due to carbonate. There is no bicarbonate alkalinity, and the hydroxyl alkalinity is insignificant.
4. The P alkalinity is less than one-half of the M alkalinity. This indicates that carbonates and bicarbonates are present.
5. The P alkalinity is zero. The M alkalinity is due to bicarbonates only. No hydroxyl or carbonate alkalinity are present.

7-6.2 pH (Hydrogen Ion Concentration).

7-6.2.1 Meaning of pH.

The pH (value) is a measure of the acidity or alkalinity of water. The test specifically measures the concentration of hydrogen ions in the water. Neutral water will have a pH of 7. Water with a value of less than pH 7 is considered acidic, while water with a value greater than pH 7 is considered alkaline. Examples are shown below.

- Common pH values for materials on the acid side include: spinach with a pH of approximately 5.5; orange juice and most soft drinks with a pH of approximately 3.5; lemon juice with a pH of approximately 2.2; and 0.1 normality (N) sulfuric acid with a pH of 1.2.
- Common pH values of materials on the alkaline side include: sodium bicarbonate with a pH of approximately 8.4; milk of magnesia with a pH of approximately 10.5; household ammonia with a pH of approximately 11.5; and 0.1 N sodium hydroxide with a pH of 13.0.

The pH scale is logarithmic. A pH of 4 is 10 times as acidic as a pH of 5 and 100 times as acidic as a pH of 6. This is important to consider when adding a strong acid to a system, because 0.1 N sulfuric acid will have more than 1 million times the acidity of neutral water.

7-6.2.2 Relationship to Causticity.

When the pH of water exceeds a value of 9.6 to 9.8, a measurable concentration of hydroxyl ions (OH^-) is present in the water. As the hydroxyl alkalinity (causticity) increases, the pH of the solution also increases. The relationship between causticity and pH is shown in Table 7-5.

Table 7-5 Relationship Between Causticity and pH

pH	Hydroxyl Alkalinity (ppm)	
	as $CaCO_3$	as OH
9.0	0.5	0.17
9.5	1.6	0.54
10.0	5	1.70
10.2	8	2.72
10.5	16	5.44
10.6	20	6.80
10.7	25	8.50
10.8	33	11.2
10.9	40	13.6
11.0	50	17.0
11.1	63	21.4
11.2	79	26.9
11.3	100	34.0
11.4	126	42.8
11.5	158	53.7
11.6	199	67.7
11.7	250	85.0
11.8	315	107
11.9	397	135
12.0	500	170

7-6.3 Conductivity and TDS.

Each of these water quality parameters is a measure of the amount of soluble minerals present in the water. Conductivity is measured with an electronic instrument based on the flow of an electrical current through the water sample. The measurement of TDS requires evaporation of a fixed amount of water to determine the weight of the remaining minerals (like the TDS in the water). The conductivity instrument may report the mineral content as micromohs or as dissolved solids. In neutral or alkaline waters, there is no consistent relationship between conductivity and TDS since each ion has its own specific conductivity. The hydroxyl ion has the highest conductivity of all the common ions found in boiler water. If alkaline boiler water is acidified to the phenolphthalein end-point with an organic acid, such as gallic acid, which neutralizes causticity but does not contribute to conductivity, the TDS is approximately equal to two-thirds of the neutralized conductivity in micromhos. This is known as “neutralized conductivity." In boiler water, a factor of 0.7 can be used for water treated with synthetic polymers as a sludge dispersant, and from 0.7 to 1.0 for water treated with Quebracho tannin, depending on the amount of tannin in the water. Conductivity and TDS are used to determine the COC and the potential for scale formation (see Chapter 4).

7-7 IN-PLANT LABORATORY WATER TESTING REQUIREMENTS.

The water tester should be provided with a separate working space to perform the required routine water control tests. This space can be a separate room having a suitable work bench, a sink and cabinet, a distilled or deionized water source, and adequate ventilation, heating, and cooling. Standard white fluorescent lighting at reading intensity can be provided. A record file for test results and references can be located in the test area.

7-7.1 Recommended Laboratory Equipment.

At each location, laboratory equipment should be selected so that all routine water tests can be performed. The equipment list can include standard glassware such as beakers, test tubes, graduated cylinders, and casseroles so the tests can be performed efficiently. The equipment required for each test can be included with the appropriate test kit.

7-7.2 Chemical Reagents.

A master list of chemical reagents can be maintained. The list includes testing reagents that are stocked, their reference number, the quantity of stock, and the test for which the reagent is used. The minimum stock level should be defined and the reagent ordered when that level is reached. The chemical reagents required for field tests will be included with the appropriate test kit. The supplier provides an SDS for each of the chemical reagents, and it should be kept in the vicinity of the test area in case of an emergency.

CHAPTER 8 WATER TREATMENT CHEMICAL FEED AND CONTROL

8-1 CHEMICAL FEED AND CONTROL SYSTEMS.

Chemical feed and control systems are designed primarily for dynamic industrial water systems that require regular use of chemicals and control of makeup water and blowdown. These systems consist of integrated components, including sensors, automatic valves, and chemical pumps. Some of the ancillary components include drum level sensors, alarms, and telecommunications for remote monitoring. Normally, a mechanical design engineer will develop the specifications for a chemical control and feed system.

8-1.1 Controller Types.

Water quality controllers are of two types. For cooling towers or boilers, a stand-alone type controller is the most commonly used and can be obtained from the manufacturer or from a water treatment service company. The other type of controller is an integrated component of a building management system. In many instances both types of controllers will be used for a given system, with one controller being used to augment the monitoring of the water system performance. This Chapter focuses on the stand-alone type controllers.

8-1.1.1 Cooling Tower Water Controllers.

Cooling tower water controllers control blowdown and chemical inhibitor feed, as a minimum. Inhibitor feed can be tied into blowdown; however, it is preferable to have inhibitor feed independent of blowdown to allow for adequate feed in cases in which excessive drift (uncontrolled blowdown) results in no requirement for controlled blowdown. Remote monitoring can also control biocide feed and pH control. The most desirable cooling water inhibitor feed control strategy incorporates real-time, continuous measurement of the inhibitor concentration in the recirculating system water. The controller should then make precise chemical feed adjustments based on the real-time measurement, so that treatment levels can be reliably maintained. The typical controllers used in cooling systems are listed in Table 8-1.

Table 8-1 Cooling System Controller Functions

Function	Type
Blowdown control	1. Conductivity 2. Timer
Chemical inhibitor feed	1. Water meter initiated 2. Function of blowdown 3. Continuous percent time 4. Calendar 5. Based on real-time, continuous measurement of the inhibitor concentration in the recirculating system water.
Biocide feed	1. Calendar 2. ORP (oxidation-reduction potential for oxidizing biocides)
pH control	pH electrode
Remote monitoring	1. Alarms 2. Telecommunications (wired, wireless, or internet)

8-1.1.2 Boiler Water Controllers.

Boiler water controllers control blowdown and chemical inhibitor feed, as a minimum. Chemical feed can be accomplished through any of several modes (continuous, water meter-initiated, blowdown, pH), depending on the requirement. Remote monitoring can also be established. The most desirable boiler water chemical feed control strategy incorporates real-time, continuous measurement of the chemical concentration in the water. The controller should then make precise chemical feed adjustments based on the real-time measurement, so that treatment levels can be reliably maintained. Typical controllers used in boiler water systems are listed in Table 8-2.

Table 8-2 Steam Boiler System Controller Functions

Function	Type
Blowdown control	1. Conductivity 2. Timer 3. Percent flow
Chemical inhibitor feed	1. Water meter initiated 2. Function of blowdown 3. Continuous percent time 4. Calendar 5. Based on real-time, continuous measurement of chemical concentration in the water
pH control	pH electrode
Remote monitoring	1. Alarms 2. Telecommunications (wired, wireless, or internet)

8-1.2 Chemical Pumps.

Chemical pumps are selected by the specific application for which they will be used, considering materials of construction, head pressure capacity, and volume capacity.

8-1.2.1 Feed Pumps.

Feed pumps tied to pulsing makeup meters or some other type of proportional feed system are recommended for most systems, especially large steam and cooling water systems and unmanned small systems. The most desirable feed method is to turn on the feed pumps when the continuous real-time measurement of the inhibitor indicator indicates that the inhibitor level is below the desired treatment level. Pumps that turn on in response to continuous real-time measurement can provide control to within 3 ppm of the desired treatment level.

8-1.2.2 Pumps of Various Types.

Pumps of various types can take suction from chemical solution tanks and inject a solution of a chemical into a line, a boiler drum, or a cooling tower basin. Pump types include piston pumps, spring-loaded diaphragm pumps, hydraulically actuated diaphragm pumps, peristaltic pumps, and gear pumps.

Piston pumps and, to a lesser degree, diaphragm pumps, have trouble with valves sticking or plugging if there are solids in the stream being pumped. Peristaltic pumps do not have this problem since they have no valves. They are especially recommended for feeding sulfuric acid, but they cannot pump against much pressure. Pumps configured for flooded suction produce a more reliable delivery than pumps that must hold a suction prime via a foot valve.

8-1.3 Water Meters, Automatic Valves, and Timers.

8-1.3.1 Water Meters.

Water meters are selected by the specific application for which they will be used, considering materials of construction, temperature rating, pressure rating, and volume capacity. Water meters fitted with an electrical contact head are used to send low-voltage signals to timers and pumps.

8-1.3.2 Automatic Valves.

Automatic valves are selected by the specific application for which they will be used, considering materials of construction, temperature rating, pressure rating, and volume capacity. Cooling towers normally use solenoid-actuated diaphragm valves. Boiler surface blowdown normally uses a motorized ball valve.

8-1.3.3 Timers.

Timers are selected by the specific application for which they will be used. The duty could be any of the following: signal timer, limit timer, percentage timer, or calendar program timer. They are often an integral piece of controller equipment but can also be stand-alone units.

8-1.4 Other Feed Devices.

8-1.4.1 Bypass Feeders.

The typical bypass pot feeder is used to feed a solid or dry product to a water stream. A bypass feeder will operate across an orifice plate, a partly closed valve, or any other restriction in the line. Bypass feeders are not recommended for steam boiler systems, cooling tower systems, or systems that require much makeup water.

8-1.4.2 Slowly Dissolving Dry Chemical Packages.

Nylon mesh bags containing slowly dissolving dry chemicals can be hung in the cold well of a cooling tower. This method of chemical addition is useful for small, remote cooling towers that require little attention.

8-1.4.3 Eductor Chemical Addition Systems.

The regenerant agent used for ion exchanger softeners is usually fed by an eductor, which is an enclosed unit having a feed rate set by the manufacturer. The sales representative should be contacted in case of an equipment malfunction.

8-1.4.4 Chemical Drip Pots.

Chemical drip pots are containers that contain treatment chemicals; they are mounted or hung in a cooling tower to feed chemical treatment, which drips into the cooling tower sump. These systems are not recommended for use, including those with a constant head.

8-2 CHEMICAL FEED METHODS.

For safety and manpower reasons, water treatment chemical feed should be accomplished using automated equipment when possible. In some situations manual feed is the most practical, or only, means available. Other situations require a combination of manual and automated chemical feed. Finally, some chemical feed systems are fully automated, thereby minimizing any direct handling of chemical treatment. The most desirable feed method is to feed product from pumps directly connected to base tanks. The base tanks are refilled by the water treatment supplier, thereby eliminating the handling of the products by the user. Pumps that turn on in response to continuous real-time measurement can provided control to within 3 ppm of the desired treatment level.

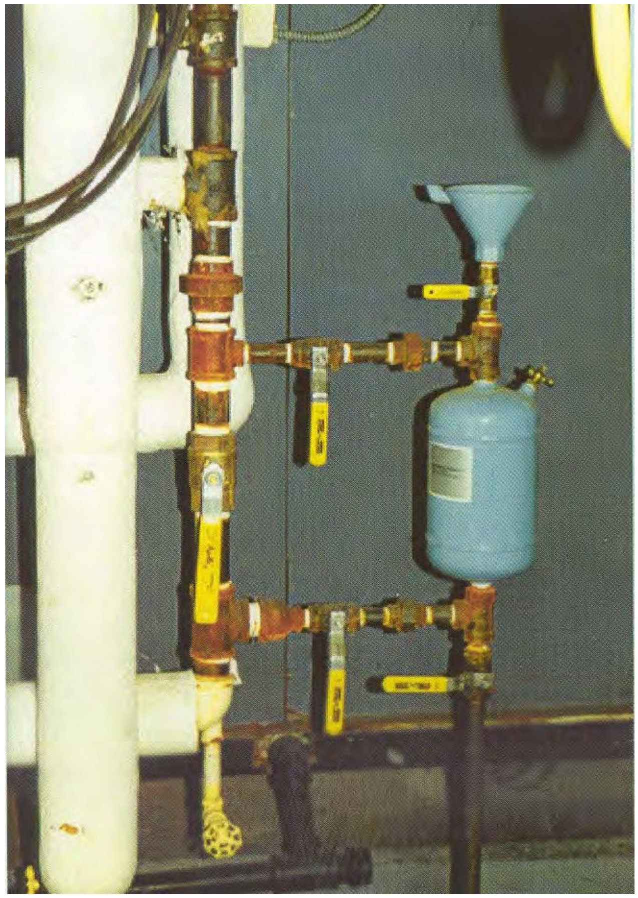
8-2.1 Manual Water Treatment Chemical Feed.

Manual water treatment chemical feed is commonly performed on closed systems, small cooling towers, and small steam boilers.

8-2.1.1 Chemical Pot Feeders.

Closed systems, such as chilled water, low- temperature hot water boilers, and even small steam boilers that return over 99 percent condensate, are usually fed manually via a chemical pot feeder (see Figure 8-1). Chemical pot feeders (also known as shot feeders) are plumbed into a system as a side stream using a three-valve bypass configuration. Feeders may have funnels or screw caps. The overall volume of a water treatment system should be considered when determining the proper size of a pot feeder. A 1-gallon (3.78-liter) pot feeder on a 20,000-gallon (75,700-liter) closed system can work, but is not practical. A larger 5-gallon (18.9- liter) pot feeder is more practical. Some pot feeders are designed to serve a dual purpose as a filter.

Figure 8-1 **Chemical Pot Feeder**



8-2.1.2 Dry Chemical Feeders.

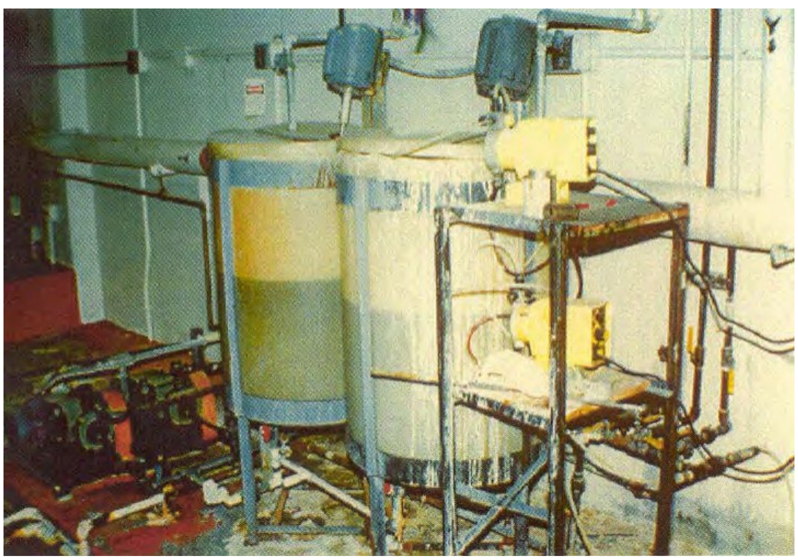
Small cooling towers often require a dry, granular, or pelletized product for control of scale, corrosion, or microbiological organisms. The dry chemical can be placed in a plastic mesh bag and hung in the cooling tower sump or put into a plastic container having small holes through which a stream of water can pass. Small cooling towers can be shock-fed with a liquid chemical agent, such as a biocide. This practice is not efficient and may be ineffective. The manual handling of biocides also raises safety concerns. A liquid chemical feed system may be more effective.

8-2.2 Automatic Chemical Feed with Manual Preparation.

This type of feed system is commonly found on steam boilers for which an operator must physically prepare a chemical mixture specific for that boiler operation. After preparation, the chemical mixture is automatically fed on demand using a chemical pump that is controlled by an external device or by tying into a feedwater or blowdown circuit. This type of setup can also be found on small cooling towers (see Figures 8-2 and 8-3).

Figure 8-2 **Manual Chemical Feed System**

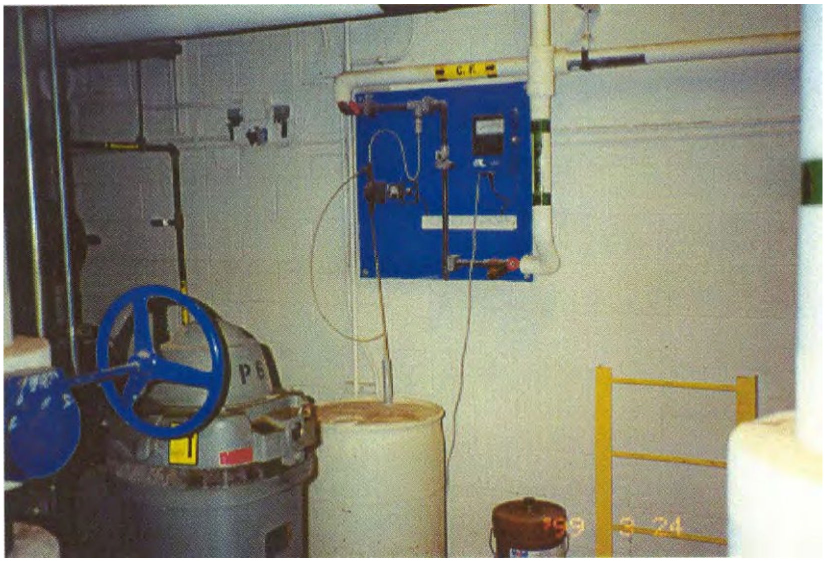
Figure 8-3 **Automatic Chemical Feed System**



8-2.3 Automatic Neat Chemical Feed.

The term “neat” refers to a concentrated chemical as received, with no dilution or mixing. An automatic chemical feed system must deliver the chemical proportionally (see Figure 8-4). Chemical pumps must be sized appropriately, and the system must have control equipment, which can consist of sensors, automatic valves, water meters, and timers. Once a system is properly connected to the chemical containers and adjusted, the only contact between the operator and the chemical containers results from maintenance of the chemical pumps, valves, and transfer lines. The most desirable chemical feed method is to feed product from pumps directly connected to base tanks. The base tanks are refilled by the water treatment supplier, thereby eliminating the handing of products by the user. The product is fed directly from pumps into the cooling or boiler water system.

Figure 8-4 **Automatic Neat Chemical Feed**



8-3 CHEMICAL CONTROL VERIFICATION.

To ensure that systems are being maintained within water treatment program control limits, it is necessary to verify that the proper water treatment chemical dosages are being used in treated water systems. Verification involves one or more of the various methods described below.

8-3.1 Continuous Testing.

Continuous water testing can be used in large systems where the service requirement justifies continuous control or the cost of the chemical feed warrants close control. This technique requires monitoring devices that are external to the system, which is equipped with probes and transmitters that send signals to the monitoring device. These systems are often linked directly to the chemical feed system to provide automatic control of the chemical feed.

8-3.2 Manual Testing.

Manual testing of the levels and dosages of water treatment chemicals is the most common method of testing. This technique is effective in systems in which the treatment chemical levels are not expected to vary widely in short periods of time, or in which the treatment chemical feed can be linked to the makeup water flow rate. Normally, the results of the manual testing are used to manually adjust the chemical feed rates. The testing frequency varies depending on the type and size of the water system. Critical systems require the most attention.

8-3.3 Little or No Testing.

Testing is necessary except in instances in which a chemical feed system does not require daily control monitoring or in which there is no treatment. This technique is used, for example, at remote cooling towers where a slowly soluble chemical is suspended in the cold well. Even for such systems an occasional test for treatment chemical level is recommended.

8-3.4 Calibrated Mass Balance.

Accurate chemical feed (rate and dosage) can be measured precisely and adjusted according to mass water balance. Some chemical delivery systems (pumps) use a calibration column to assure that chemicals are being fed. A measured volume of chemical is fed relative to makeup water or feedwater, then balanced by maintaining COC.

8-3.5 Automated Sensor Control.

This is a relatively advanced technology that automatically senses treatment level via an ion-specific electrode, such as might be used for pH control or spectro-analysis that senses chemical tracers. Chemical feed is adjusted automatically. The technology is effective as long as the sensing devices are calibrated and properly maintained. The technology for spectro-analysis control is relatively expensive. Another automated type of control is based on continuous monitoring and control of the inhibitor based on fluorescence technology. Chemical feed pumps are turned on when the continuous real-time measurement of the inhibitor indicates that the level is below the desired treatment level. Control can be reliably maintained within 3 ppm of the desired treatment levels in response to continuous real- time measurement. This type of control can be justified based on the reliability of proper treatment levels.

8-4 SAFETY AND GENERAL INFORMATION.

A water treatment program includes procedures for the feeding, handling, monitoring, storage, and disposal of treatment chemicals. General trends within the water treatment industry have been: to minimize or eliminate the physical handling of chemicals for reasons of safety and manpower; to provide container management systems to eliminate drum disposal problems; and to reduce or eliminate the need to store stockpiles of treatment chemicals.

8-4.1 Safety.

Chemicals used in water treatment, and in related maintenance activities, range from being highly toxic to mildly irritating to the persons handling them. All water treatment and testing chemicals are handled with caution, following any special instructions prescribed by the manufacturer. Areas where chemicals are handled or stored are kept clean and free of debris to minimize the chance of accidents. People who handle these chemicals can attend safety education classes, refer to the SDS for additional information, and use proper equipment for respiration and protection as recommended by the installation environmental or safety engineer.

8-4.1.1 Handling Acid.

When handling acid, avoid splashing the liquid. If acid does contact the eyes, skin, or even clothing, the affected area must be immediately flushed with water for 15 minutes. All cases of acid burns, especially to the eyes, are referred to a doctor. When acid is being diluted, water must never be added to acid because this may cause a violent reaction or splattering. NOTE: Acid is always poured into water; water is never poured into acid. When handling acid, goggles, face shield, rubber gloves, and a rubber apron must be worn. Safety equipment must be of a type approved by OSHA.

8-4.1.2 Handling Caustic Soda (Sodium Hydroxide).

Caustic soda is a strong alkali that can cause severe burns when contacted in either the liquid or solid form. If caustic soda does contact the eyes, skin, or clothing, immediately flush the affected area with water for at least 15 minutes. When water is added to caustic soda, a great deal of heat may be generated, which can cause the solution to splatter or boil. If inhaled, the dust or mist from dry caustic soda may cause injury to the upper respiratory tract. When handling caustic soda, wear close-fitting, OSHA-approved industrial goggles, rubber aprons and gloves, and coveralls that fit snugly at the neck and wrist.

8-4.1.3 Handling Other Chemicals.

Many of the other chemicals used in water treatment, including amines, soda ash, lime, sodium aluminate, sulfite, biocides, and algaecides may cause some irritation on contact with the skin. Handle all chemicals with caution, following the manufacturer's recommendations. For any contact of a chemical with skin, flush the skin immediately with water. Review the SDS that are available for the chemicals being handled for any special precautions that you should take.

Biocides and algaecides are toxic, and you should handle them only when observing special caution/precautions.

8-4.1.4 Chemical Spill Kits.

Each area where acids, caustic soda, or other hazardous materials are used or stored can be equipped with appropriate chemical spill kits. Kits for cleaning up acids, bases, and solvents are commercially available.

8-4.1.5 First Aid Information.

First aid information concerning a given chemical is listed on the SDS for that chemical.

8-4.1.6 Eyewash Fountain.

An eyewash fountain or a ready source of running tap water (a bubbler drinking fountain or hose with a soft flow of water) should be made readily available to wash out or flush the eyes. If even minute quantities of acid or caustic soda enter the eyes, immediately flush the eyes with large amounts of water for at least 15 minutes.

8-4.1.7 Safety Shower.

A readily accessible, well-marked, rapid-action safety shower should be located in the area where acid or caustic soda is being handled.

8-4.1.8 Safety Inspection.

All safety equipment should be regularly inspected to ensure it is in proper working condition. To prevent the accumulation of rust, the safety shower and eyewash equipment should be operated (checked) weekly. Clearly marked signs containing concise instructions on the use of the safety equipment should be placed near the emergency eyewash fountain and the safety shower.

8-4.2 Container Management.

The policy for container management is stated in paragraph 2-2.3 and is restated here. The military does not accept responsibility for disposal of chemical containers from water treatment suppliers or service companies. Any such company that has been contracted to provide chemicals must provide them in containers that are either reusable or returnable at the company’s cost. The containers remain the property of the contractor. All container systems should provide for secondary containment of the contents.

8-4.3 Chemical Storage.

Chemical storage procedures are required to follow OSHA directives, manufacturer’s recommendations, and the SDS. Identify products in storage areas by classifications of flammable, corrosive, oxidizers, reducers, and poisonous. Physically separate (store separately) the various classes of products as required by local codes. Because of the potential for chemical spills, storage areas for each class of products should have containment dikes. An alternate for container management is to use base tanks that are refilled by the water treatment service company, thereby eliminating the handling of the containers or products by the user.

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CHAPTER 9 NON-CHEMICAL/NON-TRADITIONAL WATER TREATMENT DEVICES

9-1 POLICY.

Most non-chemical water treatment devices or equipment are not currently authorized for use on military installations, as stated in paragraph 3-1.5. The Air Force will allow their use only under an Energy Saving Performance Contract (ESPC) in which the contractor assumes all performance-based risk. The performance standards for system component protection must meet or exceed those that are achievable with chemical treatment.

9-1.1 Function.

Non-chemical devices for use in industrial water systems are designed to require little or no chemical treatment to solve or prevent one or more types of water-related problems, including scale, corrosion, slime, and odor. Some of the technologies are represented as non-chemical, when in fact they produce chemicals (such as ozone, and copper and silver ions). These technologies could be better described as non-traditional water treatment chemical devices. The various types of non-chemical devices are described in paragraph 9-2.

9-1.2 Acceptance.

To date, there has not been a general acceptance of most non-chemical devices. Manufacturer's representations as to their effectiveness and adequacy in performing the intended functions may not be supported by adequate performance data. Non-biased, independent verification of performance conducted by a third-party entity is an important component of the process that should be used to establish performance criteria of new technologies and equipment. This verification step has not always been performed for a given technology. Recognition of the adequacy of a non-chemical technology and acceptance of its use by professional societies such as ASHRAE, the National Association of Corrosion Engineers (NACE International), and CTI could provide an increased level of confidence that the technology does in fact work, at least on some basis and to some extent.

9-1.3 Performance Standards.

Traditional water treatment evaluation techniques and performance results provide the standard by which non-chemical devices should be measured. A complete water treatment program must address deposit control, corrosion control, microbiological control, and water conservation. These standards are described in Chapter 11. If a non-chemical water treatment device addresses only deposit control, but not corrosion or microbiological control, then it cannot make a claim to eliminate the need for all chemicals. The water treatment program would still require chemicals to control the problems that the non-chemical device cannot control.

9-2 TYPES OF NON-CHEMICAL WATER TREATMENT DEVICES.

Non-chemical devices for water treatment are hardware devices that do not use chemicals for the purpose of controlling or preventing corrosion, deposition, and biological growth in industrial water systems. This Chapter discusses the various types of non-chemical devices on the market. It is not intended to endorse or validate any of these technologies, nor to describe all types offered; however, the known effectiveness of these devices will be stated where performance results have been verified.

9-2.1 Electrical Impressed Current Devices.

Electrical impressed current devices are a proven corrosion control technology, known as cathodic protection that is used to protect lengths of underground outside surfaces of steel piping and mild steel heat exchanger water boxes. An electrical current is applied to offset the natural potential difference between an anode and a cathode. This technology does not prevent scale deposition or microbiological concerns and is mainly used to protect mild steel.

9-2.2 Grounded Wire Devices.

Grounded wire devices use a wire to ground a pipe or structure to prevent corrosion. This device is useful when stray currents (electrical) are causing corrosion. These devices have been touted as being able to prevent and remove scale. The principle of operation is uncertain, but it may be based on the fact that water impurities are charged ions and grounding affects the ions from forming scale. The scale control properties of this technology have not been conclusively and unambiguously verified.

9-2.3 Sacrificial Anodes.

The use of sacrificial anodes is a proven technology that uses blocks of metal that corrode (sacrifice) to protect the metal to which they are attached. A sacrificial anode is more anodic than the metal to which it is attached (see paragraph 5-5.1). This technology is actually a form of chemical corrosion protection. As an example, a zinc or magnesium metal sacrificial anode, when attached to a mild steel surface, becomes the anode in a corrosion reaction. The sacrificial anode is corroded preferentially while the mild steel is provided some localized corrosion protection. The action of sacrificial anodes is limited by the distance over which they can be effective; usually about 2 to 6 square feet (0.18 to 0.56 square meters) around the anode is protected, depending upon the water quality.

9-2.4 Filters.

Filters are a proven non-chemical method for removing SS in water. The removal of SS (dirt, silt, sand, corrosion products, and microbiological organisms) serves to minimize both the formation of deposits and the potential for under-deposit corrosion. Filtration affects biological control by reducing the presence of macro- and microbiological organisms in water. Removal of SS via filtration can improve the performance of all chemical control agents. This is comparable to a person washing a wound before applying a disinfectant. Filters do not address deposition due to scale nor do they control corrosion.

9-2.5 Magnetic Filters.

Magnetic filters are a proven method for removing magnetic iron oxides from a water stream. The most common application is the use of magnetic filters to remove iron oxide before the condensate is returned to the boiler in steam condensate systems. Magnetic filters usually are high capital costs.

9-2.6 Ultraviolet Light Generators.

Ultraviolet light generators are a proven method for microbiological disinfection of water. However, their effectiveness is limited to the distance through which the ultraviolet light can penetrate a water stream. This technology would not be effective for controlling (destroying) sessile bacteria that are already attached to a surface that the light cannot reach or for controlling (destroying) anaerobic bacteria that live underneath deposits that the light cannot penetrate. This technology has limited effectiveness with highly turbid water.

9-2.7 Magnetic and Electromagnetic Devices.

Magnetic and electromagnetic devices use an unproven technology based on the theory that magnetic fields change the physics of water and the water impurities. Water is a polar molecule. Most water impurities are positively or negatively charged ions. These are the physical properties that the magnetic fields are supposed to act on and to alter. The magnetic device is installed at a point where the water passes by, usually at a point where the water enters the system. A claim made commonly by the manufacturer of the device is that calcium carbonate scale, and possibly other scales, can be conditioned and often prevented.

Most of the literature fails to provide a performance envelope of various water qualities. Most manufacturers also fail to mention how corrosion or microbiological control is achieved or even addressed. Magnetic filters used to remove magnetic iron oxide have been shown to work, as described in paragraph 9-2.5.

9-2.8 Electrostatic Devices.

Electrostatic devices use an unproven technology based on the theory that an electric field changes the physics of water or the water impurities. Some manufacturers market their devices for scale control only. Other manufacturers state, without providing adequate verification data, that these devices address corrosion and microbiological concerns. Performance results are not included in the marketing literature.

9-2.9 Non-Traditional Water Treatment Chemical Devices.

9-2.9.1 Ozone.

Ozone (O_3) is a chemical gas consisting of three atoms of oxygen. It has been used in cooling tower water systems. Ozone is a very effective disinfectant for the control of aerobic bacteria and is somewhat effective for sessile bacteria. Ozone has been shown to have a limited and unpredictable effect on calcium carbonate scale. The scale that may form does not adhere to heat exchange equipment, but rather forms SS that can be removed with filtration. The performance envelope for prevention of calcium carbonate scale on heat exchange equipment is very limited and is much less than what is possible when using traditional chemical treatment. Ozone does not prevent corrosion of most metals. It provides some reduction of mild steel corrosion, but will increase the corrosion of copper at rates up to 10 times versus traditional chemical treatment. Ozone also attacks galvanized steel. Increasing the level of ozone in water increases the corrosiveness of the water. Levels of 0.1 mg/l or less are acceptable.

Ozone has a short half-life and must be generated on-site. Ozone-generating equipment can have high capital costs. It is difficult to maintain an effective residual of ozone throughout the entire cooling water system because of the extreme reactiveness of ozone. It is also very volatile and can be lost from the system as the water passes through the cooling water system, resulting in biomass within the tower fill.

9-2.9.2 Copper and Silver Ionizing Devices.

Copper and silver ionizing devices use copper and silver metal rods that are electrically corroded and thus put copper and silver ions in the cooling water. Copper and silver ions are known microbiocides. Both copper and silver ions are toxic to bacteria and algae. Performance envelopes are ambiguous. There is also a potential for the copper and silver ions to plate out on mild steel pipe, galvanized steel, and other metal surfaces, creating a galvanic corrosion cell and resulting in pitting corrosion.

CHAPTER 10 CHEMICAL CLEANING OF WATER SYSTEMS

10-1 GENERAL GUIDANCE.

Chemical cleaning of water systems can be divided into two classifications: pre-operational and remedial. Pre-operational cleaning is performed to prepare the water-contacted metal surfaces to receive chemical treatment, which provides protection from scale, corrosion, and microbiological growth. Remedial cleaning is performed to restore water systems that have been fouled with scale, corrosion products, and microbiological growth due to inadequate or ineffective water treatment. Cleaning, particularly remedial cleaning, is often performed by outside contractors familiar with cleaning procedures, techniques, and safety. It should be noted that if the water system is significantly scaled, the chemical treatment program was obviously inadequate and was not properly designed, set-up, controlled, or applied. After cleaning has been completed, the chemical treatment program and QC program must be improved so the same problem does not recur. Use of a well-designed QA program would have produced identification and notification of potential and developing problems before they became serious. Pre-operational cleaning is often performed by contractors responsible for the fabrication of the water system before turning it over to the military installation. Water system operations personnel must assess the effectiveness of any cleaning process that has been performed.

10-1.1 Pre-Operational Cleaning.

Pre-operational cleaning can be performed on all new systems or pieces of equipment installed in any existing system, including new boiler tubes or new chiller copper tube bundles. New piping and coils will usually be contaminated with materials such as mill scale, rust, oil, and grease resulting from the fabrication, storage, and installation of the equipment. Pre-operational cleaning is performed to remove these materials and prepare metal surfaces to receive corrosion protection from chemical treatment. Pre-operational cleaning agents that are used include detergents, wetting agents, rust removers, and dispersants. These cleaning agents have a pH in the range of 9 to 11. Water systems containing piping or components constructed of galvanized steel and aluminum should not be subjected to procedures that require high pH (greater than 8.5) because this would contribute to initiating corrosion of these surfaces.

The requirement for performing a pre-operational cleaning process is usually written into the specification for new construction of a water system that must be performed by a mechanical contractor. The mechanical contractor is required to perform the work as directed in the specifications; however, if the specifications are not appropriate for the specific system, including consideration of all system metallurgy, the cleaning process may contribute to corrosion to mild steel, galvanized steel, copper, or aluminum, or it may result in incomplete cleaning of dirty and corroded metal surfaces. The specifications should be reviewed by a qualified base inspector or qualified independent consultant to ensure that cleaning agents and procedures have been specified appropriately. A contracting officer or other individual responsible for QA should inspect the equipment after cleaning and document the effectiveness of the cleaning process.

10-1.2 Remedial Cleaning.

Remedial cleaning is performed to restore a water system that is fouled with scale, corrosion products, or microbiological biomass due to inadequate or ineffective water treatment. The problem could have resulted from using improper chemical technology, failure to maintain treatment levels within control parameters, or the failure of pre-treatment equipment. The cleaning agents used for remedial cleaning usually include acids, chelants, neutralizing agents, and specialty cleaning chemicals.

10-1.2.1 Safety and Environmental Issues.

Remedial cleaning may pose safety issues for personnel handling acids, caustics, and various chemicals. There could also be environmental concerns associated with chemical disposal. Inexperienced personnel should not perform the chemical cleaning of an industrial water system.

10-1.2.2 Contracting Cleaning Services.

For some cleaning jobs, such as large boilers and cooling towers, it may be advisable to engage a service company specializing in chemical cleaning. If the cleaning service is contracted, it is vital that adequate lines of communication be established, and that safety procedures employed by the service company comply with military regulations. An orientation meeting should be scheduled between military installation personnel and the service company representatives. At that time, the scope of the work can be defined, proper procedures initiated, and the nature of the hazards described thoroughly. The use of proprietary cleaning chemicals or chemical formulations may be involved; disclosure of the use and nature of these chemicals should be made at the orientation meeting. Military policies and restrictions can also be explained. The inspection of equipment after cleaning is usually the final step in the overall cleaning process.

10-1.3 Reasons for Cleaning.

Maintenance of an effective water treatment program is essential to minimize scale and corrosion problems in industrial water systems; however, scale and deposits that form will require remedial cleaning (descaling). If not removed, these scale and water-caused deposits may impact the safety of operations personnel, interfere with heat transfer, and cause excessive damage to, or destruction of, the water-using equipment. Cleaning is not appropriate for the removal of deposits when corrosion of the system has advanced to the point where a large number of leaks may result from the removal of the deposits.

10-1.4 Types of Deposits.

The deposits that occur in water systems can be inorganic mineral salts and corrosion products or organic (oily) or biological in nature. Deposits range in composition from very dense crystalline structures, to very porous and loosely bound materials, to gelatinous slimes. Most of the deposits formed from water constituents consist of corrosion products such as iron and copper oxides, mineral scales, or mixtures of these materials.

10-1.4.1 Waterside Deposits Located in Heat Exchangers.

Water deposits located in heat exchangers are usually carbonate-based scales, while steamside deposits may be a mixture of metallic oxides and organic residuals from lubricating oil, particularly where reciprocating-type engines are used. In steam systems, the oxides are usually iron and copper, resulting from aggressive condensate. Microbiological deposits may form in cooling systems from bacterial or algae growths, or from decomposition products of various microorganisms.

10-1.4.2 Boiler Deposits.

Boiler deposits may take various forms. In low-pressure boilers using a relatively hard feedwater, deposits are essentially calcium and magnesium, silicates, sulfates, carbonates, phosphates and hydroxides, plus some organics. Deposits may also contain considerable amounts of silica, iron, and copper. These deposits can be spongy or porous or relatively hard and glass-like. Deposits of the latter characteristic occur where silica is present in appreciable quantities in the boiler water. Deposits in medium-pressure to high-pressure boiler systems usually are mixtures of iron and copper oxides and phosphates. Dense deposits may tend to form in high-heat transfer areas. Considerable quantities of sludge-type accumulations may be found in downcomers, mud drums, waterwall headers, crossover tubes, and areas of low water circulation in the boiler.

10-2 REMEDIAL CLEANING PROCEDURES.

Cleaning procedure information and procedures presented in this Chapter are general in nature and must be modified to fit specific applications. Because contractors perform most cleanings, these procedures are provided only for general information (see paragraphs 10-1.1 and 10-1.2).

10-2.1 Cleaning Methods.

10-2.1.1 Mechanical Methods.

Mechanical methods are the oldest techniques used for removing deposits. To perform an adequate mechanical-type cleaning, the equipment to be cleaned may need to be partially or entirely dismantled. Even when equipment is dismantled, some areas may be extremely difficult to reach and clean. Chemical cleaning has largely replaced mechanical process equipment cleaning as the most satisfactory method of removing deposits; however, mechanical methods such as wire brushing, tumbling, scraping, and abrasive blasting with sand and grit are still employed in special applications.

10-2.1.2 Cleaning Agents.

Cleaning agents may be broadly classified as being acid, alkaline, organic, or solvent cleaners. There is no general or universal cleaner that removes all deposits. The selection of a solvent or cleaning agent is based on the material's ability to remove or dissolve the deposit, as well as on cost considerations, safety hazards, and the effect of the cleaning material on the metals involved.

10-2.1.3 General Guidance and Procedures for Preparing Cleaning Solutions.

General guidance and procedures for preparing cleaning solutions of inhibited hydrochloric (muriatic) acid and inhibited sulfamic acid are provided in paragraphs 10-2.2 and 10-2.3. Inhibited acid contains special chemical inhibitors that prevent the acid cleaner from attacking the base metal while allowing the acid to remove the unwanted corrosion product or scale deposit.

10-2.2 Hydrochloric (Muriatic) Acid.

Inhibited hydrochloric (muriatic) acid in strengths of 5 to 20 percent is very effective for removing calcium scale and iron oxide; however, for most applications, a 10 percent solution is adequate. The following formulation is for a 10 percent hydrochloric acid solution. It can be used for removing scale consisting primarily of carbonates with lesser amounts of phosphates, sulfates, and silicates. This type of scale is typically found in a steam boiler system containing copper alloys that has been treated with a phosphate-based program. Depending on the specific descaling application, some of these ingredients can be omitted from the formulation. For example, diethylthiourea is not needed if there is no copper in the system. It should be noted that if diethylthiourea is used, the waste material should be treated as a hazardous waste. Where there is only carbonate scale to be removed, ammonium bifluoride, which is used to remove silica-based scales, may be omitted. The addition of a wetting agent is preferable but not absolutely necessary.

10-2.2.1 Example Procedure for 10 Percent Solution.

The following is an example procedure that can be used to make 1000 gallons (3785 liters) of a 10 percent solution:

1. Add 285 gallons (1079 liters) concentrated (36 percent strength) hydrochloric acid, American Society for Testing and Materials (ASTM) E 1146, Specification for Muriatic Acid (Technical Grade Hydrochloric Acid), to approximately 600 gallons (2271 liters) of water.
2. Add the proper amount of a corrosion inhibitor, Military Specification MIL-I-17433, Inhibitor, Hydrochloric Acid, Descaling and Pickling, recommended by the manufacturer to the diluted acid solution. The inhibitor must be compatible with hydrochloric acid and must not precipitate under any condition during the cleaning operation.
3. In a separate tank containing about 75 gallons (284 liters) of water:
    a. Add 85 pounds (39 kilograms) of the chemical (1.3) diethylthiourea to complex any copper and keep it from depositing. Do not use the diethylthiourea as the corrosion inhibitor required in paragraph 9-2.2.1(step 2) above.
    b. Add 120 pounds (55 kilograms) of ammonium bifluoride, technical grade, to help dissolve certain iron and silica scales.

c. Add 1 gallon (3.79 liters) of wetting agent, Military Specification MIL-D-16791, Detergents, General Purpose (Liquid, Nonionic).

d. Add the dissolved diethylthiourea, ammonium bifluoride, and wetting agent to the diluted acid solution. Add sufficient water to obtain 1000 gallons (3785 liters).

10-2.2.2 Carbonate Deposits.

Carbonate deposits dissolve rapidly in hydrochloric acid, with evolution of free carbon dioxide. The escaping carbon dioxide tends to create some circulation or agitation of the acid, which ensures the continual contact of fresh acid with the scale. Once the carbonate has been dissolved from a mixed deposit, a loose, porous structure may be left behind. This residual material can be effectively removed from the equipment either mechanically or by washing with high-pressure water.

10-2.2.3 Phosphate Deposits.

The removal of phosphate deposits can usually be accomplished by using hydrochloric acid; however, phosphate deposits have a tendency to dissolve rather slowly. To minimize the total cleaning time, a temperature of 120° to 140 F (49° to 60 C) is usually necessary to remove a predominantly phosphate scale.

10-2.2.4 Metallic Oxides.

Most metallic oxides found in deposits can be removed with hydrochloric acid. The rate of dissolution is a function of temperature and solution velocity. If copper oxides are present on steel surfaces, special precautions are needed to prevent copper metal plate-out on the steel.

10-2.2.5 Silica and Sulfate Scale.

Heavy silica and sulfate scale is almost impossible to remove with hydrochloric acid. Special chemicals and procedures are required to remove this scale.

10-2.2.6 Hydrochloric Acid Limitations.

10-2.3 Sulfamic Acid.

Sulfamic acid is an odorless, white, crystalline solid organic acid that is readily soluble in water. An inhibited sulfamic acid compound, in a dry powder form, is available under Military Specification MIL-B-24155, Boiler Scale Removing Compound. A 5 to 20 percent solution (5 to 20 pounds to approximately 10 gallons of water (2 to 9 kilograms to approximately 38 liters of water)) is used for removing scale from metal surfaces. The following information pertaining to sulfamic acid should be considered:

- Carbonate deposits are dissolved in sulfamic acid in a similar manner as in hydrochloric acid. All the common sulfamate salts (including calcium) are very soluble in water.

- The dry powder form of sulfamic acid is safer to handle than a liquid solution of hydrochloric acid; however, aqueous solutions of sulfamic acid are much slower in action and require heating to remove scale. The sulfamic acid solution is heated to a temperature in the range of 130° to 160 F (54° to 71 C) to obtain the same fast cleaning time that is achieved by using hydrochloric acid at room temperature. Sulfamic acid is more effective on sulfate scale than hydrochloric acid.
- Inhibited sulfamic acid, used at temperatures up to 110 F (43 C), will not corrode galvanized steel. Its use is recommended for removing scale in cooling towers, evaporative condensers, and other equipment containing galvanized steel. In general, sulfamic acid can be applied to equipment while it is operating but should be drained from the system after a few hours, and the concentration of the normally used corrosion inhibitor should be increased several-fold to protect the metal surfaces.
- Commercially prepared descaling compounds consisting of concentrated or diluted inhibited acid (containing 7 to 28 percent of the acid and inhibitor) may be purchased under various trade names at prices 4 to 30 times the cost of the ingredients themselves if purchased as generic chemicals.
- Advertisements of some of these products may contain claims that cotton clothing and skin are not attacked by the acid. These claims are usually based on a very dilute solution of the acid that causes a minimal attack on clothes and skin; however, the cost of the cleaning process may be increased because a higher quantity of dilute product may be needed. Be aware that handling acid in any strength must be performed with considerable care, caution, and adherence to safety procedures.
- The cost of diluted acid is expensive; therefore, concentrated acid of government specifications should be purchased and diluted to usable strengths. The necessary corrosion inhibitors can be added to the dilute acid solution. Users of small quantities of acid cleaners (possibly less than 10 gallons (38 liters) of diluted acid per year) may not be able to justify purchasing undiluted acid and spending the time, cost, and effort to prepare the cleaning solution; therefore, consider the specific requirements before ordering.

10-2.4 Cleaning Preparation.

The unit to be cleaned must be isolated from other parts of the system. For systems that cannot be isolated by the closing of valves, isolation may be accomplished using rubber blankets, wooden bulkheads with seals, inflatable nylon or rubber bags, rubber sponge-covered plugs, or blind flanges and steel plates with rubber seals. Long lines may require auxiliary connections for chemical cleaning. The following information should be considered before the cleaning process is started:

- Decide whether to clean using a soaking process or by circulating the cleaning solution (see paragraph 10-2.5). In either case, temporary piping or hose lines will be required to connect the cleaning solution mixing tanks or trucks to the unit, with return lines to tanks or drains. Proper precautions and adequate provisions must be made to protect equipment, isolate control lines, replace liquid level sight glasses with expendable materials, and provide suitable points for checking temperatures. It may be necessary to remove selected system components if the cleaning process might damage them.
- The entire cleaning procedure/process must be developed in detail before starting chemical cleaning operations. Factors to be considered include: the methods for controlling temperatures; the means of mixing, heating, and circulating the chemical solution; proper venting of dangerous gases from equipment to a safe area; and means for draining, filling, and flushing under inert atmospheres. Sampling points, test procedures, and control limits should also be established.

10-2.5 Methods for Removing Scale.

Removing scale may be accomplished by circulating the inhibited acid solution through the equipment or by soaking the equipment in a tank of inhibited acid. Before starting any descaling process, check the acid to make sure it is properly inhibited. You may check the acid by placing a mild steel coupon into a beaker containing the prepared, diluted acid. You should notice no reaction around the coupon. If you observe a reaction generating hydrogen gas bubbles around the coupon, add more inhibitor.

10-2.5.1 Recirculating Cleaning Process for Boilers.

The following example is an appropriate procedure for cleaning small boilers or other systems using a hot recirculating inhibited acid solution:

1. Fill the boiler or system with preheated (160° to 170 F (71° to 77 C)) dilute inhibited acid solution.
2. Allow the dilute inhibited acid solution to remain in place for 8 hours. Circulate the acid solution for approximately 15 minutes each hour at a rate of about 50 gallons per minute (3.15 liters per second) to ensure good mixing.
3. Keep the temperature of the acid solution preheated at 160° to 170 F (71° to 77 C). Measure and record the temperature at least once every 30 minutes.
4. Check and record the acid strength at least every hour (see paragraph 10-2.6).
5. Drain the system by forcing the acid solution out using 40 to 50 pounds per square inch gauge (276 to 345 kilopascals) nitrogen; follow Federal Specification A-A-59503, Nitrogen, Technical, Class 1. If leaks develop

when the system is under nitrogen pressure, you must use an alternate method for removing the acid, such as pumping.

6. Fill the boiler with preheated (150° to 160 F (65° to 71 C°) water and soak at this temperature for 15 minutes.
7. Drain under nitrogen pressure of 40 to 50 pounds per square inch gauge (276 to 345 kilopascals).
8. Prepare this mild, acid-rinse solution: Add 2 gallons (7.57 liters) of hydrochloric acid (ASTM E 1146) for each 1000 gallons (3785 liters) of water. Also add corrosion inhibitor, Military Specification MIL-I-17433, in the amount recommended by the manufacturer.
9. Fill the boiler with the preheated (160° to 170 F (71° to 77 C)) mild acid-rinse solution and soak for 30 minutes.
10. Drain the mild acid-rinse solution under nitrogen pressure at 40 to 50 pounds per square inch gauge (276 to 345 kilopascals). Maintain a positive pressure of nitrogen in the boiler to prevent outside air from leaking inside.
11. Prepare this passivating solution: To each 1000 gallons (3785 liters) of distilled water (or other water with less than 50 ppm total hardness (as CaCO3)), add 80 pounds (36 kilograms) of passivation compound 0.5 percent by weight sodium nitrite and 0.25 percent by weight monosodium phosphate.
12. Fill the boiler with the passivating solution preheated to 150° to 160 F (65° to 71 C), circulate for 10 minutes, and hold in the boiler at 150° to 160 F (65° to 71 C) for an additional 30 minutes.
13. Drain and rinse boiler until the pH of the rinse water is pH 8 to 10.

10-2.5.2 Circulating Method without Heat.

The steps below describe a typical process for descaling smaller equipment, such as enclosed vessels or hot water heater coils, without heating the inhibited acid solution:

1. Note that an acid cleaning assembly may consist of a small cart on which is mounted a pump and a 5- to 50-gallon (18.9- to 189-liter) steel or polyethylene tank with a bottom outlet to the pump.
2. Install sill cocks at the bottom of the water inlet of the heat exchanger and the top of the water outlet so that a return line can be connected directly from the acid pump and from the heat exchanger to the acid tank.
3. Prepare an inhibited acid cleaning solution (see paragraphs 10-2.2 and 10-2.3).
4. Pump the acid solution into the heat exchanger through the hose connection. Continue circulation until the reaction is complete, as indicated by foam subsidence or acid depletion.
5. If the scale is not completely removed, check the acid strength in the system (see paragraph 10-2.6). If the acid strength is less than 3 percent,

add fresh acid solution and continue circulation until the remaining scale is removed. Usually an hour of circulation is adequate.

6. Drain the heat exchanger.
7. Neutralize remaining acid by circulating a 1 percent sodium carbonate (soda ash) solution (about 8 pounds per 100 gallons (3.6 kilograms per 38 liters)) for about 10 minutes.
8. Rinse thoroughly with water until the pH of the rinse water is pH 8 to 10.

10-2.5.3 Fill and Soak Method.

1. Prepare an inhibited dilute acid solution (see paragraphs 10-2.2 and 10-2.3) in a container of suitable size.
2. Depending on the item to be cleaned and the types of scale involved, you may want to place an agitator (mixer) in the tank or install a pump outside the tank to circulate the acid solution. A method to heat the acid may be required, such as a steam coil. All equipment must be explosion-proof and acid-resistant.
3. Immerse the item to be cleaned in the dilute acid solution. Continue soaking until the reaction is complete as indicated by foam subsidence or acid depletion.
4. If the scale is not completely removed, check the acid strength (see paragraph 10-2.6). If it is less than 3 percent, add additional acid and continue soaking the items until the remaining scale is dissolved. Usually 1 to 2 hours of soaking is adequate.
5. Remove item from tank.
6. To neutralize remaining acid, immerse the item in a 1 percent sodium carbonate (soda ash) solution (about 8 pounds per 100 gallons (3.6 kilograms per 38 liters)) for 2 to 3 minutes.
7. Rinse the item thoroughly with water.

10-2.6 Checking Acid Solution Strength.

The initial strength of the dilute inhibited acid will vary from 5 to 20 percent, although 10 percent is typical. As the acid is consumed by dissolving the scale, the strength of the acid decreases. The strength of the acid solution should be measured periodically during a cleaning operation. When the acid strength falls below 3 percent, the solution may be discarded since most of its scale-dissolving capability will have been used. Use the following procedure to check the acid strength:

Apparatus:

- Burette, 0.8 ounce (25 milliliters) automatic (for sodium hydroxide solution)
- Bottle, with dropper, 2 ounces (50 milliliters) (for phenolphthalein indicator solution)

- Graduated cylinder, 0.3 ounce (10 milliliters)
- Casserole, porcelain, heavy duty, 7.1-ounce (210-milliliter) capacity
  Stirring rod

Reagents:

- Sodium hydroxide solution, 1.0 normality (N)
- Phenolphthalein indicator solution, 0.5 percent

Method:

1. Measure 0.00264 gallons (10 milliliters) of acid solution accurately in the graduated cylinder.
2. Pour into the casserole.
3. Add 2 to 4 drops of phenolphthalein indicator solution to the casserole and stir.
4. Fill the automatic burette with the 1.0 N sodium hydroxide solution; allow the excess to drain back into the bottle.
5. While stirring the acid solution constantly, add sodium hydroxide solution from the burette to the casserole until color changes to a permanent faint pink. This is the endpoint. Read the burette to the nearest 0.003 ounce (0.1 milliliter).

Results:

1. For hydrochloric acid: Percent hydrochloric acid = milliliter of 1.0 N sodium hydroxide x 0.36
2. For sulfamic acid: Percent sulfamic acid = milliliter of 1.0 N sodium hydroxide x 0.97

CHAPTER 11 DEVELOPING A WATER TREATMENT PROGRAM

11-1 GENERAL INFORMATION.

Although each water treatment program may contain unique aspects, the strategic goals of every program are regulatory compliance and safety, protection of water-contacted equipment, and acceptable costs. Achieving these goals requires the cooperative efforts of personnel from several areas, including environmental protection, engineering, contracting, operations, and outside resources. Outside resources include water treatment services companies, equipment suppliers, and mechanical contractors. In some cases, military facilities may use outsourcing for procurement of all industrial water treatment chemicals and associated services. This Chapter addresses some of the options for developing both a water treatment program and performance standards that apply to implementation of a program.

Problems can occur when water treatment programs are not developed properly. Each water treatment program is designed to address regulatory compliance and safety requirements as well as water quality and equipment protection. A potential consequence of inadequate planning and design of a water treatment program is preparing inadequate scopes of work for use in procuring (contracting) for services. If equipment protection is not adequate, the cost attributed to this failure often far outweighs the cost of the water treatment chemical program. The most obvious problem is damage to, or the need for premature replacement of, the water-contacted equipment. Loss of operational efficiency is also a problem but is not always as apparent because it is rarely measured accurately; however, the additional operational costs due to operational inefficiency can be substantial. Specific types of equipment and system failures are described in Chapters 4, 5 and 6. When developing a water treatment program, you must give adequate effort and consideration to defining goals, devoting adequate resources to accomplish goals, and assessing performance.

11-2 OPTIONS FOR SETTING UP A WATER TREATMENT PROGRAM.

There are four methods for developing and implementing a water treatment program:

a. Generic Programs. In a generic water treatment program, facility operations personnel identify and use generic or commodity chemicals as part of the water treatment program that has been developed by facility personnel. Facility operations provide all services for chemical feed and control as well as monitoring and performance assessment. Facility personnel may be required to handle and mix generic chemicals. Alternatively, a contractor can develop the program for using generic chemicals, with services being provided by facility personnel.

Outsource Proprietary Chemicals Only. Procurement of proprietary water treatment chemicals is outsourced from a qualified water treatment contractor. Facility operations provide all services for chemical feed and control, and monitoring and performance assessment

a. Outsource Proprietary Chemicals and Some Basic Periodic Services. Proprietary water treatment chemicals, control and feed equipment, and periodic services are outsourced from a qualified water treatment contractor. Facility operations provide daily services for chemical feed and control, and monitoring and performance assessment.

b. Complete Outsourcing. All chemicals and services are outsourced to a contractor. The facility provides only maintenance of operating equipment (no water-treatment-related services).

11-2.1 Generic Chemical Water Treatment Programs.

Generic chemical water treatment programs have been implemented at military installations. The advantage of using this type of program is the cost savings generated by the use of generic chemicals relative to formulated products obtained from water treatment service companies. Generic chemicals are identified in Chapters 4 through 6. Generic chemical programs can be successful, but adequate planning and resources (including technical expertise) must be devoted to the implementation of the program. Generic chemicals and specifications are listed in Appendix E.

11-2.2 Chemicals and Services Outsourcing.

The General Services Administration (GSA) has developed standardized procedures and contracting arrangements for the outsourcing of: procurement of proprietary chemicals; procurement of proprietary chemicals with some periodic services; and procurement of total program services. The standard contracts have been designed to develop the most favorable pricing of water services received from contractors. GSA-listed proprietary products should not be purchased solely on a “price-per-pound” or “price-per-volume-of- product” basis. For purchases above $2500, make a “best value” determination after reviewing schedule price lists from at least three vendors. The “best value” determination must consider the price of products and the quality of services included with the products. It is usually necessary to obtain proposals from water treatment service companies and consider the details of the services to be provided as proposed, and the “cost per 1000 gallons (3785 liters) of makeup.” Proprietary products cost 5 to 20 times more than generic chemicals. These contracts only apply to GSA-listed products. Not all products on these GSA lists may be appropriate or approved for use in military industrial water systems. The contract-specified service requirements that are to be included with the GSA-listed products must be well defined; if not, a poorly monitored and poorly implemented program may result.

11-2.3 Contracts Based on Cost per Unit of Water.

A practical approach for obtaining cost-effective water treatment can be developed based on the bid price to treat a unit of water (1000 gallons (3785 liters) of water). Optimally, the contract scope of work will specify minimally acceptable performance standards as well as service requirements to be met by the contractor. Service requirements can vary from periodic consulting service to complete outsourcing.

11-3 DEVELOPING A SCOPE OF WORK (SOW) FOR INDUSTRIAL WATER TREATMENT.

This paragraph applies only to paragraph 11-2.1.3. A SOW (sometimes called a "statement of work" or a "statement of services to be provided") is developed for inclusion in the required procurement documents (request for proposal/bid (RFP/RFB) and contract). The SOW will identify the specific services, chemicals, and equipment that a contractor is to provide under the terms of the contract. The SOW will, at a minimum, specify or identify the following: SOW to be performed; qualifications of supplier; water characteristics of each system to be treated; description of industrial water systems and their operation; performance specification (results required); service requirements; equipment requirements for control, feed, monitoring, and sampling; requirements for chemicals and test equipment; and quotation for total chemical cost and usage. These issues are described below.

11-3.1 Qualifications.

The SOW specifies the minimum qualification requirements for contractors and contractor representatives. These requirements are developed to allow the participation of qualified contractors (water treatment chemical companies) having national, regional, and local operations. The SOW can specify the minimum number of years that the company has been in business and the minimum number of years and type of experience of contractor representatives, as well as required technical service capabilities.

11-3.2 Submittal Requirements and Format.

The SOW clearly specifies the type of response (submittal) that is required from an RFP or RFB. This is necessary to avoid receiving bid responses that are so different in their presentation that they cannot be easily or objectively compared. The evaluation process can be simplified by requiring bidders to provide a comprehensive acknowledgement that they understand and accept all requirements for compliance, qualifications, service requirements, and performance standards. The RFP/RFB should require a simple, generic, technical summary that lists the proposed chemical technology and treatment ranges for each type of system to be serviced under the procurement.

11-3.3 Water Quality.

The water supplied as makeup to industrial water systems is characterized in terms of its source, treatment, and quality, including seasonal and temporal variances. If external treatment is used on individual systems such as a steam boiler, this treatment is identified.

11-3.4 Description of Systems and Operations.

A description of the number, capacity, and types of systems to be serviced under the contract is a critically important element of a SOW. The metallurgy of all water-contacted surfaces is identified. Without this information, performance standards cannot be adequately defined. The condition of equipment is documented. Operational parameters, such as the equipment duty, load, and usage, are described so that water usage (preferably total water usage for each system) and chemical restrictions can be considered in developing the proposal.

11-3.5 Performance Specification.

Performance criteria are specified for protecting equipment against deposition, corrosion, and biological growths. Certain minimally acceptable standards for performance must be met. Recommended or example performance standards are listed in Chapters 4, 5 and 6 for the respective types of industrial water systems. Allowances are made for problems that cannot be totally controlled by chemical treatment alone. One example is SS accumulation in a cooling tower system. Chemical dispersants can aid in keeping SS from settling on metal surfaces, but it may require adequate flow and physical removal to maintain good control.

11-3.6 Service Requirements.

The SOW accurately describes the services to be provided by the contractor. Service includes the frequency of on-site visits, the duties to be performed, and the methods of reporting. The duties to be performed can include these activities: water testing; making log entries; training; maintaining automated chemical control and feed equipment; manual addition of chemicals to industrial water systems; inventory control; corrosion coupon studies; microbiological population determination; equipment inspections; laboratory support; quarterly reviews; and annual reviews.

11-3.7 Control, Feed, Monitoring and Sampling Equipment Requirements.

The SOW specifies what equipment, if any, is required to achieve consistent control of the makeup water treatment chemical program. Automated control and feed equipment is required on most medium and large cooling towers and on most steam boilers. Automated control and feed equipment helps limit the demand for service maintenance. To provide for the preparation of an appropriate SOW, engineering and facility maintenance personnel carefully evaluate their capabilities in the area of water treatment and water systems. Inadequate water treatment equipment can result in higher service requirements or inconsistent control of the chemical program. Descriptions of chemical applications can be found in Chapter 8.

11-3.8 Chemicals and Test Equipment.

The SOW specifies any restrictions on the use or discharge of chemicals. Examples of restrictions can include limitations on the use of acid, shipping container size limits, microbiocide selection criteria, and limitation on use of dry chemicals.

The SOW specifies how the cost of chemicals and services is being calculated and quoted. For example, quotations for chemical treatment can be based on the cost to treat 133.666 cubic feet (3.785 cubic meters) of water. Cost for services in the SOW can be required to be included in the cost of chemical treatment or quoted separately as line items, time, and materials. Contracts that require a "not-to- exceed" quotation supply bidders with a not-to-exceed water usage estimate.

11-4 REPORTS AND AUDITS.

Reports and audits are tools for documenting performance and cost effectiveness of any industrial water treatment program. Audits serve to verify results from the water treatment service company. Audits also serve to verify the cost-effectiveness of product being supplied by the water treatment service company. Audits are performed by qualified agencies within the military branch in question or by independent consultants contracted to perform such duties.

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APPENDIX A PRACTICAL (PUCKORIUS) SCALING INDEX (PSI)

A-1 DEVELOPMENT OF PSI.

Have been used to predict the tendency of water to form or dissolve scale. Both the LSI and the RSI are based on the pH of saturation (pHs) for calcium carbonate under a specific water condition. Both indices use the measured pH of the cooling water.

1. LSI = (measured pH) - (pHs). A positive value indicates scale; a negative value indicates no scale.
2. RSI = (2 pHs) - (measured pH). A value below 6 means scale; above 6 means no scale.

A-1.1 PSI.

Use of LSI and RSI sometimes gave inconsistent or even conflicting results. Based on a long-term study relative to calcium carbonate scale formation when applying both the LSI and RSI, P.R. Puckorius and J.M. Brooke developed a new index that gives much better and more consistent indication of cooling water-scaling conditions. The new index, the Practical Scaling Index (PSI), sometimes called the Puckorius Scaling Index, is based on correcting the system pH to match the total alkalinity of the water being evaluated. This is necessary because the pH is often buffered, causing the pH to relate incorrectly to the bicarbonate alkalinity, one of the factors in the pH_s calculation.

A-2 CALCULATING PSI.

To calculate the PSI, the pH_s is determined in the same manner as for the LSI and RSI. An adjusted or equilibrium pH (pH_{eq}) is obtained from a total alkalinity/pH chart (Table A-7). The value of pH_{eq} rather than measured pH is used in the following formula:

$$\mathbf{PSI = (2\ pHs) - (pHeq)}$$

A value below 6 means scale; above 6 means no scale.

A-2.1 Calculating pHs.

The pHs can be determined from the relationship between various characteristics of water. The following factors and formula are used in determining the pHs:

a. Factors needed to calculate pHs :

A = TDS (ppm) (Table A-1)

B = Temperature (°F) (Table A-2)

C = Calcium hardness (ppm as $CaCO_3$) (Table A-3)

D = Total alkalinity (ppm as $CaCO_3$) (Tables A-5 and A-6)

Table A-1 Factor "A" for TDS

TDS (ppm)	Value of "A"
50	0.07
75	0.08
100	0.10
150	0.11
200	0.13
300	0.14
400	0.16
600	0.18
800	0.19
1000	0.20
1500	0.21
2000	0.22
2500	0.23
3000	0.24
4000	0.25
5000	0.26

Table A-2 Factor "B" for Temperature

°F	F, Units				
Tens	0	2	4	6	8
30	--	2.60	2.57	2.54	2.51
40	2.48	2.45	2.43	2.40	2.37
50	2.34	2.31	2.28	2.25	2.22
60	2.20	2.17	2.14	2.11	2.09
70	2.06	2.04	2.03	2.00	1.97
80	1.95	1.92	1.90	1.88	1.86
90	1.84	1.82	1.80	1.78	1.76
100	1.74	1.72	1.71	1.69	1.67
110	1.65	1.64	1.62	1.60	1.58
120	1.57	1.55	1.53	1.51	1.50
130	1.48	1.46	1.44	1.43	1.41
140	1.40	1.38	1.37	1.35	1.34
150	1.32	1.31	1.29	1.28	1.27
160	1.26	1.24	1.23	1.22	1.21
170	1.19	1.18	1.17	1.16	--

Find value of "B" in appropriate unit column.

Example: For water at 86° F, B = 1.88

a. pHs = 9.30 + A + B - (C + D)

b. EXAMPLE B-1:

Water from a cooling tower has a TDS of 1000 ppm, calcium hardness of 500 ppm (as $CaCO_3$), total alkalinity of 100 ppm (as $CaCO_3$) and measured pH of 8.2. The hottest temperature on the waterside of the heat exchanger is 120° F.

$pH_s = 9.30 + A + B - (C + D)$

$pH_s = 9.30 + 0.20 + 1.57 - (2.30 + 2.00) = 6.77$

A-2.2 Calculating pHeq.

a. Puckorius and Brooke developed the improved relationship between total alkalinity and pH after studying hundreds of cooling systems over some 20 years. The pH_{eq} values shown in Table A-7 for the total alkalinity measured in cooling water are used for calculating the PSI.

Table A-3 Factor "C" for Calcium Hardness (as ppm $CaCO_3$) Zero to 200 ppm

ppm Tens	ppm, Units									
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	--	--	--	0.08	0.20	0.30	0.38	0.45	0.51	0.56
10	0.60	0.64	0.68	0.72	0.75	0.78	0.81	0.83	0.86	0.88
20	0.90	0.92	0.94	0.95	0.98	1.01	1.02	1.03	1.05	1.06
30	1.06	1.09	1.11	1.12	1.13	1.15	1.16	1.17	1.18	1.19
40	1.20	1.21	1.23	1.25	1.25	1.25	1.26	1.27	1.28	1.29
50	1.30	1.31	1.32	1.33	1.34	1.34	1.35	1.36	1.37	1.37
60	1.38	1.39	1.39	1.40	1.41	1.42	1.42	1.43	1.43	1.44
70	1.45	1.45	1.46	1.47	1.47	1.48	1.48	1.49	1.49	1.50
80	1.51	1.51	1.52	1.53	1.53	1.53	1.54	1.54	1.55	1.55
90	1.56	1.56	1.57	1.57	1.58	1.58	1.58	1.59	1.59	1.60
100	1.60	1.61	1.61	1.61	1.62	1.62	1.63	1.63	1.64	1.64
110	1.64	1.65	1.65	1.65	1.65	1.66	1.67	1.67	1.67	1.68
120	1.68	1.68	1.69	1.70	1.70	1.70	1.70	1.71	1.71	1.71
130	1.72	1.72	1.72	1.73	1.73	1.73	1.74	1.74	1.74	1.75
140	1.75	1.75	1.75	1.76	1.76	1.77	1.77	1.77	1.77	1.78
150	1.78	1.78	1.78	1.80	1.80	1.80	1.80	1.80	1.80	1.80
160	1.81	1.81	1.81	1.81	1.82	1.82	1.82	1.82	1.83	1.83
170	1.83	1.84	1.84	1.84	1.84	1.85	1.85	1.85	1.85	1.85
180	1.86	1.86	1.86	1.86	1.87	1.87	1.87	1.87	1.88	1.88
190	1.88	1.88	1.89	1.89	1.89	1.89	1.89	1.90	1.90	1.90
200	1.90	1.91	1.91	1.91	1.91	1.91	1.92	1.92	1.92	1.92

Table A-4 Factor "C" For Calcium Hardness (as ppm $CaCO_3$) 200 to 990 ppm

ppm Hundreds	ppm, Units									
	0	10	20	30	40	50	60	70	80	90
200	--	1.92	1.94	1.96	1.98	2.00	2.02	2.03	2.05	2.06
300	2.08	2.09	2.11	2.12	2.13	2.15	2.16	2.17	2.18	2.19
400	2.20	2.21	2.23	2.25	2.25	2.26	2.26	2.27	2.28	2.29
500	2.30	2.31	2.32	2.33	2.34	2.34	2.35	2.36	2.37	2.37
600	2.38	2.39	2.39	2.40	2.41	2.42	2.42	2.43	2.43	2.44
700	2.45	2.45	2.45	2.47	2.47	2.48	2.48	2.49	2.49	2.50
800	2.51	2.51	2.52	2.52	2.53	2.53	2.54	2.54	2.55	2.55
900	2.56	2.56	2.56	2.57	2.57	2.58	2.58	2.59	2.59	2.60

Use Table A-3 to find values of "C" for 3 to 209 ppm calcium hardness, and Table A-4 for 210 to 990 ppm. Example: For 144 ppm calcium hardness (as $CaCO_3$), C = 1.76

Table A-5 Factor "D" for Alkalinity (as ppm $CaCO_3$) Zero to 200 ppm

ppm Tens	ppm, Units									
	0	1	2	3	4	5	6	7	8	9
0	--	0.00	0.30	0.48	0.60	0.70	0.78	0.85	0.90	0.95
10	1.00	1.04	1.08	1.11	1.15	1.18	1.20	1.23	1.26	1.29
20	1.30	1.32	1.34	1.36	1.38	1.40	1.42	1.43	1.45	1.46
30	1.48	1.49	1.51	1.52	1.53	1.54	1.56	1.57	1.58	1.59
40	1.60	1.61	1.62	1.63	1.64	1.65	1.67	1.67	1.68	1.69
50	1.70	1.71	1.72	1.72	1.73	1.74	1.75	1.76	1.76	1.77
60	1.78	1.79	1.80	1.81	1.81	1.82	1.83	1.83	1.83	1.84
70	1.85	1.85	1.86	1.86	1.87	1.88	1.88	1.89	1.89	1.90
80	1.90	1.91	1.91	1.92	1.92	1.93	1.93	1.94	1.94	1.95
90	1.95	1.96	1.96	1.97	1.97	1.98	1.98	1.99	1.99	2.00
100	2.00	2.00	2.01	2.01	2.02	2.02	2.03	2.03	2.03	2.04
110	2.04	2.05	2.05	2.05	2.05	2.06	2.06	2.07	2.07	2.08
120	2.08	2.08	2.09	2.09	2.09	2.10	2.10	2.10	2.11	2.11
130	2.11	2.12	2.12	2.12	2.13	2.13	2.13	2.14	2.14	2.14
140	2.14	2.15	2.15	2.16	2.16	2.16	2.16	2.17	2.17	2.17
150	2.18	2.18	2.18	2.18	2.19	2.19	2.19	2.20	2.20	2.20
160	2.20	2.21	2.21	2.21	2.21	2.22	2.22	2.23	2.23	2.23
170	2.23	2.23	2.23	2.24	2.24	2.24	2.24	2.25	2.25	2.26
180	2.26	2.26	2.26	2.26	2.26	2.27	2.27	2.27	2.27	2.28
190	2.28	2.28	2.28	2.29	2.29	2.29	2.29	2.29	2.30	2.30
200	2.30	2.30	2.30	2.31	2.31	2.31	2.31	2.32	2.32	2.32

Table A-6 Factor "D" for Alkalinity (as ppm $CaCO_3$) 200 to 890 ppm

ppm 100s	ppm, Units									
	0	10	20	30	40	50	60	70	80	90
200	--	2.32	2.34	2.36	2.38	2.40	2.42	2.43	2.45	2.45
300	2.48	2.49	2.51	2.52	2.53	2.54	2.56	2.57	2.58	2.59
400	2.60	2.61	2.62	2.63	2.64	2.65	2.66	2.67	2.68	2.69
500	2.70	2.71	2.72	2.72	2.73	2.74	2.75	2.76	2.76	2.77
600	2.78	2.79	2.80	2.81	2.81	2.81	2.82	2.83	2.83	2.84
700	2.85	2.85	2.86	2.86	2.87	2.88	2.88	2.89	2.89	2.90
800	2.90	2.91	2.91	2.92	2.92	2.93	2.93	2.94	2.94	2.95

Use Table A-5 for values of "D" for 1 to 209 ppm, and use Table A-6 for 210 to 990 ppm.

Table A-7 pH_{eq} Determined from Total Alkalinity

Alkalinity ppm Hundreds	Alkalinity ppm $CaCO_3$, Tens									
	0	10	20	30	40	50	60		80	90
0	--	6.00	6.45	6.70	6.89	7.03	7.14	7.24	7.33	7.40
100	7.47	7.53	7.59	7.64	7.68	7.73	7.77	7.81	7.84	7.88
200	7.91	7.94	7.97	8.00	8.03	8.05	8.08	8.10	8.15	8.15
300	8.17	8.19	8.21	8.23	8.25	8.27	8.29	8.30	8.32	8.34
400	8.35	8.37	8.38	8.40	8.41	8.43	8.44	8.46	8.47	8.48
500	8.49	8.51	8.52	8.53	8.54	8.56	8.57	8.58	8.59	8.60
600	8.61	8.62	8.63	8.64	8.65	8.66	8.67	8.67	8.68	8.70
700	8.71	8.72	8.73	8.74	8.74	8.75	8.76	8.77	8.78	8.79
800	8.79	8.80	8.81	8.82	8.82	8.83	8.84	8.85	8.85	8.86
900	8.87	8.88	8.88	8.89	8.90	8.90	8.91	8.92	8.92	8.93

a. EXAMPLE A-2:

Water from a cooling tower has a total alkalinity of 100 ppm (as $CaCO_3$) and a measured pH of 8.2 (same as example A-1). From Table A-7, the pHeq is 7.47.

PSI = (2pHs) - (pHeq) = 2 (6.77) - 7.47

= 13.54 - 7.47 = 6.07

RSI = (2pHs) - (measured pH) = 13.54 - 8.2

= 5.34

LSI = (measured pH) - (pHs) = 8.2 - 6.77

= +1.43

b. The pHeq may also be calculated as follows:

pHeq = 1.485 log TA + 4.54

Where: TA denotes total alkalinity.

A-2.3 Scaling Severity Keyed to Indices.

a. Commonly accepted interpretation of the previously described indices is shown in Table A-8.

b. In Example A-2, the LSI predicted that the water would exhibit a severe to very severe scaling tendency. The RSI predicted that the water would exhibit a moderate to severe scaling tendency. The PSI predicted that the water is stable with no tendency to form or dissolve scale.

Table A-8 Scaling Indices vs. Condition

LSI	PSI/RSI	Condition
3.0	3.0	Extremely severe scaling
2.0	4.0	Very severe scaling
1.0	5.0	Severe scaling
0.5	5.5	Moderate scaling
0.2	5.8	Slight scaling
0.0	6.0	Stable water, no scaling, no tendency to dissolve scale
-0.2	6.5	No scaling, very slight tendency to dissolve scale
-0.5	7.0	No scaling, slight tendency to dissolve scale
-1.0	8.0	No scaling, moderate tendency to dissolve scale
-2.0	9.0	No scaling, strong tendency to dissolve scale
-3.0	10.0	No scaling, very strong tendency to dissolve scale

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APPENDIX B CORROSION TESTING WITH COUPON-TYPE TEST SPECIMENS

B-1 PURPOSE.

Corrosion tests with metal coupon test specimens are used to determine how corrosive water is to a specific metal. Coupon test specimens are particularly useful in monitoring the effectiveness of chemical corrosion control programs. The extent of both general and localized corrosion can be determined. Also, examination of the specimens as they are removed from the system can provide information regarding deposit accumulation or microbiological slime growth. Corrosion test coupons are usually used as corrosion test specimens for open and closed cooling systems, closed hot water systems, and domestic water systems. See ASTM Standard Test Method: Corrosivity of Water in the Absence of Heat Transfer (Weight Loss Methods), D2688-15e1.

B-2 APPLICATION.

B-2.1 Description of Coupons.

The coupons are metal tags of various sizes. Generally, low-carbon steel specimens are used as the most susceptible metal to corrosion; however, copper, stainless steel, brass, and other metals are available for special studies. The specimens are prepared and cleaned to ensure uniformity and weighed. The general corrosion rate is determined after exposure. Coupons are cleaned and re-weighed. Corrosion rates are calculated based on the weight loss, time of exposure, and the area and specific gravity of the coupon, and are expressed in mils per year (MPY).

B-2.2 Test Conditions.

Since the goal of the corrosion testing program is to provide information regarding conditions within the system, the corrosion coupons should be exposed to conditions that reflect those in the system as a whole. Water velocity and temperature will significantly affect the corrosion rate. Corrosion rates can be significantly increased when velocity is either too low or too high. For best results, water velocity flowing by the test specimen should be 3 to 5 feet per second (0.90 to 1.5 meters per second), and both adjustable and measurable. Temperature also affects the rate of corrosion, with higher temperatures usually increasing corrosion; therefore, in cooling water systems both the cold supply water and the hot return water should be evaluated with corrosion coupons. When only one test rack can be installed, the warm water return at the tower should be used to provide an average hot water temperature.

B-2.3 Test Length.

Expose corrosion coupons for a minimum of 30 calendar days and a maximum of 90 calendar days, except for special tests. Although spot checks are useful, a regular schedule will determine trends and recognize changes within the system. When corrosion test specimens of different metals are installed in the same corrosion test rack, the more noble or resistant metal should be downstream of less resistant metals.

B-2.4 Receipt of Specimens.

Specimens are shipped in vapor-inhibited bags. Do not remove them from the bags until the specimen is to be installed. The vapor inhibited bags should be saved for returning exposed specimens. Do not handle specimens directly with fingers since fingerprints can initiate corrosion sites. Record on the appropriate form the exact location and date of installation.

B-2.5 Return of Specimens.

After the specimens have been exposed for the selected time (30, 60, or 90 calendar days), carefully remove, air dry without disturbing any deposits, and return them to the original vapor-inhibited bag. Record date of removal on the appropriate form. Then send the exposed specimens and completed forms to the supplier for evaluation. After evaluation, the results are presented and interpreted in a written report.

B-3 INSTALLATION OF COUPON-TYPE TEST SPECIMENS.

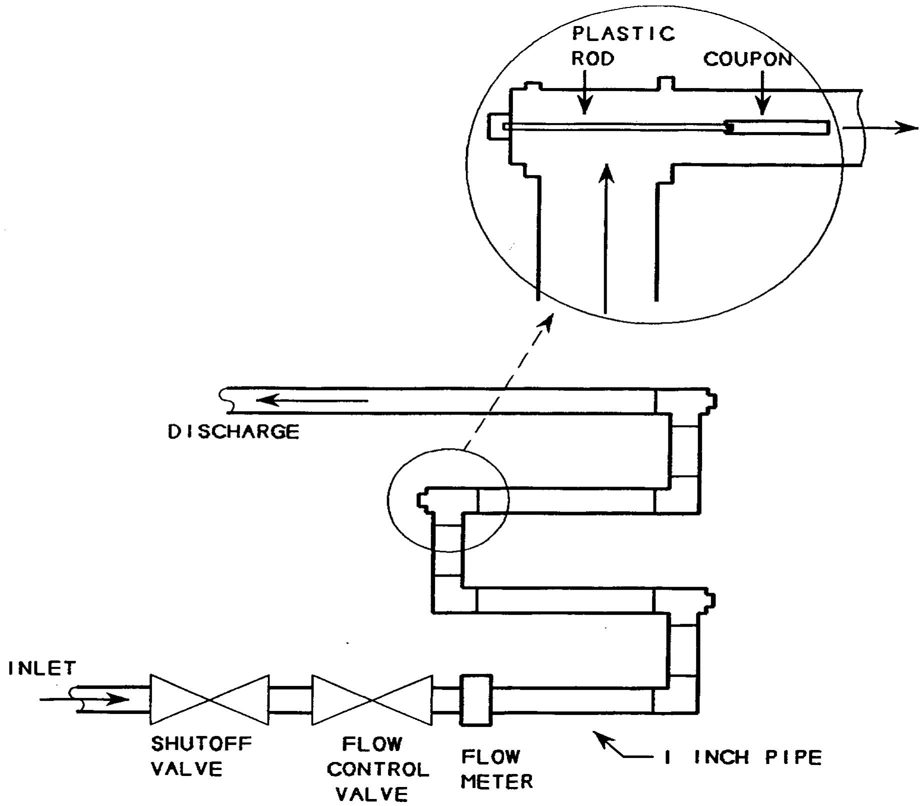
B-3.1 Method of Installation.

Coupons are usually installed in pipe "tees" by means of corrosion test racks which include a 1-inch (25-millimeter) pipe plug, drilled and tapped to accept a plastic or phenolic rod with a nylon nut and bolt for attaching the coupon to the rod. A bypass arrangement with 1-inch (25-millimeter) piping, as shown in Figure B-1, will facilitate installation and removal as well as allow the use of multiple specimens. Polyvinyl chloride (PVC) will eliminate electrical effects but cannot be used for hot condensate. A corrosion test rack may be purchased or constructed on site.

B-3.2 Placement of Coupons.

For steam and condensate return lines, install coupons in any convenient location where there are tees. When using a bypass arrangement, condensate from the outlet is piped back into the system. Bypasses should be constructed of iron pipe and fittings and installed only where there is sufficient pressure differential to ensure a continuous flow through the bypass. Direction of flow should be as shown in Figure B-1 to minimize turbulence around the corrosion test specimen and ensure that the test rack remains full of water.

Figure B-1 Bypass Piping for Corrosion Testing Cooling Water and Condensate Systems



B-3.3 Test Methods.

To ensure proper results, the following points should be checked:

1. Flow through the corrosion test rack must be continuous and measurable. Use flow meters for all installations. When a flow meter does not exist, flow must be measured by timing how long it takes to fill a container of known volume such as a 5- gallon (20-liter) pail.
2. Normally, water velocity through the corrosion test rack should be 3 to 5 feet per second (0.90 to 1.5 meters per second). The velocities in meters per second (feet per second) for given liters per second (gallons-per-minute) flows for various pipe sizes are shown in Table B-1

Table B-1 Flow Rate

Velocity ft/sec (m/s)	Line Size		
	1 in (25 mm)	1.25 in (32 mm)	1.5 in (38 mm)
3 (0.91)	8 gpm (0.5 l/sec)	14 gpm (0.9 l/sec)	19 gpm (1.2 l/sec)
5 (1.5)	13 gpm (0.8 l/sec)	23 gpm (1.5 l/sec)	30 gpm (1.9 l/sec)

NOTE: Corrosion coupons and coupon racks can be obtained from the following suppliers, among others:

1. Water treatment service companies.
2. Water treatment equipment companies.
3. Alabama Specialty Products Inc.
   152 Metals Samples Road
   Munford, Alabama 36268
   (205)358-4202
4. Advantage Controls, LLC
   4700 Harold Arbitz Drive
   Muskogee, Oklahoma 74403
   (800)743-7431

APPENDIX C CORROSION TESTING WITH TEST NIPPLE ASSEMBLY

C-1 PURPOSE.

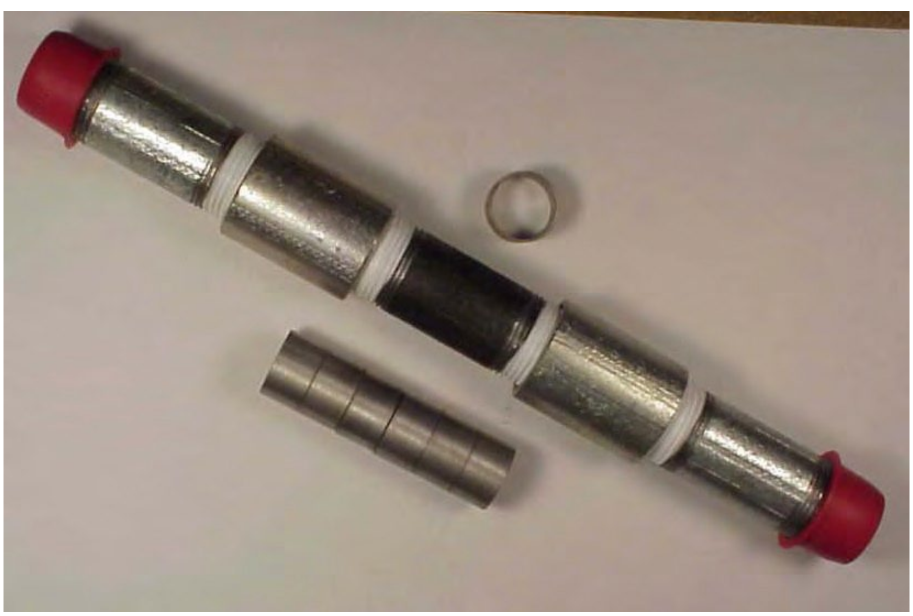
Corrosion tests with metal test specimens are used to determine how corrosive water is toward a specific metal. Although test nipple assemblies (referred to as "tester") can be used in many applications, they are used on military installations to evaluate corrosion problems in steam condensate return systems. See ASTM Standard Test Method: Corrosivity of Water in the Absence of Heat Transfer, D2688-15e1.

C-2 APPLICATION.

C-2.1 Tester Specifications.

The tester consists of three 3-inch by 0.75-inch (76 millimeter by 19- millimeter) National Pipe Thread (NPT) nipples, connected by two couplings (see Figure C-1). The center nipple contains short inserts machined from steel tubing similar to the steel pipe in the condensate system. The outside diameter of the inserts is approximately the same as the inside diameter of the center 0.75-inch (19-millimeter) machined coupling. The two end nipples of the tester are installed between two unions in such a manner that condensate will constantly flow through the tester. See paragraph C-3 for detailed installation instructions.

Figure C-1 Condensate Corrosion Tester



C-2.2 Likelihood of Corrosion.

Serious corrosion is more likely in large-area heating systems that have long return lines. More concentrated systems, such as laundries and low-pressure closed systems in which there is very little feed water makeup, generally experience much less condensate return line corrosion.

C-2.3 Scale of Testing.

If the test points are well chosen, information obtained from one or two condensate return systems on an installation or base is generally sufficient to serve as a survey of the entire facility. One or more testers would be installed in the largest area heating system and another in a smaller system. The testers should be installed at points where maintenance work has been required due to corrosion.

C-2.4 Receipt of Tester.

The supplier provides the tester complete and ready for installation. An appropriate data form is also provided with the tester. This form must be completed by the user for correct interpretation of corrosion that may occur on the tester inserts. The user is required to draw a picture to show how and where the tester was installed.

C-2.5 Removal of Tester.

At the end of the test period, the tester is removed. The tester is rinsed internally for several seconds with very hot water, drained, and immediately capped on both ends with the plastic caps that had been supplied with the tester.

C-2.6 Condensate Sample.

A condensate sample is collected from the area where the tester was installed and returned to the supplier at the same time as the tester.

C-2.7 Return of Tester.

The tester is packed in any convenient package, enclosing the completed data sheet, and returned to the supplier.

C-3 INSTALLATION OF TESTER.

C-3.1 Location of Tester.

Install the tester in a horizontal return line. If morpholine treatment is being used, install the tester in a building near the end of the steam main where the treatment would be expected to be least effective. If a mixture of morpholine and cyclohexylamine is used, install a tester at each end of the system.

C-3.2 Test Conditions.

Ensure representative sampling of the condensate by the tester. Do not install the tester to receive drips from steam mains. Drips may be less corrosive (less acidic) than the average condensate.

C-3.3 Placement of Tester.

Place the tester horizontally to receive the condensate from a hot water generator or space heater that is drained by a 0.75-inch (19- millimeter) trap. Do not install the tester downstream from a pump in the condensate line. Avoid bypasses and do not overload the tester with condensate from several traps. Enough condensate should flow to the tester to fill it at least halfway.

C-3.4 Method of Installation.

To install the tester, remove a section of the pipe from the condensate return system. Replace the section of pipe with the tester, unions, and any additional pipe needed to complete the installation.

C-3.5 Length of Test.

Leave the tester in place for about 90 days. Record the dates the tester was installed and removed.

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APPENDIX D TESTING INDUSTRIAL WATER SYSTEM SAMPLES

D-1 PURPOSE.

Testing of industrial water is performed to determine the amount of treatment chemicals so dosage levels can be properly regulated. These tests are a means by which reliable water system operations are ensured, with respect to the impact of water quality on system equipment and operation. Testing may be conducted in a permanent field laboratory or at the plant or site location using portable test kits.

D-2 USE OF PORTABLE TEST KITS.

Portable test kits are primarily for use at the site location where the sample is taken when an immediate test result is needed. They can also be used in the permanent field laboratory. Test procedures are provided with the test kit. For tests that can be conducted either in the field laboratory or with a portable test kit, use field laboratory test procedures for best results. The water analyst should periodically check the results of the portable test kit against the field laboratory test on the same water sample (perform a check sample analysis). Portable test kits are available from a number of commercial sources.

D-3 LABORATORY PROCEDURES AND TESTING TECHNIQUES.

The achievement of accurate test results is dependent on the use of proper reagents and on following good, basic laboratory procedures and techniques.

D-3.1 Management of Reagents.

D-3.1.1 Supply.

The chemical reagents stored at each field laboratory should be specific for the tests that are performed. The amount on hand should be adjusted to ensure the supply is fresh. Reagent containers must be kept tightly closed when not in use and stored in a cool place. Except for reagents with a specified shorter shelf-life, liquid reagents should be consumed within one year and dry reagents consumed within 2 years. All reagents should be properly marked with appropriate warning labels, batch control numbers, and date packaged or discard date clearly marked.

D-3.1.2 Storage.

It is necessary to keep everything in good order at all times. Have a place for everything and keep everything in its place. Be sure all bottles are properly labeled and avoid mixing bottles. All bottles should be kept tightly closed. Keep any reserve stock of solutions and reagents in a cool, dark place.

D-3.2 Apparatus.

The apparatus are precision instruments capable of very fine measurements. Measure carefully, as the results will be "off" if improper sample amounts are taken, incorrect volumes of solution are added, the burette is not read correctly, or if the methods prescribed are not performed exactly as written. Each water analysis requires specific chemical apparatus. These are scientific instruments and are to be treated as such. The apparatus will last indefinitely if given proper care. All equipment and apparatus, especially glassware, should be kept clean. Unless this is done, the tests will not be reliable and errors will be introduced. Thoroughly rinse and air-dry all glassware immediately after use. If color apparatus is employed, do not expose to heat or direct sunlight. If any liquid is spilled on any of the equipment or apparatus, wipe off at once and dry.

D-3.3 Testing Procedures.

The suspended matter or sludge will generally settle to the bottom if the sample is allowed to stand before testing. The clear water can then be used for the tests, making it unnecessary to filter (except for specific tests). Theoretically, all water analyses should be made at 77° F (25° C); however, no appreciable error will be introduced if the test is made between 68 and 86° F (20° to 30° C). In general, the shorter the time between the collection and analysis of the sample, the more reliable the results will be.

When the water sample color interferes with the analysis, it may be necessary to filter the sample through activated charcoal. NOTE: This does not apply to the sulfite and nitrite tests.

APPENDIX E NONPROPRIETARY INDUSTRIAL WATER TREATMENT CHEMICALS

E-1 ANTIFOAM.

Polyamide or polyhydric alcohol

Use: Prevent foaming carryover in steam boilers

Federal Specification: None

Package/ National Stock Number (NSN): 5-gal can, NSN: 6850-01-181-016

E-2 ANTIFREEZE.

Inhibited, 87.6 percent ethylene glycol, 300˚ F (149° C) minimum boiling point, nonflammable, protection to –60˚ F (–51˚ C)

Use: Closed hot and chilled water systems

Federal Specification: A-A-52624, *Antifreeze, Multi-Engine Type*

Package/NSN: 1-gal can, NSN: 6850-00-181-7929

5-gal can, NSN: 6850-00-181-7933

55-gal drum, NSN: 6850-00-181-7940

E-3 BIOCIDE.

Active ingredient, methylenebis (thiocynate), 10 percent in water solution.

Use: Cooling towers with pH less than 7.5

Federal Specification: None

Package/NSN: 5-gal, NSN: 6850-01-191-5033

E-3.1 BIOCIDE.

Active ingredient 20 percent

2,2-Dibromo-3-nitrilopropionamide, 80 percent inert ingredients

Use: Cooling towers with pH less than 7.5

Federal Specification: None

Package/NSN: 5-gal can, NSN: 6850-01-191-5034

E-3.2 BIOCIDE.

Active ingredients 10 percent dodecylguanidine hydrochloride, 4 percent bis (tri-n-butyltin) oxide

Use: Cooling towers with and pH less than 7.5 Federal Specification: None

Package/NSN: 5-gal can, NSN: 6850-01-194-8306

E-3.3 BIOCIDE.

Active ingredients 20 percent

n-alkyldimethylbenzylammonium chloride, and 3 to 4 percent bis (tri-n-butyltin) oxide, pH greater than 10.5

Use: Cooling towers with pH greater than 7.5 Federal Specification: None

Package/NSN: 5-gal can, NSN: 6840-01-189-8139

E-3.4 BIOCIDE.

Active ingredient 60 percent poly (oxyethylene (dimethyliminio) ethylene-(dimethyliminio) ethylene dichloride)

Use: Cooling towers with pH greater than 7.5 Federal Specification: None

Package/NSN: 5-gal can, NSN: 6840-01-190-2551

E-3.5 BIOCIDE.

Active ingredients 60 percent consisting of 14 to 15 percent disodium cyanodithioimidocarbonate and 20 to 21 percent potassium n-methyldithiocarbamate

Use: Cooling towers with pH greater than 7.5

Federal Specification: None

Package/NSN: 5-gal can, NSN: 6840-01-198-7945

E-3.6 BIOCIDE.

Active ingredient 96 to 98 percent

1-bromo-3-chloro-5,5-dimethylhydantoin, granular

Use: Remote cooling towers with any pH

Federal Specification: None

Package/NSN: 35-lb can, NSN: 6840-01-185-7455

E-4 BORAX (SEE SODIUM NITRITE-BORAX BLEND, ITEM E-43).

E-5 CALCIUM HYDROXIDE.

(slaked lime) ($Ca[OH]_2$) technical, powder, 90 percent minimum by weight

Use: Lime-soda ash water softening

Federal Specification: A-A-55821, *Calcium Hydroxide, Technical*

Package/NSN: 50-lb bag, NSN: 6810-00-656-1091

E-6 CALCIUM HYPOCHLORITE.

($Ca[OCl]_2$) technical, granular, 65 percent chlorine by weight

Use: Algae control in cooling towers and disinfectant in treatment for Legionnaire's Disease

Federal Specification: ASTM-E1229

Package/NSN: 5-lb can, NSN: 6810-00-238-8115 100-lb drum,

NSN: 6810-00-255-0472

E-7 CAUSTIC SODA (SEE SODIUM HYDROXIDE, ITEM E-37).

E-8 CYCLOHEXYLAMINE.

Boiler feedwater compound, neutralizing amine, all drums to bear adequate caution labels to protect against fire, poison and caustic burn hazards

Use: Control corrosion by CO_2 in steam condensate lines Federal Specification: O-C-940, *Cyclohexylamine,* Technical Package/NSN:

60 percent, 400-lb drum, NSN: 6810-01-074-5201

60 percent, 15-gal drum, NSN: 6810-00-515-2235

98 percent, 15-gal drum, NSN: 6810-00-530-4695

98 percent, 55-gal drum, NSN: 6810-00-805-9798

E-9 DIETHYLAMINOETHANOL (DEAE).

100 percent solution

Use: Control corrosion by CO_2 in steam condensate lines

Federal Specification: None

Package/NSN: 55-gal drum, NSN: 6810-949-8331

E-10 DIPHOSPHONIC ACID (HEDP).

1-hydroxyethylidene 1,1-diphosphonic acid, active ingredient 58 to 62 percent, specific gravity 68˚ F/59˚ F (1.45 at 20˚ C/15˚ C), pH of 1 percent solution less than 2.0

Use: Inhibitor to prevent formation of calcium and magnesium scale in cooling water applications

Federal Specification: None

Package/NSN: 5-gal can, NSN: 6850-01-190-5509

55-gal drum, NSN: 6850-01-206-4601

E-11 ETHYLENE GLYCOL (SEE ANTIFREEZE, ITEM E-2).

E-12 HEDP (SEE DIPHOSPHONIC ACID, ITEM E-10).

E-13 HYDROCHLORIC ACID.

(muriatic), (HCl), technical, 31.45 percent minimum by weight, 20˚ Baumé (Bé)

Use: Iron-fouled ion exchange material regeneration applications

Federal Specification: ASTM E 1146, Specification for Muriatic Acid (Technical Grade Hydrochloric Acid)

Package/NSN: 96-oz, NSN: 6810-00-222-9641

5-gal can, NSN: 6810-00-236-5665

15-gal carboy, NSN: 6810-00-823-8010

E-14 MORPHOLINE.

Boiler feedwater compound, all drums to bear adequate caution labels to protect against fire, poison, and caustic burn hazards

Use: Control corrosion by CO_2 in steam condensate lines Federal Specification: A-A-59665, *Morpholine,* Technical Package/NSN:

40 percent 5-gal can, NSN: 6810-00-419-4298

40 percent 55-gal drum, NSN: 6810-00-559-9889

91 percent 55-gal drum, NSN: 6810-00-616-9437

98 percent 55-gal drum, NSN: 6810-00-559-9888

E-15 OCTADECYLAMINE.

Nontoxic, creamy white dispersion of octadecylamine, chemical formula $C_{18}H_{37}NH_2$, melting point of 114° F (45° C), boiling point of 697° F (369° C), filming amine

Use: Control corrosion by CO_2 in steam condensate lines Federal Specification: None

Package/NSN: 55-gal drum, NSN: None

E-16 PHOSPHATE COMPOUNDS (SEE ITEMS E-17 THROUGH E-26).

E-17 DISODIUM PHOSPHATE.

Anhydrous (Na_2HPO_4), 49 percent P_2O_5 minimum

Use: Remove hardness in boiler water

Federal Specification: MIL-DTL-32598, Sodium Phosphate, Dibasic, Anhydrous, Technical

Package/NSN: 100-lb bag, NSN: 6810-00-264-6630

E-18 DISODIUM PHOSPHATE.

Dodecahydrate (NA2HPO41•2H2O), 19 percent P2O5 minimum

Use: Remove hardness in boiler water

Federal Specification: None Package/NSN: 100-lb bag, NSN: None

E-19 POLYPHOSPHATE GLASS.

Slowly soluble, minimum P_2O_5 content 67 percent, solubility: 10 to 20 percent per month

Use: Treatment of cooling water in smaller cooling towers Federal Specification: None

Package/NSN: 100-lb drum, NSN: 6850-00-014-3442

E-20 SODIUM HEXAMETAPHOSPHATE.

$(NaPO_3)_6$ technical, type II, 66.5 percent P_2O_5, glassy form, beads or plates.

Use: Cathodic corrosion inhibitor in cooling towers and to remove hardness in boiler water

Federal Specification: O-S-635, *Sodium Polyphosphates, Technical*, Type II
Package/NSN: 100-lb bag, NSN: 6810-00-531-7805

E-21 SODIUM TRIPOLYPHOSPHATE.

Anhydrous ($Na_5P_3O_{10}$), white granular, 56 percent P_2O_5

Use: Remove hardness in boiler water

Federal Specification: O-S-635, *Sodium Polyphosphates, Technical*, Type III
Package/NSN: 100-lb bag, NSN: 6810-00-753-5053

100-lb bag, NSN: 6810-00-926-4836

E-22 SODIUM TRIPOLYPHOSPHATE.

Hexahydrate, ($Na_5P_3O_{10}$•$6H_2O$), granular or powder, 43 percent P_2O_5 minimum

Use: Remove hardness in boiler water

Federal Specification: None Package/NSN: 100-lb bag, NSN: None

E-23 TETRASODIUM PYROPHOSPHATE.

Anhydrous, ($Na_4P_2O_7$), granular, 53 percent P_2O_5, minimum

Use: Corrosion inhibitor in cooling towers and to remove hardness in boiler water

Federal Specification: None Package/NSN: 100-lb bag, NSN: 6810-00-249-8038

E-24 TETRASODIUM PYROPHOSPHATE.

Decahydrate, ($Na_4P_2O_7$•$10H_2O$), 31 percent P_2O_5 minimum

Use: Corrosion inhibitor in cooling towers and to remove hardness in boiler water

Federal Specification: None Package/NSN: 100-lb bag, NSN: None

E-25 TRISODIUM PHOSPHATE (TSP).

Monohydrate (Na_3PO_4•H_2O) technical, powder or granular, 36 percent P_2O_5 minimum

Use: Remove hardness in boiler water

Federal Specification: MIL-DTL-32594, Sodium Phosphate, Tribasic, Anhydrous; Dodecahydrate; and Monohydrate; Technical, Type III

Package/NSN: 100-lb bag, NSN: None.

E-26 TRISODIUM PHOSPHATE (TSP).

Dodecahydrate (Na_3PO_4•$12H_2O$) granular flake or crystalline, 16 percent P_2O_5 minimum

Use: Remove hardness in boiler water

Federal Specification: MIL-DTL-32594, Sodium Phosphate, Tribasic, Anhydrous; Dodecahydrate; and Monohydrate; Technical, Type II

Package/NSN: 100-lb drum, NSN: None

E-27 POLYACRYLATE.

Low molecular weight, water white to light amber color, total solids 45 to 65 percent, pH of 2.2 to 7.5, approximate molecular weight 2000 to 5000, specific gravity 77˚ F (1.1 to 1.23 at 25˚ C), viscosity 400 to 1400 at 77° F (25˚ C).

Use: Sludge dispersant in boilers

Federal Specification: None Package/NSN: None

E-28 POLYACRYLIC ACID.

Low molecular weight, water white to light amber color, total solids 45 to 65 ±2 percent, approximate molecular weight 1000 to 4000, specific gravity 1.1 to 1.3 at 77° (25˚ C), viscosity 200-1000 cps at 77° (25˚ C).

Use: Dispersant in cooling towers to prevent fouling by nonliving matter

Federal Specification: None

Package/NSN: 55-gal drum, NSN: 6850-01-194-6613

E-29 POLYMETHACRYLATE.

Low molecular weight, clear amber liquid, total solids 29 to 41 percent, pH of 6.0 to 10.5, approximate molecular weight 3800 to 10000, specific gravity 1.18 to 1.27 at 77° (25˚ C), viscosity 50 to 700 at 77° (25˚ C).

Use: Sludge dispersant in boilers

Federal Specification: None

Package/NSN: None

E-30 QUEBRACHO TANNIN EXTRACT.

Type I, powder Use: Sludge dispersant in boilers

Federal Specification: None

Package/NSN: 50-lb bag, NSN: 6810-00-891-5741

E-31 SALT (SEE SODIUM CHLORIDE, ITEM E-35).

E-32 SLAKED LIME (SEE CALCIUM HYDROXIDE, ITEM E-5).

E-33 SODA ASH (SEE SODIUM CARBONATE, ITEM E-34).

E-34 SODIUM CARBONATE.

(Soda ash) (Na_2CO_3), anhydrous technical, granular or powder form, 99.2 percent minimum by weight

Use: Remove calcium sulfate from water, increase alkalinity in boilers

Federal Specification: A-A-59563. “Sodium Carbonate, Anhydrous, Technical”
Package/NSN: 25-lb bag, NSN: 6810-00-262-0951

100-lb drum, NSN: 6810-00-233-1715

E-35 SODIUM CHLORIDE.

(Salt) (NaCl), technical mineral type, crude-sized form, type I, water soluble salt, 98.5 percent NaCl by weight

Use: Regenerate ion exchange resins

Federal Specification: A-A-694, Sodium Chloride, Technical (Water Conditioning Grade)

Package/NSN: 50-lb bag, NSN: 6810-01-026-0951, 80-lb bag, NSN: 6810-00-227-0437

E-36 SODIUM HYDROSULFIDE.

($NaSH \bullet 2H_2O$), technical grade, flake, 70 to 72 percent NaSH by weight

Use: Regenerate iron fouled ion exchange materials

Federal Specification: None

Package/NSN: 50-lb bag, NSN: None

E-37 SODIUM HYDROXIDE.

(Caustic soda) (NaOH), technical, type I, flake form particle size gradation A/A, 96 percent minimum assay as NaOH

Use: Regenerate ion exchange material, increase alkalinity in boilers and adjust pH in water

Federal Specification: None

Package/NSN: 100-lb drum, NSN: 6810-00-174-6581

E-38 SODIUM HYPOCHLORITE SOLUTION.

(NaOCl), clear, light-yellow liquid containing not less than 10 percent available chlorine by volume

Use: Disinfectant and treatment of Legionnaires‘ disease in cooling towers

Package/NSN: 5-gal can, NSN: 6810-00-169-5163

55-gal drum, NSN: 6810-00-214-8743

E-39 SODIUM MOLYBDATE.

Dihydrate ($Na_2MoO_4 \cdot 2H_2O$), white, free flowing odorless powder, soluble in water, commercial grade

Use: Corrosion inhibitor for open cooling systems

Federal Specification: None

Package/NSN: 200-lb lined fiber drum, NSN: None

E-40 SODIUM MOLYBDATE.

Solution, 35 percent as Na_2MoO_4, clear liquid, soluble in water

Use: Corrosion inhibitor for open cooling systems

Federal Specification: None Package/NSN: 55-gal drum, NSN: None

E-41 SODIUM MOLYBDATE BLEND.

Liquid, mixture of 10 to 12 percent sodium molybdate (Na_2MoO_4), 3 to 5 percent sodium hydroxide (NaOH), and 3 to 4 percent copper corrosion inhibitor

Use: Corrosion control in hot water systems, chilled and brine systems, combined hot and chilled water systems, and diesel engine jacket cooling systems; compatible with ethylene glycol antifreeze

Federal Specification: None

Package/NSN: 55-gal drum, NSN: 6850-01-185-1188

E-42 SODIUM NITRITE.

($NaNO_2$), granular, 97 percent NO_2 by weight, technical grade

Use: Corrosion control in hot water systems

Federal Specification: O-S-634, Sodium Nitrate, Technical (Nitrate of Soda)

Package/NSN: 100-lb drum, NSN: None

E-43 SODIUM NITRITE-BORAX BLEND.

Powdered or granular, a mixture of 65 to 70 percent sodium nitrite, 8 to 12 percent borax (sodium tetraborate), 4 to 5 percent copper corrosion inhibitor, and 15 to 20 percent sodium carbonate, free of excess foreign matter

Use: Corrosion control in closed hot water systems. Compatible with ethylene glycol antifreeze.

Federal Specification: None

Package/NSN: 30-gal can, NSN: 6850-01-185-1187

E-44 SODIUM SILICATE.

Relatively low alkalinity, 41° Bé, approximately 28.8 percent SiO_2, 6 to 7 percent Na_2O, not more than 0.5 percent suspended matter

Use: Cathodic corrosion inhibitor in cooling towers

Federal Specification: Canceled

Package/NSN: 5-gal can, NSN: 6810-00-247-0607

55-gal drum, NSN: 6810-00-247-0609

E-45 SODIUM SULFITE.

(Na_2SO_3), anhydrous, granular, 96 percent by weight minimum

Use: Remove oxygen from boiler feedwater and closed hot water systems (oxygen scavenger)

Federal Specification: A-A-5916B, Sodium Sulfite, Anhydrous, Technical

Package/NSN: 100-lb bag, NSN: 6810-00-782-2677

E-46 SODIUM SULFITE.

Catalyzed with cobalt, granular, 95 percent by weight minimum

Use: Remove oxygen from boiler feedwater (oxygen scavenger)

Federal Specification: None

Package/NSN: 50-lb bag, NSN: 6850-01-109-5604

E-47 SULFONATED STYRENE COPOLYMER.

Low molecular weight, clear amber color, total solids, 23 to 27 percent, pH of 6.8, molecular weight 5000 to 10,000, specific gravity 1.2 at 25° C, viscosity 10 to 40 at 25° C

Use: Sludge dispersant in boilers

Federal Specification: None Package/NSN: None

E-48 SULFURIC ACID.

(H_2SO_4), technical, class A, grade 2, 93 percent sulfuric acid concentration, 66° Bé

Use: Regenerate ion exchange resins, adjust pH in cooling towers

Federal Specification: None

Package/NSN: 13-gal carboy, NSN: 6810-00-975-0707 Bulk, NSN: 6810-00-251-8007

E-49 TOLYLTRIAZOLE (TTA).

Active ingredient 50 percent sodium tolyltriazole (43 percent TT)

Use: Corrosion inhibitor for copper alloys in cooling water systems

Federal Specification: None

Package/NSN: 5-gal can, NSN: 6850-01-189-9949

E-50 ZINC SULFATE.

Monohydrate ($ZnSO_4 \bullet H_2O$), white, free-flowing powder, soluble in water

Use: Cathodic corrosion inhibitor in cooling towers

Federal Specification: None

Package/NSN: 50-lb bag, NSN: 6810-01-198-3832

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APPENDIX F GLOSSARY

F-1 ACRONYMS.

ABMA American Boiler Manufacturer's Association

AFCESA Air Force Civil Engineer Support Agency

AFI Air Force Instruction

AFP Air Force Pamphlet

AFR Air Force Regulation

AMP Amino-tri (methylene) phosphonic acid

ASHRAE American Society of Heating, Refrigeration, and Air-Conditioning Engineers

ASME American Society for Mechanical Engineers

Bé Baumé

Br_2 Bromine

BTU British thermal unit

BTUH British thermal units per hour

BZT Benzotriazole

C Celsius

$CaCO_3$ Calcium carbonate

CFR Code of Federal Regulations

Cl_2 Chlorine

ClO_2 Chlorine dioxide

CO_2 Carbon dioxide

COC Cycles of concentration

CTI Cooling Technology Institute

CWA Clean Water Act

D.R. Distribution ratio

DEAE	Diethylaminoethanol
EDTA	Ethylene diamine tetra-acetic acid
EPA	Environmental Protection Agency
ESPC	Energy Saving Performance Contract
F	Fahrenheit
FDA	Food and Drug Administration
FMA	Free mineral acids
ft	Foot
ft^3	Cubic foot
g	Grams
gal	Gallon
gpm	Gallon per minute
gr	Grain
GSA	General Services Administration
H_2O	Water
H_2O_2	Hydrogen peroxide
HEDP	1-hydroxyethylidene-1, 1-diphosphonic acid
HMP	Sodium hexametaphosphate
HOBr	Hypobromous acid
HOC1	Hypochlorous acid
hp	Horsepower
HTH	Dry calcium hypochlorite
HTHW	High-temperature hot water
HTW	High-temperature water
HVAC	heating, ventilation, and air conditioning
IUPAC	International Union of Pure and Applied Chemistry

kg	Kilogram
km	Kilometer
KPa	Kilopascals
kW	Kilowatt
lb	Pound
l/sec	Liters per second
LSI	Langelier Saturation Index
LTW	Low-temperature water
m/s	Meter per second
m^3	Cubic meter
m^3/d	Cubic meter per day
m^3/hr	Cubic meter per hour
mg	Milligrams
$MgSO_4$	Magnesium sulfate
MIC	Microbiologically influenced corrosion
MIL-HDBK	Military handbook
ml	Milliliter
mm	Millimeter
mmpy	Millimeters per year
mpy	Mils per year
MTW	Medium-temperature water
N	Normality
NACE	National Association of Corrosion Engineers
NaCl	Sodium chloride
NAVFAC	Naval Facilities Engineering Systems Command
NAVFACINST	Naval Facilities Instruction

NAVSEASYSCOM	Naval Sea Systems Command
NSN	National Stock Number
NTA	Nitrilo-triacetic acid
O_3	Ozone
OC1	Hypochlorite ion
ORP	Oxidation-reduction potential
OSHA	Occupational Safety and Health Administration
oz	Ounce
PACDIV	Pacific Division
PBTC	2-phosphonobutane-1,2,4-tricarboxylic acid
pH_{actual}	Actual measured pH
pH_{eq}	pH of equilibrium
pH_s	pH of saturation
ppb	Parts per billion
ppm	Parts per million
PSI	Practical (Puckorius) Scaling Index
psig	Pounds per square inch gauge
PVC	Polyvinyl chloride
PWTB	Public Works Technical Bulletin
QA	Quality assurance
QC	Quality control
RCRA	Resource Conservation and Recovery Act
RFB	Request for bid
RFP	Request for proposal
RO	Reverse osmosis
RSI	Ryznar Stability Index

SDI	Silt density index
SDS	Safety data sheet
SO3	Sulfite
SOW	Statement of work
SRB	Sulfate-reducing bacteria
SS	Suspended solids
TA	Total alkalinity
TDS	Total dissolved solids
TSCA	Toxic Substances Control Act
TSP	Trisodium phosphate
TSS	Total suspended solids
TTA	Tolytriazole
UFC	Unified Facilities Criteria
USACE	U.S. Army Corps of Engineers
W	Watt

F-2 DEFINITION OF TERMS.

Acid: A compound, usually having a sour taste, which can neutralize an alkali or base; a substance that dissolves in water with a formation of hydrogen ions.

Aeration: Intimate contact between air and liquid by one of the following methods: spraying the liquid in the air; bubbling air through the liquid; or agitating the liquid to promote surface absorption of air.

Algae: Tiny plant life, usually microscopic, existing in water. They are mostly green, blue-green, or yellow-green, and are the cause of most tastes and odors in water. They create suspended solids (SS) when they grow in an industrial water system.

Alkalinity: (a) A term used to represent the content of carbonates, bicarbonates, hydroxides, and occasionally borates, silicates, and phosphates in water. (b) The capacity of water to react with hydrogen ions.

Alkalinity, total or mixed indicator (M): A measure of the total alkalinity of water. Measured by the quantity of 0.02 normality (N) sulfuric acid required to bring water to pH of 4.4, as indicated by the change in color of methyl orange or a mixed indicator. Results are expressed in parts per million (ppm) as calcium carbonate.

Alkalinity, Phenolphthalein (P): A measure of hydroxide ions (OH) plus one-half of the normal carbonates in water. Measured by the quantity of 0.02 normality (N) sulfuric acid required to bring the water to pH 8.2, as indicated by the de-colorization of phenolphthalein indicator. Results are expressed in parts per million (ppm) as calcium carbonate.

Alkalinity, Hydroxyl: A measure of hydroxyl ion (OH^-) contribution to the alkalinity. This is related to the system pH and also may be referred to as “causticity.”

Backwash: The reversal of flow through a filter or an ion exchanger to wash clogging material out of the filtering medium and reduce conditions causing loss of head.

Backflow preventer: A device for a water supply pipe to prevent the backflow of water into the water supply system from the system which it supplies.

Bacteria: Simple single-cell microscopic organisms generally free of pigment. They do not require light for their life processes.

Base: An alkali or hydroxide of alkali metals and ammonia. They can neutralize acids to form salts and water. A base will ionize to form hydroxyl ions (OH).

Biocides: Material typically used to destroy microorganisms (also called “microbiocides”).

Biological Deposits: Water-formed deposits of organisms or the products of their life processes. Biological deposits may be composed of microscopic organisms, as in slimes, or of macroscopic organisms such as barnacles or mussels.

Blowdown: Draining a portion of water from a system to reduce the concentration of dissolved solids or to discharge accumulations of materials carried by the water.

British Thermal Unit (BTU): The amount of heat necessary to raise the temperature of one pound of water one degree Fahrenheit (°F).

Brine: A saturated solution for ion exchange regeneration, refrigeration, or cooling processes. It is usually a sodium chloride water solution for ion exchange regeneration. It may be sodium chloride water solution or calcium chloride water solution for refrigeration.

Causticity: A common term that describes hydroxyl alkalinity or the alkalinity resulting from the presence of the hydroxyl ion (OH).

Concentration: A measure of the amount of dissolved substances contained per unit volume of solution. This may be expressed as grains per gallon, pounds per million gallons, milligrams per liter, ppm, or percent.

Condensate: The material formed when vapor returns to the liquid state. In steam heating systems, the water condensed from steam. In air conditioning, water extracted from air by condensation on the cooling coil of a refrigeration machine.

Conductivity, Specific Conductance: The reciprocal of the resistance in ohms measured between opposite faces of a centimeter cube of an aqueous solution at a specified temperature. Electrical conductivity is expressed in micromhos (µmhos), the reciprocal of megohms. This is used as a measure of total dissolved solids (TDS).

Corrosion: The destruction of a substance, usually a metal, or its properties because of a reaction with its (environmental) surroundings.

Cycles of Concentration (COC): In a system in which water lost through evaporation and blowdown is replaced with makeup water, COC is the ratio of the makeup quantity to the blowdown quantity (COC = M/B). It is the number of times the makeup water is concentrated in the system. The COC can also be calculated by dividing either the conductivity or the chloride content of the blowdown by the conductivity or chloride content of the makeup ($COC = Cond_{bd}/Cond_{mw}$).

Deaerator: Device for removing non-condensable gases from the boiler. It may operate on the principle of either heat or vacuum.

Dealkalization: Exchange of bicarbonate for chlorides in an ion exchange process.

Deionization: Complete removal of ions from water.

Demineralization: Reduction of the mineral content of water by a physical or chemical process; removal of salts.

Disinfection: The process of killing most (but not necessarily all) of the harmful and objectionable microorganisms in a fluid by various agents such as chemicals, heat, ultraviolet light, ultrasonic waves, or radiation.

Dissolved solids: (a) Solids, usually minerals, which are present in solution. (b) The dried residue from evaporation of the filtrate after separation of suspended solids (SS).

Distribution Ratio (D.R.): This is a measure of the vapor/liquid ratio for a given material. Extremely high and low values are generally unadvisable. A high D.R. results in either high amine losses at any vents or little availability of amine at points of initial condensation, or both. A low D.R. results in high amine losses in the blowdown.

Evaporation: The process by which water passes from a liquid state to a vapor. It is the main process by which heat is removed from a cooling tower and steam is produced in a boiler.

Feed water: Water being applied to the feed water heater or to the boiler, consisting of both makeup and condensate return.

Filming Amines: Chemicals that form an impervious barrier between metal and the steam condensate to prevent corrosion.

Foulants: Deposition of materials normally in suspension. This includes silt, air-scrubbed dust, microbiological residuals, reaction products from treatment, and corrosion products.

Generic Chemicals: A chemical identified and purchased by the recognized chemical name, such as the International Union of Pure and Applied Chemistry (IUPAC) designation. These generic chemicals may be blended or used separately. They are usually much less expensive than special chemical blends developed by manufacturers under a trade name.

Hardness: (a) A characteristic of water, chiefly due to the existence of carbonate and sulfate (and occasionally the nitrite and chloride) salts of calcium, iron, and magnesium. (b) Commonly computed from the amount of calcium and magnesium in the water and expressed as equivalent calcium carbonate. (c) Causes "curding" of water when soap is used, increased consumption of soap, deposition of scale in boilers, injurious effects in some industrial processes, and sometimes objectionable taste in the water.

Hardness, Carbonate: Hardness caused by the presence of carbonates and bicarbonates of calcium and magnesium in water. Such hardness may be removed to the limit of solubility by boiling the water. This is also called temporary hardness.

Hardness, Non-Carbonate: Hardness caused by calcium and magnesium sulfates and chlorides and compounds other than carbonates which cannot be reduced materially by boiling the water. (Also called "permanent hardness".)

Hardness, Total: The sum of carbonate and non-carbonate hardness.

Hydrogen Ion Concentration: Commonly expressed as the pH value that represents the logarithm of the reciprocal of the hydrogen ion concentration.

Inhibitor (applied to corrosion): A chemical substance or mixture that effectively decreases corrosion when added to a liquid (usually in small concentrations).

Ion: A particle, atom, or group of atoms, carrying either a positive or negative electrical charge, formed when an electrolyte is dissolved in water.

Ion Exchange: A process where water is passed through a granular material wherein ions on the granular material are replaced by ions contained in the water. For example, in the zeolite softening process, the sodium ions (Na^+) of the granular zeolite are replaced by the calcium ions (Ca^{++}) in the water to leave the water free of calcium (the cause of hardness), but with an increased amount of sodium.

Langelier Index (saturation index): An index based on the calcium hardness, total alkalinity, total dissolved solids (TDS), temperature, and pH. It is used to classify waters by their ability to either dissolve or deposit calcium carbonate. It is the algebraic difference between the actual pH and the calculated pH of saturation (pH_s) (LI = pH -

pH_s). A positive value indicates a scale-forming tendency, a negative value indicates a scale-dissolving tendency. It was one of the first indices developed for this purpose and was designed specifically for municipal water flowing in distribution lines.

Makeup Water: Water supplied to replace the loss in a system due to leaks, evaporation, wind drift, bleed-off, blowdown, or withdrawal.

Microbiocide: A material added to cooling tower water and chilled water to control the growth of microorganisms such as algae, bacteria, and fungi.

Micromho: An electrical unit of conductance (one-millionth of a mho), which is the reciprocal of electrical resistance.

Microorganism: A minute plant or animal in water or earth that is visible only through a microscope.

Milligrams per Liter (mg/l): A unit of the concentration of water or wastewater constituent. It is 0.001 gram of the constituent in 1000 milliliters (ml) of water.

Neutralizing Amines: Chemicals used to neutralize carbon dioxide in steam condensate to prevent corrosion.

Normality (N): The concentration of a solution in relation to a normal solution. Normality is a measure of the “strength” of a given solution. The normal solution contains a specific weight of a substance per liter based on the characteristics of the substance. Thus, a half-normal solution would be expressed as 0.5 N or N/2.

Oxygen Scavenger: A chemical used to remove final traces (trace amounts) of oxygen from boiler feedwater.

pH: Logarithmic measure of hydrogen ion concentration indicating degree of acidity or alkalinity of a solution. The pH range varies from 1 to 14. Values below 7.0 indicate acidity and above 7.0 indicate alkalinity (basicity).

pH_{eq}: The pH of equilibrium. The adjusted pH value of a water based on the empirical relationship between total alkalinity and pH developed from studies of hundreds of cooling systems. Development of an empirical relationship was necessary because pH in cooling waters is often buffered, a factor which affects the relationship between pH and bicarbonate alkalinity.

pH_s: The pH of saturation. It is the pH value below which a material will go into solution (dissolve) and above which it will precipitate. It is applied to calcium carbonate in the Langelier, Ryznar, and Practical Scaling Indices. It is a function of the calcium hardness, the total alkalinity, the total dissolved solids (TDS) and the temperature. It is determined with graphs, tables, or special slide rules. This equation is useful:

$$pH_s = 12.27 - 0.00915T - \log CaH - \log TA + (\log TDS)/10.$$

Phosphates: Chemicals used for corrosion control in cooling towers and deposit control in boilers. Commonly, these occur as orthophosphates or polyphosphates. The level of the active phosphate chemical is reported either as percent P_2O_5 (phosphorus pentoxide) or as PO_4 (phosphate), with these two oxides of phosphate being related by factor as follows: $PO_4 = 1.34 \times P_2O_5$.

ppm: Parts per million; one pound of material dissolved in one million pounds of water.

Precipitate: (a) To separate a dissolved substance in the solid form by its removal from a solution. (b) The substance in solid form that has been separated from solution.

Practical Scaling Index (PSI) — A modified scaling index developed by P.R. Puckorius and J.M. Brooke to provide a better and more consistent indication of scaling conditions of cooling water. It is based on using the pH of equilibrium (pH_{eq}) rather than the actual pH, and is calculated as follows:

$$PSI = 2\ pH_s - pH_{eq}.$$

As with the RSI, a value less than 6.0 in natural water indicates a scale-forming tendency. A value greater than 6.0 in natural water indicates a scale-dissolving tendency.

Regeneration: That part of the operating cycle of an ion exchange process in which a specific chemical solution is passed through the ion exchange bed to prepare it for a service run (return the ion exchange bed to its original composition).

Ryznar Index (stability index): An index classifying water as to its ability to dissolve or deposit calcium carbonate scale. It is calculated as twice the pH of saturation minus the actual pH ($RI = 2\ pH_s - pH$). Although in theory an RI of 7.0 should be neutral, experiments indicate that 6.0 is a better value. A value less than 6.0 in natural water indicates a scale-forming tendency. A value greater than 6.0 in natural water indicates a scale-dissolving tendency.

Scale: Deposition on a heat transfer surface of normally soluble salts. Scale is usually crystalline and dense, frequently laminated, and occasionally columnar in structure.

Shock Feed: The process of adding one or more water treatment chemicals in one application rather than gradually.

Slime: Biological growths that may accumulate to the extent that they foul equipment.

Sludge: A water-formed deposit that will settle, and may include all suspended solids (SS) carried by water. Sludge is commonly formed in boilers where it may be baked into place and become hard and adherent.

Softening Water: The process of removing from water the mineral substances that produce a condition called hardness. There are two softening processes in general use: chemical precipitation (lime and lime/soda softening) and the zeolite ion exchange process.

Solids, Suspended (SS): All matter in water that is not dissolved and can be removed with filtration.

Solids, Dissolved: The total concentration of all substances in a filtered solution which exist as solids after the liquid is completely evaporated from the solution.

Solids, Total: The sum of the suspended and dissolved matter (solids).

Zeolite: Natural minerals as well as synthetic resins used for ion exchange.

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APPENDIX G REFERENCES

G-1 GOVERNMENT PUBLICATIONS.

CODE OF FEDERAL REGULATIONS (CFR)

Title 21 CFR Part 173.310, Boiler Water Additives

DEPARTMENT OF DEFENSE

A-A-694, *Sodium Chloride, Technical* (*Water Conditioning Grade*)

A-A-52624, *Antifreeze, Multi-Engine Type*

A-A-55821, *Calcium Hydroxide, Technical*

A-A-5916B*, Sodium Sulfite, Anhydrous, Technical*

A-A-59503, *Nitrogen, Technical*

A-A-59665, *Morpholine, Technical*

MIL-B-24155, *Boiler Scale Removing Compound*

MIL-DTL-32594 *Sodium Phosphate, Tribasic, Anhydrous; Dodecahydrate; and Monohydrate; Technical*

MIL-DTL-32598, *Sodium Phosphate, Dibasic, Anhydrous, Technical*

DEPARTMENT OF THE NAVY

NAVSEA S9086-GX-STM-020, Section 220, Volume 2, *Boiler Water/Feedwater Test and Treatment*

UNIFIED FACILITIES CRITERIA

https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc

UFC 1-200-01, *DoD Building Code*

UFC 3-420-01, *Plumbing Systems*

UFC 3-430-07, *Operation and Maintenance: Inspection and Certification of Boilers and Unfired Pressure Vessels*

UFC 3-430-11, *Boiler Plant Instrumentation and Control Systems*

G-2 NONGOVERNMENT PUBLICATIONS.

ASTM INTERNATIONAL

https://www.astm.org/

ASTM D2688-15e1, *Standard Test Method for Corrosivity of Water in the Absence of Heat Transfer (Weight Loss Methods)*

ASTM E1146, *Standard Specification for Muriatic Acid (Technical Grade Hydrochloric Acid)*

AMERICAN SOCIETY OF MECHANICAL ENGINEERS (ASME)

https://www.asme.org/

ASME PTC 19.11, *Steam and Water Sampling, Conditioning, and Analysis in the Power Cycle*

NATIONAL ASSOCIATION OF CORROSION ENGINEERS (NACE)

TPC Publication 1, *Cooling Water Treatment Manual*, 1990, ISBN 0-915567-69-5

UFC 3-240-01
1 May 2020
Change 4, 1 October 2024

UNIFIED FACILITIES CRITERIA (UFC)

WASTEWATER COLLECTION AND TREATMENT

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UNIFIED FACILITIES CRITERIA (UFC)

WASTEWATER COLLECTION AND TREATMENT

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

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING COMMAND (Preparing Activity)

AIR FORCE CIVIL ENGINEER CENTER

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

Change No.	**Date**	**Location**
1	1 Aug 2020	Corrected oil droplet sizes in section A-12.1.
2	1 Jan 2021	1. Changed heading 33.42 Minimum Flow Depths from [Replacement] to [Delete] and deleted the paragraph. 2. Deleted heading and paragraph for 34.11 Ladders [Addition] and replaced it with 34.11 Steps, Rungs and Ladders [Addition], revise the previous criteria for ladders and included new criteria for steps in manholes.
3	1 Mar 2024	Added the IPC as a modified standard in Chapter 1 and added modifications to the IPC in Chapter 3.
4	1 Oct 2024	Revised reference to 29 CFR 1910.23(d) for fixed ladder criteria in Chapter 3.

This UFC supersedes UFC 3-240-01 dated November 2012, UFC 3-240-02 dated November 2012 and UFC 4-832-01N dated January 2004.

FOREWORD

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

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

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

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

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

AUTHORIZED BY:

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UNIFIED FACILITIES CRITERIA (UFC)
REVISION SUMMARY SHEET

Document: UFC 3-240-01 *Wastewater Collection and Treatment*

Superseding: UFC 3-240-01 dated 1 November 2012, with Change 1 dated 1 November 2014, UFC 3-240-02 dated 1 November 2012 with Change 2 dated 1 January 2019, and UFC 4-832-01N dated 16 January 2004.

Description: This revised UFC consolidates criteria for domestic wastewater collection, domestic wastewater treatment, industrial wastewater collection and industrial wastewater treatment into one UFC. The use of industry standards and federal codes aided in the consolidation of these criteria documents. This revision updates technical requirements, industry standards, and maximizes uniformity among Tri-Service requirements. Appendix C contains a complete list of referenced wastewater requirements and Appendix B contains a complete list of referenced best practices.

Reasons for Document:

- This revised UFC updates wastewater collection and treatment criteria that was previously contained in multiple criteria documents and efficiently consolidates them into a single UFC.
- Establishes technical requirements by maximizing the use of industry standards to meet DOD requirements.
- Reorganizes the content to align with industry standards.
- Coordinates criteria requirements in other core and specialty UFC criteria documents.

Impact:

- This revision will have minimal impacts on design cost.

Unification Issues:

- FC 1-300-09N is referenced for Navy design procedures.

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CHAPTER 1 INTRODUCTION

1-1 BACKGROUND.

People have used different terminology to describe wastewater treatment facilities for many years. Today people use terms such as sewage treatment plant, wastewater treatment plant, wastewater treatment facility, or publicly owned treatment works to describe domestic wastewater treatment facilities. *Recommended Standards for Wastewater Facilities* uses the terms wastewater facilities or wastewater treatment facilities. The EPA generally uses the terms municipal wastewater treatment facilities and wastewater treatment facilities. In recent years, Water Environment Federation (WEF) started using the term water resource recovery facilities (WRRF) to describe domestic wastewater treatment facilities since the wastewater industry is becoming more focused on resource recovery. These terms apply only to domestic wastewater treatment. This terminology should not be used interchangeably with industrial wastewater treatment facilities.

1-2 PURPOSE AND SCOPE.

This Unified Facilities Criteria (UFC) provides requirements for domestic wastewater collection, domestic wastewater treatment, industrial wastewater collection and industrial wastewater treatment for the Department of Defense (DoD).

1-3 APPLICABILITY.

This UFC applies to service elements and contractors involved in the planning, design, and construction of permanent DoD facilities worldwide. It is applicable to all methods of project delivery and levels of construction. The contingency operation wastewater flows are applicable to facilities supporting military operations.

1-4 GENERAL BUILDING REQUIREMENTS.

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

1-5 CYBERSECURITY.

All control systems (including systems separate from an energy management control system) must be planned, designed, acquired, executed, and maintained in accordance with UFC 4-010-06, and as required by individual Service Implementation Policy.

1-6 NON-GOVERNMENT STANDARD MODIFICATIONS.

UFC 3-240-01 modifies Recommended Standards for Wastewater Facilities (known hereafter as the “10 States Standards”) for domestic wastewater collection treatment

\3 and the International Plumbing Code (IPC) in coordination with the modifications made by UFC 3-420-01. **/3/** Chapters 3 modifies **\3** the IPC and **/3/** Chapters 10, 20 and 30 of the 10 State Standards. Chapters 4 through 11 modify chapters 40 through 110 of the 10 States Standards. The 10 State Standards section modifications are one of four actions, according to the following legend:

[Addition] – Add new section, including new section number, not shown in 10 States Standards.

[Deletion] – Delete referenced 10 States Standards section.

[Replacement] – Delete referenced 10 States Standards section or noted portion and replace it with the narrative shown.

[Supplement] – Add narrative shown as a supplement to the narrative shown in the referenced section of 10 States Standards.

1-7 COMMENTARY.

Limited commentary has been added to the chapters. Section designations for such commentary are preceded by a "[C]" and the commentary narrative is highlighted with light gray.

1-8 GLOSSARY.

APPENDIX B contains acronyms, abbreviations, and terms.

1-9 REFERENCES.

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

1-10 BEST PRACTICES.

Appendix A provides guidance for accomplishing engineering services related to wastewater collection and treatment systems. The Designer of Record (DoR) is expected to review and interpret this guidance as it conforms to criteria and contract requirements and apply the information according to the needs of the project. If a Best Practices document has guidelines or requirements that differ from the Unified Facilities Guide Specifications (UFGS) or UFC, the UFGS and the UFC prevail. If a best practices document has guidelines or requirements that are not discussed in the UFGS or UFC, the DoR must submit a list of the guidelines or requirements being used for the project with sufficient documentation to the Authority Having Jurisdiction (AHJ) for review and approval before beginning design.

CHAPTER 2 PLANNING AND DESIGN

2-1 SAFETY.

Comply with DODINST 6055.01 and applicable Occupational Safety and Health Administration (OSHA) safety and health standards.

2-2 PLANNING.

Use UFC 3-201-01 for planning topics such as wetlands and flood hazard areas. Use the Installation's existing utility maps and planning documents to develop population estimates and plans for new service areas. Use WEF MOP 8, Chapter 2, *Principles of Integrated Design* for additional planning guidance.

2-2.1 Domestic Wastewater Collection.

In addition to population estimates, account for flow from industrial pretreatment, and ship to shore sources. Permits may be required for domestic wastewater collection systems.

2-2.2 Domestic Wastewater Treatment.

Plan the domestic wastewater treatment facility for current population and future population growth, minimum 5 years, using the Installation's master development plan. Account for seasonal fluctuations, low flow, peak flow, existing combined sewer flows, flow from industrial pretreatment, flow from ship to shore sources, receiving waterbody quality and discharge requirements. Plan for future expansion of new treatment components. Provide space for future expansion in the layout of new treatment components and processes. A life-cycle cost analysis should be conducted to account for future capacity issues, capital investment, operation and maintenance, and constructability. Applicable construction and operating permits are required for the treatment of domestic wastewater.

2-2.2.1 Pilot Testing.

Pilot testing should be performed as part of the planning effort because of the time required to perform tests. Evaluate the need for pilot testing using the 10 State Standards. Pilot testing can be used to verify performance predictions or determine the effectiveness of unit treatment processes needed for the design of a domestic wastewater treatment facility.

2-2.3 Industrial Wastewater Systems.

Plan the industrial wastewater treatment facility for the largest current and future peak flow, minimum 5 years, using the Installation's master development plan. Industrial wastewater may be discharged directly to a receiving waterbody when industrial wastewater effluent meets or exceeds receiving waterbody discharge requirements or indirectly to a domestic wastewater treatment facility when the industrial wastewater effluent meets or exceeds pretreatment requirements. Applicable construction and operating permits are required for the treatment or pretreatment of industrial wastewater. Refer to Figure 2-1 for an illustration of planning considerations. Use WEF MOP FD-3, Section 1, *Planning and Managing Industrial Wastewater Pretreatment Processes*.

Figure 2-1 Planning Considerations

Industrial Waste Characterization

- Identify industrial wastewater sources
- Identify types of pollutants
- Identify pollutant loads and flows
- Identify any variation in loads or flows
- Identify any existing treatment processes

↓

Regulatory Requirements and Treatment Criteria

- Define treatment objectives
- Identify discharge options, direct or indirect
- Identify categorical standards
- Identify permit requirements

2-2.3.1 Pilot Testing.

Pilot testing should be performed as part of the planning effort because of the time required to perform pilot testing. Pilot testing can be used to verify performance predictions or determine the effectiveness of unit treatment processes needed for design of industrial wastewater treatment facilities. Conduct pilot testing on the wastewater stream requiring treatment, when available, or on an equivalent wastewater stream.

2-2.4 Solids Management.

Use WEF MOP 8, Chapter 18 through 25 for guidance on solids or biosolids management.

Use *Solids Process Design and Management,* Chapter 2, *Considerations of Planning of Biosolids Management Projects,* for guidance on developing a biosolids management plan.

2-2.5 Planning For Non-War Emergencies.

Use *Emergency Planning, Response, and Recovery* for guidance when planning for non-war emergencies such as, earthquakes, hurricanes, tornadoes, and floods.

2-3 EXISTING CONDITIONS.

Use UFC 3-201-01 for preliminary site analysis, and evaluation of existing conditions such as geotechnical site investigation, environmental considerations, surveying, and topographic surveying.

2-3.1 Existing Sewers.

Use WEF MOP FD-6 for guidance when evaluating and rehabilitating existing sewers.

2-3.2 Modifications to Existing Wastewater Treatment Facilities.

Evaluate the effect of modifications on each individual wastewater treatment processes and notify the AHJ of any undersized treatment process or required upgrades to accommodate the modifications.

2-4 DESIGN.

Use UFC 3-201-01 for topics such as site development, grading, and storm drainage systems.

2-4.1 Design Criteria.

2-4.1.1 Within the United States.

For Installations located in the United States and its territories and possessions the wastewater system must comply with the following criteria precedence:

1. EPA or State as applicable and local regulations for the project location;
2. Utility provider’s requirements;
3. Criteria indicated in this UFC;
4. UFC 01-200-02 for energy and sustainability; and
5. Appendix A for design guidance.

2-4.1.2 Foreign Countries.

For Installations located outside of the United States and its territories and possessions, the wastewater system must comply with the following criteria precedence:

1. The Foreword of this UFC (All construction outside of the United States is also governed by Status of Forces Agreements (SOFA), Host Nation

Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA));

2. Final Governing Standards (FGS);
3. DoD 4715.05-G, Overseas Environmental Baseline Guidance Document (OEBGD);
4. Utility provider's requirements;
5. Criteria indicated in this UFC;
6. UFC 01-200-02 for energy and sustainability; and
7. Appendix A for design guidance.

DoD 4715.05-G, Overseas Environmental Baseline Guidance Document (OEBGD) applies when there are no FGSs in place. Therefore, in foreign countries this UFC will be used for DoD projects to the extent that it is allowed by and does not conflict with the applicable international agreements and the applicable FGS or OEBGD.

2-4.2 Design Approval.

The DoR must identify, assist, and provide, as applicable, all permits, approvals, and fees required for the design and construction of the new project from federal, state and local regulatory authorities or overseas equivalent. The DoR must be a Professional Engineer experienced and licensed. Licensure in the location of the project may be required to obtain permits and approvals. For new or rehabilitated sanitary sewer systems or facilities such as service extensions, domestic wastewater treatment, or industrial wastewater treatment, coordinate with the applicable primacy agency to determine permitting requirements. Consult with the Government Project Manager to determine the appropriate signatories for permit applications.

2-4.2.1 Within the United States.

In the United States and its territories and possessions, the Government will review permits for acceptability.

2-4.2.2 Foreign Countries.

In locations outside of the United States and its territories and possessions with host nation agreements, follow permit approval procedure as directed in project scope and by the Government Project Manager.

In locations outside of the United States and its territories and possessions without host nation agreements, the Government will review and approve plans for compliance.

2-5 FEDERAL DISCHARGE REQUIREMENTS.

In the United States and its territories and possessions, the EPA implements the Clean Water Act and regulates quality standards for surface waters. The Clean Water Act provides Federal regulations for the discharge of pollutants into the waters of the United States. The National Pollutant Discharge Elimination System (NPDES) 40 CFR 122 and the National Pretreatment Program 40 CFR 403.6 provide specific discharge standards and requirements for pollutants based on industry, pollutant, available technology and type of source. The EPA may delegate this authority to individual states territories or possessions.

2-6 CORROSION CONTROL.

Use AWWA M27, WEF MOP 8, Chapter 8, *Materials of Construction and Corrosion Control* and ASCE MOP 60, Chapter 4, *Corrosion Processes and Controls in Municipal Wastewater Collection Systems* for guidance on corrosion control.

2-6.1 Hydrogen Sulfide and Other Internally Corrosive Conditions.

In areas where high hydrogen sulfide concentrations, such as piping in wet wells or manholes, provide corrosion resistant materials, coatings or linings.

2-6.2 Materials Selection.

Approach selection of construction materials for corrosion control systems in accordance with the recommendations of WEF MOP 8, Chapter 8, Materials of Construction and Corrosion Control and AWWA M27. Corrosion control systems, such as, coatings, linings, polyethylene encasement or cathodic protection may be used to protect materials from corrosion. Explicit approval by the AHJ is required prior to providing a cathodic protection system on a buried pipeline. Use UFC 3-570-01 for the design of cathodic protection systems.

2-7 SECURITY.

Security must be an integral part of wastewater resource recovery system design. Planners, engineers, and security and antiterrorism personnel must determine site specific protective measures for wastewater systems. Use UFC 4-020-01 to establish protective measures. The engineering risk analysis, conducted as part of UFC 4-020-01, should be consistent with the terrorism risk analysis conducted by installation security or antiterrorism staff.

2-8 OPERATION AND MAINTENANCE.

Provide a design that:

- Minimizes operation and maintenance requirements, including additional training, higher level of operator certifications, or equipment that is not provided by the project. The AHJ must approve any operating equipment that is not provided by the project and required to maintain continuous operation of the wastewater treatment facility;

- Minimizes the number of operators required to operate the wastewater treatment facility. For new wastewater treatment facilities, the number of operators and level of training or operator certification required to operate the wastewater treatment facility must be approved by the AHJ. For existing wastewater treatment facilities, any increases to the number of operators, level of training, or operator certification required to operate the wastewater treatment facility must be approved by the AHJ. Give special consideration to minimizing operation and maintenance requirements in remote locations, including the limited availability of qualified operators available, technical support, and training opportunities;
- Includes operator training required to operate the wastewater treatment facility;
- Provides more than one piece of equipment, tank, or piping and isolation valves required to maintain continuous operation. Size equipment, tanks, and piping to maintain continuous operation with one piece of equipment or tank out of service.
- Provides space for the repair and removal of equipment without requiring the removal of equipment or pipe not in need of repair or replacement;
- Provides access, walkways, and space that complies with the applicable OSHA general industry and construction standards for operations, maintenance, and inspections;
- Provides tanks with isolation valves and drains to facilitate cleaning, inspection, and maintenance; and
- Provides drains with means of draining and containing pollutants that cannot be released to the environment.

2-8.2 Operation and Maintenance Manuals.

Prepare and furnish a site-specific operation and maintenance manual for wastewater pump stations and wastewater treatment systems, domestic or industrial. Operation and maintenance manual must include operating and maintenance procedures for the type of equipment specified or approved during construction, including any changes made during construction.

CHAPTER 3 – 10 STATES STANDARDS CHAPTERS 10, 20, AND 30

3-1 MODIFICATIONS TO CHAPTER 10 ENGINEERING REPORTS AND FACILITY PLANS.

For Navy: Use Chapter 10 except as modified by FC 1-300-09N.

3-1.1 SECTION 11 ENGINEERING REPORT OR FACILITY PLAN.

11.23 Population Projection and Planning Period [Replacement].

Use Chapter 2 to determine the minimum project planning period. Phased construction of wastewater facilities should be considered in rapid growth areas. Sewers and other facilities should be designed for the applicable Installation and project planning period.

11.23.1 Design Population [Addition].

Determine design population by the resident and nonresident populations. The effects of factors such as birth rates, death rates, and immigration are not applicable to military installations. The present and future populations may be obtained from the Installation's planning documents. Facilities that are not occupied and are included in the Installations current demotion plan should not be considered when determining resident and nonresident populations.

11.23.1.1 Resident Population [Addition].

Determine the resident population on full occupancy of all housing and quarters served. When the actual family population is unknown, the population of family housing units is typically estimated to be 3.6 residents per unit. Consider the number of National Guard, ROTC, reserve personnel, boarding schools, guesthouses, and any satellite functions such as service to a local community or other Federal agencies when estimating resident populations.

11.23.1.2 Non-resident Population [Addition].

Determine the non-resident population on full occupancy of all non-residential facilities. Consider the number of civil service personnel, contractor personnel, and daytime students when estimating non-resident populations.

11.242 Hydraulic Capacity for Wastewater Facilities to Serve Existing Collection Systems [Supplement].

When actual flow data is not available, use paragraph 11.243.

11.243 Hydraulic Capacity for Wastewater Facilities to Serve New Collection Systems [Replacement].

Hydraulic capacity for wastewater collection systems and wastewater facilities serving new collection systems.

a. Use Table 3-1 plus wastewater flow from industrial plants and major institutional and commercial facilities to compute the average daily flow unless water use data or other justification upon which to better estimate flow is provided.

b. When designing wastewater collection systems serving areas with wastewater generated by nonresidents or other short term uses, compute the average hourly flow rate based on the actual time period of waste generation.

c. Use the values in Table 3-1 and the peaking factors in Table 3-2 to compute peak flows. These peaking factors cover normal infiltration for wastewater collection systems built with modern construction techniques, refer to Chapter 30.

Table 3-1 Domestic Wastewater Allowances [1]

Permanent			
Type of Installation or Building	**Per Unit**	**gal/unit/day (L/unit/d)**	**Flow duration, Hours**
Single Family Housing [2,]	Per unit	300 (1136)	24
Multifamily Housing [2]	Per Unit	250 (946)	24
Type of Installation or Building	**Per Person**	**gal/cap/day (L/cap/d)**	**Flow duration, hours**
Military Installations	Per Person	100 (379)	24
Nonresident Personnel and Civilian Employees	Per Person	30 (114)	8
Military Training Camps	Per Person	50 (189)	24
BOQ and BEQ	Per Person	70 (265)	24
Barracks	Per Person	50 (189)	24
Temporary Host Nation Facilities			
Military Installations	Per Person	35 (132)	24
BOQ and BEQ	Per Person	20 (76)	24
Barracks	Per Person	15 (57)	24

1. Allowances do not include industrial or process wastes.
2. For the purpose of calculating populations in family housing areas, each housing unit is typically estimated to be 3.6 residents per unit.

Table 3-2 Minimum Peak Flow Factors

Population	Peak Factor
Greater than 500,000	2.5
Between 100,000 and 500,000	3.0
Less than 100,000	4.0

[C] 11.243 Hydraulic Capacity for Wastewater Facilities to Serve New Collection Systems [Replacement].

Peaking factors for military facilities are higher than most peaking factors to accommodate small populations, small service areas and unexpected operational changes.

d. Peak wastewater flow determined by total drainage fixture units may be used in lieu of estimated per capita peak flows if total drainage fixture unit flow is determined to be higher. Use UFC 3-420-01 and ASCE MOP 60 Chapter 3, titled *Quantity of Wastewater* to compute peak flow using total drainage fixture units.

[C] 11.243 Hydraulic Capacity for Wastewater Facilities to Serve New Collection Systems [Replacement].

Using total drainage fixture units to determine peak flow is not typically used by civil engineers to design wastewater collection systems. Using total drainage fixture units for facilities in which a large number of people may assemble in one place may be beneficial.

e. When actual flow data is not available and the condition of existing wastewater collection systems is unfavorable, an additional allowance for infiltration and inflow should be made.

f. When a new collection system serves existing facilities, evaluate the potential for infiltration and inflow from existing service lines or non-wastewater connections. Make an additional allowance for infiltration and inflow when infiltration and inflow from existing service lines is expected. Non-wastewater flows should be disconnect and rerouted or demolished.

11.244 Combined Sewer Interceptors [Replacement].

In addition to the above requirements, interceptors for existing combined sewers must have capacity to receive a sufficient quantity of combined wastewater for transport to treatment facilities to ensure attainment of the appropriate water quality standards.

11.244.1 Combined Sewers [Addition].

New combined sewers are not allowed. When an existing combined sewer is rehabilitated the stormwater interceptor should be separated from the wastewater collection system. Where stormwater interceptors are not separated from the wastewater collection system, rehabilitation of existing combined sewers may be approved when applicable regulations and permits allow rehabilitation of existing combined sewers.

11.245 Ship Chemical Holding Tank Discharges [Addition].

Use UFC 4-150-02 or contact the Government Project Manager for ship wastewater discharge capacities. Domestic wastewater discharges from ships have varying discharge capacities and high rates of flow.

11.246 Arctic Locations [Addition].

Wastewater systems in arctic locations practice water conservation. Water consumption is typically low, and infiltration is nil. If actual water consumption data are not available, base average daily wastewater flow for arctic locations on 80% of the flow determined for similar uses.

11.25 Organic Capacity [Supplement].

Pretreat normal laundry wastes when laundry flow exceeds 25% of the average daily wastewater flow.

11.250 Ship Chemical Holding Tank Discharges [Addition].

Ship wastewater discharges are more concentrated than typical domestic wastewater and may contain high concentrations of sodium from seawater use.

3-2 MODIFICATIONS TO CHAPTER 20 – ENGINEERING PLANS AND SPECIFICATIONS.

For Navy: Use Chapter 20 except as modified by FC 1-300-09N.

3-3 MODIFICATIONS TO CHAPTER 30 – DESIGN OF SEWERS.

3-3.1 SECTION 31 APPROVAL OF SEWERS [Supplement].

Use a gravity collection system unless justification is provided to and approved by the AHJ. A gravity sewer system is typically justified until the cost of the gravity system exceeds the cost of a pumped system by more than 10 percent.

31.1 Sewers for Collection of Ship Wastewater [Addition].

Use UFC 4-152-01 and UFC 4-150-02 for the design of piers, wharfs, and drydock wastewater collection facilities.

3-3.2 SECTION 33 DETAILS OF DESIGN AND CONSTRUCTION [SUPPLEMENT].

Design structural components of gravity sanitary sewer systems in accordance with UFC 1-200-01, ASCE MOP 60 Chapter 9, and the pipe manufacturer's recommendations. Provide appropriate seismic protection in areas subject to earthquakes. Use EPA 810-B-18-001 for seismic design guidance.

33.1.1 Building Connection [Addition].

\3 Use UFC 3-420-01 for building connections except as modified by this UFC.

[C] 33.1.1 Building Connection [Addition].

UFC 3-420-01 adopts and modifies the IPC. This section adopts and modifies Chapter 7 of the IPC which contains criteria for building sewer design. The building sewer is intended to begin 5 ft (1.5 m) from the building.

33.1.1.1 Modifications to the IPC.

701.3 Separate sewer connection. [Replacement].

Delete the last sentence and replace with the following:

Do not combine building sewers unless the connection is made in a manhole with a discharge pipe that is a minimum of 8 inches (200 mm) in diameter.

708.1.2 Building sewers. [Replacement].

Delete the first two sentences and replace with the following:

All building sewers must have a manhole located 5 ft (1.5 m) from the perimeter of the building or not more than 200 ft (61 m) from the connection to the building drain. Where a manhole is provided 5 ft (1.5 m) from the perimeter of the building, use the manhole to make the connection between the building drain and building sewer.

Where a manhole is not provided 5 ft (1.5 m) from the perimeter of the building, the junction of the building drain and the building sewer must be served by a cleanout that is located not more than 5 ft (1.5 m) from the perimeter of the building. When the length of the building sewer prior to the first manhole is greater than 100 ft (30.5 m), provide an additional cleanout so that either interval is not greater than 100 ft (30.5 m).

[C] 708.1.2 Building sewers.

Location and maximum spacing between manholes are covered in the 10 States Standards.

708.1.4 Changes in direction. [Replacement].

Where a manhole is not provided 5 ft (1.5 m) from the perimeter of the building and prior to the first manhole, provide cleanouts where the building sewer has a change of horizontal direction or a change of slope.

710.1 Maximum fixture unit load. [Supplement].

Add the following after the last sentence:

The minimum size for building sewers is 4 inches (100 mm) in diameter.

[C] 710.1 Maximum fixture unit load.

This supplement modifies Table 710.1(1) BUILDING DRAINS AND SEWERS and deletes pipes less than 4 inches (100 mm) in diameter from use as building sewers.

/3/

33.2 Depth [Supplement].

Minimum cover over sewer pipes must be the most stringent of the following requirements:

- 2 ft (0.61 m);
- 3 ft (0.91 m) for plastic pipe subject to traffic loading;
- greater than frost penetration according to UFC 3-301-01; or
- sufficient to support imposed dead and live loads for the pipe materials and pipe bedding used.

Evaluate temporary conditions during construction and final conditions. Provide calculations for minimum cover.

33.41 Recommended Minimum Slopes [Replacement].

Design and construct sewers with a diameter of 42 inches (1050 mm) or less to give minimum cleansing velocities, when flowing full, of not less than 2.0 feet per second (0.6 m/s), based on Manning's formula using an "n" value of 0.013. Minimum slopes for sewers with a diameter of 42 inches (1050 mm) or less are indicated in Table 3-3. Best

Practice: For sewer with a diameter of 42 inches or less, design sewers to provide a minimum velocity of 2.5 ft/sec (0.76 m/s), when flowing full.

Design and construct sewers with a diameter of 48 inches (1200 mm) or larger to give mean velocities, when flowing full, of not less than 3.0 feet per second (0.9 m/s), based on Manning's formula using an "n" value of 0.013.

33.42 \2\ Minimum Flow Depths [Delete] /2/.

Table 3-3 Minimum Slopes

Nominal Sewer Size	Minimum Slope in Feet Per 100 Feet (m/100 m)
8 inch (200 mm)	0.40
10 inch (250 mm)	0.28
12 inch (300 mm)	0.22
15 inch (375 mm)	0.15
18 inch (450 mm)	0.12
21 inch (525 mm)	0.10
24 inch (600 mm)	0.08
27 inch (675 mm)	0.067
30 inch (750 mm)	0.058
33 inch (825 mm)	0.052
36 inch (900 mm)	0.046
39 inch (975 mm)	0.041
42 inch (1050 mm)	0.037

33.43 Minimization of Solids Deposition [Replacement].

Select the pipe diameter and slope to minimize settling problems. Do not use oversized sewers to justify flatter slopes.

33.45 High Velocity Protection [Supplement].

Design gravity sewers to maintain subcritical flow conditions. Where steep slopes are unavoidable, use drop manholes to prevent supercritical flow conditions. Design downstream pipes to prevent hydraulic jumps and other flow disturbances.

33.47 Maximum Flow Depths [Addition].

Design sewer mains to carry the peak flow at a flow depth of no more than 0.9 d, where d is the sewer diameter.

33.5 Alignment [Replacement].

Use straight alignments between manholes.

Curvilinear alignment of sewers is not allowed.

33.7.1 Trenchless Technology [Addition].

Before beginning trenchless pipe design, obtain approval from the AHJ. Use UFC 3-230-01 for fusible pipe design.

3-3.3 SECTION 34 MANHOLES.

34.1 Location [Replacement].

Install manholes at the end of each line; all changes in grade, size, or alignment; at all intersections; at distances not greater than 400 ft (120 m) for sewers that are 15 inches (375 (mm) or less, and at 500 ft (150 m) for sewers that are 18 inches (450 mm) to 30 inches (750 mm). Distances of up to 600 ft (185 m) may be approved in cases where adequate modern cleaning equipment for such spacing is provided. Greater spacing may be permitted in larger sewers when approved by the AHJ.

34.1.1 Building Connections [Addition].

UFC 3-420-01 provides requirements for building sewers. These requirements include items such as making connections, changes in direction, location of cleanouts and for building connections larger than 8 in. (200 mm), and manhole location.

34.6 Watertightness [Supplement].

Watertight manhole frames and covers must be used when the manhole rim elevation is in the 100 year flood plain.

34.10 Frames and Covers [Addition].

Frames and covers must be sufficient to withstand impact from wheel loads where subject to vehicular or airfield traffic.

34.11 Steps, Rungs and Ladders [Addition].

\2 Provide steps or rungs in accordance with 29 CFR 1910.24(b) and ANSI A14.3 for manholes with a depth of 4 feet (1.2 m) or more above a lower level.

Provide a fixed ladder in accordance with **\4** 29 CFR 1910.23(d) **/4/** and ANSI A14.3 for manholes with a depth greater than 20 ft (6.1 m). ***/2/***

3-3.4 SECTION 35 INVERTED SIPHONS [SUPPLEMENT].

Depressed sewers must withstand internal pressures greater than atmospheric. Use pipe materials rated for force mains. Use inverted siphons only if no other option can be used.

3-3.5 SECTION 38 PROTECTION OF WATER SUPPLIES.

38.3 Relation to Water Mains [Replacement].

Use UFC 3-230-01 for horizontal and vertical separation distances from contaminated sources and wastewater sewer crossings.

38.31 Horizontal and Vertical Separation [Delete].

38.32 Crossings [Delete].

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CHAPTER 4 – MODIFICATIONS TO CHAPTER 40 WASTEWATER PUMPING STATIONS

4-1 SECTION 41 GENERAL [SUPPLEMENT].

Use pumping stations only where specifically identified in the project scope of work or upon written approval from the AHJ. Obtain written approval before beginning design.

41.1 Flooding [Supplement].

Use UFC 3-201-01 for flood design.

41.2 Accessibility and Security [Replacement].

Provide pumping stations with adequate access for personnel and equipment maintenance and replacement. Access points must be lockable and meet Installation security requirements.

All pump stations must be readily accessible from an all-weather road. For stations that are not enclosed, provide access for direct maintenance from a truck equipped with hoist attachments. For enclosed stations, include provisions in the structure to facilitate access for repair and to provide a means for removal and loading of equipment.

41.4 Safety [Supplement].

Design the pump station to protect maintenance personnel from toxic, explosive, or otherwise hazardous atmospheres.

41.5 Site Selection [Addition].

Pumping facilities must not be constructed beneath buildings, streets, roadways, railroads, aircraft aprons or runways, or other major surface structures. Consider availability of utilities such as electric power, potable water, fire protection, gas, steam, and telephone service.

Maintain a minimum setback to buildings and other occupied facilities of 500 ft (152 m) for medium and large pumping stations, unless adequate measures are provided for odor and gas control. Small wastewater pumping stations are defined as having peak flows less than 500 gpm (31.5 L/s); medium wastewater pumping stations are defined as having peak flowrates of 500 gpm (31.5 L/s) to 3200 gpm (202 L/s); and large wastewater pumping stations are defined as having peak flows greater than 3200 gpm (202 L/s).

41.6 Architectural [Addition].

Design pump station buildings to be architecturally compatible with the surrounding buildings in accordance with the Installations Appearance Plan.

41.7 Upgrades to Existing Pumping Stations [Addition].

Existing pumping stations may be upgraded where a complete hydraulic analysis shows that the upgraded pumping station can operate at the proposed capacity in conformance with the jurisdictional requirements for a new pumping station of equal capacity. The hydraulic analysis must include effects on the existing force main to its point of discharge and, if networked, the effects on all other pumping stations connected to the system. This analysis is required whenever additional flow is added to a pump station, even if physical changes to the station are not proposed.

4-2 SECTION 42 DESIGN.

42.22 Equipment Removal [Supplement].

Provide space required to remove bolts from thrust harnesses of sleeve couplings and to slide couplings off joints. In the dry well or structure, provide a minimum clearance of 4 ft (1.2 m) between adjacent pump casings and a minimum of 3 ft (1.0 m) from each outboard pump to the closest wall. Maintain a 7 ft (2.1 m) minimum clearance between floor and overhead piping, where practicable.

42.3 Pumps [Supplement].

Evaluate the system characteristics and determine the requirements for the pumping systems, such as flow rates, system head-capacity curves, pump station location, area served and force main velocities when selecting pumps. To determine system requirements, develop a system head-capacity curve which includes minimum, average and peak flow rates for the design condition and, if applicable, any interim conditions. Select a minimum of three different pump manufactures or pump models capable of:

- Discharging the peak flow for the system with one pump out of service and simultaneous pump operation;
- Operating for the full range of wet well levels;
- Discharging to either a gravity sanitary sewer or force main as applicable; and
- Operating in the manufacturer’s recommended performance curve and maximizing pump efficiency for the design average and peak flow conditions.

Use WEF MOP FD-4 for guidance when developing system head-capacity curves and selecting pumps.

42.31 Multiple Units [Supplement].

A single pump may be used for a wastewater pumping stations serving extremely low flows, such as a remote gate house, when justification is provided to and approved by the AHJ.

42.35.1 Pump Motors [Addition].

Select a pump motor enclosure suitable for the pump location. Provide totally enclosed fan-cooled motors for dry well pump installations. Ensure submersible pumps have watertight motor enclosures. Ensure temperature ratings of motors installed outdoors are adjusted to suit ambient operating conditions. To prevent condensation in dry wells, provide heat for pump motors designed to operate on an intermittent basis. Use motors rated for hazardous locations. Use motor starter technology for large motors to limit inrush current and mitigate electrical transients on electrical supply.

42.35.2 Motor Horsepower [Addition].

Select the pump motor horsepower such that it will accommodate any variation in flow and head along the entire design impeller curve without motor overload or failure.

42.38 Pumping Rates [Supplement].

Use a computer program for water hammer analysis of large pump stations.

42.39 Cavitation [Addition].

Confirm net positive suction head available is greater than the manufacturer’s net positive suction head required at all anticipated operating conditions.

42.4.1 Adjustable Speed Drives [Addition].

Select the simplest system that allows pumps to accomplish the required hydraulic effects. Evaluate cost, efficiency, reliability, structural requirements, ease of operation, and degree of maintenance necessary. Operation and maintenance are critical at military installations where adequate personnel cannot always be provided. Coordinate with the electrical DoR when using adjustable speed drives for variable speed pump operation. In general, adjustable speed drives are more expensive, less efficient, and require a higher degree of maintenance than across-the-line full voltage motor starters. However, in some instances, adjustable speed drives may be the best approach.

42.4.2. Selection of Control Points [Addition].

Provide a minimum of 6 in. (150 mm) between pump control points used to start and stop successive pumps or to change pump speeds.

Set the high-water level in the wet well below the lowest incoming invert of the sewer and minimize the fall of wastewater releasing hydrogen sulfide.

42.62 Size [Supplement].

The minimum length, width, or diameter is 4 ft (1.2 m).

42.65 Pressure Gauges [Addition].

Provide pressure gages on discharge piping directly downstream of the pump in dry well pumping stations.

4-3 SECTION 46 ALARM SYSTEMS [SUPPLEMENT].

Provide alarms such as low level and high temperature when required by pump manufacturer to maintain the pump manufacturer's warranty.

Remote monitoring systems must meet the requirements in UFC 4-010-06. Use UFC 4-010-06 for cybersecurity Risk Management Framework (RMF).

4-4 SECTION 49 FORCE MAINS.

49.1 Velocity and Diameter [Replacement].

For grinder pumps use a minimum 1¼ in. (32 mm) diameter. For small non-clog submersible pumps and pneumatic ejectors use a minimum 4 in. (100 mm) diameter. Size force mains based on hydraulic calculations considering factors such as velocity, friction loss, and power requirements.

Flow velocities should range from 2 to 5 feet per second (0.6 to 1.5 meters per second) for the design flow. The maximum velocity depends on new and existing piping materials and appurtenances. Ensure that the maximum pressure of the piping materials and appurtenances exceeds the maximum pressure of the system, including the potential for surge pressure.

49.2 Air and Vacuum Release Valves [Supplement].

Use AWWA M51 for guidance on air and vacuum release valves.

49.4.1 Rigid Conduit [Addition].

For ductile iron force mains, use AWWA C150/ANSI A21.50 to calculate the required pressure class or special thickness class.

49.4.2 Flexible Conduit [Addition].

For PVC force mains use AWWA M23 and applicable AWWA and ASTM standards.

49.61 Friction Coefficient [Supplement].

Hazen-Williams Roughness: values lower than 80 are not allowed unless verified by flow and pressure tests; if verified, consider replacement.

49.10 Cover [Supplement].

Minimum cover over force mains must be the most stringent of the following requirements:

- 2 ft (0.61 m);
- 3 ft (0.91 m) for plastic pipe subject to traffic loading;
- greater than frost penetration according to UFC 3-301-01;
- greater than the depth required to install valve riser; or
- sufficient to support imposed dead and live loads for the pipe materials and pipe bedding used.

Evaluate temporary conditions during construction and final conditions. Provide calculations for minimum cover.

49.11 Thrust Restraint [Addition].

Use DIPRA for thrust restraint design procedures. Provide calculations for restrained joints using a minimum safety factor of 1.5. Use the geotechnical investigation report and consult with the Geotechnical Engineer to determine soil bearing capacity.

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CHAPTER 5 – MODIFICATIONS TO CHAPTER 50 WASTEWATER TREATMENT FACILITIES

5-1 SECTION 51 PLANT LOCATION.

51.2 Flood Protection [Supplement].

Use UFC 3-201-01 for flood design and the minimum design flood elevation for flood design class 2. Provide wet proofing or dry proofing when station hatches are below the design flood elevation. Extend venting above the design flood elevation.

51.3 Location [Addition].

Maintain a minimum distance of 1,000 ft (305 m) between drinking water source and any wastewater treatment system.

For wastewater treatment facilities with a treatment capacity of 50,000 gpd (189 m^3/d) or less, maintain a minimum separation distance of 500 ft (152 m) from living quarters, working areas, and public use areas, when this minimum distance will not result in unacceptable noise or odor levels. Larger facilities, and wastewater treatment ponds regardless of size, must be more than one-quarter mile from living quarters, working areas, and public use areas.

51.3.1 Arctic and Cold Locations Outside the United States [Addition].

Exceptions to the 500 ft (152 m) restriction in paragraph 51.3 can be made for cold climate module complexes where the treatment system is a part of the module complex. Do not locate wastewater treatment equipment within the same module as living quarters.

5-2 SECTION 53 DESIGN.

53.1 Type of Treatment [Supplement].

The DoR must examine each unit operation in the proposed treatment system for potential problems caused by remote locations, limited availability of construction materials, available labor, time required for construction, cost of construction and operation and maintenance cost.

53.1.1 Arctic and Cold Locations Outside the United States [Addition].

For wastewater treatment unit operations in cold and arctic climates, the DoR must examine each unit operation in the proposed treatment system for potential problems caused by extreme cold, wind and snow, thermal stress on structures, frost heaving, and permafrost.

53.1.2 Tropic and Semiarid Locations Outside the United States [Addition].

For wastewater treatment unit operations in the tropics, the DoR must examine each unit operation in the proposed treatment system for potential problems caused by high temperature, torrential tropical rain, and variations in local wastewater characteristics.

53.2 Required Engineering Data for New Process and Application Evaluation [Supplement].

Provide three acceptable products when using a packaged wastewater treatment plant, equipment or component for approval. When approved by the AHJ, two acceptable products may be allowed. When only one suitable product is available, the DoR must submit a justification and authorization to the Government for approval. When a justification and authorization is approved by the Government Contracting Officer, one acceptable product will be allowed. Add the Government-approved product to the project specification.

53.2.1 Special Conditions for New Equipment Evaluation [Addition].

New equipment or components must be pre-approved for the proposed application and project conditions in the state or host nation where the project is located or approved by the applicable regulatory agencies. If the host nation does not maintain a pre-approved wastewater treatment equipment, equipment that is pre-approved for similar applications and project conditions by another state or host nation may be used when approved by the applicable regulatory authorities. Provide documentation indicating the location and conditions of the pre-approval and describe how the proposed application is similar to the project application.

5-3 SECTION 55 PLANT OUTFALLS.

55.1 Discharge Impact Control [Supplement].

A special study may be needed when effluent is discharged into a bay or similar area. Use ASCE MOP 60 for outfall studies and design guidance.

55.2 Protection and Maintenance [Supplement].

Anchor or pile support all sections of outfall pipelines subject to movement from the high water level to prevent movement.

Evaluate the low-water depth above the outfall pipe, ship and boat traffic, and use of anchors. Provide buoys, marking, or other means of warning as required.

55.4 Sizing and Capacity [Addition].

Design the minimum size of the outfall for peak hourly flow at the maximum anticipated stage of the receiving water. If the receiving water is tidal, evaluate both high and low conditions and tidal flow directions. If a diffuser is installed, use mixing models to select the port sizes and spacing. Ensure that port sizes are 2 in. (50 mm) in diameter or greater to avoid clogging by scaling or barnacles.

55.5 Outfall Depth [Addition].

Outfalls are typically a minimum of 8 ft (2.4 m) deep to provide mixing opportunity. Evaluate extending existing outfalls to deeper water. Factors for extending existing outfalls may include conditions such as, shallow water, shallow outfall depth, or permit compliance.

5-4 SECTION 57 SAFETY [SUPPLEMENT].

Ensure adequate safety by providing the following, as applicable:

- Continuous toxic gas monitors with alarms.
- Facility designs that eliminate the need to reach beyond safe limits.
- Facility designs that minimize the need for manual lifting.
- Directive, hazard-warning, and instructional signs, where appropriate.
- Equip pump and other equipment that handles corrosive solutions with spray or splash guards to protect the personnel working in the area.

57.2 Hazardous Chemical Handling [Supplement].

Include the following in a chemical handling area, as applicable:

- Easily accessible, clearly marked, well-lighted unloading stations.
- Guard posts to protect equipment and storage tanks from vehicle damage.
- A roofed platform or dock for unloading containerized chemicals.
- Mechanical devices to aid unloading and transporting chemicals to storage areas.
- Separate receiving and storage areas for chemicals that react violently when mixed together.
- Unique pipe configuration and valving for each chemical storage tank on-site to prevent the wrong chemical from being loaded into a tank.
- Dust control equipment for dry bulk and bagged chemicals.
- Protection of concrete against corrosive chemicals.
- Washdown and cleanup facilities for all chemical handling areas and separate drainage systems for noncompatible chemicals.
- A bulk tank level control system with a high-level alarm audible at the truck unloading station.

57.29 Eyewash Fountains and Safety Showers [Supplement].

Comply with the latest edition of ANSI Z358.1 for emergency eyewashes and shower equipment.

57.4 Chemical Storage [Addition].

Determine compatibility of all chemicals stored and store incompatible chemicals separately. Label all chemical storage areas. Follow the chemical manufacturer's recommendations regarding material compatibility and selection of system components in direct chemical contact. Include the following in a chemical storage areas, as applicable:

- Storage for peak demands.
- Light switches and ventilation controls located outside of the chemical storage rooms or areas.
- Automatic controls to actuate forced ventilation and lighting when chemical storage rooms are occupied.
- Protect exposed materials from the corrosive effects of stored chemicals.

57.4.1 Storage for Dry or Containerized Chemicals [Addition].

Provide the following:

- Dry rooms to store materials in original containers on boards or pallets.
- Adequate room to maneuver hand trucks, pallet jacks, or forklifts.
- Storage for dry chemicals at feed hopper inlet level or a platform capable of supporting a pallet of containers at the feed hopper inlet level.
- Signage indicating the safe load limits for floors, platforms and shelving.

57.4.2 Storage for Liquid Chemicals [Addition].

Provide the following:

- Containment of store volume plus a safety margin.
- Isolated containment for incompatible materials such as strong acids and strong bases.
- Capacity to hold the contents of one standard tank truck plus a sufficient reserve supply between shipments.
- Fire-rated storage facilities for flammable liquids.
- Freeze protection for exposed piping, valves, and bulk tanks.

5-5 SECTION 58 LABORATORY [SUPPLEMENT].

Do not locate administrative and laboratory buildings close to or downwind from primary treatment tanks, sludge drying beds ,or similar treatment processes that may cause unfavorable conditions.

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CHAPTER 6 MODIFICATIONS TO CHAPTER 60 SCREENING, GRIT REMOVAL, AND FLOW EQUALIZATION

Use 10 State Standards Chapter 60.

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CHAPTER 7 MODIFICATIONS TO CHAPTER 70 SETTLING

Use 10 State Standards Chapter 70.

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CHAPTER 8 MODIFICATIONS TO CHAPTER 80 SLUDGE PROCESSING, STORAGE, AND DISPOSAL

8-1 SECTION 81 GENERAL. [ADDITION].

Comply with 40 CFR 501 and 40 CFR 503.

81.1 Domestic Wastewater and Septage [Addition].

For the disposal of sewage sludge generated during the treatment of domestic sewerage in a treatment works comply with:

40 CFR 258 for the disposal of sludge in a solid waste landfill; or

40 CFR 503 for land application, incineration, surface disposal and any other sludge use or disposal that may be regulated by 40 CFR 503. Refer to 40 CFR 503.6 for exclusions.

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CHAPTER 9 MODIFICATIONS TO CHAPTER 90 BIOLOGICAL TREATMENT

Use 10 State Standards Chapter 90.

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CHAPTER 10 MODIFICATIONS TO CHAPTER 100 DISINFECTION

10-1 SECTION 102 CHLORINE DISINFECTION.

102.1 Type [Supplement].

Do not use chlorine gas for disinfection in small treatment systems.

[C] 102.1 Type [Supplement].

Chlorine gas introduces additional safety concerns for both operators and others in close proximity. Operation of chlorine gas disinfection systems typically requires additional operator training.

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CHAPTER 11 MODIFICATIONS TO CHAPTER 110 SUPPLEMENTAL TREATMENT PROCESSES

Use 10 State Standards Chapter 110.

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CHAPTER 12 SMALL TREATMENT SYSTEMS

12-1 GENERAL.

Small treatment systems are defined as treatment systems and components with 10,000 or fewer people or an average wastewater flow of less than 1 mgd (3,785 m^3/d). Small treatment systems using conventional processes must comply with the 10 State Standards as modified by this UFC. Small treatment systems using innovative approaches to wastewater treatment may be allowed when approved by the AHJ. Use paragraph 53.2 for required engineering data and process evaluation for innovative approaches that do not conform to the 10 State Standards as modified by this UFC.

12-2 PACKAGED TREATMENT PLANT.

Packaged treatment plants are typically used for small treatment systems associated with military operations in remote locations. These systems combine processes such as aeration, settling, and solids treatment in a multi-compartment unit or units. Typical types of treatment include extended aeration (activated sludge), rotating biological contactors (RBC), and sequencing batch reactors (SBR). Various processes within the packaged treatment system may include proprietary components. The DoR is responsible for specifying performance requirements, construction quality control, testing and verification, providing operation and maintenance procedures, equipment startup and operator training. WEF MOP OM-7 provides operation and maintenance guidance for extended aeration systems.

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CHAPTER 13 ON-SITE WASTEWATER TREATMENT AND DISPOSAL

13-1 GENERAL.

When a project is not served by a wastewater collection system, provide an on-site wastewater disposal system capable of handling the wastewater generated. Typical military applications include facilities such as remote training locations and remote entry control facilities. Use the IPSDC for on-site treatment systems.

13-2 ALTERNATIVE SEWER SYSTEMS.

Provide gravity collection systems when possible. Use the IPSDC for the design of alternative sewer systems.

13-3 HOLDING TANKS.

Holding tanks may be used when connecting to an approved wastewater collection system and constructing an on-site treatment system is not feasible. When a holding tank is used, the Installation must be able to demonstrate the means for regularly disposing of the sewage. Holding tank must be large enough to store peak flows for the Installation's disposal interval.

13-4 NONLIQUID SATURATED TREATMENT SYSTEMS.

Nonliquid saturated treatment systems, such as waterless toilets, may be used for composting human waste. Do not use a nonliquid saturated treatment system when a facility has a water supply source such as a potable water distribution system or potable well. Do not use non-potable water for handwashing or human consumption. Provide handwashing by waterless bacteriological hand cleaner and disposable hand towels or pre-moistened hand towels. Use the IPSDC for nonliquid saturated treatment systems.

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CHAPTER 14 INDUSTRIAL WASTEWATER COLLECTION AND TREATMENT

14-1 INDUSTRIAL AND OILY WASTE CONTROL SYSTEMS.

This chapter provides design requirements for the collection and treatment of industrial and oily wastewater control systems. These requirements are intended to serve as a general guide to assist the DoR in determining all applicable requirements and include items such as permits, effluent discharge limits, and disposal of solids. The DoR must take into account new regulations, widely accepted practices and proven treatment technologies. More stringent state requirements may be applicable when the EPA has delegated their permitting authority to an approved state program or when the project is located outside of the jurisdiction of U.S. laws. The criteria provided does not eliminate, change or modify any statutory or regulatory requirement.

Collect and hold all fire suppression system discharge for offsite disposal. Do not collect fire suppression system discharge in domestic or industrial wastewater collection systems, combine with other industrial wastes, or provide industrial wastewater treatment for fire suppression system discharge. Use UFC 3-600-01 and UFC 4-211-01 for fire suppression system discharge collection and containment requirements.

14-2 SPILL PREVENTION, CONTROL, AND COUNTERMEASURE PLANS.

Use UFC 3-460-01 for spill prevention, control and countermeasures plan requirements associated with petroleum fuel facilities. 40 CFR 112.1 establishes the general applicability of the spill prevention, control and countermeasure rule. 40 CFR 112.1(d)(6) exempts wastewater treatment facilities or portions thereof that are used exclusively for wastewater treatment. This exemption does not apply to wastewater treatment devices such as oil water separators that are used to provide secondary containment under 40 CFR 112.8(c)(2) for oil storage containers. The exemption also does not apply to containers that are used to store recovered oil in an oily waste treatment process or facility. Refer to EPA 550-B-13-002 for additional guidance.

14-3 INDUSTRIAL DISCHARGE LIMITS.

Industrial wastewater may discharge wastewater either directly or indirectly. Indirect discharge is typically the most cost effective approach to treating industrial wastewater. For indirect discharge, effluent discharge limits are determined by pretreatment regulations and POTW requirements. For indirect discharge, the DoR must comply with pretreatment regulations, requirements set by the POTW and control mechanisms in the POTW’s NPDES permit. For direct discharge, effluent discharge limits are determined by direct discharge regulations and NPDES permits. For direct discharge, the DoR must obtain and comply with direct discharge regulations and the terms of the NPDES permit. EPA 833-R-12-001A provides industrial user permitting guidance.

14-4 GENERAL PRETREATMENT REGULATIONS FOR EXISTING AND NEW SOURCES OF POLLUTION (40 CFR 403).

The National Pretreatment Program, 40 CFR Part 403, provides the regulatory basis to require nondomestic dischargers to comply with pretreatment standards to ensure compliance with the Clean Water Act (CWA). The National Pretreatment Program controls toxic, conventional, and non-conventional pollutants from nondomestic sources that discharge into publically owned treatment works (POTW). EPA 833-B-11-001 provides federal pretreatment requirements and guidance.

14-4.1 Industrial Discharges.

Industrial discharges can fall into several different categories. Understanding and applying the requirements for industrial discharges is essential to understanding industrial wastewater treatment requirements and correctly applying responsibilities. 40 CFR 403.3 contains a complete list of definitions.

14-4.2 Industrial User (40 CFR 403.3(j)).

The National Pretreatment Program requires indirect discharges to obtain permits or other control mechanisms to discharge wastewater to the POTW. The permit may specify the effluent quality that necessitates that an industrial user pretreat or otherwise control pollutants in its wastewater before discharging it to a POTW.

14-4.3 Categorical Industrial User.

An industrial user subject to national categorical pretreatment standards.

14-4.4 Non-Significant Categorical Industrial User (40 CFR 403.3(v)(2)).

In general, non-significant industrial users never discharge more than 100 gallons per day of total categorical wastewater and some additional conditions apply including never discharging any untreated concentrated waste. Refer to 40 CFR 403.3(v)(2) for a definition and additional conditions.

14-4.5 Significant Industrial User (40 CFR 403.3(v)).

In general, significant industrial users are subject to categorical pretreatment standards and any other industrial user that discharges:

- An average of 25,000 gallons per day or more of process wastewater to the POTW,
- Contributes a process waste stream which makes up 5 percent or more of the average dry weather hydraulic or organic capacity of the POTW, or
- Is designated as such by the Control Authority on the basis that the industrial user has a reasonable potential for adversely affecting the

POTW's operation or for violating any Pretreatment Standard or requirement (in accordance with 40 CFR 403.8(f)(6)).

14-4.6 Middle-Tier Categorical Industrial User (40 CFR 403.12(e)(3)(i)-(iii)).

A classification that a POTW, in the case of a POTW with an approved pretreatment program, or the Approval Authority, in the case of a POTW without an approved pretreatment program may apply to certain industrial users if their discharge of categorical wastewater does not exceed certain conditions. Refer to 40 CFR 403.12(e)(3)(i)-(iii). In terms of discharge, the industrial user does not discharge more than 5,000 gallons per day.

14-4.7 National Pretreatment Standards: Prohibited Discharges (40 CFR 403.5).

40 CFR 403.5 identifies prohibited discharges for national pretreatment standards.

1. General prohibitions: 40 CFR 403.5(a)(1);
2. Specific prohibitions: 40 CFR 403.5(b);
3. When specific limits must be developed by POTW: 40 CFR 403.5(c);
4. Local limits: 40 CFR 403.5(d);
5. EPA enforcement actions under section 309(f) of the Clean Water Act: 40 CFR 403.5(e).

14-4.8 National Pretreatment Standards: Categorical standards (40 CFR 403.6).

Pretreatment standards are implemented through the National Pretreatment Program. Discharges from indirect dischargers are regulated through categorical standards. Existing and new categorical standards for specific industrial subcategories are included in 40 CFR 405 through 40 CFR 471.

14-5 DIRECT DISCHARGE (40 CFR 122).

A direct discharge is the discharge of any pollutant into waters of the United States from any point source. Refer to 40 CFR 122.1 for a complete list of regulatory requirements. Refer to 40 CFR 122.2 for a complete list of definitions. Unless covered by an exclusion, the NPDES Permit Program requires point source pollutant discharges to waters of the United States to obtain an NPDES permit. Refer to 40 CFR 122.3 for exclusions. For point sources that introduce pollutants through direct discharge, the EPA has promulgated effluent guidelines through the NPDES Permit Program and at the same time as pretreatment standards. Direct discharges are required to comply with the same categorical pretreatment standards as indirect discharges using effluent limitation guidelines established in the categorical pretreatment standards. Direct discharge usually requires extensive wastewater treatment to reduce pollutants and achieve effluent requirements. Refer to EPA 833-K-10-001 for direct discharge guidance.

14-6 INDIRECT DISCHARGE.

Once pretreatment effluent requirements have been met, industrial wastewater may be combined with domestic wastewater in the domestic wastewater collection system and conveyed to a POTW. Indirect discharge to a receiving water body occurs after the wastewater has passed through a POTW.

14-7 CONVENTIONAL POLLUTANTS (40 CFR 401.16).

Five conventional pollutants are defined in 40 CFR 401.16. Conventional pollutants are expected to be present in domestic wastewater. They are:

- Biochemical oxygen demand (BOD);
- Total suspended solids (TSS);
- Fecal coliform;
- pH;
- Oil and grease (O&G).

14-8 INDUSTRIAL POLLUTANTS.

Industrial wastewater may contain toxic or non-conventional pollutants in addition to conventional pollutants. POTW are not design to treat most toxic or non-conventional pollutants. When a POTW has the capability to remove toxic pollutants from industrial wastewater the pollutants can end up in the POTW’s sludge.

14-8.1 Toxic Pollutants (40 CFR 401.15).

40 CFR 401.15 provides a complete list of toxic pollutants. The list currently contains 65 toxic pollutants.

14-8.2 Priority Pollutants (40 CFR 423).

40 CFR 423, Appendix A to Part 423 - 126, provides a complete list of Priority Pollutants. The Priority Pollutants are a set of chemical pollutants that EPA regulates and for which EPA has published analytical test methods. The Priority Pollutant list is more practical than the list of toxic pollutants for testing and for regulation. Priority pollutants are described by their individual chemical names. In contrast, the list of toxic pollutants contains open-ended groups of pollutants. For example, chlorinated benzenes contain hundreds of compounds and there is no test for the group as a whole. The Clean Water Act, 33 USC 1317(a)(1), references the Toxic Pollutant List.

14-8.3 Nonconventional Pollutants.

Nonconventional pollutants are any pollutant not specified as a toxic pollutant or conventional pollutant. Nonconventional pollutants include parameters such as chlorine, ammonia, nitrogen, phosphorus, chemical oxygen demand (COD), and whole effluent toxicity (WET).

14-9 INDUSTRIAL WASTEWATER SURVEYS.

Identify all industrial wastewater sources and flows through field investigation and existing records to extent possible. The composition of industrials pollutants and flows can be variable and depend on the type and operation of the facility.

14-9.1 Physical Characteristics.

Use existing records to identify the physical characteristics of the industrial wastewater collection system. Determine the extent of available records such as existing maps or drawing files. Field verified all existing records to verify accuracy. Compile records and carefully review to see if they accurately represent the existing wastewater collection system.

14-9.2 Waste Stream Characteristics.

Being able to identify all pollutants and their concentrations is an important part of the industrial wastewater survey. North American Industry Classification System and Standard Industrial Classification codes may be helpful when determining the appropriate industrial category. Use existing records such as prior sampling results to identify pollutants and pollutant concentrations. If existing records are not available or are not sufficient to identify pollutant concentrations a field monitoring program should be established to verify and update existing records.

14-9.3 Waste Stream Flows.

Use existing records to identify waste stream flows to the extent possible. Most Installations meter water usage from water treatment facilities. Metered data may be used to perform a water balance evaluation. Add water obtained directly from other sources, such as wells.

14-10 PRELIMINARY DESIGN.

14-10.1 Facility Industrial Wastewater Survey.

Use WEF MOP FD-3, Chapter 4 *Industrial Wastewater Survey and Characterization* for industrial wastewater survey and waste stream characterization. The DoR must identify the physical characteristics, composition of industrials pollutants, flow characteristics for the facility type, and planned operation procedures.

14-10.1.1 Physical Characteristics.

If existing sewer maps are not available, they must be prepared. Show how the facility's industrial waste stream will connect to the existing industrial or domestic wastewater collection system and how the new connection will affect any existing industrial or domestic wastewater flows. Prepare a comprehensive schematic flow diagram of the facility's wastewater systems.

14-10.1.2 Waste Stream Characteristics.

For existing facilities, when existing records are not available or sufficient to identify pollutant concentrations identify wastewater characteristics through field investigation. Identify wastewater sources using typical industrial waste survey techniques such as identifying sources, establishing a sampling plan and dye tracer testing. Refer to EPA 833-K-10-001 for additional guidance.

14-10.1.3 Waste Stream Flows.

When existing flow records are not available, use actual measurement to establish flow rates or estimate flows from equipment ratings, process analysis, or other reliable methods. Identify variations in peak flow such as modes of occurrence (continuous or intermittent) and period of discharge. Correlate flowrates with process production rates and concentration variations.

14-11 DESIGN.

14-11.1 Process Changes.

Evaluate process changes that reduce waste stream volume, pollutant concentration, or treatment processes before proceeding on any industrial waste collection and treatment project. Process changes may include:

- Segregating or combining industrial waste streams based on waste stream characteristics;
- Changing cleanup operations from wet to zero discharge or dry methods;
- Product recovery;
- Using wastewater from one process as a source of water for another process (when the quality of the effluent from the first source meets or exceeds the required water quality of the following processes); or
- Recycling all or a portion of wastewaters.

Use WEF MOP FD-3, Chapter 7 *Management Strategies for Pollution Prevention and Minimization* for additional minimization practices.

14-11.1.1 Waste Stream Minimization.

Investigate waste stream minimization techniques to eliminate or reduce wastewater volume and pollutant concentrations. Reducing wastewater volume may be more economical than providing wastewater treatment. Evaluate process changes such as reducing waste stream volume, segregating waste streams, recycling treated effluent, and product recovery. Some pollutants have discharge limitations that require a zero discharge system. Segregate all industrial and domestic waste streams. Segregate stormwater drainage from all waste streams.

14-11.1.2 Separating Waste Stream Sources.

Isolate waste streams requiring different treatment processes, when pretreatment reduces downstream treatment requirements, containing recoverable materials, or with non-compatible or hazardous pollutants. The additional cost of source separation is typically offset by reducing treatment processes and operational cost.

14-11.1.3 Combining Waste Stream Sources.

Evaluate combining separate waste flows that are compatible for co-treatment, such as neutralization by combining acid and alkaline flows. Consider combining compatible waste streams when waste stream combination reduces the cost of treatment processes. Prohibit combining industrial and domestic wastewater.

14-11.2 Establishing the Design Flow.

Base design flow on the maximum flowrate to be treated, including any future expansions for the project planning period. Evaluate seasonal, daily and shift variations in determining peak flowrates. Where appropriate, establish production-based generation rates for projecting future flows. If unit wastewater generation rates from another facility are used, account for differences, including size, type of facility, and differences in operating procedures.

14-11.2.1 Peak Flows.

Design industrial wastewater collection systems for the peak industrial flow, as determined for the industrial process or activity involved. Peak hourly flows may be higher during a specific 8-hour shift during the day or for a specific day at single shift shops.

14-11.3 Industrial Wastewater Collection.

Collect industrial wastes in a manner that avoids unsafe conditions to personnel, equipment, and facilities. Select pipe materials, pumps, and appurtenances that are rated for the characteristics of the industrial waste stream. During the materials selection process, obtain and follow manufactures' recommendations. Obtain approval from the AHJ for any exceptions to manufactures' recommendations. Some waste streams may contain pollutants that can damage materials such as oily waste, solvents, high temperature, and unusual pH ranges. Some pipe materials are not rated for high-temperature waste streams. Use piping rated for the high-temperature of the wastewater being collected to prevent detrimental effects on the wastewater collection system. Use Chapters 2, 3, and 4 for the design of gravity sewer systems.

14-11.4 Industrial Wastewater Treatment.

Most POTW are not designed to treat industrial wastes that may contain toxic or non-conventional pollutants. Where pollution prevention techniques such as reducing or recycling industrial waste are not sufficient to reduce pollutants such as primary or toxic pollutants to the required regulatory levels, provide pretreatment for industrial wastewater sources in accordance with 40 CFR 403 or provide a separate industrial wastewater collection and treatment system. Document the industrial wastewater sources and the treatment or pretreatment strategies used for compliance.

Industrial wastewater treatment may include removal of fat, oil, and grease; organic or inorganic constituents; and pH control. Use Chapters 2 and 5 - 11 for the design of industrial wastewater treatment systems. Use WEF MOP FD-3 for industrial wastewater treatment and pretreatment guidance. Select industrial wastewater treatment processes based on the characteristics of the pollutants, the full range of industrial wastewater flows, permitted discharge limits, technical ability of personnel operating the industrial wastewater treatment facility, cost of construction, and operation and maintenance costs. Identify adverse effects from upstream treatment processes on subsequent treatment steps and methods of mitigating the adverse effects. For projects with wastewater flows from industrial sources, include evidence of adequate treatment or pretreatment strategies for review and approval by Installation EV staff and the AHJ.

14-11.4.1 Treatability.

Length and configuration of the collection system, liquid transport velocities, pumping, and associated appurtenances can significantly influence wastewater characteristics. Use WEF MOP FD-3 Chapter 5 *Wastewater Treatability Assessments* for treatability assessment guidance.

14-11.4.2 Pretreatment.

Use Chapter 2 and WEF MOP FD-3, Section 2, for design of pretreatment processes.

Identify daily and process-related variations in wastewater characteristics related to current and future production operations to develop control strategies. Evaluate combining separate waste flows that are compatible for co-treatment, such as neutralization by combining acid and alkaline flows.

14-11.5 Flow and Load Equalization.

Evaluate equalization on a large scale for compatible wastes received at a treatment facility, or on a smaller scale for specific process batch discharges. Processes with short duration and high flow and loading rates can adversely impact collection and treatment systems, evaluate at-the-source equalization to minimize hydraulic and pollutant load surges.

Evaluate the relative cost of constructing and implementing effective flow equalization, and the anticipated cost savings of reducing the size of downstream treatment processes. Determination of the need for flow equalization is based on the potential effects of peak hourly flow on pretreatment, industrial treatment facility, or POTW operating parameters such as flow rate, pH, BOD, COD, ammonia, toxicity, and variations in peak flow.

14-11.5.1 Basin Sizing.

Use peak flows for equalization, and as the basis for sizing treatment facilities.

The three basic types of equalization processes are alternating flow diversion, intermittent equalization, and completely mixed equalization. Completely mixed combined flow equalization is most common. Determine the minimum volume of a completely mixed combined flow equalization basin using the below formula.

$$V = (\Sigma f_i) T_e k$$

Where

V = equalization volume (m^3);

f_i = individual flowrates (m3/min);

T_e = equalization time (hours); and

k = conversion factor for units (min/hour)

For additional information and sizing information on alternating flow diversion or intermittent equalization processes and sizing using a cumulative flow curve, use WEF MOP FD-3, Chapter 8 *Flow and Load Equalization.*

14-11.5.2 Basin Construction.

Evaluate the need for liners based on frequency of basin use and solids deposition and clean-out. If required, provide a protective liner compatible with wastewater characteristics. Earth embankment lagoons are not allowed unless permitted by local regulatory agencies.

14-11.5.3 Mixing Conditions.

For biodegradable wastes provide minimum airflow rate of 4 ft^3/min/1000 gal (0.5 L/m^3 s) of basin volume to keep solids in suspension. Consult manufacturers as to circulation capacity of aeration or mixing equipment for manufacturer specific basin configuration.

14-11.6 Solids Removal.

Provide for removal of deposited solids from the basin, by either draining and cleaning during off-peak hours or by cleaning without draining. This can be through manways installed in steel tanks, depressed floor pits for solids accumulation and pumping, or by sloped floors in basins to collection pits.

14-11.6.1 Solids Separation and Handling.

Use WEF MOP FD-3 Chapter 9 *Solids Separation and Handling*. Remove suspended solids from industrial wastewater prior to discharge to a POTW. Concentrations greater than 500 mg/L can overload POTW systems and clog sewer lines and pumping station wet wells, and, if biodegradable, cause odors.

Classify solids by size and removal technique:

- Large solids – solids greater than 1 inch (25 mm)
- Grit – suspended matter that settles more rapidly than organic matter
- Settleable solids – particles with diameters between 1 µm and 25 mm that settle out of wastewater during a standard Imhoff cone test and may be organic or inorganic.
- Colloids – particles between 0.001 and 1 µm and may be organic or inorganic. Colloids are typically removed with chemical coagulation and flocculation.

14-11.6.2 Removal Methods.

Select methods based on the initial concentration of solids in the wastewater, the final concentration needed, and particle size and characteristics. For wastewater streams with TSS less than 1% (10,000 mg/L) the typical methods used include straining, gravity separation, and filtration. Use WEF MOP FD-3 Chapter 9, *Solids Separation and Handling*, and Chapters 6 and 7 of this UFC.

14-11.6.3 Solids Handling and Processing.

Industrial solids processing, particularly for industrial biological sludges, may be more difficult to dewater than domestic sludge. Solids conditioning, thickening, dewatering, and disposal are discussed in Chapter 8.

14-11.6.4 Disposal of Industrial Sludge.

Coordinate with Installation EV staff and industrial wastewater treatment operators to determine the optimal treatment strategy and waste disposal methods. All sludges resulting from industrial wastewater treatment processes must be evaluated as a potentially hazardous waste in accordance with 40 CFR 261; specifically 40 CFR 261.2 and 261.3. Treatment strategies, disposal methods and applicable exemptions or exclusions will be based on the results of that regulatory evaluation and must be approved by Installation EV staff and the AHJ.

14-11.7 pH Control.

Use WEF MOP FD-3 Chapter 11 *pH Control.* Adjust pH of wastewater if required prior to direct or indirect discharge. For direct discharge the effluent pH required is typically between 6 – 9 to protect receiving waters. POTW requirements will vary based on treatment processes, but typically will require 5.5 – 10 to protect collection systems and prevent process upset, and 6.5 – 8 if the POTW uses biological pretreatment processes.

Evaluate possible adverse chemical reactions due to acidity of wastewater such as reactions with cyanide and sulfides.

14-11.7.1 Acidity And Alkalinity.

Determine the wastewater's total acidity or alkalinity by performing a titration. Use the titration curve and flow variability to define reagent, dose, and process control characteristics.

Select neutralizing agents based on cost, reaction time, solids production, safety, maximum and minimum pH in overtreatment, ease of chemical handling, and availability. Solids produced during neutralization may require removal and processing.

14-11.8 Removal of Inorganic Constituents.

Refer to WEF MOP FD-3 Chapter 12 *Removal of Inorganic Constituents.* Inorganic constituents found in industrial wastewater include heavy metals, cyanide, sulfides, and nutrients (primarily nitrogen and phosphorus). Control heavy metals and other inorganic compounds present in some industrial wastes to avoid upset or pass-through problems to the POTW.

14-11.8.1 Treatment Strategies and Processes.

Inorganic pollutants may require treatment in individual rather than combined streams due to the variety of compounds and sources. Common treatment techniques include neutralization – precipitation, chemical reduction, oxidation, stripping, ion exchange, adsorption, membrane filtration, electrodialysis, and evaporation.

14-11.9 Removal of Organic Constituents.

Use WEF MOP FD-3 Chapter 12 *Removal of Organic Constituents.*

14-11.9.1 Biological Treatment Processes.

Use biological treatment processes for waste streams with a significant biodegradable fraction or to destroy hazardous organics by converting to more benign forms. Consider carbon source and nutrient and growth factors in design.

Conventional biological treatment systems can remove some organic compounds via biodegradation, volatilization (stripping) from aeration, and adsorption onto sludge, while others pass through. Actual removal performance depends on the operating characteristics (sludge age, mixed liquor suspended solids) of the treatment facility, the method of oxygenation, and the amount and nature of other compounds present in the wastewater.

14-11.9.2 Organic Treatment Approaches.

Evaluate reaction kinetics, bacterial growth and pollution removal rates, and process control parameters. One or more treatment technologies may be required to meet effluent limits. Treatment technologies include: activated sludge; sequencing batch reactors; facultative ponds; aerobic, anaerobic and combination ponds; fixed film technologies; trickling filters; and submerged media attached growth reactors.

Remove nitrogen via physical – chemical means or biological processes. If wastewater contains organic nitrogen, convert to ammonia by deamination followed by nitrification. Remove phosphorus by precipitation or biological processes.

CHAPTER 15 OILY WASTE TREATMENT

15-1 OILY WASTE SOURCES.

Oily waste originates in numerous locations on board ships and throughout shore facilities, including equipment washracks, vehicle maintenance, fueling and petroleum, oil and lubricant sources, metal products and machinery, floor drains, shipboard oily wastewater, and stormwater runoff. Design oil-water separators to handle anticipated maximum oily waste loads.

15-1.1 Oily Waste Characteristics.

The types and concentrations of pollutants in oily wastes will depend on the source of the oily wastewater and the source of the pollutants. Identify the source of the oily wastewater and the source of the pollutants to determine the appropriate treatment process. Oil, grease, and total suspended solids are the typically primary conventional pollutants found in oily waste. Oils may be present in the form of free, dispersed, emulsified, or dissolved oil. Other types of pollutants may include pollutants such as fuel, heavy metals, or solvents. Pollutants may be present individually or in combination with other pollutants.

15-1.2 Oily Waste Waste Oil.

Oily wastes and waste oils are byproducts of operating ocean-going vessels. Oily bilgewater is the mixture of water, oily fluids, lubricants and grease, cleaning fluids, and other wastes that accumulate in the lowest part of a vessel from a variety of sources including engines (and other parts of the propulsion system), piping, and other mechanical and operational sources found throughout the machinery spaces of a vessel. This type of oily waste is commonly referred to as oily waste waste oil (OWWO). Refer to Chapter 16 for additional OWWO criteria.

15-1.3 Sampling.

When the specific pollutant or combination of pollutants is unknown, develop a sampling plan for the type of activities performed at the facility. Analyze oily wastewater using approved EPA methods. The EPA publishes laboratory analytical methods, or test procedures that are used by industries and municipalities to analyze the chemical, physical ,and biological components of wastewater and other environmental samples that are required by the Clean Water Act. Most of these methods are published in 40 CFR 136. An American Society for Testing and Materials (ASTM) standard using an approved EPA method may be used. The completed analysis must identify the amounts of free, dispersed, emulsified, and dissolved oil fractions present. When pollutants other than only conventional pollutants may be present additional sampling and analysis will need to be included in the sampling plan. The additional sampling and analysis may include an analysis of volatile suspended solids (VSS) to determine the full range pollutants present. Refer to *Standard Methods for the Examination of Water and Wastewater* for guidance on sampling and analysis.

Sampling for facilities such as vehicle wash facilities will typically be limited to temperature, pH, total suspended solids and total oil and grease. Use grab samples to analyze for pH and total oil and grease. Use composite samples to analyze for total suspended solids. For composite samples, collect five grab samples evenly spaced over an 8-hour period or if the discharge is less than 8 hours, evenly spaced for the duration of the discharge.

15-2 IDENTIFICATION OF FLOWS.

Estimate the peak flow rate of the oily wastewater requiring treatment, including the addition of any future oily wastewaters. When determining peak flow rates, evaluate flow variations between shifts, daily operations and seasonal flow variations. Estimate peak flows by monitoring and measuring existing flows during peak operating periods for existing flows or by estimating peak flow based on the estimated peak flow of the water used at the facility for new flows. For example, the peak flow from a new aircraft washing facility may be estimated from the water used per aircraft multiplied by the maximum number of aircraft to be washed in a given period. Peak flow rates from a similar facility may be used when differing conditions are evaluated and accounted for, such as differences in the pressure of the water supplied, vehicle type and washing procedures.

15-3 OILY WASTE OIL COLLECTION.

Do not mix high flashpoint oil with low flashpoint oil, or halogenated solvents with non-halogenated oil. Evaluate segregation of oily wastewater streams based on the characteristics of the wastewater and the source of pollutants. Segregate oily wastewater and solvents at their source when possible. Do not mix oily wastewater with industrial wastewater such as wastewater containing metals and phenols.

Minimize the formation of chemical and physical emulsified oils. Avoid using emulsifying agents such as detergents and creating turbulent flow, such as pumping oily waste. Segregate oily wastewater containing emulsified oil from oily wastewater without emulsions when possible.

15-3.1 Waste Stream Minimization.

In addition to the waste stream minimization requirements indicated in Chapter 14, facilities such as washracks should be covered to prevent rainfall events from increasing the volume of oily waste requiring treatment. When cover is not provided, provide a waste collection system capable of segregating oily wastewater flows from stormwater runoff during periods when oily wastewater flows are not being generated.

15-3.2 Pumps.

Avoid pumping oily wastewater to a gravity or enhanced-gravity oil water separator. If pumping is required, use positive displacement pumps to prevent the formation of physical emulsions. When oily wastewater is pumped, an enhanced oil water separator should be used.

Manufacturers typically indicate peak influent flow capacity using gravity flow with no pumps upstream of the separator. When positive displacement pumps are used, de-rate the flow capacity of the oil water separator to account for non-quiescent conditions. When oily wastewater is pumped, the DoR must provide documentation from the specified manufacturers indicating the proposed oil water separator has been de-rated for the anticipated pump flowrates and is sized to meet effluent standards.

15-4 OILY WASTE TREATMENT.

Design the oily waste treatment system for the peak flow at the minimum expected operating temperature. Use the minimum operating temperature to determine the properties of the oil water mixture, such as density and absolute viscosity.

15-4.1 Oil Water Separators.

Use UFC 3-240-03 to evaluate the need for new or existing oil water separators. Coordinate with the Installation EV staff for direct discharge permitting requirements or POTW approval.

Design grit chambers and gravity separators located below grade for traffic loads. Use H-20 traffic loading as the minimum design load. When a gravity oil water separator is open to the atmosphere, the wall of the separator must extend a minimum of 6 in (150 mm) above the surrounding ground surface. Separators that are not designed for traffic loads must extend a minimum of 6 in (150 mm) above the surrounding ground surface.

15-4.1.1 Gravity Separators.

Separators that are open to the atmosphere may require removable grates or covers to prevent people from accidentally falling into the separator. Design grates or covers to be removable by no more than two people.

15-4.2 Conventional Pollutants.

Oily wastewater with pollutants limited to conventional pollutants typically includes facilities such as vehicle wash racks, aircraft washing, and vehicle maintenance facilities. When only conventional pollutants are present, gravity oil water separators are typically the most efficient type of treatment for free oil and in some cases, dispersed oil.

15-4.3 Emulsified Oils.

Gravity separators are not capable of removing emulsified oils without providing additional treatment processes. Do not use gravity separators as a single unit process for emulsified oil removal. Bench or pilot plant testing should be performed to determine an effective emulsion breaking method. An effective treatment process for emulsified oil treatment may include gravity separation to remove free oil followed by dissolved air flotation (DAF).

15-4.4 Dissolved Oils.

Treatment technologies for the treatment and direct discharge of dissolved oils are typically not performed on military installations. Dissolved oil may be removed through biological treatment processes employed by the downstream wastewater treatment plant or POTW.

15-4.5 Industrial Pollutants.

Oily wastewater containing pollutants other than conventional pollutants will typically require more than one treatment process. A single treatment process or commercial device is not typically capable of removing non-conventional pollutants and oil. Especially when oil is in the form of dispersed, emulsified or dissolved oil. A series of treatment processes or units is typically required to achieve the desired effluent quality. The treatment processes or devices provided must be able to meet the direct discharge or POTW discharge limits.

15-4.6 Pretreatment Techniques.

Provide pretreatment as close to the source as possible to help avoid emulsification. If flow is highly variable, flow equalization may be required to maintain quiescent conditions and ensure efficiency of the separator.

15-4.6.1 Grit Removal.

Provide a separate grit removal basin when the total suspended solids exceed 200 mg\l. Use a minimum detention time of 5 minutes for gravity separation. A grit removal basins will also assist with flow equalization.

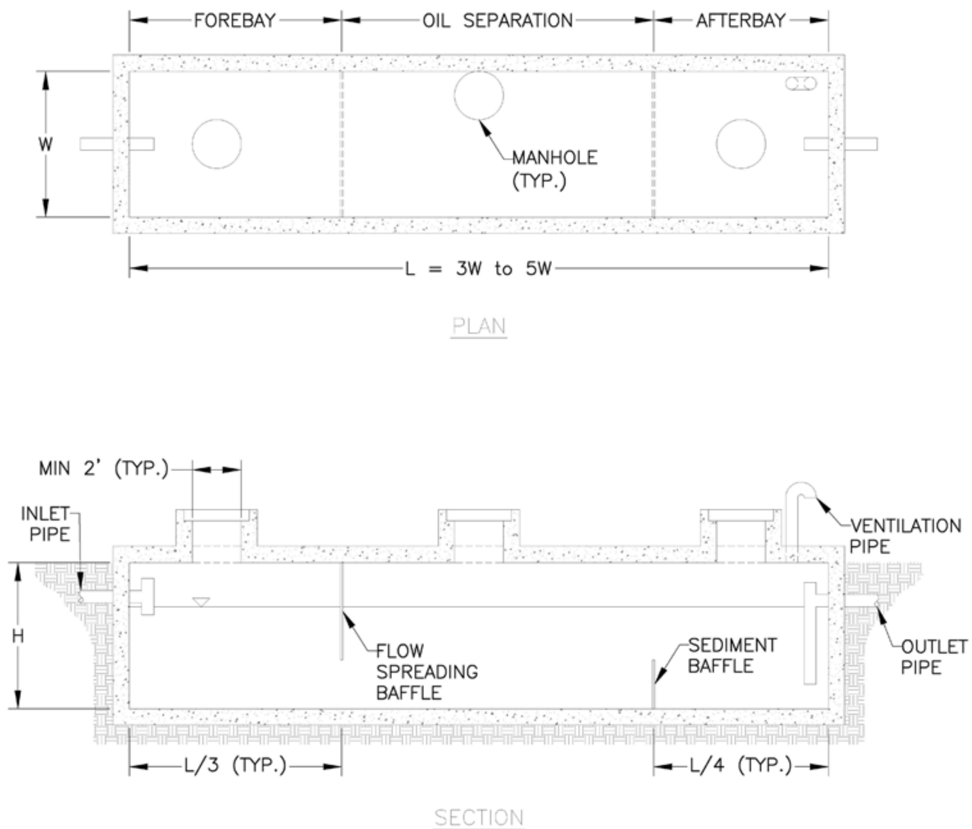
15-4.6.1.1 Maintenance.

Provide access for inspection and a truck with suction equipment to remove grit.

15-4.7 Gravity Separation.

Use gravity separation for the removal of free oil and settleable solids. Gravity separation of dispersed oil is typically more difficult and may require using parallel plate coalescing media to meet discharge requirements.

Figure 15-1 Gravity Oil Water Separator



15-4.7.2 Gravity Separator Sizing.

Use the following procedure to size a gravity oil water separator using the smallest oil droplet size to be removed:

1. Use stokes law to compute the rate of rise, V_t.

$V_t = [(g)(\rho_w - \rho_o)(d^2)] / [(18*\mu_w)]$

Where:
V_t = rise rate of the oil droplet (cm/s or ft/sec)
g = acceleration due to gravity (cm/s² or ft/s²)
ρ_w = density of water at the design temperature (g/cm³ or lbm/ft³)
ρ_o = density of oil at the design temperature (g/cm³ or lbm/ft³)
d = oil droplet diameter (cm or ft)
μ_w = absolute viscosity of the water at the minimum expected operating temperature (g/cm-s or lbm/ft-s)

2. Compute mean horizontal velocity, V_h or use a maximum value of 3 ft/min (0.91 m' min). Best practice; use a maximum value of 1 to 2 ft/min (0.3 to 0.61 m/min)

$V_h = 15 * V_t$

Where:
V_h = mean horizontal velocity (m/min or ft/min)
V_t = rise rate of the oil droplet (m/min or ft/min)

3. Compute the minimum vertical cross sectional area, Av.

$A_v = Q_{peak} / V_h$

Where:
A_v = minimum vertical cross sectional area (m^2 or ft^2)
Q_{peak} = peak flow rate (m^3/min or ft^3/min)
V_h = mean horizontal velocity (m/min or ft/min)

4. Select the depth, d. Use a minimum depth of 3 ft (0.9 m). Best practice; use a maximum depth of 8 ft (2.4 m). Additional depth may be required when mechanical sludge removal equipment is included.
5. Select the width, w. Best practice; use a minimum width of 6 ft and maximum width of 20 ft (6.1 m).
6. Compute the number of separators or separator channels, n.

n = Av / w * d

Where:
n = number of separators or separator channels
A_v = minimum vertical cross sectional area (ft^2 or $m^{2)}$
w = width of the separator (m or ft)
d = depth of the separator (m or ft)

7. Compute the depth to width ratio, d/w. Minimum depth to width ratio = 0.3 and maximum depth to width ratio = 0.5. If the depth to width ratio obtained is not in the acceptable range, repeat calculations until depth to width ratio is in the acceptable range.
8. Select the length, L. The minimum length should be 3 to 5 times the width. Best practice; use a minimum length equal to five times the width.
9. Compute the overflow rate, Vo.

$V_o = Q_{peak}/ L*w$

Where:
V_o = overflow rate (m/min or ft/min)
Q_{peak} = peak flow rate (m^3/min or ft^3/min)
L = length of the separator (m of ft)
W = width of the separator (m or ft)

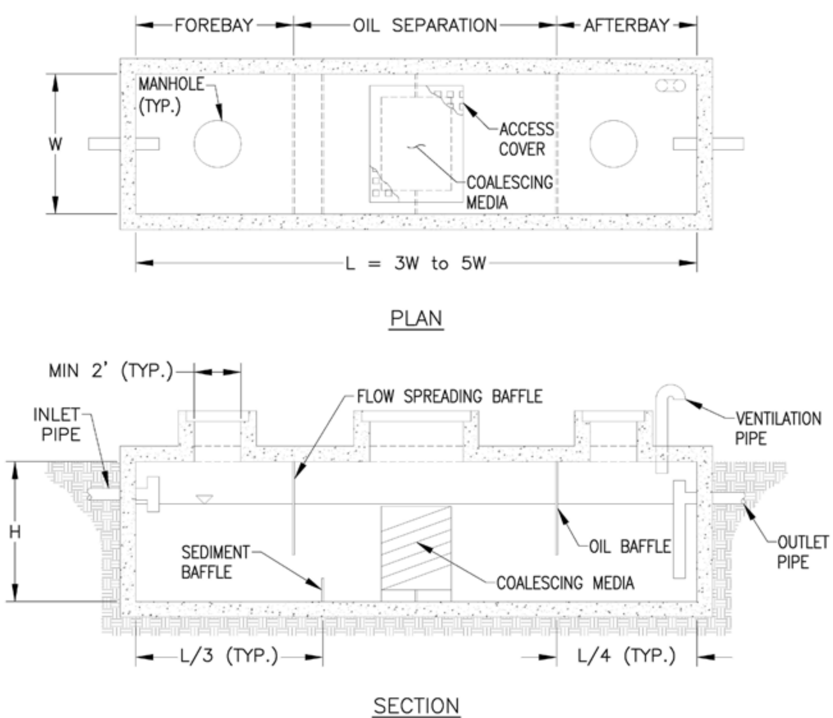
10. Verify that the oil droplet's rate of rise, Vt, equals or exceeds the over flow rate, Vo. When the oil droplet's rate of rise does not equal or exceed the overflow rate, repeat calculations until oil droplet's rate of rise equals or exceeds the over flow rate. When repeating calculations, try increasing the length of the separator first.
11. Select an appropriate freeboard based on fluctuations in peak flow and rainfall if the separator is not covered and has an open top. Use a minimum freeboard of 6 in (150 mm).

Removing oil with a droplet size smaller than 150 microns will significantly increase the size of the oil water separator. For example, an oil droplet size of 150 microns will rise nine times faster than a 50 micron oil droplet.

15-4.8 Enhanced Gravity Separation.

Coalescing media assists with gravity separation of oil droplets smaller than 150 microns. The coalescing media increases the surface area of the gravity separator and allows for efficient removal of oil droplets. Enhanced gravity separation can typically be used to treat oil droplets as small as 60 microns. Some more efficient enhanced separators may be able to treat oil droplets as small as 30 to 40 microns but successful removal will depend on many variables. When enhanced gravity separation is used to meet direct discharge limits, additional tertiary treatment may still be required to meet discharge limits indicated in the NPDES permit, especially for the removal of oil droplets in the 20 to 60 micron range. Discharges to a POTW typically do not require an enhanced gravity separator.

Figure 15-2 Enhanced Gravity Oil Water Separator



15-4.8.1 Enhanced Gravity Separator Sizing.

In general, the design of enhanced oil water separators is similar to gravity oil water separators with two general exceptions:

1. The surface area of the coalescing media reduces the surface area required for gravity oil water separator design.
2. The enhanced oil water separator can operate efficiently at higher horizontal velocities.

Most manufacturers have empirically derived design data that they use for enhanced oil water separator design. In these cases, the manufacturer is the best source of design data. For 60 micron oil droplets, the required horizontal surface area of parallel plates can be computed using the following equation:

$$A_h = Q_{peak}/V_t = Q_{peak} / (.00386) * ((S_w - S_o)/(\mu_w))$$

Where:
A_h = horizontal surface area of the plates (ft^2)
V_t = rise rate of the oil droplet (ft/min)
Q_{peak} = design flowrate (ft^3/min)
S_w = specific gravity of water at the design temperature
S_o = specific gravity of oil at the design temperature
μ_w = absolute viscosity of the water (poise)

Laminar flow through the coalescing media is required. Verify the Reynolds Number for flow through the coalescing media is less than 500.

15-4.9 Other Types of Treatment.

The degree of treatment required will be determined by the type of discharge, indirect or direct. For direct discharges, treatment requirements will also be identified in the NPDES permit. For indirect discharges, the POTW may identify additional treatment requirements. Sludge disposal requirements will be determined by the level of treatment provided and the characteristics of the sludge. Refer to WEF MOP FD-3 Chapter 10 *Removal of Fats, Oil and Grease,* for oily waste treatment guidance. Bench or pilot plant testing should be performed to determine the effectiveness of the treatment system.

15-4.10 Inspection and Maintenance.

Design oil water separators to be readily accessible for inspection by one person. Design each oil water separator bay or compartment to be readily accessible for inspection, maintenance and cleaning. Provide access for a truck with equipment capable of removing grit, oil or sludge from each oil water separator bay or compartment.

15-4.10.1 Enhanced Gravity Separators.

Enhanced gravity separators with coalescing media require a higher level of maintenance then gravity separators. Provide enhanced gravity separators with access for inspection and removal of the coalescing media units or packs. The coalescing media units or packs must capable of being removed as complete units or packs. Do not use coalescing media that requires disassembly in the separator prior to removal.

15-4.11 Redundancy.

Provide a minimum of two treatment units or channels when continuous operation is required. Two treatment units or channels will allow one channel to be taken out of service without bypassing the separator. The most cost effective design minimizes the number of treatment units or channels.

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CHAPTER 16 OILY WASTE AND WASTE OIL COLLECTION AND TREATMENT.

16-1 SOURCES.

Most ships have oil water separators, waste oil tanks (WOT), oily waste holding tanks (OWHT), and oily waste transfer pumps (OWTP). A brief description of oily waste equipment is presented below:

1. OWHT can usually contain the oily waste generated in one-half day by a ship in auxiliary mode. It holds at least 1,000 gallons.
2. WOT can usually contain the oily waste separated during a 60-day mission.
3. OWTP is normally a segregated electric driven pump that pumps bilge water to the OWHT and waste oil or oily waste to shore facilities. Some older ships use rotary vane pumps, but the newer ones use sliding shoe pumps. Pumps discharge at least 10 psi at the lowest weather deck of the ship. These pumps normally have capacity of off-loading the OWHT in approximately 1- 2 hours. On aircraft carriers, the off-loading time may take up to 4 hours.

16-2 SHIP DISCHARGE VALUES.

Use UFC 4-150-02 or contact the Government Project Manager for ship oily waste discharge capacities.

16-3 SITE LAYOUT.

Use UFC 4-152-01 for the design of oily waste and waste oil (OWWO) collection systems serving piers, wharfs, and drydocks. Design the oily waste collection system to segregate oily and non-oily wastewater sources, minimize oil-water separator hydraulic loading, minimize emulsification, and maximize oil and grease concentration.

Include the following concepts when laying out a pier collection pipeline:

a. Ships of same class type often berth together.
b. Install valves at head of each pier to allow for isolation in case of pier pipeline damage.
c. Allow for minimum slope toward free discharge to prevent liquid stagnation and freezing.
d. Evaluate need for freeze protection.
e. Use a minimum fluid velocity that will prevent settling of suspended solids and minimize emulsification of oils.
f. Provide cleanouts at junctions, directional changes, end of pipe run and every 400 ft (122 m).

g. Provide single wall piping unless double-walled pipe or secondary containment is required by local regulations. Check local regulatory agencies for requirements.

h. Provide thrust support for OWWO pipeline. Use Chapter 4 for thrust restraint requirements.

i. Provide pipe supports or hangers spaced at intervals suitable for supporting the OWWO pipeline. Use MSS SP-58-2018 or pipe manufacturer's requirements, whichever are more stringent.

j. Use materials and coatings capable of withstanding marine environment conditions.

16-4 IDENTIFICATION OF FLOWS.

Ship bilge daily flow varies with the class of ship, shipboard operations, and condition of the ship's mechanical equipment. The three measures of oily waste discharge flow are average (Q_{ave}), peak (Q_{peak}), and additional oily waste discharge from compensating fuel tanks (Q_{comp}). These flows are used in various combinations (depending on facility size) to estimate the total daily oily waste flow (Q_{daily}) from a pier. Q_{comp} is determined based on the fueling capability of the facility. If no fuel capability exists on the pier, then this quantity is zero. Fuel capability may be in the form of piping, trucks or barges. If fueling capability exists, then this quantity is equal to the maximum fueling rate for one day. Q_{daily} is used to estimate ship utility discharges and shoreside oily waste treatment plant capacity, operating costs, and operating schedule. The size of the pier facility depends on the historical usage rates and pier berthing plan. Use UFC 4-150-02 or contact the Government Project Manager for ship oily waste discharge capacities. Use the following subparagraphs to estimate flows.

16-4.1 Facility Daily Flow.

Determine the number and classes of ships present during maximum holiday berthing and average daily berthing. Determine if the activity is a "small" or "large" facility. Determine the number and classes of ships present during maximum holiday berthing and average daily berthing. Compute Q_{daily} for small facilities. Compute Q_{daily} and $Q_{maximum}$ for large facilities.

16-4.1.1 Small Facilities.

Use the following equation for pier facilities with fewer than 15 vessels:

$$Q_{daily} = Q_{comp} + \sum_{n=1}^{N} Q_{peak}$$

Where:

Q_{daily} = design daily flow for facility in gpd (L/day)
Q_{comp} = maximum fueling flow per day from shore to ships in gpd (L/day)
N = number of ships at piers during maximum holiday berthing or special peacetime exercise
Q_{peak} = peak daily flow from each ship in gpd (L/day)

16-4.1.2 Large Facilities.

Use the following equation for pier facilities with 15 or more vessels:

$$Q_{daily} = Q_{comp} + \left(1.33 * \sum_{n=1}^{M} Q_{average}\right)$$

Where:

Q_{daily} = design daily flow for facility in gpd (L/day)
Q_{comp} = maximum fueling flow per day from shore to ships in gpd (L/day)
M = number of ships at piers during maximum holiday berthing or special peacetime exercise
$Q_{average}$ = average daily flow from each ship in gpd (L/day)

16-4.1.3 Maximum Daily Flow.

Use the following equation to determine maximum daily flow ($Q_{maximum}$) using the maximum number of ships berthed during special exercises or holiday operations:

$$Q_{maximum} = Q_{comp} + \sum_{n=1}^{N} Q_{average}$$

Where:

$Q_{maximum}$ = maximum daily flow during holiday berthing in gpd (L/day)
Q_{comp} = maximum fueling flow per day from shore to ships in gpd (L/day)
N = number of ships at piers during maximum holiday berthing or special exercises
$Q_{average}$ = average daily flow from each ship in gpd (L/day)

16-4.2 Design Flow For Pier Oily Waste.

Use the following equation to determine size of main and laterals, and pump station capacity:

$$Q_{main} = 0.31 \sum_{i=1}^{S} (n_i)\,(q_i)$$

Where:

Q_{main} = design daily flow in gpd (L/day)
S = maximum number of ships at piers, use ship mix that produces largest daily flow including holiday berthing
q_i = discharge rate from each OWTP (assume one pump per riser) in gpd (L/day)
n_i = total number of OWTP connected to the main, lateral or pump station

16-5 GRAVITY FLOW COLLECTION SYSTEM.

Compute the diameter of mains and laterals using Q_{main} as shown in the following subparagraph. Use a minimum design velocity of 2 fps (0.6 m/s) during discharge operations for collection mains. Use a minimum design velocity of 5 fps (1.5 m/s) during discharge operations for collection mains. The design velocity should be in the range of 5 to 7 fps (1.5 to 2.1 m/s).Compute maximum design velocity to prevent scour. Use pipe manufacturer data to compute scour velocity. The minimum slope must be capable of maintaining a full flow velocity of 2 fps (0.6 m/s) using manning's formula and a manning's n value 0.013.

Use a minimum 6 inch (150 mm) pressure main with a minimum 4 inch (100 mm) pressure laterals to main. Facilities berthing only submarines or MSO ships may use 3 inch (75 mm) lateral. Space laterals and pier riser at 150 feet (46 m). This relatively close spacing facilitates flexible berthing configurations, mission change and flexibility. Hose riser assemblies are not needed at the end of piers unless specifically required by the activity. Use dual hose receivers to provide capability for nesting ships. Nesting may occur during major exercises, holidays and during periods when nearby berths are down because of damage or repair. Provide containment according to 33 CFR 154.530.

16-5.1 Design Flow For Pier Oily Waste.

Use the following equation to determine size of main and laterals, and pump station capacity:

$$Q_{main} = 0.31 \sum_{i=1}^{S} (n_i)\,(q_i)$$

Where:

Q_{main} = design daily flow in gpd (L/day)
S = maximum number of ships at piers, use ship mix that produces largest daily flow including holiday berthing
q_i = discharge rate from each OWTP (assume one pump per riser) in gpd (L/day)
n_i = total number of OWTP connected to the main, lateral or pump station

16-5.1.1 Head Loss.

Since the ship's OWTP feeds the gravity collection system, head loss must be evaluated. Compute head loss at each main and lateral intersection and verify the discharge pressure from each ship's OWTP exceeds the estimated head loss at each main and lateral intersection. Determine deck riser elevation, ship discharge pressure and berthing plan, including nesting, for each ship class berthed at pier. If a ship's discharge pressure does not exceed the computed head loss, additional computations must be performed. Typically head loss can be reduced by increasing the main diameter first and then increasing lateral diameter if head loss still needs to be reduced. Evaluate the gravity collection system characteristics that contribute to head loss such as length of main, length of lateral, elevation of pier riser assembly, elevation of ship's deck riser, hose length and fittings. Evaluate maximum hose length for nested ship berthing.

16-6 PRESSURIZED PIER COLLECTION SYSTEM.

Only use pumps when gravity collection systems are not hydraulically feasible. Slope pressurized systems to prevent fluid stagnation, freezing, and for cleaning purposes. The minimum slope should be capable of maintaining a full flow velocity of 2 fps (0.6 m/s) using meanings formula and a manning's n value 0.013. Design requirements for pump systems:

a. Locate pumps as close to oily wastewater source as possible to maximize detention time between pumping and treatment and minimize impact of mechanical emulsification. Equalization tanks may be used as an alternative approach. If equalization is employed, avoid detention times that would likely result in odor and gas production. Use vapor controls as required by applicable environmental regulations.

b. Use reciprocating positive displacement or screw pumps to transfer oily wastewater to treatment unit or equalization facility. Maximize size of wet well and select a number of pumps and an operating schedule to minimize surge effect of pump off-on cycle times. Consider adjustable speed drives on transfer pumps.

c. If rotary displacement or centrifugal pump is used, design for low speed (≤900 rpm) to minimize mechanical emulsification.

d. Maximize size of wet well and select the number of pumps and an operating schedule to minimize surge effect of pump off-on cycle on downstream oil-water separators.

e. Consider the use of a pump control valve and a surge tank with control orifice to throttle discharge to oil water separator. Consider adjustable speed drives on transfer pumps.

16-7 PUMP STATIONS.

Design pump stations to handle the cumulative Q_{main} for piers served assuming that individual pier main flows occur simultaneously. Design requirements for pump stations:

a. Provide a protective wet well liner or protective coating capable of resisting oil, grease, and saltwater.

b. Provide continuous ventilation with complete air changeover every 2 minutes.

c. Provide basket or bar type inlet screens on a pump inlet which can be removed and cleaned from the ground surface without requiring confined space entry.

d. Determine pump capacity and operating cycle for peak flows. Use positive displacement pumps with pressure relief valve, rather than centrifugal pumps, to reduce mechanical formation of emulsion at oily waste treatment plants. Pumps should pass solids having a diameter 0.125 inches (3 mm).

e. Provide controls suitable for Class I, Division 1, Group D safety classification. Use float or sonic type mechanisms, not air bubblers, for pump control and alarm. Provide discharge pump control valve to minimize surge effect on equalization basins at oily waste treatment plants (not applicable for positive displacement pumps). Provide an alarm system for overflow or power failure. Provide manual override of pump controls but not of low level alarms.

f. Provide an accumulating flow meter, elapsed time meter for pumps, pump suction and discharge pressure gages with oil-filled diaphragm, and cutoff valves to monitor station activity.

16-8 OILY WASTE TREATMENT.

OWWO may contain free, dispersed, emulsified ,or dissolved oil. Gravity type oil water separators can typically provide complete treatment for free oil. A single treatment process or commercial device will not typically remove emulsified and dissolved oils in oil water mixtures. A series of treatment process units is typically required to remove emulsified and dissolved oils. The degree of treatment required will be determined by the type of discharge, indirect or direct. For direct discharges, treatment requirements will also be identified in the NPDES permit. For indirect discharges, the POTW may identify additional treatment requirements. Sludge disposal requirements will be determined by the level of treatment provided and the characteristics of the sludge. Refer to EPA 800-R-11-007 for OWWO guidance.

Design oily waste treatment systems to operate on a 40-hour workweek with emergency response for alarms outside of normal work hours unless the activity, state or local have extended operational requirements. Treatment systems should be sized for the following flows.

16-8.1 Equalization.

Use an equalization basin to equalize peak flows and store oily wastewater flows prior to oil-water separation. Equalization systems can be concrete or steel tanks. Equalization systems should be covered or under a roof in a rainy climate or where wildlife is present.

16-8.2 Primary Treatment.

Primary treatment is required. The extent to which receiving waters or treatment works are impacted by effluent determines whether additional treatment is required.

16-8.2.1 Gravity Separation.

Bench testing should be performed to determine time required for optimum gravity separation. During treatment, free oil floats to the surface. Skimmers may be used to collect and remove oils on the surface. Settleable solids, also referred to as sludge, sink to the bottom and can scraped into a hopper for withdrawal, additional treatment or disposal. Provide multiple LET to allow for continuous (fill and drawoff) operation of the facility.

16-8.2.2 Load Equalization Tank.

A load equalization tank (LET) is a batch operated, gravity oil-water separator. Oily wastes are discharged to the LET for a predetermined collection period. Wastes are settled, the oil skimmed off to storage, and sludge withdrawn for further processing and disposal. Clarified water is passed on for additional treatment or discharge. Batch treatment in a LET is recommended for treatment of OWWO. When a treatment method other than a LET is used, the alternate treatment method must be able to meet or exceed all LET requirements.

16-8.2.2.1 Load Equalization Tank Sizing.

Method 1: Use actual flow data to the extent possible.

Method 2: Estimate the type and number of berthed ships discharging to the pierside collection system including the number of ship waste oily barges and discharge frequency. Use historical records to the extent possible.

Method 3: Use Q_{daily}, $Q_{maximum}$, and Q_{peak} established for design of pierside collection systems.

16-8.2.2.2 Load Equalization Tank Design.

LET design requires multiple tanks for normal operation of the gravity separation process. At larger Installations subject to periodic surges in ship berthing, the capability to process sudden, abnormally high oily waste flows may warrant extra reserve capacity. At smaller Installations where available land area imposes layout restrictions, a minimum of three reduced volume LET may be necessary to provide operating flexibility for normal peak flow occurrences and for tank cleaning downtime. When oily waste generated from shore facilities will be treated in addition to OWWO additional LET may be required. Oily waste generated from shore facilities will typically have different oily waste characteristics and need to be segregated from OWWO for treatment. Each tank should have a minimum capacity equal to the average flow for 7 days. Determine the total number of tanks required using the maximum flow with one tank out of service. Longer LET operating periods or large volume upstream receiving tanks should not be used since they promote anaerobic conditions and hydrogen sulfide gas production. Hydrogen sulfide gas will corrode metal and concrete, cause odor problems, and create potential health hazards when hydrogen sulfide concentration exceeds 10 ppm. Design requirements for LET:

a. To the extent possible, use aboveground LET to facilitate gravity flow to downstream processes or the discharge point.

b. Provide mechanical oil skimming equipment.

c. Provide a separate oil containment tank for the oily waste collected from the surface of the LET.

d. Provide a sludge hopper on the inlet side of the LET to facilitate sludge removal.

e. Slope LET to facilitate the transport of settled solids to the sludge hopper.

f. Provide mechanical sludge collection for sludge removal and processing.

g. Provide mechanical efficiency and simplicity appropriate for the characteristics of the OWWO and sludge being treated.

h. Identify sampling requirements and provide sample taps or ports to facilitate sampling. Locate sample taps or ports in locations that are easily accessible or provide additional access to sampling taps or ports.

i. Provide multiple potable or non-potable water supply discharge points to facilitate tank cleaning, foam control, and general housekeeping. Space water supply discharge points to facilitate cleaning all LET for all possible operational procedures. Do not exceed 100 feet of tank length between water supply discharge points. Provide backflow prevention when potable water supply is used.

16-8.2.2.3 Circular Tanks.

At smaller Installations, where LET of less than 15,000 gallons (56,781 liters) are required, circular steel LET may be more cost effective than a rectangular concrete LET. Evaluate local availability and cost of materials. A circular tank may allow for more efficient use of available ground for system layouts on smaller parcels of land.

16-8.3 Secondary Treatment.

Secondary treatment may be required for direct discharges or discharges to a POTW. Dissolved air flotation (DAF) is recommended for secondary treatment. A DAF unit will remove significant amounts of residual OWWO and emulsified oils. Typical effluent discharges from a DAF unit may be as low as 10 to 15 mg/L. It may be necessary to add coagulating and emulsion breaking chemicals to the DAF influent to optimize removal of contaminants. Bench testing should be performed to size the secondary treatment system and determine optimum coagulant dose.

16-8.4 Tertiary Treatment.

To provide consistent direct discharge quality effluent, tertiary treatment may be required for direct discharge depending on permit requirements. The recommended process is multimedia filtration with relatively fine graded media followed by carbon adsorption. In certain situations, primarily where flows are higher and space limitations prevent installation of a sufficient number or size of multimedia filters, coalescing filtration units may be considered. Coalescing filters are mechanically complex, but they perform reliably if operated and maintained properly.

16-8.5 Redundancy.

Provide redundancy for OWWO treatment. It is important to avoid the loss of a key unit operation during maintenance, scheduled or unscheduled, for any piece of equipment. Provide redundancy for individual processes such as downstream polishing treatment units, transfer pumping equipment, and effluent monitoring instrumentation required for continuous operation.

16-8.6 Discharge to Publicly Owned Treatment Works.

For free oil removal, effluent discharge requirements may be achieved by batch treatment gravity separation processes. The oily waste is discharged into a short-term storage or separation tank referred to as a load equalization tank (LET). The typical effluent from a LET contains less than 50 ppm of oil and grease. Discharges to a POTW must be coordinated with and approved by the POTW.

16-8.7 Direct Discharge.

Effluent discharge requirements for direct discharge are more stringent. Additional treatment is required to remove oils, such as free oil or emulsified oil, remaining after

LET treatment. An NPDES permit would be required. Sulfide control and metals removal may also be necessary to meet effluent discharge requirements.

16-8.8 Emulsified Oil Treatment.

Unlike free oils, simple gravity settling is not effective for emulsified oils. Minimize the formation of chemical and physical oil emulsions. Avoid excessive turbulence such as pumping or turbulent flow and the use of detergents or emulsifying agents. Emulsions are usually complex, and bench or pilot plant testing is generally necessary to determine an effective method for emulsion breaking. Segregate emulsions or provide additional treatment for their removal from the waste stream. Use WEF MOP FD-3, Chapter 10 for emulsified oil treatment.

16-8.9 Hydrogen Sulfide Formation.

The presence of sulfides in oily wastewater is primarily due to biological reaction involving anaerobic bacteria that use hydrocarbons as their energy source and convert sulfates to sulfides. The pH of wastewater affects the distribution of sulfide species. If low pH oily wastewater is exposed to the atmosphere, hydrogen sulfide gas is released causing severe odors and corrosion problems. At alkaline pH, the sulfide species do not escape to the atmosphere. Exposure to small concentrations of hydrogen sulfide in the air is also a health hazard as it can affect the respiratory system.

The time gap between the generation and treatment and disposal of oily wastewater is a major factor for sulfide formation. During this time, oxygen is rapidly depleted causing a decrease in the ORP which favors the activity of sulfate reducing bacteria. This time should be kept at a minimum to limit sulfide production.

16-8.9.1 Control Techniques.

The principal physical and chemical methods for sulfite control at oily waste treatment plants include chemical oxidation, chemical precipitation, and wastewater aeration. Other techniques such as biological processes or adsorption have limited application due to cost and operational requirements of these processes.

16-8.10 Dissolved Metals Removal.

Oily wastewater may contain significant amounts of dissolved metals. The removal of dissolved metals may be necessary to meet comply with POTW requirements or direct discharge permit requirements. Metals such as iron, zinc, lead, copper, and nickel may be reduced to low levels by chemical precipitation.

16-8.10.1 Dissolved Metals Removal.

The removal of dissolved metals can typically be accomplished by raising the pH of the wastewater above 8 by using additives such as lime or sodium hydroxide. Most metals form highly insoluble precipitates at higher pH levels. The minimum solubility of different metals occur at different pH values. Therefore, a laboratory investigation is essential to determine the optimum pH level for removal of dissolved metals. For plants using sulfide control by chemical precipitation, additional treatment for metals removal may not be necessary. As alkaline solution is added for sulfide control, it will affect metals precipitation and metals will be co-precipitated as hydroxides and sulfides. The metal precipitates may be separated from wastewater in the oil-water separation equipment, such as DAF. For improved removal of these precipitates, addition of polyelectrolytes may be necessary. The laboratory investigation should be conducted to select the type and amount of polyelectrolyte for simultaneous suspended solids (metals precipitates) and emulsified oil removal from wastewater.

16-8.11 Sludge Disposal.

The characteristics of oily sludge are specific to the oily waste treatment facility and treatment process. Sludge may have toxic or hazardous characteristics. Evaluate the characteristics of the sludge to determine the appropriate method of disposal.

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APPENDIX A BEST PRACTICES

Appendix A provides design guidance.

A-1 WHOLE BUILDING DESIGN GUIDE.

The Whole Building Design Guide (WBDG) provides access to DoD criteria such as Unified Facilities Criteria (UFC), Unified Facilities Guide Specifications (UFGS), and for approved Government employees, access to non-government standards.

A-2 MATERIALS.

A-2.1 Rigid Conduit.

For concrete pipe use *Concrete Pipe Design Manual* for guidance. For ductile iron pipe use AWWA M41 for guidance. For cast iron soil pipe use *Cast Iron Soil Pipe and Fittings Handbook* for guidance.

A-2.2 Flexible Conduit.

For PVC pipe use the *Handbook of PVC Pipe Design and Construction* for guidance.

A-3 TRENCHLESS TECHNOLOGY.

Trenchless Technology Pipeline and Utility Design, Construction and Renewal and WEF MOP FD-6 provide guidance on trenchless renewal technology.

A-4 DOMESTIC WASTEWATER FLOWS.

Per capita rates should be determined using actual wastewater flow and load data, water usage rates or average daily per capita wastewater estimates for the specific facility type. For some facility types, it may be appropriate to use data from a similar facility type. When a similar facility type is used, differences in water conservation practices should be evaluated.

WEF MOP 8, Chapter 2, *Principals of Integrated Design* provides typical flowrates for commercial and institutional sources. Do not use these typical waste loading values for temporary host nation facilities.

A-4.1 Average Hourly Flow.

Example 1: 1,000 residents at 100 gal/cap/day (379 L/cap/day) will generate 100,000 gallons/day (379 m^3/day) in 24 hours for an average hourly flow rate of 4,167 gal/h (15.77 m^3/h).

Example 2: 1,000 nonresidents at 30 gal/cap/day (114 L/cap/day) will generate 30,000 gallons/day (114 m^3/day) in 8 hours for an average hourly flow rate of 3,750 gal/h (14.2 m^3/h). Note that the average daily flow is 30,000 gal/day (114 m^3/day), but the wastewater system must be designed to carry the 30,000 gallons (114 m3) in 8 hours not 24 hours.

A-5 WASTEWATER COLLECTION.

A-5.1 Pump Stations.

WEF FD-4 provides guidance for the design of wastewater pump stations.

A-5.2 Thrust Restraint for Force Mains.

Online thrust restraint calculators can assist in performing thrust restraint calculations. See EBAA IRON Restraint Length Calculator located at http://rcp.ebaa.com/ or DIPRA located at https://www.dipra.org/ductile-iron-pipe-resources/calculators/thrust-restraint-of-ductile-iron-pipe. Consider the bearing surface of the fitting when designing thrust blocks. Compact fittings reduce the bearing surface of the thrust block.

A-6 WASTEWATER TREATMENT FACILITIES.

A-6.1 Health and Safety.

WEF MOP 1 provides comprehensive guidance for health and safety at wastewater treatment facilities.

A-6.2 Security.

Water and Wastewater Systems Sector-Specific Plan, and Emergency Planning, Response and Recovery provide guidance for the protection of wastewater treatment facilities.

A-6.3 Operator Considerations.

Meetings with the wastewater treatment operator should held prior to development of the 35 percent design submittal. Operators can provide valuable input about problems with existing processes or operational lessons learned. Consider the experience and level of operator training when designing wastewater treatment systems.

A-6.4 Plant Location.

WEF MOP 8, Chapter 3, provides guidance for site selection.

A-6.4.1 Separation Distances.

Greater separation distances between occupied areas and the wastewater treatment facilities may be required to eliminate odors. Consider using greater separation distances when occupied areas are located on the leeward side of the wastewater treatment facilities, in areas subject to prolonged or frequent air stagnation, fog, or mist cover, at a lower elevations than the treatment works, or with surface and groundwater flow from the wastewater treatment facilities toward the occupied area.

A-6.5 Special Consideration for the Tropics and Semiarid Locations Outside of the United States.

Consider that brackish water may be used for washing, cooling, or cleaning; if it is allowed to enter the waste stream, the increased salinity will lower biological process efficiencies. Also, high dissolved solids concentrations have an effect on the treatment process efficiency. If gray water is separated from the waste stream and recycled or used directly for irrigation, washing, or cooling, wastewater flow will be low and much more concentrated. Loss of water by evaporation and from pipelines into the ground may further decrease flow to the POTW.

A-6.5.1 High-Temperature Parameters.

A major design parameter will be water temperature. Use of rooftop rain storage, cistern water, brackish water, and the ambient conditions will result in a very warm wastewater. The engineer should expect high salt content, including sulfate, chloride, phosphate, borate, and nitrate ions, and both alkali and alkaline earth cations. Oxygen levels will be very low and chalcogenides as well as dissolved hydrogen sulfide should be anticipated. The most dramatic effect of high temperature will be on biochemical reaction rates.

A-6.5.2 Unit Operations in the Tropics.

Although activated sludge, trickling filter, or rotating biological filter processes may be used in hot climates, strong sunlight and adequate space will make the use of wastewater treatment ponds advantageous. Temperature and sunlight intensity will control algal growth, which will be intense. The most useful type of pond will be the facultative pond. Pond retention time may be over 30 days; depth is typically between 5 and 10 ft (1.5 and 3.0 m).

For trickling filters and rotating biological disc filters, filter media volumes decrease proportional to temperature increases. Sludges dry much more rapidly in hot climates; but, in the humid tropics, covers may be required. Odor problems have been common in the sludges produced in hot climates, indicating that aerobic digestion or aerobic composting are potentially useful. Investigate anaerobic digestion and gas production because a hot climate encourages microbiological fermentation reactions.

A-6.6 Special Consideration for Cold and Arctic Locations Outside the United States.

Extreme low temperature is common: as low as -75° F (-59° C) in interior locations in northern Canada; below -100° F (-73° C) in Antarctica; and a month or more of subzero air temperature in the Arctic. Water, sewer, electric utilities, and steam lines are typically run in utilidors above ground to conserve their heat, allow for easy access, and conserve materials. Utilidors are kept insulated from the ground because the permafrost can be alternately melted and frozen if trenches are used.

A-6.6.1 Wind Protection.

Wind in the arctic zone produces a great heat loss problem, which is reflected in wind chill factors. Snow and wind loads on structures require careful consideration. Precipitation in northern climates is typically quite low, but the snow produces drifts and can cause severe problems in transportation and operation if the engineer fails to consider wind. Rotating biological equipment and other covered equipment should be well insulated, and designed to withstand thermal extremes, buffeting wind loads and wet spring snow.

A-6.6.2 Conservation Practices.

Because wastewater is transported above the ground surface or in well-insulated, well-constructed tunnels, fresh water use is almost the same as wastewater return. Design conditions can be expected to be about 300 ppm (300 mg/L) for BOD, BOD_5 at 60 to 80 gpd/cap (2.63 x 10-6 to 3.51 s 10-6 to 0.30 m^3/cap·s). Wastewater will typically be delivered to the facility at approximately 50° F (10° C).

A-6.6.3 Processes.

Chemical and biological processes are negatively affected by extreme cold. Chemical reaction rates are generally slower at low temperatures, and chemical solubilities are reduced. All chemical reactions, especially those involving partially soluble salts, should be recalculated to reflect the low solubility of chemicals in cold water. Each flocculent or deflocculant, each polymer, and each detergent or other organic chemical used should be tested for unanticipated interaction brought about by low temperatures.

The rates of biological reactions are also reduced greatly, which affects the sizing of biological treatment processes. The biological processes that have been used most successfully in cold climates include wastewater treatment ponds, either facultative or aerated; activated sludge with long solids retention times; and attached growth systems. Design biological processes such as lagoons and ponds to withstand the effect of ice and use submerged aeration systems. Attached growth systems such as trickling filters and RBCs should not be used unless they are adequately enclosed and protected from the cold. Suspended growth systems with short solids retention times such as conventional activated sludge should be avoided.

A-6.6.4 Modifications for Viscosity and Dissolved Oxygen Variations.

All operations where operation is viscosity dependent should be corrected for increased viscosity. This includes sedimentation tanks, filters, and wastewater treatment ponds. All processes that involve oxygen transfer will be aided by the increased solubility of oxygen at low temperatures; but, to overcome the deleterious effect of increased viscosity, more mixing may be required. An absorption process such as oxygen bubble-water transfer is enhanced by the lower temperature, but the lower viscosity reduces the rate of contact so that, overall, neither oxygen transfer nor absorption change in rate.

A-6.6.5 Insulation of Appurtenances.

Trash racks, bar screens, grit chambers, unit process tanks, biological reactors, aerators, gates, walkways, and instrumental sensing devices should be enclosed, covered, heated, insulated, redesigned to withstand icing and snowpack, or a combination.

A-6.7 Preliminary Treatment.

WEF MOP 8, Chapter 9, *Preliminary Treatment,* provides guidance for the design of preliminary treatment systems.

A-6.8 Primary Treatment.

WEF MOP 8, Chapter 10 *Primary Treatment,* provides guidance for the design of preliminary treatment systems.

A-6.9 Settling.

A-6.9.1 Primary Settling.

Table A-1 Best Practices for Primary Settling

Best Practices for Primary Settling					
Rectangular Tank	Minimum Length	Maximum Length	Minimum Width	Maximum Width	Maximum Depth
	50 ft (15 m)	300 ft (90 m)	10 ft (3 m)	80 ft (24m)	16 ft (4.9 m)
Circular Tank	Minimum Diameter	Maximum Diameter			Maximum Depth
	10 ft (3 m)	200 ft (60 m)			16 ft (4.9 m)
Best Practices for Secondary Settling					
Rectangular Tank	Minimum Length	Maximum Length	Minimum Width	Maximum Width	Maximum Depth
	100 ft (30 m)	200 ft (60 m)	20 ft (6 m)	33 ft (10m)	16 ft (4.9 m)
Circular Tank	Minimum Diameter	Maximum Diameter			Maximum Depth
	30 ft (9 m)	140 ft (43 m)			16 ft (4.9 m)

A-6.9.2 Surface Overflow Rates.

Table A-2 Surface Overflow Rates

Best Practices for Surface Overflow Rates				
	Design Average Flow		Design Peak Hourly Flow	
Primary Settling				
Tanks not receiving waste activated sludge	Minimum	Maximum	Minimum	Maximum
	800 gpd/ft^2 (33 m^3/m^2 d)	1000 gpd/ft^2 (41 m^3/m^2 d)	1000 gpd/ft^2 (41 m^3/m^2 d)	1500 gpd/ft^2 (61 m^3/m^2 d)
Tanks receiving waste activated sludge	550 gpd/ft^2 (22 m^3/m^2 d)	700 gpd/ft^2 (29 m^3/m^2 d)	800 gpd/ft^2 (33 m^3/m^2 d)	1200 gpd/ft^2 (49 m^3/m^2 d)

A-6.10 Biological Treatment.

A-6.10.1 Biofilms.

WEF MOP 8, Chapter 11 *Biofilm Reactor Technology and Design,* provides design guidance for biofilms and biofilm reactor systems.

A-6.10.2 Activated Sludge.

WEF MOP 8, Chapter 12: Suspended-Growth Treatment Processes, provides design guidance for aerobic activated sludge.

A-6.10.2.1 Solids Loading Rate.

The average solids loading rate is typically between 20 – 30 lb/d/ft^2 (98 – 146 kg/m2 d) and the peak solids loading rate is typically between 40 – 50 lb/d/ft^2 (195 – 244 kg/m2 d).

A-6.10.3 Integrated Biological Treatment

WEF MOP 8, Chapter 13: *Integrated Biological Treatment,* provides design guidance for fixed-biofilm treatment in series with suspended-growth treatment.

A-6.11 Support Systems for Wastewater Treatment Operations.

WEF MOP 8, Chapter 7 provide guidance on designing wastewater support systems such as instrumentation and control, chemical storage and chemical feed systems.

A-6.12 Advanced Wastewater Treatment.

WEF MOP 8 Chapter 14 *Physical and Chemical Processes for Advanced Wastewater Treatment* provides guidance for the design of advanced treatment systems. Advanced treatment systems include secondary effluent filtration, activated carbon adsorption, chemical treatment, membrane processes, air stripping, ammonia removal by breakpoint chlorination, and effluent reoxygenation.

A-6.13 Disinfection.

WEF MOP 8, Chapter 17 *Disinfection* provides guidance on disinfection design. Disinfection guidance includes chlorine disinfection, dichlorination, ultraviolet disinfection, ozone disinfection, and other disinfection methods.

A-7 SOLIDS PROCESS DESIGN AND MANAGEMENT.

Solids Process Design and Management provides guidance for processing sludge for disposal and sludge to biosolids.

A-8 NATURAL SYSTEMS.

WEF MOP 8, Chapter 16: *Natural Systems* and WEF MOP FD-16 provide design guidance for natural systems. Natural systems include infiltration, stabilization ponds, aquatic plants, and constructed wetlands.

A-8.1 Facultative Ponds.

A facultative pond is easy to maintain and has stable to flow and load variations. The facultative pond has low capital and operating costs. Organic loadings are generally much higher in summer than in winter. A facultative pond is applicable in climates where evaporative losses exceed the average annual rainfall. One disadvantage to facultative ponds is that they will require a larger amount of large land area to maintain area BOD_5 loadings in a suitable range.

A-8.2 Algae Control.

Algae present in pond effluent represents one of the most serious performance problems associated with facultative ponds. Refer to WEF MOP FD-16, Chapter 7, Section 22, for algae control.

A-8.3 Aerated Ponds.

The main advantage of aerated ponds compared with facultative lagoons is that they require less land area.

A-8.4 Aerobic Ponds.

Aerobic ponds, also referred to as high-rate aerobic ponds are not typically used and are typically limited to warm, sunny climates. The chief advantage of the high-rate aerobic pond is that it produces a stable effluent with low land and energy requirements and short detention times. Operation is more complex than for a facultative pond. Without an algae removal step d, the effluent will contain high suspended solids. Short detention times also mean that very little coliform die-off will result. Because of their shallow depths, these ponds need to paved or lined to prevent weed growth.

A-9 ON-SITE TREATMENT SYSTEMS.

A-9.1 Alternative Sewer Systems.

WEF MOP FD-12 provides design guidance for alternative sewer systems. Alternative sewer systems include pressure sewers systems, vacuum sewer systems, and effluent sewers.

A-10 BIOASSAY OF WASTEWATER.

Observed toxicity of effluent may be measured using bioassay procedures to determine the possible effects on the ecosystem of the receiving stream. Industrial process wastewater installations may contain toxic compounds that exhibit none of the generic pollutant parameters or cannot be disclosed for security reasons. Regulatory agencies may require bioassay monitoring of these effluents.

A-10.1 Standard Bioassay Procedures.

A bioassay measures the concentration of pollutant at which a designated percentage of selected test organisms exhibits an observable adverse effect. These require extensive equipment, time, and test procedures and do not provide a rapid assessment of effluent toxicity. The percentage is typically 50%, and the adverse effect is typically death or immobility. Concentrations (percent by volume) are expressed as LC50 for median lethal concentration and EC50 for median effective concentration.

- Test organisms—Effluent tests should be conducted with a sensitive species that is indigenous to the receiving water. The test organisms do not have to be taken from the receiving water. Refer to EPA 600/4-90-027F for a complete list of acceptable test organisms and temperatures.
- Methodology—refer to EPA 600/4-90-027F and S*tandard Methods for the Examination of Water and Wastewater* for a complete description of required test equipment, laboratory and test procedures, sampling and

analytical procedures, procedures for data gathering and reporting, and methods for data reduction and analysis to determine LC50 or EC50.

Regulatory bioassay requirements and LC50 or EC50 are typically based on 48- or 96-hour tests using fish or invertebrates (e.g., minnows or Daphnia, respectively).

A-10.2 Rapid Bioassay Procedures.

In lieu of standard procedures investigate the use of rapid bioassay procedures (RBPs). RBPs are useful tools in effluent monitoring, providing inexpensive yet reliable toxicity data quickly. Check with state or local regulatory agency for approval of RBPs before developing a test program.

A-11 INDUSTRIAL WASTEWATER TREATMENT

A-11.1 Biological Systems.

Control toxic substances such as heavy metals and certain organic compounds present in some industrial wastes to avoid upset or pass-through of biological systems. Use WEF MOP FD-3 Chapter 5 Wastewater Treatability Assessments to examine the degree and methods of removal of pollutants, including organic pollutants. Conventional biological treatment systems can remove some organic compounds via biodegradation, volatilization (stripping) from aeration, and adsorption onto sludge, while others pass through. Actual removal performance depends on the operating characteristics (sludge age, mixed liquor suspended solids) of the treatment facility, the method of oxygenation, and the amount and nature of other compounds present in the wastewater. Refer to WEF MOP FD-3 Chapter 6 *Industrial Wastewater Characteristics and Approach* to Wastewater Management for appropriate treatment options.

A-11.2 Nutrients.

Evaluate nutrient levels for separate and combined industrial waste treatment systems. Maintain minimum amounts of nutrients required for efficient biological treatment. Normal proportions needed for active microbiological growth are typically about 1 lb (0.45 kg) of phosphorus (as P) and 5 lb (2.25 kg) of nitrogen (as N) for each 100 lb (45 kg) of BOD removed (requirements are somewhat lower for lightly loaded systems). Evaluate mixing industrial wastes with domestic wastewater to avoid the need for supplemental nutrients as wastewater contains excess amounts. Mixing domestic wastewater with industrial waste may also affect disinfection requirements and increase disposal of waste solids from treatment because of human waste components in the solids.

A-11.3 Source Separation.

Examples of industrial wastewater to be separated are precipitation treatment of copper and lead (incompatible because optimum pH of precipitation of each metal is not equal) and acid reduction of hexavalent chrome in the presence of cyanide (hazardous because it produces toxic hydrogen cyanide gas).

A-12 OIL-WATER SEPARATORS.

Gravity oil-water separators and enhanced gravity separators with coalescing media should not be used to treat emulsified or dissolved oil.

A-12.1 Types of Oily Waste.

Oil is one of the most common types and highly visible forms of water pollution. Even small quantities **\1\ /1/** can cause harm to the aquatic environment.

A-12.1.1 Free Oil.

Oil droplets with a diameter of 150 microns and larger.

A-12.1.2 Dispersed Oil.

Oil droplets with a diameter **\1** greater than 20 microns and less than 150 microns. **/1/**.

A-12.1.3 Mechanically Emulsified Oil.

Oil droplets with a diameter **\1** less than 20 microns **/1/**.

A-12.1.4 Chemically Emulsified Oil.

Oil droplets with a diameter **\1** less than 20 microns with a chemical bond to other molecules **/1/**.

A-12.1.5 Dissolved Oil.

An oil-water mixture with oil in soluble form.

A-12.2 Field Investigation.

When possible, investigate existing operations and evaluate:

- Making process changes to reduce the amount of oily waste generated.
- Using spill prevention, control, and countermeasures such as minimizing leaks, avoiding spills, and using drip trays and dry absorbents to minimize the oily waste.
- The potential for toxic and hazardous materials in the waste stream.

A-12.3 Oily Waste Treatment.

The level of required treatment for oily wastewater depends on the method of discharge, POTW or direct discharge.

A-12.3.1 Discharge to POTW.

Effluent discharge limits to a POTW can range from 25 to 50 mg/l of oil and grease on the low end or as high as 100 mg/l to 200 mg/l of oil and grease for more efficient treatment works. Coordinate with the operator of the POTW to see what level of oily waste effluent they will be able to accept. Typical effluent quality requirements can be achieved by gravity oil-water separators.

A-12.3.2 Discharge to Navigable Water.

Effluent discharge limits for direct discharge depend on the water quality of the receiving water. Average oily waste effluent discharge limits typically range from 5 to 15 ppm (5 to 15 mg/l). Peak oily waste effluent discharge limits may be as high as 30 ppm (30 mg/l). Applicable permits, such as an NPDES permit, will need to obtained for direct discharges. As part of the permitting process, effluent limits for other types of contaminates such as pH and total suspended solids may also be required. Total suspended solids discharge limits are typically around 60 mg/l and pH discharge limits are typically a minimum of 6.0 to a maximum of 9.0.

Oily waste streams containing hazardous materials, metals, or other wastes with discharge should not be discharged to navigable waters without providing additional treatment.

A-12.4 Emulsions.

Minimize the formation of oil emulsions. Segregate emulsified oil for special treatment wherever possible.

A-12.4.1 Chemical Emulsions.

Using detergents increases emulsification and inhibits gravity oil-water separation.

A-12.4.2 Physical Emulsions.

Use of high-pressure water or centrifugal pumps cause emulsification of the oily waste. Physical emulsions are generally less detrimental to oil-water separation than the use of detergents.

A-12.5 Grit Removal.

Grit removal should be provided prior to entering the oil-water separator compartment for the removal of total suspended solids. When the suspended solids are minimal, the grit chamber may be included as the first oil-water separator compartment. For wastewaters with a high suspended solids concentration the design should include a separate grit chamber. A detention time of 5 minutes at the maximum rate of flow may be used to size the grit chamber. Settleable solids sink to the bottom of the chamber and will need to be removed and disposed of. Allow space for accumulated grit between for the expected grit removal maintenance cycle. Access should be provided for a truck with suction equipment to periodically remove grit.

A-12.6 Gravity Separators.

Gravity separators are used for the removal of free oil and in some cases dispersed oil. In gravity oil-water separators free oil floats to the surface where it can be separated from the clean effluent. Typical effluent depends on the flow rate through the oil-water separator and typically contains less than 50 ppm of oil and grease. Dispersed oil can be more difficult to remove as the micron size decreases. When removing dispersed oil the size of a gravity oil-water separator will need to need to be increased to improve the quality of the effluent. Using gravity separators to remove dispersed oil will typically require an oil-water separator that may be prohibitively large. Access should be provided for a truck with suction equipment to periodically remove the oil. Some gravity oil water separators are covered with steel grating that can be easily removed to provide access to the entire oil separation compartment.

A-12.7 Parallel Plate Separators.

Parallel plate coalescing media can enhance the performance of gravity separators and can typically remove the lower ranges of dispersed oil where gravity oil-water separators are ineffective or prohibitively large. The lower range of oil removal is typically in the range of 30 to 40 microns. Oil is removed by passing the wastewater at laminar velocity through the parallel plate coalescing media. Parallel plate coalescing media is inclined to aid in the removal of oil. Inclines typically range from 45 to 60 degrees. The plates may be made of oleophilic (oil-attracting) material to promote coalescence of oil droplets. For this reason, the units are sometimes referred to as coalescing plate separators. Coalescing plates are typically recommended where the facility is committed to the additional maintenance procedures required to periodically remove and clean the parallel plate coalescing media. Access should be provided for removing the parallel plate coalescing media unit without the need for entering the oil-water separator or disassembling the parallel plate coalescing media unit.

Some manufactures are starting to provide additional post-separation treatment capable of removing oil not typically removed by parallel plate separators. These additional treatment processes should be evaluated based on compliance with discharge limits, maintenance requirements and the cost associated with purchasing material required for maintenance.

A-12.8 Maintenance.

Lack of proper maintenance is one of the biggest causes of oil-water separator failure. Design oil-water separators with accessible chambers for monitoring and maintenance.

A-12.9 Emulsified Oil Treatment.

Emulsions are typically complex, and bench or pilot facility testing is generally necessary to determine an effective method for emulsion breaking. Common emulsion-breaking (demulsification) methods are a combination of physical and chemical processes. The most common approach to removing emulsified oils from wastewater is by the use of chemicals. Chemicals commonly used include alum, ferrous sulfate, ferric sulfate, ferric chloride, sodium hydroxide, sulfuric acid, lime, and polymers. The effectiveness of various chemicals in breaking emulsions can be determined by laboratory testing. Refer to *Standard Methods for the Examination of Water and Wastewater* (Method 5520 Oil and Grease and Method 2540 Solids) for the testing procedure.

A-12.9.1 Destabilization.

Treatment of oil emulsions is typically directed toward destabilizing the dispersed oil droplets, causing them to coalesce and form free oil. A typical process consists of rapidly mixing coagulant chemicals with the wastewater, followed by gentle mixing (flocculation). The agglomerated oil droplets may then be removed by gravity or flotation.

A-12.10 Oil and Oily Sludge Removal and Disposal.

Reliable oil removal is critical from the surface of the separation chamber for both commercially available units and custom-designed separators. Oil may be removed by suction or vacuum equipment. This equipment is sometimes referred to as a vacuum or truck and may also be used for cleaning catch basins.

Oils and oily sludges removed from the oil-water separator may be disposed of by sale by the Defense Logistics Agency, Disposition Service. Evaluate final disposal options with oil-water separation methods such as landfill, incineration or land disposal and associated environmental requirements to establish the most cost-effective total system. The sludge may require regulation as a toxic or hazardous waste if levels of pollutants exceed Resource Conservation and Recovery Act or state hazardous waste levels.

A-13 LOAD EQUALIZATION TANK SIZING.

Table A-3 Load Equalization Tanks

Sizing Guidance - 7 Day Capacity		
Let Volume	0.1 to 0.5 Mgal (379 to 1,893 m^3)	1.0 to 1.5 Mgal (3,785 to 5678 m^3)
Length to Width Ratio	3:1	5:1
Depth	10 ft (3.05 m)	20 ft (6.1 m)
Freeboard	1.5 ft (0.5 m)	1.5 ft (0.5 m)

A-14 BEST PRACTICE REFERENCES.

GOVERNMENT PUBLICATIONS:

Environmental Protection Agency:

EPA 550-B-13-002, *SPCC Guidance for Regional Inspectors*

EPA 600/4-90-027F, *Methods For Measuring The Acute Toxicity Of Effluents And Receiving Waters To Freshwater And Marine Organisms*

EPA 800-R-11-007, Oily Bilgewater Separators

EPA 810-B-18-001 *Earthquake Resilience Guide for Water and Wastewater Utilities*

EPA 833-B-11-001, *Introduction to the National Pretreatment Program*

EPA 833-K-10-001, *NPDES Permit Writers' Manual*

EPA 833-R-12-001A, *Industrial User Permitting Guidance Manual*

Department of Homeland Security:

Water and Wastewater Systems Sector-Specific Plan

NON-GOVERNMENT PUBLICATIONS:

AMERICAN PUBLIC HEALTH ASSOCIATION

https://www.apha.org/

Standard Methods for the Examination of Water and Wastewater, a joint publication with APHA, AWWA and WEF

AMERICAN WATER WORKS ASSOCIATION

AWWA M23, *PVC Pipe – Design and Installation*

AWWA M27, *External Corrosion for Infrastructure Sustainability*

AWWA M41, *Ductile Iron Pipe and Fittings*

AWWA M51, *Air Valves: Air Release, Air/Vacuum, And Combination*

AMERICAN CONCRETE PIPE ASSOCIATION

Concrete Pipe Design Manual

CAST IRON SOIL PIPE INSTITUTE

Cast Iron Soil Pipe and Fittings Handbook

Najafi, Mohammad, Ph. D, P.E.

Trenchless Technology Pipeline and Utility Design, Construction and Renewal

WATER ENVIRONMENT FEDERATION

Solids Process Design and Management, 2012

Emergency Planning, Response, and Recovery, 2013

WEF MOP 1, *Safety, Health, and Security in Wastewater Systems*

WEF MOP 8, *Design of Water Resource Recovery Facilities,* a joint publication with ASCE (ASCE Manuals and Reports on Engineering Practice No. 76), Sixth Edition

WEF MOP FD-4, *Design of Wastewater and Stormwater Pumping Stations, 1993*

WEF MOP FD-6, *Existing Sewer Evaluation and Rehabilitation*, Third Edition

WEF MOP FD-12, *Alternative Sewer Systems*

WEF MOP FD-16, Natural Systems for Wastewater Treatment, 3rd Edition

WEF MOP OM-7, *Operation of Extended Aeration Package Plants*

UNI-BELL PVC PIPE ASSOCIATION

INDUSTRIAL PRESS

Handbook of PVC Pipe Design and Construction, 5th Edition

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APPENDIX B GLOSSARY

B-1 ACRONYMS.

AFCEC	Air Force Civil Engineering Center
AHJ	Authority Having Jurisdiction
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
BEQ	Bachelor Enlisted Quarters
BIA	Bilateral Infrastructure Agreements
BOD	Biochemical Oxygen Demand
BOQ	Bachelor Officer Quarters
COD	Chemical Oxygen Demand
DAF	Dissolved Air Flotation
DoD	Department of Defense
DoR	Designer of Record
FGS	Final Governing Standards
HQUSACE	Headquarters, U.S. Army Corps of Engineers
HNFA	Host Nation Funded Construction Agreements
\3 IPC	International Plumbing Code **/3/**
IPSDC	International Private Sewage Disposal Code
LET	Load Equalization Tank
NAVFAC	Naval Facilities Engineering Command
NPDES	National Pollution Discharge Elimination System
MOP	Manual of Practice
OEBGD	Overseas Environmental Baseline Guidance Document
OSHA	Occupational Safety and Health Administration

OWHT	Oily Waste Holding Tanks
OWTP	Oily Waste Transfer Pumps
OWWO	Oily waste and Waste Oil
O&G	Oil and Grease
POTW	Public Owned Treatment Works
RBC	Rotating Biological Contactors
RBP	Rapid Bioassay Procedures
RMF	Risk Management Framework
SBR	Sequencing Batch Reactor
SOFA	Status of Forces Agreements
TSS	Total Suspended Solids
UFC	Unified Facilities Criteria
UFGS	Unified Facilities Guide Specifications
U.S.	United States
VSS	Volatile Suspended Solids
WEF	Water Environment Federation
WET	Whole Effluent Toxicity
WOT	Waste Oil Tanks
WRRF	Water Resource and Recovery Facility

APPENDIX C REFERENCES

GOVERNMENT PUBLICATIONS:

CODE OF FEDERAL REGULATIONS

\2 29 CFR 1910.24(b) *Manhole Steps*

29 CFR 1910.23(d) *Fixed Ladders* **/2/**

33 CFR 154.530 - *Small discharge containment*

40 CFR Subchapter N – *Effluent Guidelines and Standards*

40 CFR 112 - *Oil Pollution Prevention*

40 CFR 122 - *EPA Administered Permit Programs: The National Pollutant Discharge Elimination System*

40 CFR 136 – *Guidelines for Establishing Test Procedures for the Analysis of Pollutants*

40 CFR 257 - *Criteria for Classification of Solid Waste Disposal Facilities and Practices*

40 CFR 261 – *Identification and Listing of Hazardous Waste*

40 CFR 401.15 – *Toxic pollutants*

40 CFR 401.16 - *Conventional pollutants*

40 CFR 403 – *General Pretreatment Regulations for Existing and New Sources of Pollution*

40 CFR 423, Appendix A to Part 423 - 126 – *Priority Pollutants*

DEPARTMENT OF DEFENSE

DoD 4715.05-G, *Overseas Environmental Baseline Guidance Document*

DODINST 6055.01, *DoD Safety and Occupational Health (SOH) Program*

UNIFIED FACILITIES CRITERIA

http://dod.wbdg.org/

UFC 1-200-01*, DoD Building Code*

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

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

UFC 3-201-01, *Civil Engineering*

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

UFC 3-240-03, *Operation and Maintenance (O&M): Wastewater Treatment*

UFC 3-301-01, *Structural Engineering*

UFC 3-420-01, *Plumbing Systems*

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

UFC 3-570-01, *Cathodic Protection*

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

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

UFC 4-020-01, *DoD Security Engineering Facilities Planning Manual*

UFC 4-150-02, *Dockside Utilities for Ship Service*

UFC 4-152-01, *Design: Piers And Wharves*

UFC 4-211-01, *Aircraft Maintenance Hangars*

NON-GOVERNMENT PUBLICATIONS:

AMERICAN SOCIETY OF CIVIL ENGINEERS

ASCE MOP 60, *Gravity Sanitary Sewer Design and Construction*, a joint publication with WEF (WEF MOP FD-5)

AMERICAN NATIONAL STANDARDS INSTITUTE

\2 ANSI A14.3 *American National Standard for Ladders – Fixed –Safety Requirements* **/2/**

ANSI Z358.1, *Standard for Emergency Eyewash and Shower Stations*

AMERICAN WATER WORKS ASSOCIATION

AWWA C150/ANSI A21.50, *Thickness Design of Ductile Iron Pipe*

DUCTILE IRON PIPE RESEARCH ASSOCIATION

DIPRA, *Thrust Restraint Design for Ductile Iron Pipe*, latest edition

GREAT LAKES – UPPER MISSISSIPPI RIVER BOARD OF STATE PUBLIC HEALTH AND ENVIRONMENTAL MANAGERS

10 State Standards, *Recommended Standards for Wastewater Facilities*, 2014

INTERNATIONAL CODE COUNCIL

\3 IPC, International Plumbing Code, (same version as International Plumbing Code as required by UFC 3-420-01) **/3/**

IPSDC*, International Private Sewage Disposal Code*, (same version as International Plumbing Code as required by UFC 3-420-01)

Manufacturers Standardization Society of the Valve and Fittings Industry, Inc., 127 Park Street, NE, Vienna, Virginia 22180-4602

MSS SP-58-2018, Pipe Hangers and Supports, Materials, Design, Manufacture, Selection, Application, and Installation

WATER ENVIRONMENT FEDERATION

WEF MOP FD-3, *Industrial Wastewater Management, Treatment, and Disposal, third edition*

UFC 3-240-03
03 October 2019
Change 1, 01 April 2024

UNIFIED FACILITIES CRITERIA (UFC)

OPERATION AND MAINTENANCE (O&M): WASTEWATER TREATMENT

UNIFIED FACILITIES CRITERIA (UFC)

OPERATION AND MAINTENANCE (O&M) WASTEWATER TREATMENT

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

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING COMMAND (Preparing Activity)

AIR FORCE CIVIL ENGINEER CENTER

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

Change No.	**Date**	**Location**
1	01 April 2024	Updated non-unified references and added sewer inspecting and cleaning guidance in Appendix A.

This UFC supersedes UFC 3-240-03N, dated January 2004.

FOREWORD

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

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

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

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

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

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UNIFIED FACILITIES CRITERIA (UFC)
REVISION SUMMARY SHEET

Document: UFC 3-240-03, *Operation and Maintenance (O&M) Wastewater Treatment*

Superseding: UFC 3-240-03N, Wastewater Treatment System Augmenting Handbook Operation and Maintenance, dated January 2004

Description: UFC 3-240-03 provides technical requirements and guidance for the operation and maintenance of wastewater treatment systems.

Reasons for Document:

- The new UFC updates technical requirements and increases the use of industry standards.

- The majority of existing criteria was outdated and needed a major revision.

Impact:

- This update revises an existing Navy only UFC and unifies wastewater treatment operation and maintenance criteria across DoD. This operation and maintenance criteria will assist owners and operators with maintenance and operation of wastewater treatment systems and provide increased guidance.

Unification Issues:

AIR FORCE

- AFH 32-1290 provides additional requirements for cathodic protection systems.
- **\1** AFMAN 32-1062 provides additional requirements for electrical systems, power plants, and generators. **/1/**
- **\1\\ /1/**
- **\1** AFMAN 32-1067 provides further guidance water and fuel systems requirements and reporting. **/1/**
- **\1** AFMAN **/1/** 32-1068 provides further guidance on boiler personnel schedule requirements.
- **\1\\ /1/**
- AFI 32-7001 provides further guidance on reporting requirements.

ARMY

- AR 420-1 provides additional operating data requirements.

- PWTB 200-1-142 provides additional requirements for water reuse.
- TM 5-682 provides additional requirements for electrical facilities safety.
- TM 5-683 provides additional requirements for electrical interior facilities.
- TM 5-684 provides additional requirements for electrical exterior facilities.
- TM 5-685 provides additional requirements for operation, maintenance, and repair of auxiliary generators.
- PWTB 420-49-29 provides additional requirements for cathodic protection systems.
- TM 5-814-3 provides additional requirements for cold weather operation.

NAVY

- OPNAVINST 5090.1D provides Navy only requirements.
- OPNAVINST 5100.23G provides Navy only safety requirements.
- MCO P5090.2A provides Marine Corps only requirements.

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FIGURES

TABLES

CHAPTER 1 INTRODUCTION

1-1 PURPOSE AND SCOPE.

This UFC provides technical guidance and procedures for operations and maintenance (O&M) of wastewater treatment facilities.

1-2 APPLICABILITY.

This UFC applies to all service elements and contractors involved in the operation and maintenance of permanent DoD wastewater treatment plants worldwide.

1-3 GENERAL BUILDING REQUIREMENTS.

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

1-4 CYBERSECURITY.

All control systems (including systems separate from an energy management control system) must be planned, designed, acquired, executed, and maintained in accordance with UFC 4-010-06, and as required by individual Service Implementation Policy.

1-5 GLOSSARY.

Appendix B contains acronyms and definition of terms.

1-6 REFERENCES.

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

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CHAPTER 2 REGULATORY COMPLIANCE AND MONITORING

2-1 OPERATION AND MAINTENANCE CRITERIA.

DoD wastewater systems must achieve, maintain, and monitor compliance with applicable environmental requirements and monitor these environmental requirements worldwide. Operate and maintain wastewater treatment systems in accordance with the requirements of applicable federal, state and local government agencies or overseas equivalent.

2-1.1 Within the United States.

For Installations located in the United States and its territories and possessions the wastewater system must comply with the following criteria precedence:

a. State wastewater or local regulations for the project location;

b. DoDI 4715.06;

c. Navy Only: OPNAVINST 5090.1D and MCO P5090.2A;

d. Additions to the above criteria as indicated in this UFC;

e. IPSDC;

f. WEF MOP 11; and

g. Refer to Appendix A for guidance.

2-1.2 Foreign Countries.

For Installations located outside of the United States and its territories and possessions the wastewater system must comply with the following criteria precedence:

a. The Forward of this UFC (All construction outside of the United States is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA));

b. Final Governing Standards (FGS);

c. DoDI 4715.05 and DoD 4715.05-G, Overseas Environmental Baseline Guidance Document

d. Navy Only: OPNAVINST 5090.1D and MCO P5090.2A;

e. Additions to the above criteria as indicated in this UFC;

f. IPSDC;

g. WEF MOP 11; and

h. Refer to Appendix A for guidance.

2-2 FOREIGN COUNTRIES.

DoD 4715.05-G, *Overseas Environmental Baseline Guideline Document* (OEBGD), applies when there are no Final Governing Standards (FGS) in place. Therefore, in foreign countries this UFC will be used for DoD projects to the extent that it is allowed by and does not conflict with the applicable international agreements and the applicable FGS or OEBGD.

2-2.1 Wastewater Quality Standards.

DoD wastewater systems must achieve, maintain, and monitor compliance with applicable environmental requirements and monitor these environmental requirements worldwide.

2-3 SAFETY.

All DoD facilities must comply with DoDI 6055.1, DoDI 4715.1E, and applicable Occupational Safety and Health Administration safety and health standards.

For the Navy, also use OPNAVINST 5100.23G.

2-4 PLUMBING.

UFC 3-420-01 adopted the use of the International Plumbing Code (IPC) to comply with Public Law 104-113. Refer to UFC 3-420-01 for modifications to the IPC.

2-5 OPERATING REQUIREMENTS.

Wastewater treatment plant systems must operate within their approved permits and with federal, state, and local requirements or overseas equivalent. Operations and management staff at wastewater treatment plants (WWTP) are expected to understand, comply with these requirements and inform the Installation Environmental Program staff of any problems that may affect compliance.

2-5.1 Recordkeeping.

Equipment maintenance and repairs records are used for maintenance planning and scheduling to ensure that each piece of equipment is properly maintained to ensure it is reliable for the wastewater treatment process. All maintenance and repairs for each piece of equipment must be captured in a formal method to allow for an operator in the future to review the equipment history. The most common and effective way is to use a computerized maintenance management system.

The records for each piece of equipment can be used to make decisions on the repairs and replacement of the equipment. Such decisions look at the age of the equipment, the amount of time spent maintaining and repairing the equipment, and the cost of repairing and maintaining the equipment.

2-6 PERMITS.

Permits are issued for the construction, modification, discharge of treated effluent, discharge of stormwater runoff, and solids management practices. These permits may be issued by the Environmental Protection Agency (EPA), state, and local governments. In some cases, permits may be required from all three levels of government. Coordinate with the Installation Environmental Program staff during the permitting process.

2-6.1 Federal Permit Requirements.

Permits under Part 503.3(a), the requirements in Part 503 may be implemented through:

a. permits issued to treatment works treating domestic sewage by EPA or by states with an EPA approved solids management program; and

b. permits issued under Subtitle C of the Solid Waste Disposal Act; Part C of the Safe Drinking Water Act; the Marine Protection, Research, and Sanctuaries Act of 1972; or the Clean Air Act.

Treatment works treating domestic sewage submit a permit application to the approved state program, or, if there is no such program, to the EPA Regional Sludge Coordinator. Direct Enforceability under Part 503.3(b), the requirements of Part 503 automatically apply and are directly enforceable even when no permit has been issued.

2-6.2 National Pollutant Discharge Elimination System.

Code of Federal Regulations (CFR), Section 40, Part 122 describes the National Pollutant Discharge Elimination System (NPDES) permitting program. The NPDES permit program has separate regulations found in 40 CFR 125, 40 CFR 129, 40 CFR 133, 40 CFR 136, 40 CFR 400 through 460, and 40 CFR 503. When the EPA has designated authority to an individual state, Federal law allows these individual states to have more stringent requirements. WWTP owners or owner's designated representative needs to know if the EPA has delegated permitting authority to their state.

2-6.2.1 NPDES Permit Compliance.

Failing to comply with the NPDES permit may result in fines and other penalties. In some cases, it may even result in criminal prosecution. Since the NPDES program relies on self-reporting for implementation, EPA places special emphasis on timely and complete reporting. Enforcement actions are often swift and severe for being late with the monthly operating reports or for failing to report violations.

Exceedance of water quality limits will also draw regulatory attention and possible enforcement action. However, proactive planning prior to beginning the permit renewal process can reduce the likelihood of enforcement actions. In most states, the permitting agency may establish water parameters that the WWTP is not currently meeting. The permitting agency and WWTP owner or owner's designated representative should work together to determine a date when the parameter becomes effective in the future. This allows the WWTP time to upgrade or change the process to meet the parameters.

2-6.2.1.1 Negotiation of Effluent Limits.

Careful review by the discharger of the specific basis used for the water quality-based effluent limits is advisable. In many cases, the basis used in the development of the effluent limits is open to negotiation. Address effluent limits during the permit renewal process.

2-6.2.2 NPDES Permit Renewal.

NPDES permits require periodic renewal. The application and renewal of the permit is to be completed by the Installation as they may have different departments applying for permits. Permits may be modified by regulators prior to the normal permit renewal periods. Permit renewal applications need to be submitted 180 days (about 6 months) before the expiration date. If the existing permit is being violated regularly, the WWTP may need to develop a Wastewater Master Plan with a list of plant improvements and costs to bring the WWTP back into compliance with the discharge permit limits or as required by the permitting agency.

2-6.3 Operating NPDES Permit.

An operating NPDES permit is required before a WWTP can begin operating. An operating NPDES permit may include topics such as identifying the owner, describing the treatment process, describing the discharge location, frequency, and limits, and contain specific and general conditions. The owner is required to meet the discharge limits stated in the operating NPDES permit. The WWTP operator is responsible for keeping a copy of the permit on file at the WWTP. An operating NPDES permit is typically combined to contain the Federal, state, and local regulations and standards in a single document for the WWTP. In addition to treated wastewater, operating NPDES permits may address stormwater and other disposal options. When the EPA has designated authority, the state also may establish groundwater monitoring or discharge requirements. For example, disposal of treated effluent to the subsurface will require an Underground Injection Control permit from the state as required by the Safe Drinking Water Act.

Note: For the Army, AR 420-1 provides additional operating data requirements.

Note: For the Air Force, AFI 32-7001 and **\1** AFMAN **/1/** 32-1067 provide further guidance on reporting requirements.

2-6.3.1 Licensing and Staff Requirements.

The operating NPDES permit and applicable regulatory requirements determine the licensing and staffing requirements. Many states require that the chief operator be certified to complete the reports that are necessary to comply with state and federal water pollution control laws and regulations. Some facilities are required to have a certified operator on shift work when the chief operator is not on site. In some locations, all operators may require certification for the operation of a treatment plant. The EPA has stated that it would like to have all plants operated by qualified personnel; certification is a method of demonstrating an operator's level of qualification. Failure to have the correct number and level of certified operators can be considered a compliance violation.

2-6.3.2 WWTP Modifications.

An operating NPDES permit is not a construction permit. The EPA requires a modification to the operating NPDES permit when there is a significant change in the operation of the WWTP. In some states, an owner may construct or modify a facility, but it is a violation to place the modified facility in operation until a valid operating permit is obtained. Other states limit all construction activities until the changes or modifications are approved. Coordinate permit requirements with the Installation Environmental Program staff.

2-6.4 Disposal Permit Options.

Each Installation is responsible for disposal of waste such as solids, screenings, and grit in accordance with the approved WWTP permits. Treated effluent that is entirely disposed into the groundwater or onto land application sites does not need an operating NPDES permit from EPA to discharge, but it may be subject to NPDES permits for stormwater or solids.

2-6.5 Solids NPDES Permit.

Residual solids management has received special attention under 40 CFR 503. Solids management is typically addressed as part of the operating NPDES permit. However, a solids NPDES permit may still be required.

2-6.6 Stormwater NPDES Permit.

Each Installation is responsible for stormwater state management per the applicable permits. WWTPs that treat more than 1 million gallons per day (mgd) or are equal to or larger than 5 acres are included in the stormwater NPDES permitting program as a categorical industrial facility. Although stormwater could be included in the operating permit described above, many facilities obtain a general stormwater NPDES permit. This permit is maintained separately from the operating permit.

2-7 EMERGENCY REPORTING.

Emergency failures or spills typically require that the appropriate agencies be notified within 24 hours. Emergency reporting requirements should be included in the WWTP Operation and Maintenance Manual and displayed in obvious locations. Federal, State and Local governments may be involved with reporting emergency failures or spills.

2-7.1 Spill Prevention and Response Plan.

A stormwater NPDES permit typically requires best management practices and includes a spill prevention and response plan.

2-8 FACILITY OPERATION AND MAINTENANCE MANUAL.

The WWTP develops and updates the facility operations and maintenance manual. This manual includes a sapling and testing procedures required for day-to-day operations, reporting requirements, license requirements, and operating instructions (both normal operation and emergency operation). The operating instructions include single line drawings as applicable. Include maintenance and regulatory compliance requirements.

Retain shop drawings, catalogue cut sheets, and any other equipment information.

2-9 SAMPLING OF WASTEWATER.

A sampling and analysis program needs to be conducted as required by the NPDES operating permit. Typically, if a well-executed sampling plan is implemented, the process monitoring, and control program is more effective. Sampling is conducted for compliance with legal requirements, process monitoring and control, and historical data collection.

The NPDES operating permit's effluent limits are evaluated and monitored for compliance by sampling. Each permit specifies the sampling location, type, and frequency; analyses to be performed at each sample location; and frequency of reporting the results to the regulatory agency.

2-10 REPORTS.

The WWTP owner is responsible for ensuring all reporting requirements are completed by the chief operator or designated certified operator.

2-10.1 Capacity Analysis Report.

The Capacity Analysis Report documents the predicted future flows and loads within the treatment facility and evaluates the capacity of existing unit processes to reliably treat those loads for the next permitting cycle. The historical flows and the treatment performance of the preceding 5 years need to be analyzed. The carbonaceous biochemical oxygen demand (CBOD) and total suspended solids (TSS) loading (in pounds per day) also need to be verified. Population, flow, and load projections are then made to estimate what future loads will be, based on historical growth trends. The capacity of each unit process needs to be determined. These capacity assessments may already have been done for past renewals. However, the capacity rating of each process needs to be checked against the latest loadings and flow.

Use a 5-year period for future projections. Include future projects and realignment decisions when making future projections. If the plant is undersized, an expansion needs to be initiated and a Preliminary Engineering Report for improvements developed. Higher discharge rates also will precipitate additional permit application requirements to address anti-degradation issues.

2-10.2 Operation and Maintenance Report.

The Operation and Maintenance Report reviews plant operations data over the last permit cycle to evaluate needed improvements to the facility. Any upsets or spills need to be reviewed to determine the cause and possible solution. Some water quality exceedances may be a result of operation practices and need to be reviewed. The condition of the facilities is evaluated, such as the need for painting and other routine maintenance. Some needs may require changes to the process or construction approval. However, not every maintenance item needs to be reported to the agencies. Confirmation from the agency on which items need permitting is recommended after the Operation and Maintenance Report is completed.

2-10.3 Preliminary Engineering or Feasibility Report.

Use the Preliminary Engineering or Feasibility Report when modifications to the WWTP are required. This is a preliminary design study that will outline what changes are required to attain or maintain compliance. Typically, this report will contain a summary of the future flows and loads to be treated from the Capacity Analysis Report, a review of any alternative evaluations used to select the appropriate treatment technologies, and a conceptual-level design for upgraded facilities. A professional engineer sizes and plans for appropriate process changes. The Preliminary Engineering Report is submitted as part of the permit application renewal. Some states may require final construction drawings and specifications before approving the changes, whereas others may issue a construction permit based solely on the Preliminary Engineering Report.

2-11 REPORTING REQUIREMENTS FOR SEWAGE SOLIDS.

Reporting requirements for these solids are found in Part 503.18 for land application and Part 503.28 for surface disposal. These requirements apply to Class I solids management facilities and to WWTPs with a design flow rate equal to or greater than 1 mgd or that serve 10,000 or more people. Submit to the permitting authority the records they are required to keep as “preparers” of biosolids, owner of surface disposal sites. There are no reporting requirements associated with the use or disposal of domestic septage.

2-12 OPERATOR CERTIFICATION.

Operator certification is a process by which an individual is awarded a certificate from the state water quality regulatory agency for meeting specific criteria associated with the operation of wastewater treatment plants. Most states require that the responsible wastewater treatment plant operator possess a current state operator certification for the plant to meet the state's operating permit requirements. This certification process varies from state to state. Most states have different levels of certification that depend upon plant complexity and size or individual expertise. Certification requirements are usually contained in the permit or in state regulations. Certified operators demonstrate a specific level of proficiency in their selected field.

2-12.1 Training for Certification.

Additionally, operators may be required to attend classes or obtain a required amount of training prior to obtaining certification. Operators may contact state agencies to obtain specific information about training requirements for their certification.

Note: For the Air Force, **\1** AFMAN **/1/** 32-1067 provides additional requirements regarding operator training and certification.

2-12.2 Obtaining Certification.

Each state regulatory agency has a program for achieving certification. Operators should contact the state agency where the WWTP is located to obtain specific information about requirements and reciprocity programs. Although reciprocity exists between many states, certifications may not be transferable between some states. A certified operator may be able to apply for certification in other states that have reciprocity with the state issuing an operator certification. State regulatory agencies can help with reciprocity of certifications.

2-12.3 Training for Renewal of Certification.

States may require continual training by the operator to maintain their certification. Operators are required to review and complete the required amount of training to maintain their certification in the time periods set by their state regulations.

2-13 WASTEWATER REUSE.

Several states and communities are promoting the reuse of wastewater as a beneficial way of reducing both drinking water demands and wastewater discharge to the environment. The most common reuse projects involve using treated wastewater for irrigation purposes (e.g., golf courses). Other uses of water may include residential irrigation, fire protection, landscape features (e.g., ponds and fountains), and industrial supply. Generally, a project is only considered a reuse project if the reclaimed effluent replaces drinking water demand. Groundwater discharge is sometimes referred to as "groundwater recharge" and may be considered reuse if it is used to replenish the drinking water supply. However, contamination of the drinking water supply is a concern, and the discharge may have as many disincentives as incentives. Most land application projects that rely on groundwater infiltration for effluent disposal would be considered disposal projects, not reuse projects. Any disposal to natural surface waters will be considered an NPDES discharge and will be subject to all applicable rules.

2-13.1 Reuse Feasibility Study.

An engineering study is required to determine the actual water usage for a given reuse project. For example, an irrigator will not need water in wet periods or winter. The WWTP may therefore need to dispose of all its effluent for extended periods of time. The permit requirements need to be flexible to accommodate such seasonal effects. The objective of the engineering study is to determine a conceptual reuse system, including customers, available capacity, the size of the pipeline, pumps, and storage. This study is not a design-level project. Further design and permitting is required to implement a project.

2-13.2 Reuse Treatment Facilities.

Additional treatment processes may be needed to provide reuse-quality water. If there is a possibility of public contact with the water, provide high-level disinfection (<20 most probable number per 100 milliliters [mL]) for the effluent. Filtration before disinfection or discharge to an irrigation system also would be likely. If only a portion of the effluent flow is used for reuse, then these additional facilities would need to be sized accordingly and would treat only a side stream. An engineering feasibility study would need to determine the size and layout of these treatment facilities.

Note: For the Army, PWTB 200-1-142 provides additional requirements for water reuse.

2-13.3 Sludge Reuse.

Biosolids have beneficial plant nutrients and soil-conditioning properties. However, biosolids also may contain heavy metals, bacteria, viruses, protozoa, parasites, and other microorganisms that cause disease. If improperly treated and applied, they may also attract nuisance vectors such as insects and rodents. EPA actively promotes management practices that provide for the beneficial reuse of biosolids while maintaining or improving environmental quality and protecting human health. However, while the Part 503 regulations encourage the beneficial reuse of biosolids, they do not mandate it; traditional disposal methods, such as landfilling, may still be selected.

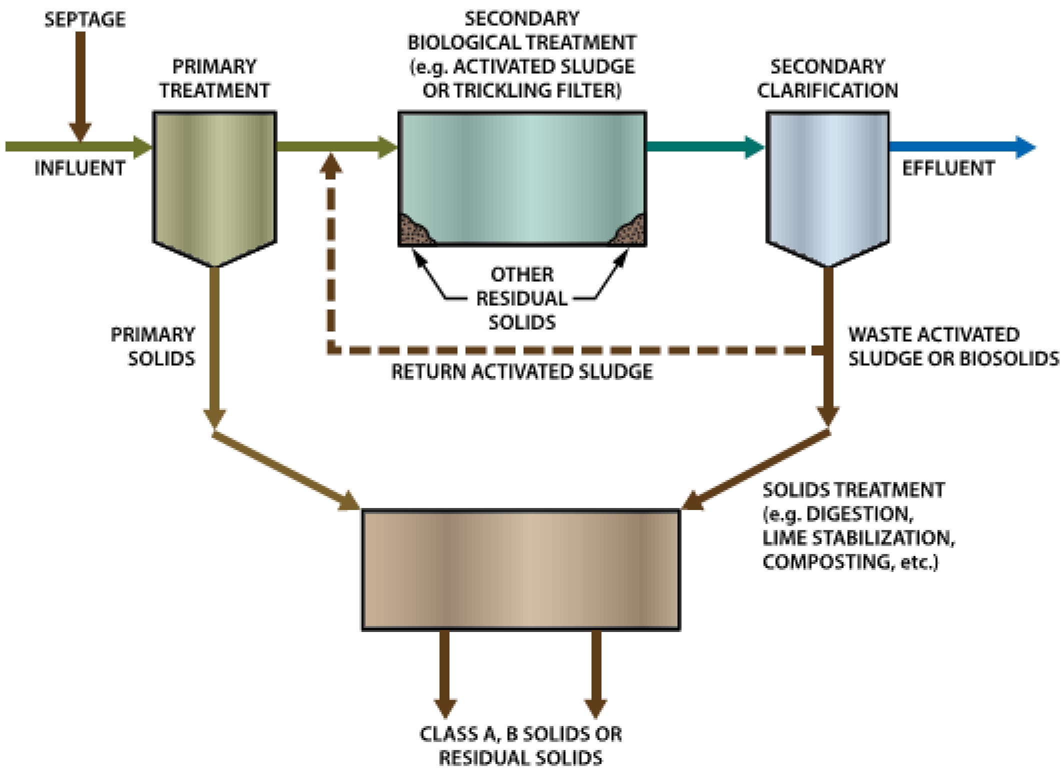
The use and disposal of biosolids, including domestic septage, are regulated under 40 CFR 503. This regulation, promulgated on February 19, 1993, was issued under the authority of the Clean Water Act, as amended in 1977, and the 1976 Resource Conservation and Recovery Act. For additional guidance on the Part 503 regulations, refer to EPA/625/R-92/013.

2-13.4 Solids Definition.

The Part 503 regulations promulgated the word “sludge” to describe a variety of solids residuals from wastewater treatment processes. The wastewater treatment industry and regulatory agencies have recently tried to minimize the use of the word “sludge” because the term is too general, and its negative connotations do not accurately reflect the industry’s goal: to promote the beneficial reuse of properly treated wastewater solids as useful soil amendments for agricultural users and the general population. In keeping with current industry practices, this document avoids the word sludge except when directly referred to in Part 503 regulations or a widely accepted process name, such as the “activated sludge process.” Figure 2-1 shows a secondary wastewater treatment plant and identifies the terminology used by industry and this document to replace the word sludge.

The primary solids referred to in Figure 2-1 are those derived from primary treatment processes. Solids drawn from the secondary treatment system are referred to as “waste activated sludge” or “biosolids.” The word biosolids refers to the residual treatment bacteria and inert solids contained in the biological treatment process. Solids that have undergone treatment for beneficial reuse generally are referred to as “residual solids” or classified according to their level of treatment, such as “Class A Solids.” In some cases, treatment facilities do not further treat primary or secondary solids and dispose of these in a permitted landfill; in this case, the residuals are referred to as “sludge,” meaning the product has not received treatment to reduce pathogens or vector attraction. The phrase “other residual solids” refers to the dense, grit-like solids that accumulate in process tanks and are removed when the tanks are periodically emptied and cleaned.

Figure 2-1 Residual Solids



2-14 PROTECTION OF PUBLIC HEALTH AND THE ENVIRONMENT.

In the judgment of the EPA administrator, Part 503 protects public health and the environment through requirements designed to reduce the potential for contact with the disease-bearing microorganisms (pathogens) and heavy metals in biosolids applied to the land or placed on a surface disposal site. These requirements are divided into the following categories:

- Requirements designed to control and reduce pathogens in solids
- Requirements designed to reduce the ability of the solids to attract vectors (rodents, birds, insects, and other living organisms that can transport solids pathogens away from the land application or surface disposal site)
- Requirements designed to limit the amount of heavy metals in solids applied to land or placed on a surface disposal site

Subpart D of Part 503 includes both performance- and technology-based requirements that aim to reduce pathogens and vector attraction. It is designed to provide a more flexible approach than Part 257, which required solids to be treated by specific listed or approved treatment technologies. Under Part 503, treatment works may continue to use the same processes they used under Part 257, but they can modify conditions and combine processes with each other if the treated solids meet the applicable requirements.

2-14.2 Pathogen and Vector Attraction Reduction.

Part 503.15 covers the applicability of the pathogen and vector attraction reduction requirements. The Subpart D requirements apply to solids (both bulk solids and solids that are sold or given away in a bag or other container for application to the land) and domestic septage applied to the land or placed on a surface disposal site. The regulated community includes anyone who generates or prepares solids for application to the land, as well as those who apply it to the land, including anyone who:

- Generates solids that are land-applied or placed on a surface disposal site
- Derives a material from solids
- Applies solids to the land
- Owns or operates a surface disposal site

2-15 LAND APPLICATION OR DISPOSAL.

Solids cannot be applied to land or placed on a surface disposal site unless they have met the two basic types of requirements in Subpart D: pathogen and vector attraction reduction requirements. These two types of requirements are separated in Part 503, which allows flexibility in how they are achieved. Demonstrate compliance with both types of requirements separately. Therefore, demonstration that a requirement for reduced vector attraction has been met does not imply that a pathogen reduction requirement also has been met, and vice versa.

2-16 PATHOGEN REDUCTION.

Sewage Sludge [503.32(a) and (b)]. The pathogen reduction requirements for sewage sludge are divided into two categories: Class A and Class B. These requirements use a combination of technological and microbiological requirements to ensure reduction of pathogens. The implicit goal of the Class A requirements is to reduce the pathogens in sewage sludge (including enteric viruses, pathogenic bacteria, and viable helminth ova) to below detectable levels. The implicit goal of the Class B requirements is to ensure that pathogens have been reduced to levels that are unlikely to pose a threat to public health and the environment under the specific-use conditions. For Class B solids that are applied to land, site restrictions are imposed to minimize the potential for human and animal contact for a period of time following land application until environmental factors have further reduced pathogens. Class B solids cannot be sold or given away in bags or other containers for application to the land. There are no site restrictions for Class A solids.

Domestic Septage [503.32(c)]. Domestic septage is a form of sewage sludge. Domestic septage is a liquid or solid material that is removed from a septic tank, cesspool, portable toilet, type III marine sanitation device, or similar system that only receives domestic septage (household, noncommercial, and non-industrial sewage). The requirements for domestic septage vary, depending on how it is used or disposed. Domestic septage applied to a public contact site, lawn, or home garden must meet the same requirements as other forms of sewage sludge. Separate, less complicated requirements for pathogen reduction apply to domestic septage applied to agricultural land, forests, or reclamation sites. These requirements include site restrictions to reduce the potential for human contact and to allow for environmental attenuation or pH adjustment with site restrictions only on harvesting crops. No pathogen requirements apply if domestic septage is placed on a surface disposal site.

2-17 VECTOR ATTRACTION REDUCTION.

Subpart D specifies 12 options to demonstrate reduced vector attraction. Eight of the options apply to sewage sludges that have been treated in some way to reduce vector attraction (e.g., aerobic or anaerobic digestion, composting, alkali addition, and drying). These options consist of operating conditions or tests to demonstrate that vector attraction has been reduced in the treated solids. Three options cover methods for injection or incorporating solids into the soil to reduce vector attraction.

One option is a requirement to demonstrate reduced vector attraction in domestic septage through elevated pH. This option applies only to domestic septage.

2-18 FREQUENCY OF MONITORING.

Sewage Sludge [503.16(a) and 503.26(a)]. The Class A and Class B pathogen requirements and the first eight vector attraction reduction options (the treatment-related methods) all involve some form of monitoring. The minimum frequency of monitoring for these requirements is given in Part 503.16(a) for land application and Part 503.26(a) for surface disposal. The frequency depends on the amount of solids used or disposed of annually. The larger the amount used or disposed of, the more frequently monitoring is required.

Domestic Septage [503.16(b) and 503.26(b)]. One of the options that can be used for demonstrating both pathogen reduction and vector attraction reduction in domestic septage is to elevate pH to >12 for 30 minutes without the addition of more alkali. When this option is used, monitor each container of domestic septage (e.g., each tank truck load) applied to the land or placed on a surface disposal site for pH.

2-19 RECORDKEEPING REQUIREMENTS.

Recordkeeping requirements are covered in Part 503.17 for land application and Part 503.27 for surface disposal. Records are required for both sewage sludge and domestic septage. Retain all records for 5 years except when the cumulative pollutant loading rates in Part 503 Subpart B (Land Application) are used. In that case, keep certain records indefinitely. Some records must be reported to the permitting authority.

- Land Application: Keep records to confirm that the solids meet the applicable pollutant limits, management practices, one of the pathogen requirements, one of the vector attraction reduction requirements, and where applicable, the site restrictions associated with land application of Class B biosolids. When bulk solids are applied to land, both the person preparing the solids for land application and the person applying them must keep records. The person applying solids that are sold or given away does not have to keep records.
- Surface Disposal: When solids are placed on a surface disposal site, the owner of the surface disposal site must keep records. In the case of domestic septage applied to agricultural land, forest, or a reclamation site or placed on a surface disposal site, the person applying the domestic septage. The owner of the surface disposal site may be subject to pathogen-related recordkeeping requirements, depending on which vector attraction reduction option was used.

Certification Statement: In every case, recordkeeping involves signing a certification statement that the requirement has been met. Parts 503.17 and 503.37 of the regulation contain the required certification language.

CHAPTER 3 WASTEWATER TREATMENT

3-1 INTRODUCTION.

For an operator to understand a wastewater treatment plant, it is important to have an accurate characterization of the wastewater influent. The wastewater characterization provides the operator with information to control the wastewater treatment processes. There are typically two types of influent water: domestic and industrial. Domestic wastewater comes from residential units such as single-family households, condominiums, apartments, cottages, or resorts. Industrial wastewater comes from non-residential sources such as institutional, commercial, or industrial facilities.

3-2 MAINTENANCE.

The maintenance requirements for preliminary treatment varies, depending on the type of equipment used. Recommended maintenance should be completed by operators and maintenance staff to maintain all warranties and performance guarantees. Refer to the equipment manufacturers operation manual and operate preliminary treatment equipment in accordance with manufacturers recommendations and all NPDES permits.

3-3 WASTEWATER INFLUENT CHARACTERISTICS.

Nonresidential sources vary, depending on the type of establishment. There are differences in waste-generating sources present, water usage rates, and other considerations. The characteristics for existing nonresidential buildings are characterized by sampling and metering the discharge wastewater. For new nonresidential establishments, use available characterization data from similar facilities. Refer to EPA/625/R-00/008 for typical loadings and concentrations.

Higher than typical ammonia influent levels may occur at some WWTPs because of water conservation programs. Higher than normal influent ammonia levels will require operational adjustments and additional process control monitoring.

3-4 PRELIMINARY TREATMENT METHODS.

The preliminary treatment processes are intended to remove large solids and abrasive material from the influent wastewater prior to damaging equipment or clogging piping. The failure of any of these units will affect downstream processes in the wastewater treatment plant. Therefore, it is important to keep the preliminary treatment units working as effectively as possible.

Refer to *Operation of Wastewater Treatment Plants*, Volume 1, Chapter 4 for additional guidance on preliminary treatment.

3-4.1 Preliminary Screening.

The screening system at a wastewater treatment plant is a system that is either machine run or a completely manual operation. The purpose of the screening system is to remove material that can damage equipment and clog piping in the wastewater treatment plant.

1-1.1.1 Screening Operation.

Manual bar screens and mechanical bars screens both operate in a manner to remove large material. Both come with different spacing between the screen's bars. The smaller the spacing between the screen bars the more material that will be captured by the screen.

3-4.1.1.1 Manual Bar Screens.

Inspect the manual bar screen for spacing between bars, damage to the bars, and any loose fasteners. Manual bar screens are manually cleaned with a tool that allows the operator to pull the captured material off the bar screen.

3-4.1.1.2 Mechanical Screens.

Mechanical screens normally operate in a fully automatic mode. Some newer designs of mechanical screens function with the differential level as the primary means of starting the mechanical screen with the timer as a backup. Determine the correct differential level for the mechanical screen and timers to prevent surging flow through the mechanical screen and wastewater treatment plant.

3-4.1.2 Screening Maintenance.

The maintenance for manual bar screens and mechanical screens are widely different due to the simplicity of manual bar screens and the complexity of mechanical screens.

3-4.1.2.1 Manual Bar Screens.

The maintenance requirements for manual bars screens is limited to periodic inspections of the bar screen with the channel drained and cleaned.

3-4.2 Grit Removal.

Wastewater flow contains material of fine, discrete, non-biodegradable particles called grit. The sources of grit include sand, cinders, rocks, coffee grounds, and cigarette filter tips. The purpose of a grit system is to remove material that can damage equipment and clog piping in the wastewater treatment plant. If grit is not removed during preliminary treatment the grit will accumulate in the bottom of aeration tanks, digesters, and sludge holding tanks which reduces the usable volume in the tanks. Typical grit parameters can be found in WEF MOP11, Table 18.1.

In an aerated grit removal system, the amount of air can also be changed. These changes impact the amount of grit that is removed. If the air to the aerated grit chamber is decreased, the amount of grit captured will increase, but the amount of organics captured also will increase.

3-4.2.1 Grit System Operation.

Grit is removed during preliminary treatment manually or by mechanical equipment. Perform periodic inspections of the grit removal system and inspect for wear and damage.

3-4.2.1.1 Manual Grit Removal.

Manual grit removal is the simplest form of grit removal. The manual grit removal system consists of one or more tanks. Multiple tanks allow a decrease in stream velocity so that grit particles may be allowed to settle out.

3-4.2.1.2 Mechanical Grit Removal Systems.

A mechanical grit removal system is a grit tank that includes a mechanical scrapper or a chain-flight system that pushes the grit to a sump. The grit is removed from the sump by a grit elevator or grit pumps where it is cleaned by a grit washer or grit classifier.

Normal operation is for the mechanical scrapper or chain-flight equipment to be operating continuously. To prevent clogging the grit pump suction or damaging the grit elevator, the operator determines the amount of time that the grit elevator or grit pump runs. The operator inspects the grit collected daily for the amount collected and the effectiveness of the grit washing.

3-4.2.1.3 Aerated Grit Removal Systems.

Aerated grit removal systems consist of one or more tanks that use compressed air to remove organics from the grit as it settles to the bottom of the grit tank. At the bottom of the tank, a longitudinal screw moves the grit to a sump where a grit pump takes suction and pumps the grit slurry to a grit classifier or grit washer to be cleaned. The grit also can be removed by a grit elevator that lifts the grit slurry to a grit classifier or grit washer.

Operators monitor the flow to ensure that the aerated grit removal system does not exceed its designed detention time. Normal operation is for the aerated grit chamber to have the aeration blower continuously running. To prevent clogging the grit pump suction or damaging the grit elevator, the operator determines the amount of time the grit elevator or grit pump runs. The operator inspects the grit collected daily for the amount collected and the effectiveness of the grit washing.

3-4.2.1.4 Vortex Grit Removal Systems.

Vortex grit removal systems spin the wastewater in a chamber to force the grit to be forced to the outer walls of the grit chamber. The grit then slides to the center of the grit chamber where it is removed by a grit pump. The grit slurry is pumped to a grit classifier or grit washer where it is cleaned and dried.

The vortex grit removal system requires the centrifugal force from the spinning of the wastewater to remove the grit. All the vortex grit removal systems have a minimum and maximum flow for which the system is designed. Ensure that the minimum and maximum flows are not exceeded in multiple vortex grit removal tanks. Some vortex grit removal systems have a mixer in the center to help induce the spinning action of the wastewater in the vortex grit chamber. Run the mixer continuously to ensure the vortex grit removal system is operating correctly. To prevent clogging the grit pump suction, the operator determines the amount of time that the grit pump runs. The operator inspects the grit collected daily for the amount collected and the effectiveness of the grit washing.

3-5 PRIMARY TREATMENT.

Primary treatment removes settleable and non-settleable materials. Settleable solids are typically inorganic materials such as grit. Non-settleable materials such as organic materials. The volume of settleable solids collected during primary treatment is typically reduced by the proper operation of the preliminary treatment system. The solids that are removed in the primary treatment process can reduce the treatment in the biological process by 25 to 30%.

Refer to *Operation of Wastewater Treatment Plants*, Volume 1, Chapter 5 for additional guidance on primary treatment.

3-5.1 Operation.

When a primary treatment tank is in operation, a mechanical scraper or a chain-flight system pushes the primary sludge to a sump. The sludge is removed from the sump by a pump and is then pumped to either a thickening process or a digester. In some cases, the primary treatment tank also acts as a gravity thickener for the primary sludge. The floatable material (known as scum) is pushed to a collection point. The scum is then removed from the primary treatment tank via a scum trough where the scum flows to a collection point where it is pumped to be removed from the wastewater treatment plant. In some WWTP processes, the scum is pumped to the digester for processing.

3-5.1.1 Process Control.

The various processes in the wastewater treatment plant vary based on wastewater flow and the environment in which the treatment plant operates. Adjust the number of primary treatment tanks in service to optimum detention time. The optimum detention time is 6 hours. Typically, there is minimal benefit with longer detention times.

The operator determines the best time to pump sludge out of the primary treatment tank, prevent sludge from going septic and maintain the required sludge thickness as required by downstream processes such as digesters and thickening. If the wastewater treatment plant sends WAS to the primary treatment process (co-settles), operators must ensure that the primary treatment pumping is enough to prevent denitrification from occurring in the primary treatment tanks and causing the sludge blanket from being carried into the biological treatment process.

3-5.1.1.1 Mean Cell Retention Time and Sludge Retention Time.

Determine a method of controlling the amount of mixed liquor (WAS) removed from the activated sludge system based on daily operating temperatures. The two common methods are mean cell residence time (MCRT) and Solids Retention Time (SRT_a). MCRT and SRT_a are similar, except for how they are calculated.

MCRT can be as low as 4 days during warm weather periods, and keep nitrification, but without any buffer to counteract an upset such as a slightly low pH. Wastewater treatment plants operation may vary between 4 days in warm weather and 10 days or more in cold weather.

Equation 3-1. Mean Cell Retention Time

$$MCRT = \frac{MLSS_{Total} + TSS_{Clarifier}}{TSS_{WAS} + TSS_{eff}}$$

Where:
MCRT = mean cell residence time (days)
$MLSS_{Total}$ = total activated sludge tanks mixed liquor (lb)
TSS_{WAS} = wasted mixed liquor (lb)
$TSS_{Clarifier}$ = clarifier total suspended solids (lb)
TSS_{Eff} = clarifier effluent total suspended solids (lb)

Equation 3-2. Aerobic Solids Retention Time

$$SRT_a = \frac{MLSS_a}{TSS_{WAS} + TSS_{eff}}$$

Where:
SRT_a = aerobic solids retention time (days)
$MLSS_a$ = aeration tank mixed liquor (lb)
TSS_{WAS} = wasted mixed liquor (lb)
TSS_{Eff} = clarifier effluent total suspended solids (lb)

3-5.1.1.2 Food to Mass Ratio.

Another item to consider when determining MCRT or SRT_a is the food to mass ratio (F:M). This is the ratio of the amount of BOD_5 to the mass of microorganisms in the total activated sludge tanks.

Equation 3-3. Food to Mass Ratio

$$F/M = \frac{BOD_{PE}}{MLSS_{Total}}$$

Where:
F:M = food to mass ratio
BOD_{PE} *= BOD_5 in primary effluent (lb)*
$MLSS_{Total}$ *= total activated sludge tanks mixed liquor (lb)*

Refer to WEF MOP 11, Table 20.1 for typical range of F:M parameters. Individual wastewater treatment plants may operate outside of the ranges listed below. Reference the F:M ratio as a check to see if it is relatively consistent. Investigate the F:M ratio if there are changes. This can indicate that the amount of WAS is incorrect or that there are significant changes to the wastewater flow constituents.

3-5.1.1.3 Alkalinity Adjustment.

Operators can adjust for alkalinity if the raw wastewater does not contain enough. Alkalinity is not lost in any process of the wastewater treatment plant unless coagulants are used to remove phosphorus. Monitor and adjust the alkalinity feed to maintain enough alkalinity in the wastewater to ensure complete nitrification is possible and to maintain at least a 75-mg/L residual in the effluent unless there is a required limit in the wastewater treatment plant NPDES permit.

3-6 BIOLOGICAL TREATMENT.

Most wastewater treatment occurs through biological treatment. Biological treatment occurs by creating an environment in the wastewater treatment tanks that allows a targeted type of bacteria to thrive and treat a specific constituent in the wastewater prior to the treated water being released to the environment. Constituents that are normally removed in the wastewater are biochemical oxygen demand (BOD_5) and CBOD, ammonia, nitrate, and phosphorus.

Refer to *Operation of Wastewater Treatment Plants*, Volume 1, Chapters 6, 7, 8, 9, and 10; *Operation of Wastewater Treatment Plants*, Volume 2, Chapter 11; *Advanced Waste Treatment*, Chapter 2 for additional guidance on biological treatment.

3-6.1 Biological Treatment Methods.

There are multiple methods of containing the bacteria (microbiology) in a space to treat the wastewater. These methods include activated sludge that uses large tanks, trickling filter which the wastewater flows through a tank with media, rotating biological contactors (RBCs), in which wastewater flows through a tank that contains a big wheel that rotates in the tank, and natural biological treatment (such as a lagoon). In all cases, there are biological-chemical reactions that occur. The most common biological-chemical reactions are nitrification (the conversion of ammonia to nitrates by bacteria) and denitrification (the conversion of nitrates to nitrogen gas by bacteria). Refer to *Advanced Waste Treatment* for various constituent removal requirements.

3-7 ACTIVATED SLUDGE.

The activated sludge process is a process in which wastewater treatment plants have one or more tanks filled with the microbiology in suspension with water. The bacteria water mixture is known as mixed liquor suspended solids (MLSS) and flows through the tanks to a clarifier, where it settles at the bottom and thickens slightly. The settled solids are then collected and pumped back to the biological process tanks. After the settled solids are pumped and returned to the process, its name is changed to return activated sludge (RAS). A portion of the settled solids is removed from the process and thickened or dewatered for disposal. The portion of the settled solids that is removed is called waste activated sludge (WAS).

Some treatment plants use two or more tanks in which all the activated sludge is processed. These tanks are called sequencing batch reactors (SBRs). SBRs allow a portion of the wastewater flow to enter them and then run all the activated sludge process on the single tank while another tank is filling. When the process is complete, the SBR drains the supernatant (treated water) before filling again to repeat the process.

3-7.1 Activated Sludge Operation.

The operation of the activated sludge process is complex and requires the most monitoring and adjustment in the wastewater treatment process. Any changes that are made in the activated sludge system take long periods of time (days to weeks) to see the full effect of any changes due to the growth rates of the microbiology in the activated sludge process. Operators must make small changes to the activated sludge system and wait some amount of time prior to making another change to see the effects of the change before making another. The amount of time that the operator will wait depends on the change made and hydraulic, organic, and nutrient loading. Changes, such as dissolved oxygen (DO) levels, can be seen within 1 hour of the change, whereas a change to the amount of WAS removed can take weeks to see the full effect of the change.

Refer to *Advanced Waste Treatment*, Chapters 5 and 6 for additional guidance on phosphorus and nitrogen removal.

3-7.2 Activated Sludge Process Control.

Process control in the activated sludge process is done to maintain and maximize the treatment of the wastewater to remove the various constituents as efficiently as possible. The removal of BOD_5 and nitrogen from the wastewater are only accomplished by the microbiology, whereas the phosphorus can be removed by both the microbiology and chemicals. Water temperature is an important factor to monitor and adjust in the wastewater treatment plant. As temperature decreases, the biological activity of the mixed liquor also decreases. Inversely, as the temperature increases, so does the biological activity of the mixed liquor. Nitrifying bacteria are only active between 4 and 40 ˚C.

3-7.2.1 SBR Process Control.

Review the timers for the process to ensure that the treatment goals are met. There may be adjustments that operators can make to the timers to improve the process, but this may affect the amount of wastewater that the facility can treat per day.

3-7.2.2 Chlorination.

It may become necessary to chlorinate the activated sludge to control unwanted microorganisms, such as filamentous organisms, and for sludge bulking events. In general, the range of dosage is 2 to 3 mg/L of chlorine per 1,000 mg/L of mixed liquor volatile suspended solids (MLVSS) in the aeration tanks. In severe cases, dosages up to 8 to 10 mg/L of chlorine per 1,000 mg/L of MLVSS in the aeration tanks have been required to be effective in controlling the bulking. The result of chlorination is often a turbid effluent since the nitrifiers are particularly affected by the chlorination. It is common for the chlorination of the activated sludge to last several weeks. Complete a daily microscopic exam during chlorination. Once the filamentous growth begins to decrease, gradually reduce the amount of chlorine feed to reduce the toxicity to the nitrifiers and re-establish the effluent quality.

3-7.2.3 Return Activated Sludge Pump.

Run the RAS pump (pump out of the clarifier) to keep the sludge blanket (thickened mixed liquor) between 1 and 2 feet in thickness in the clarifiers. This allows the RAS to be a thicker concentration. If the WAS is removed from the RAS, it reduces the amount of polymer needed for sludge thickening and keeps the sludge blanket low enough to prevent a hydraulic surge from washing it out in the effluent. The normal flow rate of the RAS pump is between 40 and 60% of influent flow on conventional activated sludge systems and 100 to 150% on extended aeration systems.

3-8 AEROBIC AND ANAEROBIC ZONE TREATMENT.

Every activated sludge wastewater treatment plant has an aerobic tank DO above 1.0 milligrams per liter [mg/L] in which oxygen is introduced by a mechanical aerator or a blower pushing air through air diffusers at the bottom of the tank. To remove BOD_5 and convert ammonia to nitrate, the DO level must be between 1.0 and 2.0 mg/L to ensure that enough oxygen is being provided to allow for the complete oxidation of the ammonia and BOD_5. This tank or portion of the tank is known to be “aerobic.” The size, detention time, temperature, and sludge age are the key factors in determining if an aerobic zone will oxidize BOD_5 and nitrify ammonia. If the wastewater treatment plant is designed to remove nitrogen, the plant will contain a pump near the end of the aerobic tank to pump MLSS that contains nitrates to the anoxic zone, which is normally at the beginning of the activated sludge process. In the portion of the tank where nitrate is being converted to nitrogen gas, the DO level must be below 0.5 mg/L, with sufficient BOD_5 and alkalinity available to complete the conversion. This tank or portion of the tank is known to be “anoxic.” In some wastewater treatment plants, there may be two anoxic zones. The first is where a majority of the denitrification occurs, but the second, which is after the aerobic zone, is used to remove any remaining nitrates to get to low total nitrogen levels. It is common to have to feed a supplemental carbon source into the second anoxic zone. This carbon source can be methanol, a glycerin product, or another preparatory substance. Review and understand the amount of BOD_5 that is in the carbon source and dose it appropriately to remove the nitrates without exceeding the operating NPDES permit requirements for BOD_5.

In some wastewater treatment plants, there is a tank or portion of a tank that is “anaerobic.” Anaerobic means that there are no nitrates in the portion of the tank and that DO is very close to 0.0 mg/L. In treatment plants that have an anaerobic zone, the activated sludge has certain bacteria in it that release phosphorus in the anaerobic zone but absorb more than they release in the aerobic zone. This allows for biological removal of phosphorus from the wastewater.

3-8.1 Mixer Operation.

In both the anoxic and anaerobic zones of the biological process, there are mixers that must be in operation at times to keep the MLSS from settling to the bottom of the tank. The mixers also allow the MLSS to move throughout the water, encountering various constituents and thus improving the biological process efficiency.

3-8.2 Clarifier Operation.

The MLSS flows out of the biological tanks into a clarifier. The clarifier is a tank that includes a continuously running mechanical scraper or chain-flight system that pushes the settled solids to a sump. The settled solids are continuously removed from the sump by the RAS pumps and pumped back to the biological tanks. The clarifiers also collect any remaining scum from the surface of the water. Collect and disposed of to prevent it from flowing out of the clarifier and into the clarifier’s effluent where it may cause an Operating NPDES permit violation by interfering with the disinfection process or by changing a water characteristic above the allowable limits. In some WWTP processes, the scum is sent to the digester for processing.

Periodically remove some of the settled solids from the process as WAS. By removing some of the mixed liquor from the biological tanks, the operator can promote growth in the biological tanks and remove old and unhealthy microbiology and any non-organic materials from biological process.

3-8.3 Nitrogen Removal Process.

In the clarifiers and the aerobic portion of the biological tank, there are pumps (internal recycle) that are used to help in the nitrogen removal process. These pumps and the

RAS pump return nitrates to the anoxic zone to allow denitrification to occur. Run the internal recycle pumps the design portion of the influent wastewater flow. A total recycle flow for denitrification of around 400% of influent provides the most denitrification with the lowest energy usage. After 400% recycle flow, the amount of nitrogen removed is significantly reduced.

3-8.4 Trickling Filters and Rotating Biological Contactors.

Trickling filters and RBCs operate similarly to each other to treat the wastewater. Trickling filters spray the wastewater over the surface of the media where the biological mass grows to treat the wastewater, whereas the RBC rotates large wheels of media with the biological mass on it into the wastewater flow to treat the wastewater. In trickling filters, the media can be either natural (such as stone or coal) or plastic, whereas the RBC media are always plastic. After either a trickling filter or RBC, a clarifier is used to capture any of the biological mass that is removed from the media.

Refer to *Operation of Wastewater Treatment Plants*, Volume 1, Chapters 6 and 7 for additional guidance.

3-8.4.1 Operation.

Trickling filters and RBCs are relatively simple in their operation. Run the trickling filters and RBCs at their design hydraulic and organics loading. Failure to do so will overload the trickling filter or RBC and cause the biomass to be scoured off the media and possibly cause an NPDES permit violation. The clarifiers that follow both the trickling filters and RBCs must periodically have the sludge pumped out for disposal.

Trickling filters do not normally have any mechanical equipment to make the distribution arm move as this is accomplished by the force of the wastewater exiting the distribution arm on to the media. To improve performance, trickling filters may have aeration blowers that either blow air into the bottom of the media or draw air through the top to aid in providing oxygen to the biomass.

3-8.4.1.1 Rotating Biological Contactor.

RBCs must always have their drive shaft running to turn the media to provide treatment to the wastewater. RBCs may have additional aeration to increase the efficiency of the wastewater treatment process.

3-8.4.2 Process Control.

There is little process control in trickling filters. RBCs have some adjustments that can be made to improve the treatment of the wastewater. RBCs can have their zone sizes changed, or wastewater can be step fed into different zones, which can allow increased treatment of the wastewater. RBCs also may be able to increase the speed and/or direction of the drive shaft to allow more oxygen to be introduced into the zones for increased treatment. Additional aeration can be used to increase the treatment efficiency of the units. The aeration system provides additional oxygen to the biomass to treat the wastewater.

3-9 NATURAL BIOLOGICAL SYSTEMS.

Natural biological systems include ponds (also known as lagoons) and land application. In both situations, the constituents in the wastewater are removed by natural occurring bacteria and require little to no operator intervention to maintain the treatment process.

Refer to *Operation of Wastewater Treatment Plants*, Volume 1, Chapter 9 for additional guidance.

3-9.1 Pond Operation.

Ponds have many factors that can affect their operation. Refer to *Operation of Wastewater Treatment Plants*, Volume I for additional guidance.

3-9.1.1 Oxygen Introduction.

Ponds use algae to provide oxygen to the bacteria in the pond through photosynthesis. Along with the algae, wind and waves also introduce oxygen to the pond to promote the growth of bacteria to treat the wastewater. In every pond, there are locations with little DO. Do not try to aerate every portion of a natural pond.

In some ponds, there is a mechanical method of providing the air to the pond, thus, increasing the amount of DO to the pond. Operate the aeration equipment as long as possible to achieve the best treatment results.

3-9.1.2 Operating Level and Testing.

Keep ponds at the same operating level to ensure that the level of treatment is adequate throughout the year. The level must be high enough to ensure that vegetation will only grow on the edge of the pond, typically 3 feet (900 mm). When allowing wastewater into ponds, the amount of water released into each pond in operation must be equal to ensure that no single pond is overloaded. If the pond is designed to work in a batch operation, the pond must be allowed to discharge only when it has the highest quality effluent.

Test the pond for DO, pH, and temperature at least twice per week to determine if any action is needed to improve the pond’s effectiveness and comply with operating NPDES permit requirements.

3-9.2 Land Application.

Land application of wastewater is a simple method of treating the wastewater with little operator action. The amount of wastewater pumped on the land is determined by the soil properties. Ensure that the amount of wastewater pumped on to the land does not exceed the permitted amount, as this may cause contamination of the groundwater.

3-10 DISINFECTION.

Provide disinfection of the treated effluent from wastewater treatment facilities to reduce the risk of human exposure to pathogens into receiving water bodies. Human pathogens of greatest concern are bacteria, viruses, and parasites. The most prevalent methods of disinfection include ultraviolet and chlorine disinfection. Additional methods, such as peracetic acid (PAA) and ozone addition, are used less frequently but are also discussed.

Refer to *Operation of Wastewater Treatment Plants*, Volume 1, Chapter 10 for additional guidance.

3-10.1 Disinfection Operation.

The operation of the disinfection system is to either kill or inactivate pathogens while minimizing cost and protecting the environment. The ultraviolet and chlorine disinfection systems operate very differently to achieve the disinfection of the treated water.

Evaluate bulk chemical purchases and onsite storage chlorine disinfection and dechlorination products for "shelf-life degradation" for the proper onsite storage size to be selected. This will optimize the expected shelf life of these types of products.

Maintain an adequate amount of chemicals in the storage tanks to ensure that pump suctions remain flooded. Order the bulk storage tanks chemicals in time to ensure that the bulk tanks are not drained before the delivery occurs. The amount of advanced time depends on delivery lead time and includes additional time for a short delay in delivery. Determine the chemical usage rate such that at the end of the season there is little chemical left and/or test the chemical prior to use to determine the actual concentration if using the chemical during the next season.

3-10.2 Ultraviolet.

The use of ultraviolet (UV) light for disinfection arose from concerns over the storage, handling, and water quality impacts of traditional chlorine disinfection. Ultraviolet light is a form of invisible light radiation. The use of UV light on pathogens in the wastewater stream will inactivate them, making it impossible to replicate. The intensity of the UV radiation is measured at a wavelength of 253.7 nanometers. The flow, UV transmittance (UVT), and UV intensity are continuously monitored to ensure that the correct dose is achieved.

Monitor process control parameters to ensure the effectiveness of the UV light disinfection, include UVT, design dose, wastewater quality, age of the UV lamps, and iron concentration. The UVT, which is impacted by both suspended and dissolved matter, is measured by the percentage of UV light intensity not absorbed after passing through 1 centimeter (cm) of water column. The lower the UVT, the lower the intensity of the light reaching the pathogens, which will result in less effective disinfection. The presence of suspended solids can negatively impact UVT as the solids can bind with the pathogens and provide a barrier between them and the UV light. Run the UV system in automatic control. This will allow the UV system to adjust the number of UV lamps and their intensity to account for changes in the wastewater flow and the changing UVT of the treated wastewater. The equation to determine the UV dose is shown below.

Equation 3-4. UV Dose

$$\boldsymbol{UV_{dose} = (I_{UV}) \times t}$$

Where:
UV_{dose} = UV dose (millijoules/cm^2)
I_{UV} = UV intensity ((milliwatts)/*cm^2)*
t = time (seconds [sec])

3-10.2.1 Impact of Ferrous Salts and UV Lamp Age.

The use of ferrous salts in wastewater treatment may also impact the performance of UV disinfection. Ferrous salts, which are often used for enhanced coagulation and sedimentation, can absorb invisible UV light, lessoning the effectiveness of UV disinfection. The age of the UV lamp has an influence on the intensity of the UV radiation. Monitor lamp output to determine lamp age. Store an adequate supply of backup lamps the facility if an older lamp needs to be changed out or in the case of lamp breakage.

3-10.3 Chlorination.

In chlorine disinfection, a chlorine solution is fed into the wastewater stream at a known flow rate. The solution is then mixed thoroughly for a predetermined contact time. The mechanism of disinfection through chlorination is the oxidation of the cellular material. Chlorination compounds include chlorine gas, liquid hypochlorites, and chlorine dioxide, which is used less commonly in wastewater applications.

These reactions are both temperature and pH dependent. The hypochlorite solutions form a weak hypochlorous acid, which dissociates to form an equilibrium of hypochlorous acid and hypochlorite ion. When pH is above 8.5, the equilibrium approaches 100% dissociation, and when the pH is below 6.0, the solution approaches 100% HOCl. Between pH of 2.0 and 6.0, chlorine exists predominately at HOCl. Chlorine gas is predominate in pH below 2.0. At pH above 7.8, hypochlorite ions persist.

3-10.3.1 Chlorine Dosing Equipment.

Run the chlorine dosing and dechlorination equipment in automatic control based on a desired free chlorine residual in the chlorine contact basin. This will allow the controls system to adjust the chlorine feed to maintain the setpoint based on changes in flow and water quality. Check the chemical feed pump's actual stroke volume against the displayed setting for volumetric accuracy.

3-10.3.2 Process Controls.

Important process controls that play an important role in any chlorination method include detention or contact time, chlorine residual, oxidation reduction potential, indicator bacteria results, and handling of the chlorine containers or cylinders. The actual amount of chlorine present in each chlorine disinfection solution will vary. Bulk delivery sodium hypochlorite is typically commercially available in a solution containing 15 grams per liter (g/L) (15%) as available chlorine. As sodium hypochlorite ages, its solution strength goes down and will stabilize at around 5 g/L (5%). Factors that affect the speed at which sodium hypochlorite degrades are sunlight, temperature, and atmospheric pressure. Due to this degrading property of sodium hypochlorite, operators must check the strength of the solution to determine the correct feed rate.

In systems that use sodium hypochlorite or calcium hypochlorite, operators must rotate pumps regularly to ensure pump operation and to remove any chlorine gas that has degassed from solution. As part of the pump operation, run the pumps at various speeds to ensure that the pumps are not gas bound.

3-10.3.3 Chlorine Residual.

Chlorine residual is comprised of free, combined, and total chlorine. Free and total chlorine are often the two parameters that are monitored in the effluent line. Combined chlorine consists of both chloramines as well as other chloro-organic compounds that form by the reaction of chlorine with ammonia and organic compounds present in the effluent. A chlorine demand exists in all wastewater effluent. The chlorine demand is defined by the amount of chlorine that is consumed or converted to other less active forms of chlorine by matter present in the wastewater. Examples of substances in wastewater that may consume chlorine include ammonia compounds, organic materials, ferrous iron and some sulfur compounds. Free chlorine residual is what exists after the breakpoint has been achieved. The total chlorine residual includes both the combined and free chlorine present in the effluent, but always test chlorine concentration for process quality assurance.

3-10.3.4 Dechlorination.

The presence of chlorine in high enough concentrations can be toxic to fish and other aquatic life. Common chemicals used for dechlorination include sulfur dioxide (SO_2), sodium metabisulfite ($Na_2S_2O_5$), and sodium bisulfite ($NaHSO_3$). Proper dosage is critical to produce a non- detectable chlorine residual. On a mass basis, 0.9 parts sulfur dioxide (or 1.46 parts $NaHSO_3$ or 1.34 parts $Na_2S_2O_5$) is required to dechlorinate 1.0 part residual chlorine. In practice, approximately a one- to-one ratio is used.

Three of the most important parameters that must be monitored and controlled for adequate dechlorination to occur are mixing efficiency, chlorine residual, and contact time. Mixing allows the chlorine to get mixed thoroughly into the water column to disinfect the water prior to discharge, whereas the contract time is required to provide adequate time to allow the chlorine to disinfect the water.

3-10.4 Ozone.

Ozone can be used to disinfect the treated wastewater. Ozone disinfects by destruction of the cell wall, reaction of radical byproducts of ozone decomposition, and damage to the nucleic acids inside the cells, thus, preventing cell replication. Ozone is provided in concentrations of 1 to 4% using dry air and 3 to 10% using pure oxygen. Ozone is created on site. Ozone has the same operating requirements as chlorine in that it requires mixing into the water column and detention time.

Collect ozone samples to determine the ozone percentage sufficient to treat the wastewater effluent. To prevent equipment damage, inspect the ozone cooling water system to ensure that it is operating correctly.

3-10.5 Bromine Chloride and Chlorine Dioxide.

Bromine chloride and chlorine dioxide can also be used for disinfection as they perform the disinfection in the same methods as ozone. The bromine chloride is fed as a gas into the wastewater, whereas the chlorine dioxide is created on site and fed into the treated wastewater flow as a liquid. Bromine chloride and chlorine dioxide have the same operating requirements as chlorine in that they require mixing into the water column and detention time.

3-10.6 Peracetic Acid.

PAA is a liquid solution of acetic acid and hydrogen peroxide. PAA is normally between 12 and 15% solution strength and has a long shelf life; therefore, it does not change solution strength as quickly as sodium hypochlorite. PAA is normally dosed under 4 mg/L, which meets most bacteria effluent limits and has a residual of less than 1 mg/L, which is the EPA established limit.

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CHAPTER 4 SOLIDS MANAGEMENT

4-1 INTRODUCTION.

The treatment of wastewater creates sludge. This sludge contains organic material, inorganic material, and various types of bacteria, which when mixed are called solids. All this material is usually treated at the same location as the wastewater treatment plant. To aid, in the storage, transportation, and method of disposal wastewater treatment plants thicken, reduce the amount, and dewater the solids prior to being removed from the wastewater treatment plant.

Refer to *Operation of Wastewater Treatment Plants*, Volume 2, Chapter 12 for additional guidance.

4-2 MAINTENANCE.

The maintenance requirements for solids treatment varies, depending on the type of equipment used. Recommended maintenance should be completed by operators and maintenance staff to maintain all warranties and performance guarantees. Refer to the equipment manufacturers operation manual and operate solids treatment equipment in accordance with manufacturers recommendations and all NPDES permits.

4-3 DIGESTER OPERATING CHARACTERISTICS.

Refer to WEF MOP 11, Table 30.7 for typical characteristics of an aerobic digester. The values represent operating parameters that will be monitored at the plant. They will be able to monitor trends and predict potential digester upsets.

4-4 SLUDGE VOLUME REDUCTION.

Sludge volume reduction is intended to remove water from waste solids or biosolids and is also known as thickening or dewatering. It is desirable to thicken/dewater the sludge to reduce the process volume and therefore the costs associated with pumping, equipment sizes, and disposal.

4-4.1 Operation.

There are multiple methods to reduce the sludge volume, including, gravity thickening, mechanical thickening, mechanical dewatering, and natural dewatering. The difference between thickening and dewatering is the amount of water that is removed from the sludge. Thickened sludge normally contains between 1 and 8% solids, whereas dewatered sludge normally contains between 15 and 30% solids. Due to the variation in the different systems components and operations, operators must refer to the vendor equipment manual for proper operation of their system.

4-4.1.1 Gravity Thickening.

Sedimentation is the driving force for gravity thickeners through the acceleration of gravity. Gravity thickeners are typically circular but may also be rectangular. Depending on the solid being thickened, the nature of the flocculent and concentration of the solid will vary.

The rake or scraper mechanism is used to deposit the thickened sludge to the underflow. The drag is created between the thickened sludge and the rakes to generate a load on the raker drive. If this load becomes too high, an alarm notifies the operator of an overload caused by the sludge being too thick or a jam in the rake. The underflow rate is then increased to mitigate the problem, although this reduces the cake blanket.

4-4.1.1.1 Sludge Septicity.

A common potential problem with gravity thickeners is the sludge septicity. This is a problem if the sludge is floating, solids are being carried to the overflow, and/or there are foul odors and reduced sludge outflow concentrations. Sludge septicity is caused from storing the sludge too long in the thickener, either because the thickened sludge pumping rate is too low or the thickener overflow is too low. Depending on the cause of the problem, increase the pumping rate, increase the influent flow to the thickener, or incorporate dissolved oxygen via aeration. The addition of chlorine or hydrogen peroxide can temporarily solve septicity.

4-4.1.1.2 Sludge Pumping Rate.

Determine and monitor the pumping rate of the thickened sludge. If the wastewater treatment plant pumps WAS to the primary clarifiers and/or to the gravity thickeners, increase the amount of pumping to prevent the sludge from denitrifying in the gravity thickener or allowing it to stay in the gravity thickener so long as to allow for microorganisms to release phosphorus into the supernatant. If the sludge denitrifies in the gravity thickener, the nitrogen bubbles can cause the sludge blanket to rise to the surface and be washed out with the supernatant, which will cause an increased organic loading to the biological treatment system. If the sludge is allowed to settle in the gravity thickener and phosphorus is released, this can cause an increase phosphorus loading on the biological system and/or increase the amount of chemical usage to precipitate the phosphorus in the wastewater treatment plant. If either of these occur, it is possible the operating NPDES permit may be violated.

4-4.1.2 Mechanical Thickening.

Mechanical thickening systems include dissolved air flotation, gravity belt, centrifuge, and rotary drum thickening. These thickening methods require two or more pieces of equipment to accomplish the thickening process.

4-4.1.2.1 Dissolved Air Flotation Thickening.

Dissolved air flotation (DAF) thickeners are comprised of a flotation unit and a saturator. The flotation unit is utilized to divide the solid phase from the liquid phase and the saturator dissolves air into the compressed water. A reducing valve allows the pressure-saturated water to flow into the flotation unit and become supersaturated with the air. The wastewater feed is introduced downstream of the reducing valve. Small bubbles from the saturated feed are formed and attached to the wastewater particles, forming bubble-particle agglomerates. Then, mixing occurs to make sure chemical dispersion occurs. The buoyancy in the flotation unit causes the agglomerates to float and accumulate at the water level. The solids are removed by scrapping, and the solids concentration is increased from draining the interstitial water from the float.

Typically, DAF units are operated continuously but may be operated with short shutdown periods or only during certain hours of the day. When the units are not running continuously, a feed sludge holding and mixing tank can be utilized. Minimize the entrance velocity to the flotation unit to avoid shearing of flocculated sludge particles. The float skimmers are placed above the water level and the speed is set to maximize the solids concentration. Set the controlling pressure at the lowest value that allows optimal operation but not below 50 pounds per square inch (psi). There are three typical parameters that are monitored for DAF units: solids and hydraulic loading rates, air-to-solids ratio, and air volume and pressure.

- The solids loading rate is the weight of solids added (including recycle flow) to the unit divided by the flotation surface area. The efficiency of the DAF will decrease if the solids loading rate is exceeded. The typical values for WAS conditioned with polymer is 2 to 4 lb/square foot (ft^2) per hour (h). The hydraulic loading rate is the solids feed rate and recirculation rate divided by the flotation surface area. The rise rate, subnatant solids concentration, and overall efficiency are affected by the hydraulic loading rate. The peak hydraulic loading rate of WAS using polymer is 2.5 gallons per minute (gpm)/ft^2.
- The air-to-solids ratio is the mass of air divided by the mass of solids added to the DAF. As the air-to-solids rate increases, the float concentration increases. The typical range of air-to-solids ratio is 0.02 to 0.04 lb/lb.
- The air pressure in the DAF unit determines the size of air bubbles. The air pressure is an indicator of whether the DAF has good “float.” If the pressure is increased, the rise rate of solids decreases. An air flotation test can be conducted to monitor conditions in the DAF such as recycle rate, solids loading rate, air pressure and others.

4-4.1.2.2 Gravity Belt Thickeners.

Gravity belt thickeners take conditioned sludge and release additional water, utilizing gravity drainage on a porous belt that is typically horizontal. To separate the solids from the free water, chemical conditioning occurs, often by injecting the chemical through an injection ring into the sludge. The sludge is then collected in a retention tank where the velocity is reduced to allow solids to float to the top and flow by gravity to the moving belt. As the sludge moves along the belt, plows are used to turn over the solids and allow filtrate to drain. The sludge accumulates at the end of the belt before discharging to a dam or adjustable ramp, allowing further water removal. The belt is cleaned by a scrapper and high-pressure wash water spray system.

Many factors affect the functioning of the gravity belt thickeners. The proper polymer needs to be selected to achieve optimal thickening. The recommended solution range for polymers to condition sludge is 0.05 to 2% by weight for dry polymers, 0.1 to 0.5% by volume for emulsion/dispersion polymers, and 1 to 3% by volume for mannich polymers. If the concentration of polymer is above this range, it could cause the polymer to not mix properly and deteriorate the thickening process. Sludge that settles more easily (higher percent solids) will require less polymer. Only inject the minimum amount of polymer required to thicken the sludge because the extra will go out the drain. The retention time is the amount of time required for the polymer to react with the sludge and flocculate. The ideal retention time is ideally 15 to 20 seconds. If too much time is allowed, the flocs will be too large, and with a short time, the flocs will be too small. The belt speed can be adjusted to go slower or faster and adjusted in the field to reach the optimal speed. When the belt is traveling slower, there is more time for the cake to dry. When the belt is traveling faster, there is a larger amount of throughput or a quicker process time.

4-4.1.2.3 Centrifuge Thickening.

Centrifuges can thicken and dewater sludge through the same piece of equipment by only changing the weir setting. The solids are separated from the liquid through sedimentation because of the differences in density. The centrifuge generates thousands of times the acceleration of gravity through centrifugal force to separate the solids even further.

Centrifuges rely on constant feed to quality. This can be achieved by taking centrifuges on or offline as the production increases or decreases. Typical problems occur from varying primary and secondary sludge concentrations or septic feed. Centrifuges are designed for flow conditions of 25 to 1,500 gpm. The bowl speed is set by the manufacturer and rarely changed. The speed can be adjusted to determine if the set speed is operating optimally.

4-4.1.2.4 Rotary Drum Thickening.

Rotary drum thickening consists of drums of varying sizes with wedge wires, perforated holes, stainless steel fabric, or a combination of stainless steel and synthetic fabric to obtain the solids. The drum is rotated at 5 to 20 revolutions per minute by a variable-speed drive unit. Sludge enters the drum, and the water is drained through openings in the drum to an underdrain. The sludge is transported through the drum by a continuous internal screw or diverted angle to a discharge chute. The drum is periodically cleaned by wash water to ensure the high solids capture and dewatering efficiency.

Four process variables are utilized for effective thickening: sludge feed rate, polymer feed rate, pond depth, and drum speed. The pond depth is controlled by the angle of the drum, which can be adjusted to up to 6˚ from the horizontal. A typical starting range is between 2 to 3˚. If the incline increased, the solids are dryer but the capacity of the drum decreases. If the incline is decreased, the capacity increases but the solids are wetter.

4-4.1.3 Mechanical Dewatering.

Mechanical dewatering includes belt filter presses, centrifuges, and vacuum and pressure filters.

These processes may require polymer to enhance the dewatering of the solids from the liquid. The polymer dosage determines the amount of polymer needed per amount of feed solids. The polymer dosage equation is below.

Equation 4-1. Polymer Dosing

$$Dose_{polymer} = \frac{C_{polymer}}{C_{feed}} \times \frac{Q_{polymer}}{Q_{feed}} \times 2000\frac{lb}{ton}$$

Where:
$Dose_{polymer}$ = polymer dose (lb/ton)
$C_{polymer}$= polymer concentration (%)
C_{feed} = sludge feed solids concentration (%)
$Q_{polymer}$ = polymer feed rate (gpm)
Q_{feed} = sludge feed rate (gpm)

1-1.1.1.1 Belt Filter Press.

The operation of a belt filter press occurs in three zones: the gravity drainage zone, low-pressure zone, and high-pressure zone. The gravity drainage zone is where the sludge is thickened from the water draining out through movement on a porous belt. Then, low-pressure is applied to the feed to remove more water and create a biosolids matrix. This matrix is then passed through decreasing rollers to create a high-pressure zone to further filter the water.

The capture rate for the belt filter press must be 95% or higher and is therefore not a parameter that can be changed. Cake dryness, loading, and polymer dosage directly affect each other, and changing one variable affects the performance of the other. For example, if dryer cake is desired, the polymer dosage rate is increased, or the loading rate is decreased. Most belt filter presses have an inline mixing system to inject the polymer. The amount of polymer and intensity of mixing is adjusted based on the sludge and polymer being used.

4-4.1.3.2 Centrifuge Dewatering.

A dewatering centrifuge works like a thickening centrifuge. The capture rate for the centrifuges must be 95% or higher and is therefore not a parameter that can be changed. Cake dryness, loading, and polymer dosage directly affect each other, and changing one variable affects the performance of the other. For example, if dryer cake is desired, the polymer dosage rate is increased, or the loading rate is decreased. Centrifuges prefer warmer temperatures of up to 60 ˚F to operate most efficiently. The hydraulic loading rate is not as limited for centrifuges compared to filtration devices because thinner feed sludge does not impact the performance as much. The solids loading with more biosolids will have a lower residence time and wetter solids. The conveyor torque and speed, the bowl speed, the weir setting, and the polymer addition are additional mechanical variables that affect the operation. The conveyor differential speed is adjusted to control the cake removal rate. Decreasing the speed causes the cake to become dryer because the sludge blanket in the centrifuge builds up. Increasing the speed causes a lower height of the sludge blanket and increases the biosolids removal. The conveyor torque increases as the cake becomes drier because the viscosity increases. The speed is controlled automatically and keeps a constant torque value. The bowl speed is directly related to the process performance with an increase in speed equal to an increase in process performance. However, centrifuges are typically operated at lower speeds to avoid excessive wear, vibration, and noise. Evaluate the weir setting every 2 years to determine if it is still at the optimal setting.

4-4.1.3.3 Vacuum and Pressure Filters.

Vacuum and pressure filters utilize inorganic chemical conditioning with, most commonly, lime and ferric chloride. These chemicals are used to increase the ability to filter the sludge and remove the sludge from the filter media. Lime has a larger range of effective dosage than polymers. The solids capture rate is ideally 99% for a conventional filter press. The feed pressure falls between one of the two ranges: 95 to 130 psi or 200 to 250 psi. The filter media varies, depending on the application. Typically for dewatering organic biosolids, polypropylene filaments are used with 2.3 to 3.4 cubic meters (m^3)/min porosity. Refer to Appendix A for the typical conditioning doses of ferric chloride and lime.

The filter press needs to be checked periodically prior to initiation of the automatic filter cycle. Once sufficient feed stock has accumulated and the chemical solution is prepared, a high feed rate is initially required to completely fill in the press in a short time until the system reaches 55 psi. Then, only a small high-pressure pump is used to continue feeding to a maximum pressure of 95 to 130 psi. The cycle stops once a set cake concentration is obtained.

4-4.1.4 Natural Dewatering.

Natural dewatering occurs through air-drying by natural evaporation or induced drainage. Typically, anaerobic or aerobic digestions are utilized to stabilize the biosolids prior to air-drying. Air-drying may be more energy-efficient, and the systems are less complex compared to mechanical dewatering. Although, they can require a large amount of land and more labor to remove the cake. The natural systems are most common for small and rural treatment facilities where there is warm weather. There are multiple types of beds, including, reed beds, sand beds, vacuum-assisted beds, wedge-wire beds, and paved beds. They all have similar process variables such as being affected by the weather, chemical conditioning, feed solids, system design, and residence time. Since all depend on the weather, backup storage or treatment needs to be provided during low production. Multiple beds are required because cleaning requires the beds to be taken out of service.

4-5 SLUDGE DIGESTION.

Sludge digestion is a biological process intended to decompose organic solids into stable substances to reduce the amount of sludge and decrease the number of disease-causing microorganisms. Digester failure can make it harder to dewater the digested sludge and cause the plant to not meet sludge disposal requirements. Therefore, it is important to keep the sludge digestion processes functioning as effectively as possible.

4-5.1 Sludge Digestion Operations.

Sludge digestion at a wastewater treatment plant occurs by aerobic or anaerobic digestion. Both require a source of elemental oxygen, but anaerobic digesters prevent gaseous oxygen from entering the system.

4-5.1.1 Aerobic Digestion.

For effective operation, uniformity and consistency of the incoming sludge is important; otherwise, the digester performance may be inhibited and lead to foaming. It is ideal to feed the digester continuously, 24 hours per day, but if this is not possible, develop a consistent feeding plan.

4-5.1.1.1 Short Circuiting.

To prevent short circuiting, the withdrawal of solids occurs immediately after feeding raw sludge. Solids are withdrawn concurrently with the inflow if there is a surface overflow. At least once per day, withdraw solids from the digester to avoid a drop in the active microorganism population.

4-5.1.1.2 Mixing System.

Scum can accumulate on the digester liquid surface if the mixing system is not properly operating. A properly designed and operated mixing system keeps the scum mixed with the digester contents.

4-5.1.1.3 Addition of Oxygen.

Add oxygen to the digester while feeding and mixing the aerobic digester to promote the digestion process of the sludge. Target DO in the digester to a range of 0.3 to 3.0 mg/L.

The digestion process lowers the vector attraction of pathogens. EPA requires a 1.5 mg/L/g standard oxygen uptake rate at 20 ˚C for adequate vector reduction in vector attraction.

4-5.1.1.4 Temperature Requirements.

Aerobic digesters require warm weather to complete the digestion process. Normally, aerobic digesters are not provided heat from any other source other than the environment. If the digester temperature drops below 10 ˚C, digestion will not occur.

4-5.1.2 Anaerobic Digestion.

Anaerobic digestion works to stabilize organic material through a multistage biochemical process. The anaerobic digestion process requires mixing, heating, removing sludge, and feeding raw sludge. Proper mixing of the sludge will create the optimal environmental conditions. The mixing system typically runs continuously.

4-5.1.2.1 Digester Mixing.

There are two types of mixing systems: unmixed digestion and mixed digestion. In unmixed digesters, there is a top layer of scum on the liquid surface and bottom layer of stabilized biosolids and grit with a small area for mixing in between. Unmixed digestion is used for low-rate and standard-rate digesters at small facilities less than 1 mgd.

In mixed digestion, high rate digestion and higher loading rates are achieved by controlled mixing and heating, uniform feed rates, and thickening of digester feed. There are two common types of mixed digestion: mechanical and gas mixing systems. Mechanical mixing includes pumped and impeller-type mixing. Pumped mixing systems have pumps installed outside of the tank, and the mixing nozzles are installed inside the tank to create a flow pattern for complete mixing. Impeller mixing consists of a draft tube containing the impeller with a discharge nozzle into the tank at an angle to cause mixing of the sludge. An impeller, a drive shaft, and a drive are provided with the mixing systems. Most often, the drive shaft is reversible to allow for clearing blockages. Gas mixing systems consist of bottom diffusers, lances, bubble guns, and gas lifters. The central component is the compressor where the moisture and sediment from the gas needs to be removed upstream of the compressor. Flow-balancing manifolds may be required to evenly partition the flow to mixer inside the digester. To prevent a vacuum from being created in the digester when there is low pressure, monitor the pressure with a low-pressure regulator. When the compressor discharge surpasses a set level, the high-pressure regulating valves bypass gas to the suction of the compressor or to storage.

4-5.1.2.2 Digester Feeding.

It is ideal for digesters to be fed continuously 24 hours per day. If this is not possible, keep the feeding schedule continuous and uniform. Feed the digesters a mixture of feeds, such as waste activated sludge and primary sludge. To prevent short circuiting, the withdrawal of solids occurs immediately after feeding raw sludge. Solids are withdrawn concurrently with the inflow if there is a surface overflow. At least once per day, withdraw solids from the digester to avoid a drop in the active microorganism population.

4-5.1.2.3 Digester Covers.

Digester covers, specifically fixed covers, need to be monitored. When sludge is fed or withdrawn, and the tank is full, the inflow and outflow must be equal, or the tank could overpressure and push the cover from its mountings. If sludge is withdrawn without adding more sludge, a vacuum can be created. These obstacles can be prevented by installing safety relief valves, which often develop gas leaks.

4-5.1.2.4 Secondary Digesters.

Secondary digesters are typically utilized at medium and large wastewater plants. The primary digester is used to optimize digestion and is where most of the gas production occurs. The secondary digester may or may not be mixed and/or heated. It may be designed to be mixed and heated when the primary digester is out of service. Secondary digesters without heating can be used as a storage tank, standby primary tank, and a source of seed sludge. For storage vessels, floating or membrane covers work best because they allow for drawdown without creating a vacuum under the cover, which can damage the digester cover and tank walls.

4-5.1.2.5 Digestion Temperature Ranges.

Most anaerobic digestion occurs in mesophilic conditions (32 to 38 ˚C). The biochemical process occurs in one tank and typically as a high-rate process because it is more stable and has a shorter detention time. Volatile solids are reduced by 40% to 60% in the digester to create stable conditions.

Thermophilic digestion is operated at thermophilic temperatures (55 ˚C or higher) and conducted in one or more stages. The goal of thermophilic digestion is to reach greater pathogen destruction, which causes higher volatile solids destruction and lowers retention times. More energy is required compared to mesophilic digestion; therefore, it is important to utilize heat recovery techniques.

4-5.1.2.6 Volatile Solids Reduction.

The following equation can be used to calculation the volatile solids reduction based on the volatile solids in the feed and digester discharge:

Equation 4-2. Volatile Solids Reduction

$$\boldsymbol{VSR, percent = \left(\frac{VS_{feed} - VS_{digested\ sludge}}{VS_{feed}}\right) \times 100}$$

Where:
VSR = volatile solids reduction (%)
VS_{feed} = volatile solids in feed sludge (lb)

$VS_{digested\ sludge}$ = volatile solids in digested sludge (lb)

If the digesters do not have significant grit accumulation, the Van Kleeck equation may be used to calculate volatile solids reduction.

Equation 4-3. Van Kleeck

$$\boldsymbol{VSR, percent = \left(\frac{VS_{feed} - VS_{digested\ sludge}}{VS_{feed} - (VS_{feed} \times VS_{digested\ sludge})}\right) \times 100}$$

Where:
VSR = volatile solids reduction (%)
VS_{feed} = volatile solids in feed sludge (lb)
$VS_{digested\ sludge}$ = volatile solids in digested sludge (lb)

4-5.1.2.7 Digester Gas.

The gas from digesters can be utilized as it contains methane. The digester gas can be used by a boiler that is designed to use the digester gas after it has been conditioned (hydrogen sulfide removed) or on unconditioned digester gas. Digester gas can be used to create power through a turbine, but the gas must be conditioned to ensure that all impurities are removed from the digester gas to prevent damage to the turbines. The digester gas can also be directly burned to the atmosphere through a flare. In general, digester gas systems will always have a flare to ensure that the digester gas is properly disposed of, and it may have one or more other components to transform the digester gas into a useful energy source.

Note: For the Army, AR 420-1 provides further guidance on boiler operations.

Note: For the Air Force, **\1** AFMAN **/1/** 32-1068 provides further guidance on boiler personnel schedule requirements.

4-6 OTHER SLUDGE STABILIZATION METHODS.

In addition to anaerobic and aerobic digestion, there are other conventional ways to stabilize sludge such as composting, lime stabilization, thermal treatment, heat drying, and incineration. These methods are commonly used to reach Class A or Class B levels for beneficial reuse and disposal. These methods are critical to reduce odors or nuisances, reduce level of pathogens, and facilitate efficient disposal or reuse of the product.

4-6.1 Composting.

The most common use of composting is to stabilize raw sludge. Composting is also commonly used to further stabilize digested sludge. For compositing to work, the initial solids content must be between 40 and 50% solids. To obtain this solids level and to raise the carbon to nitrogen ratio, a bulking agent is normally added. The desired carbon to nitrogen ratio is between 26:1 and 31:1. Composting heats the compost pile to 50 to 70 ˚C to destroy most pathogenic organisms.

In a windrow system, the compost piles are turned over daily to aerate the compost pile. This occurs for at least 3 weeks, which must include 3 days at 55 ˚C after which the windrow is then considered ready for use as compost. In systems that the windrow is not turned over, a blower either pulls or pushes air through the windrow to provide oxygen to the interior portion of the windrow.

4-6.2 Lime Stabilization.

Lime stabilization is the process of adding lime to sludge to a pH of 12.0 or more for at least 2 hours. Lime stabilization destroys or inhibits pathogens and microorganisms in the sludge. Lime stabilization can occur on raw primary sludge, WAS, and anaerobically digested sludge. The lime can be added to the sludges either before or after dewatering, although before dewatering is more typical of lime addition. When shutting down the lime system, empty all lime to prevent issues during startup.

In addition to monitoring the pH, the operator must take biological samples every quarter or as required by the operating NPDES permit. Include the organisms as required on the operating NPDES permit for the samples. If none are stated, use indicator organisms, such as fecal coliforms and fecal streptococci.

4-6.3 Thermal Stabilization.

Thermal stabilization kills the microorganisms by breaking apart the cells and releasing the water inside of the cell. Thermal treatment uses heat and steam to raise the temperature and pressure of the sludge.

Note: For the Army, AR 420-1 provides further guidance on thermal processes for sludge.

4-6.4 Sludge Drying.

Sludge drying is used to reduce the volume of sludge being hauled and reduces the number of pathogenic organisms. The sludge is dried by exposing it to hot gases from a furnace. Variables that affect the sludge drying process are:

- Percent solids in the feed sludge
- Ratio of wet sludge to dry sludge
- System operating temperature
- Amount of hot gases that can be used for drying

Note: For the Army, AR 420-1 provides further guidance on thermal processes for sludge.

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CHAPTER 5 CHEMICAL TREATMENT

5-1 INTRODUCTION.

Various chemicals are used at wastewater treatment plants. Chemicals range from sodium hypochlorite which is used for disinfection of the treated wastewater, to polymers, which are used for solids capture in a clarifier or for solids capture on a thickening or dewatering machine. Chemicals can come in gas form (such as chlorine), liquid form (such as sodium hydroxide), or solid form (such as soda ash). Operators must review their facility's O&M manual and the various equipment manuals to fully understand what each chemical is and how it is used at their wastewater treatment plant. Operators must also maintain and review the safety data sheet for each chemical used on site. The safety data sheet provides health and safety requirements for the specific chemical along with the chemical's physical properties and actions to complete if a spill occurs.

Degrees Baumé is used in the chemical industry to measure density of various liquids when ordering onsite chemicals. The Baumé scale is a pair of hydrometer scales with one for liquids with densities heavier than water and one for liquids with densities lighter than water. If the degrees Baumé of a chemical is known, the specific gravity can be calculated. Then, the specific gravity of the chemical can be used to find the actual chemical concentration.

5-2 MAINTENANCE.

The maintenance requirements for chemical treatment varies, depending on the type of chemicals and equipment used. Recommended maintenance should be completed by operators and maintenance staff to maintain all warranties and performance guarantees. Refer to the equipment manufacturers operation manual and operate solids treatment equipment in accordance with manufacturers recommendations and all NPDES permits.

5-3 OPERATIONAL REQUIREMENTS.

Store chemicals in accordance with UFC 3-600-01 and applicable National Fire Protection Association codes and standards. The operation of each chemical system is specific to the individual wastewater treatment plant. At some plants, a chemical, such as a polymer, can be delivered in a liquid ready for use, whereas at larger wastewater treatment plants, the polymer can be delivered in a dry powder, which requires the polymer to be added to water and mixed prior to use. Operators must review their facility's O&M manual and the various equipment manuals to understand how each piece of equipment works to add the chemical to the wastewater treatment process. Several industrial associations, including The Chlorine Institute, The National Lime Association, and The American Chemistry Council provide guidance for operators that can be used for the storage and use of the chemicals.

When loading bulk chemicals, follow the requirements in the spill control plan and applicable standard operating procedures to prevent spills and addition of the chemicals to the wrong chemical storage tank. Use the chemical usage rate and storage volume to determine the amount of the chemical remaining in storage and to see if there is any possible indication of a leak. Report any indications of leaks to the Installation Environmental Program staff. The chemical may be tested prior to use to determine the actual concentration. Chemical that has been stored for use during the next season should be tested to confirm chemical concentrations.

5-3.1 pH Adjustment.

Normally, at wastewater treatment plants, pH is not in need of adjustment for the biological process to occur. The high and low pH chemicals are used for cleaning items such as membranes, UV lamps, and for adjusting pH for chemical odor control systems. The common bulk pH-adjusting chemicals used at wastewater plants are citric acid and sodium hydroxide (caustic soda).

Citric acid can be delivered in either dry or liquid form. Normally, when citric acid is delivered in dry form, it is for small batches where the operator adds the dry acid to a tank to achieve a desired pH. Liquid citric acid is used to create large batch of low pH cleaning solutions. Sodium hydroxide is always delivered as liquid, but it can vary in solution strength of either 25 or 50%.

5-3.2 Indoor Chemical Storage.

Chemical storage rooms may have Heating, Ventilation, and Air Conditioning (HVAC) systems installed. Operators must ensure that all HVAC equipment is operating, to maintain a safe environment and preserve chemical quality. HVAC equipment may maintain temperature, humidity, and ventilation requirements for the chemicals being stored. HVAC systems can also be used to limit the amount of corrosion caused by the chemical vapors in the chemical storage room.

5-3.3 Outdoor Chemical Storage.

Outdoor chemical storage tanks may have tank heaters that are used to prevent freezing. Operators should inspect chemical storage heaters to ensure they are operating during cold weather to maintain the bulk chemical quality and prevent the chemicals from freezing in the storage tank.

Freezing of chemicals can damage equipment and piping, causing chemical leaks. A chemical of specific concern is a solution of 50% sodium hydroxide. The 50% sodium hydroxide solution will freeze at 59 ˚F (15 ˚C).

5-3.4 Cleaning Considerations.

After cleaning with an acid, do not add the low pH cleaning byproduct directly to the biological process as it will have a significant effect on the biological process. Neutralize the acid with a base (to a pH of around 7.0) or dilute the acid with water prior to disposing of it through the wastewater treatment plant. If neither option is possible, add the acidic solution to the wastewater flow slowly, taking long periods of time to add it, thus allowing the influent wastewater flow to dilute it prior to entering the biological process.

5-3.5 Alkalinity Adjustment.

Alkalinity adjustment is typical at wastewater treatment plants. The alkalinity is normally increased in the wastewater to support the nitrification of ammonia in the wastewater. Additionally, alkalinity may need to be adjusted to support the use of chemicals for phosphorus removal.

Alkalinity addition chemicals can come in liquid and dry powder form. The two liquid chemicals used are 50% sodium hydroxide and 62% magnesium hydroxide. Chemicals in solid form are typically dissolved in water to make a slurry. The slurry can then be pumped into the wastewater flow to increase its alkalinity. Lime and soda ash are the two most common chemicals.

5-3.5.1 Chemicals Used for Alkalinity.

Each chemical has specific operating procedures that operators must ensure are correct. The 50% sodium hydroxide solution must remain above 15 ˚C to prevent the chemical from freezing, which will damage equipment and piping. The location where the sodium hydroxide is stored must have its heating system checked regularly. If a tank heater and heat tracing are used on the piping, they must be checked for proper operation. Adjust the carrier water (motive water) to reduce the sodium hydroxide concentration in the carrier piping and to ensure that water velocity is fast enough to minimize the possibility of freezing.

Mix magnesium hydroxide and both soda ash and lime slurries. Magnesium hydroxide must remain constantly mixed to prevent the chemical pump suction from becoming clogged. Soda ash and lime must be mixed into the water to become a slurry.

5-3.6 Coagulants and Phosphorus Removal.

To remove phosphorus by chemical precipitation, various chemicals can be used. These chemicals can also be used to coagulate the suspended solids in the wastewater to increase the clarity of the water. The addition of these chemicals will increase the amount of sludge that is created at the wastewater treatment plant. The common chemicals that are used for phosphorus removal are aluminum and ferric salts.

Refer to *Advanced Waste Treatment*, Chapter 5 for additional guidance on phosphorus removal.

5-3.7 Aluminum Salts.

The aluminum salts come from three chemicals: aluminum sulfide (known as alum), aluminum chloride, and sodium aluminate. Sodium aluminate is the only aluminum salt that comes in a solid and must be dissolved on site. Alum consumes about 0.55 mg/L of alkalinity per every 1.0 mg/L of solution added, whereas aluminum chloride and sodium aluminate do not affect the water alkalinity. The theoretical amount of aluminum needed to remove phosphorus is 2:1 as a molar ratio. Below is the general equation for aluminum reaction to remove phosphorus.

Equation 5-1. Aluminum Phosphorus Removal

$$Al^{+3} + H_nPO_{-4}^{n+3} \leftrightarrow AlPO_4 + nH^+$$

5-3.8 Iron Salts.

The most common iron salt is ferric chloride (known as ferric), which is normally in a liquid form. Other ferrous salts can be used, but they require a pH higher than 8.5 or must be combined with chlorine to change the ferrous iron to ferric iron. Ferric consumes 0.93 mg/L of alkalinity per 1.0 mg/L of ferric added. The theoretical amount of iron ranges from 15 up to 30 mg/L (45 to 90 mg/L of ferric chloride) for every 1 mole of phosphorus. Below is the general equation for ferric reaction to remove phosphorus.

Equation 5-2. Ferric Phosphorus Removal

$$Fe^{+3} + H_nPO_{-4}^{n+3} \leftrightarrow FePO_4 + nH^+$$

On all the coagulants, they start to crystalize at 0 ˚C. Operators must check tank heaters and heat tracing on all the coagulant chemical system to ensure that no equipment damage occurs.

5-3.9 Polymers.

Polymers come in liquid and dry form. They are used for thickening and dewatering sludge but can be used to improve solids capture in a clarifier. Polymers range from cation (positive charge) to non-charge (neutral) and to anionic (negative charge). Some manufacturers also produce polymers that contain both cation and anion in the polymer. Keep liquid polymers in a cool dry location. Liquid polymer will degrade at temperatures higher than 50 ˚C. Keep dry polymers in a dry location to prevent clumping and clogging of piping after being introduced into the dilution water.

Conduct bench testing with a polymer manufacturer to determine the correct polymer and its dosing. As part of the bench testing, determine the correct solution strength to make the polymer, aging of the polymer, and mixing requirements of the polymer. In general, mix the dry polymer for at least 30 minutes at a low speed to allow the polymer to uncoil prior to use.

5-3.10 Oxidizers.

At wastewater treatment plants, oxidizers are used for odor control and control of hydrogen sulfide. The two most common oxidizers used are hydrogen peroxide and potassium permanganate. These chemicals normally are only used during warm weather to reduce odors and prevent the formation of hydrogen sulfide in the pipes and process of the wastewater treatment plant.

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CHAPTER 6 ODOR CONTROL

6-1 MAINTENANCE.

The maintenance requirements for odor control systems varies depending on the type of chemical and biological odor control systems used. Recommended maintenance should be completed by operators and maintenance staff to maintain all warranties and performance guarantees. Refer to the equipment manufacturers operation manual and operate solids treatment equipment in accordance with manufacturers recommendations and all NPDES permits.

6-2 ODOR CONTROL SYSTEMS.

Wastewater, whether it is being collected, treated, or disposed, emits strong odors and potentially other air containments. Odor control is also implemented because of public concern for health and safety and/or intolerable odors. Odors can be treated with microbiology, which uses compounds in the odorous air for an energy source, or with chemicals, which react with the compounds in the odorous air and change the compounds into a non-odorous compound. Some compounds can be adsorbed into activated carbon as the air passes by it.

Refer to *Advanced Waste Treatment*, Chapter 1 for additional guidance on odor control.

6-3 OPERATION.

The operation of both chemical and biological odor control systems are different in their requirements. In both cases, sampling may be used to verify proper operation and verify performance to ensure that the treated air meets applicable permit requirements.

Record all operating data and evaluate any changes and trends in the data collected for each type of odor control system.

6-3.1 Chemical Odor Control Systems.

Operate chemical odor control equipment in accordance with the manufacturer's operation manual. Common setpoints may include pH, oxidation reduction potential, and free chlorine. Operators must ensure that the amount of makeup water supplied to the odor control system is enough to ensure proper operation of the odor control system without wasting a large amount of water. Refer to *Advanced Waste Treatment* for typical oxidant dosages for a chemical odor control system.

For an odor control system that contains activated carbon, monitor activated carbon performance. If the activated carbon shows signs of breakthrough, it must be replaced.

6-3.2 Biological Odor Control Systems.

Maintain the moisture content in the biological odor control media. The amount of water required to be applied to the media is dependent on the location of the biological odor control system and time of year. Times of dry weather and when the atmosphere contains dry air generally will require more water to be applied to the media than times of the year when there is precipitation and humidity in the air. Generally, biological odor control system media must be kept between 50 and 60% moisture content. Some biological odor control systems may have a system to increase the humidity in the odorous air prior to entering the media. Adjust the amount of water to raise the odorous air humidity to the manufacturers recommended humidity level.

Biological odor control system may have a nutrient addition system. Operate the nutrient addition system per the manufacturer requirements to ensure that the microorganisms have sufficient nutrients to allow them to grow and maintain treatment of the odorous air.

CHAPTER 7 COLD WEATHER OPERATION

7-1 INTRODUCTION.

Cold weather can affect every aspect of the wastewater treatment plant operation. Items to consider for cold weather operation for each process at the wastewater treatment plant follow.

7-2 MAINTENANCE.

Recommended maintenance should be completed by operators and maintenance staff to maintain all warranties and performance guarantees. Refer to the equipment manufacturers operation manual and operate equipment in accordance with manufacturers recommendations and all NPDES permits.

7-3 SCREENINGS.

Clean screens more frequently during cold weather, either automatically on timers or manually, because the screenings will freeze to the metal bars. Once this occurs, removing screenings from the bars is difficult. Mechanical mechanisms may also become jammed and inoperable. Weatherproofing or enclosing the area and providing heat may be desirable. Be aware of the potential for combustible materials entering with the wastewater. Provide proper ventilation and equipment to prevent explosive conditions.

Screenings may freeze to the sides and bottom of containers; prevent this from happening if possible. Grinders may bind because of ice if they are not run often enough. Consider operating the grinders continually or often enough to prevent ice buildup. Covering channels with rigid insulating materials may contain enough heat from the wastewater within the channel to prevent ice buildup on the grinder. Gear oil viscosity will be affected by freezing weather. Condensation also will occur in the gear boxes of this equipment, adversely affecting the gear oil. Check the oil routinely (twice monthly) in the winter.

7-4 GRIT REMOVAL.

Operation of grit-handling facilities may be difficult during extremely cold weather. The grit that is collected and transported will freeze easily in the equipment used to clean and move it to the holding container. Temporary enclosures may assist in keeping the process warm. If this process is to be enclosed, choose the materials carefully to prevent dangerous or explosive conditions. Heat-tracing the metal equipment may help prevent ice buildup. Heat-tracing involves wrapping an electrified wire loop around the equipment. Running warm water across cleaning areas also may prevent freezing, depending upon local conditions.

7-5 PRIMARY TREATMENT.

Clarifiers are affected in several ways by the decrease in seasonal temperatures. The density of water changes with temperature, and this change affects the settling characteristics of the solids. Materials at the surface of these quiescent basins will tend to freeze. Weirs and launders may also freeze, depending upon the ambient and wastewater temperature.

Settling characteristics change when temperatures lower; solids settle at a slower rate in colder (near freezing) waters. Stoke’s Law governs the physics of settling in primary clarifiers, and it is affected by temperature. For example, when the temperature drops from 68 ˚F (20 ˚C) to 38 ˚F (3 ˚C), the settling time for a particle increases 64%. Under these conditions, additional clarifiers may facilitate the process. The use of additional clarifiers may result in lower water temperatures and a higher risk of freezing. Evaluate the use of additional clarifiers and the risk of freezing. If the solids loading is high (above 2,000 mg/L), Stoke’s Law does not apply.

7-5.1 Inspection.

Inspect the aerobic digester for ice on the primary treatment surface and around the sludge flight and chain or the scum skimmer when cold weather occurs. If any ice is found, the operator must break up or remove the ice before it damages the primary treatment equipment.

7-5.2 Biological Treatment.

Cold weather affects the biological systems in the same way, in that the microbiology process slows down. But, the cold weather affects the mechanical equipment to each of the various types of biological system differently and thus each system is described below.

7-5.3 Activated Sludge.

Cold weather does not affect conventional activated sludge systems with a detention time of 4 to 6 hours as significantly as systems with longer detention times. Extended aeration systems having detention times of 10 to 24 hours will experience a temperature decrease that will affect the biological process Systems that use diffused air for oxygen transfer will add heat to the system in the air flow; conversely, mechanical mixing systems will have significant temperature decreases across the aeration basin as cold air is mixed into the activated sludge. Operators must take these temperature changes into consideration when selecting or changing aeration methods in a cold climate. Avoid ice buildup across the surface of the basins. The ice buildup will limit the oxygen transfer and may interfere with mixing equipment. Removing floating scum before winter will help prevent this extra material from freezing in the aeration basin.

7-5.3.1 Maintenance.

When a tank is offline and drained, protect equipment from cold weather and damage. Refer to the equipment manufacturers operating and storage instructions for storage and follow the recommended practices.

7-5.4 Biological Reaction Rates.

Biological reaction rates depend upon temperature. A reduction in temperature of 18 ˚F (10 ˚C) decreases the reaction rates by one-half. In cases where the temperature is affecting the process, changes to the process control are required. Process adjustments would include increases to the MCRT, aerobic Solids Retention Time (SRT_a), or a decrease in the food-to-microorganism ratio to maintain the same process performance and loading rates.

7-5.5 Aeration Equipment.

Ice buildup around mechanical aeration equipment will also affect safety and may overload equipment if it attaches to equipment surfaces. Continuous operation of mechanical mixers at low speed or intermittent operation will reduce the oxygen transfer and reduce ice buildup. Monitor oxygen concentration closely if this method is attempted. Heat tracing the components also may be helpful.

7-5.6 Clarifiers.

The most serious problems associated with clarifiers is freezing on the surface, surface scum, and ice buildup on the scum beach plate. These problems damage skimming mechanisms and may even cause the clarifier rake mechanism to jam or fail. Removing the skimming arm in winter may prevent this problem; however, the problems of scum freezing and removal remain. Hot water sprays, heat tape, and enclosed lamps may help in addressing these problems. Many times, ice must be carefully chopped off the surface of the tanks and removed to the launders. Covering clarifiers will typically help eliminate these potential problems. When designing covers, consider snow loads, weatherproofing of electrical controls, and the possibility of humidity within the covers. Torque limits on the rake mechanism need to be properly set to ensure proper operation if ice affects the collector.

7-5.6.1 Maintenance.

Routinely check torque limits on the rake mechanism and repair them if necessary.

7-5.7 Trickling Filters and Rotating Biological Contactors.

In trickling filter plants, the potential for icing is high. In the winter, turn off the draft in forced-draft systems unless a source of warm air is available to prevent ice from forming in the filter. The forced draft systems are used primarily when the outside air is less than 5 ˚F (3 ˚C) above or below the process liquid temperature. If ice forms within the unit, flood it to melt the ice. Take care when flooding the media and be cautious of structural loading as well as leaking and overloaded pumping systems, gates, and valves. Ice can form on the top of the media, which may affect the distributor arm. Covers are advised in extremely cold areas to prevent this situation. RBCs are usually covered to control odors but keep the covers in good condition to keep the heat within the wastewater. If the RBCs do not already have covers, install them to keep the media from freezing and affecting the shaft with additional loading and potential failure.

7-5.8 Natural Biological System.

Aerated lagoons will typically freeze during the winter. Remove mechanical mixers to prevent them from becoming covered with ice and turning over or sinking. Remove any baffles or be prepared to repair them in the spring. Because the ice will affect the depth of the lagoon, run winter operations at the highest liquid levels possible to increase lagoon volume. Because of the ice coverage, little to no algae activity will occur under the ice and snow. Adding the lower water temperature to the situation, lagoon performance in the winter may be marginal. With the rise in spring temperatures, the lagoons will have a liquid turnover, with a possible washout of solids.

7-5.9 Aerobic Digester.

While aerobic digesters are not normally in locations that experience long periods of cold weather, they can experience short spells of cold weather that can damage equipment. Inspect the aerobic digester for ice on the digester surface and around the mixing equipment when cold weather occurs. If any ice is found, the operator must break up or remove the ice before it damages the digester equipment. If an extended period of cold weather is experienced, consider building a temporary shelter around the digester to limit the amount of ice that forms on the digester.

Aerobic digesters operate at lower efficiencies. Longer detention times are required to obtain the needed levels of stabilization. Increase digester solids concentrations to accommodate these changes. Thus, decanting the digesters may take longer because of increases in viscosity.

7-5.10 Anaerobic Digester.

It will take more energy to keep the contents up to the processing temperature because of the lower feed temperature. Tank insulation (dome and sides) will need to be inspected in the fall of each year and repaired as needed.

7-6 ODOR CONTROL SYSTEM.

Both the chemical and biological odor control systems have heat traced and insulated water piping, which must remain full of water and is exposed to the cold weather. This will prevent freezing of the piping, which may cause equipment damage. Chemical piping in the chemical odor control system should be heat traced and insulated to prevent the chemicals from freezing or crystalizing in the piping.

To drain the biological odor control system, isolate the irrigation water system and drain to prevent equipment damage. To fully drain the system, consider using compressed air to remove all possible water. Inspect the odor control air duct for condensation in the interior piping by opening all water drain ports to remove water and then shutting them once all water has been drained out.

7-7 UTILITIES.

In electrical panels, frost may arc across some electrical circuits. A small warm-air fan in the vent of the electrical panel will keep the internal components warm and dry if this is a local issue.

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Note: For the Army, TM 5-814-3 provides additional requirements for cold weather operation.

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CHAPTER 8 WET WEATHER FLOW OPERATION.

Due to the infiltration of groundwater and use of combined sewers, the operation of a wastewater treatment plant must change when a large amount of precipitation is expected.

8-1 SCREENING PROCESS.

The increase in raw wastewater influent will increase the amount of material that it carries with it. Run mechanical screens more often by either reducing the differential level for the screen to start or reducing the timer to make the mechanical screen start. For manual bar screens, increase the number of times the screen is cleaned during a storm.

For both the mechanical screen and manual bar screen the increased removal of material will minimize the possibility of a sewer overflow in the collections system. The increased frequency of removing the materials also will minimize the surging of water flow through the wastewater treatment plant, thus, maintaining a high level of treatment for all water that flows through it.

8-2 GRIT REMOVAL PROCESS.

The increase in wastewater flow can increase the amount of grit that it contains due to velocity of the water flowing through the collection system. Prior to a wet weather event, it is recommended that the amount of time that the grit removal equipment runs to remove grit from the grit chamber be increased to remove the increased grit load.

8-3 BIOLOGICAL PROCESS.

Each of the biological systems are affected by wet weather. The increased flow can cause NPDES permit violations if operators do not take action. Below are recommended actions for the various biological process to maintain permit compliance during a wet weather event.

8-4 ACTIVATED SLUDGE.

When wet weather occurs, the constituent loading on the biological system may slightly increase, but the major increase will be the hydraulic loading on the activated sludge process. The increased flow will decrease detention times for treatment of the wastewater and settling of the mixed liquor in the clarifier. Prior to a major wet weather event, if possible, increase the amount of mixed liquor and increase the amount of tankage available to treat the wastewater. Additionally, increase the number of clarifiers in service to allow as much settling of the mixed liquor from the treated wastewater prior to it flowing out to the environment. Consider increasing how much RAS they return from each clarifier to minimize the possibility of washing out any mixed liquor from the bottom of the clarifiers.

8-5 TRICKLING FILTERS AND ROTATING BIOLOGICAL CONTACTORS.

As with activated sludge, the constituent loading on the biological system may slightly increase, but the major increase will be the hydraulic loading when a wet weather event occurs. If possible during a wet weather event, start up another trickling filter or RBC and increase the recirculation rate of the units. This will provide more time to allow treatment, and if the trickling filter and RBC do not have a biomass, the recirculation will seed the units to start growing the biomass on the media.

CHAPTER 9 UTILITIES.

A wastewater treatment plant cannot perform its function without the support of other utilities such as electrical distribution and natural gas. All the utilities have required operation and maintenance requirements that operators must be aware of and follow to ensure that proper treatment of wastewater continues without interruption to the treatment process.

9-1 ELECTRICAL DISTRIBUTION.

The electrical distribution system is typically required to have two independent power sources. Normally, the second power source is provided by emergency generators, but it can be provided by a second electrical power supply line that independent of the first electrical power supply. The electrical distribution system normally contains various voltages within it. These voltages are supplied by the power provider or emergency generators.

An electrical distribution has at least one power supply line that provides power the wastewater treatment plant. The power is then distributed to motor control centers, or to other power panel and lighting panels.

9-1.1 Operation and Maintenance.

Use UFC 3-540-07, UFC 3-550-07 and UFC 3-560-01 for additional operation and maintenance requirements. The operation of the electrical distribution system is limited to backup generators. Operators should inspect, test and store fuel in accordance with written standard operating procedures to maintain the operational integrity of backup generators. Any other operation of the electrical distribution must be completed by a qualified person to ensure personnel and equipment safety.

Note: For the Air Force, **\1** AFMAN **/1/** 32-1062 provides additional requirements for generators.

Note: For the Army, TM 5-682 provides additional requirements for electrical facilities safety. TM 5-683 provides additional requirements for electrical interior facilities, TM 5-684 provides additional requirements for electrical exterior facilities, and TM 5-685 and AR 420-1 provide additional requirements for operation, maintenance, and repair of auxiliary generators.

9-2 POTABLE WATER.

Potable water is used throughout the wastewater treatment plant for various uses. These uses include drinking water, seal water for pumps, chemical carrier water, fire protection, and equipment wash water.

9-2.1 Operational and Maintenance.

Use UFC 3-230-02 for operation and maintenance of water supply systems. Potable water supply systems are required to be protected from backflow by an approved backflow prevention device. Use UFC 3-230-01, UFC 3-420-01 and UFC 3-600-01 for backflow protection and cross control. Verify Installation specific requirements and testing frequency with the Installation Environmental Program staff.

Potable water may be piped to a hydropneumatic tank or a tank with an air gap to prevent any possibility of contaminating the potable water system with chemicals, sludge, or wastewater. Operate the hydropneumatic tanks per the manufacturer's operating instructions to prevent damage to the equipment and protect the potable water system.

Note: For the Air Force, **\1** AFMAN **/1/** 32-1067 provides additional requirements regarding potable water.

9-3 NATURAL GAS.

Natural gas may be used at wastewater treatment plants as a fuel source for a heating unit, a hot water heater, a sludge incinerator, or an emergency generator.

9-3.1 Operational and Maintenance.

Operators at a wastewater treatment plant typically do not have any operational requirements for the natural gas service up to and including the gas meter. Contact the natural gas utility provider for any emergency or service related questions. Post the natural gas service providers emergency contact information on-site.

Call the local utility marking service prior to any digging or excavation and obtain a permit or clearance to dig from the utility marking service.

9-4 CATHODIC PROTECTION.

Cathodic protection provides additional corrosion protection, supplementing the normal protection offered by protective coating systems. Use UFC 3-570-06 for operation and maintenance of cathodic protection systems.

Note: For the Army, PWTB 420-49-29 provides additional requirements for cathodic protection systems.

Note: For the Air Force, AFH 32-1290 provides additional requirements for cathodic protection systems.

9-5 HEATING, VENTILATION, AND AIR CONDITIONING.

The heating, ventilation, and air conditioning (HVAC) system is comprised of various pieces of equipment that are used to maintain the desired atmosphere inside a single room or the entire building. The atmosphere of the room or building includes temperature and humidity of the room or building.

The HVAC system is also used to maintain the number of air exchanges that occur in a room to reduce the potential for health effects on an operator when they enter the room and the potential hazard of fire or explosion from the accumulation of sewer gases. The HVAC system can also be used to maintain differential pressure in various locations in a building to prevent the migration of odors from sludge and other wastewater processes. The HVAC system may also work in conjunction with the odor control system to remove odors from a space or building.

9-5.1 Heating, Ventilation, and Air Conditioning Equipment.

The HVAC systems are comprised of some equipment that is simplistic in its function, whereas other pieces of equipment are complex and perform various functions for the HVAC system.

9-5.1.1 Heating Equipment.

The heating of air can be accomplished by various pieces of equipment. Unit heaters are industrial electric heaters, whereas gas unit heaters use natural gas to heat the air. Both unit and gas unit heaters are simple heaters that operate independently of any control system. Rooftop units can provide both heating and cooling of a space, but they require a control system to determine when the heat or cooling system of the rooftop unit will be used. The rooftop unit can use electricity or natural gas as its fuel source to heat the air.

9-5.1.2 Ventilating Equipment.

Ventilation is accomplished by fans and rooftop units. Fans can either supply air (push air into a space) or exhaust air (draw suction on a space). This method of supplying and exhausting the same amount of air is the simplest method of cooling a space, and it also can be used to provide air exchanges to maintain the atmosphere in the space. If the amount of air differs, then a pressure differential is created between the space and the outside atmosphere. Rooftop units normally provide air into a space; thus, if they are the only method of ventilation, the space will be pressurized, which will push out of the building into the outside atmosphere.

9-5.1.3 Air Conditioning Equipment.

Air conditioning of a space or building is accomplished by rooftop air conditioning units. These air conditioning units run to maintain the temperature setpoint in the control system. In addition, the air conditioning unit can run to maintain a humidity setpoint in the control system.

9-5.2 Operational Requirements.

The HVAC system must have all components operating as designed to maintain a safe environment. Operators must review all setpoints entered into the HVAC control system to ensure the temperature setpoints are correct and all times for occupancy are correct for the work day.

When entering a space, operators must turn on or ensure that the HVAC equipment is operating correctly. When operators exit a space, they must turn off the HVAC system if applicable.

Note: For the Army, AR 420-1 provides further guidance on boiler operations.

Note: For the Air Force, **\1** AFMAN **/1/** 32-1068 provides further guidance on boiler personnel schedule requirements.

9-6 FIRE PROTECTION SYSTEMS.

Use UFC 3-600-02 for the inspection, testing and maintenance of fire protection systems.

CHAPTER 10 SEPTIC SYSTEMS, GREASE TRAPS, AND OIL-WATER SEPARATORS

10-1 INTRODUCTION.

Septic sewer systems collect and treat wastewater where it is not feasible to provide a wastewater collection and treatment system. The majority of septic systems collect and treat domestic wastewater. Food-service operations typically use grease traps to prevent excessive discharge of grease and oil into the wastewater collection and treatment system. Refer to EPA/625/R-00/008 for additional guidance.

10-2 MAINTENANCE.

The maintenance requirements for septic system, grease traps and oil-water separators varies depending on user operating procedures and the type of equipment used. Recommended maintenance should be completed by operators and maintenance staff to maintain all warranties and performance guarantees. Refer to the equipment manufacturer's operation manual and operate equipment in accordance with manufacturer's recommendations and all NPDES permits.

10-3 SEPTIC TREATMENT AND DISPOSAL SYSTEM.

Septic systems are used when collection of wastewater by a centralized wastewater collection and treatment system cannot be provided. Septic systems collect domestic septage, provide treatment and dispose of the treated effluent on-site. A state or local permit may be required to construct, operate or modify a septic system.

Septic systems collect domestic wastewater flows from the building into the septic tank through a sewer pipe. In the tank, bacteria attack and digest organic matter by anaerobic digestion. The wastewater itself provides the bacteria for this process. The anaerobic digestion process changes the waste into gas, biosolids (residual organic and inorganic material), and treated effluent. The gas escapes into the air, the treated effluent is discharged to the leaching system, and the residual solids remain in the tank. The treated effluent is discharged into the soil through the perforated or open-jointed pipes in the drain field. Soil bacteria destroy remaining organic material in the effluent. Use IPSDC for septic treatment and disposal system requirements. Use EPA 932-F-99-068 and *Maintaining Your Septic System - A Guide for Homeowners*, for additional guidance on maintaining septic systems.

10-3.1 Domestic Wastewater Characteristics.

There are many factors that influence septage characteristics such as climate, user habits, septic tank size, design, pumping frequency, water supply characteristics, piping material, and use of water-conservation fixtures, garbage disposals, household chemicals, and water softeners. Refer to EPA 932-F-99-068 for domestic wastewater characteristics.

10-3.2 Monitoring Waste Discharged to System.

Because the septic tank treatment system is a biological process, it is particularly important that toxic or hazardous chemicals are not discharged into it. These chemicals would kill the bacteria used for treatment of the wastewater. Discharge of industrial wastewater to septic tanks violates the underground injection provisions of the SDWA. In addition, do not discharge grease and non-biodegradable into the system. The system is not designed to treat these products, and they can cause clogging in the system components. Use household cleaners, such as bleach, disinfectants, and drain and toilet bowl cleaners, in moderation and only in accordance with product labels. Overuse of these products can harm the septic tank system.

10-3.3 Water Conservation.

Water conservation is critical for proper operation of the drain field. Continual saturation of the soil in the drain field can significantly reduce the ability of the soil to naturally remove toxins, bacteria, viruses, and other pollutants from the wastewater. In addition to conserving water discharged to the septic tank and drain field, try to restrict water from roof drains, sump pumps, and other sources from draining into the area of the drain field.

10-3.4 Septic System Components.

10-3.4.1 Tank.

The size of the septic tank depends on the number of people using the building or the volume and type of waste. Figure 10-1 depicts a two-compartment septic tank system.

10-3.4.1.1 Septic Tank Maintenance.

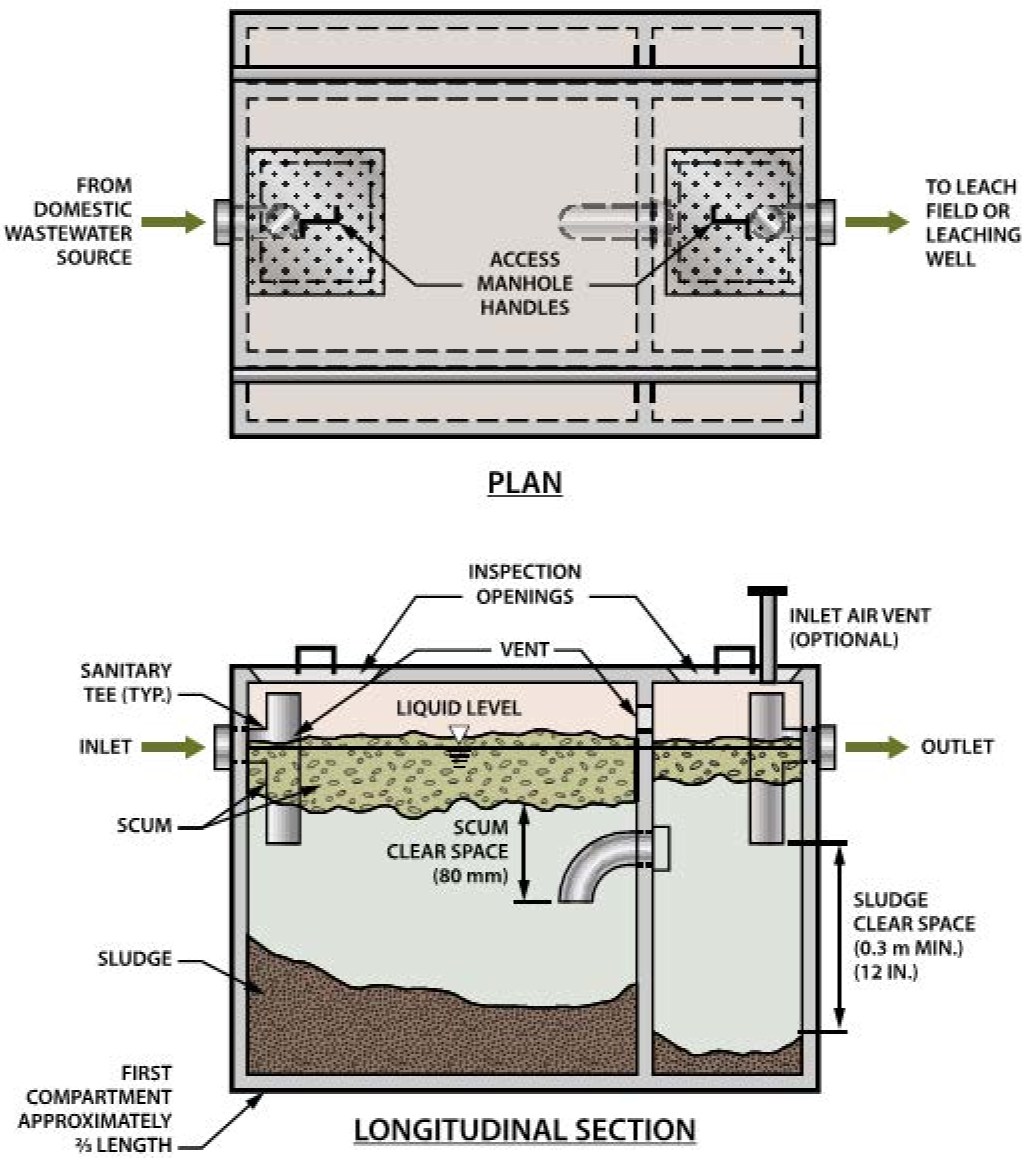
The primary maintenance requirement for the septic tank system is periodic removal of scum and settleable solids. It is not necessary to add yeast or bacteria to the system as a maintenance procedure. If human and kitchen wastes are being discharged to the system, there will be sufficient bacteria in the tank for treatment. Table 10-1 shows the estimated tank pumping frequencies, based on tank size and household size.

10-3.4.1.2 Inspecting the Septic Tank.

Inspect the septic tank every 1 to 5 years to determine if solids need to be removed. If garbage disposals discharge to the septic tank should be inspected annually.

Exercise extreme care when inspecting the septic tank as inhalation of toxic gases have been known to cause sickness or death. Never enter or inspect a septic tank alone. Toxic gases are produced by the natural treatment processes in septic tanks and special precautions need to be used to prevent inhaling these toxic gases. Contact the Installation Safety Officer to obtain a confined space permit if entry is required. Guidance on confined space entry requirements can found in *Operation of Wastewater Treatment Plants*, Volume 2, Chapter 14.

Figure 10-1 Typical Two-Compartment Septic Tank



10-3.4.1.3 Measuring Solids and Scum Inside the Tank.

There are two frequently used methods for measuring the scum layers inside the tank.

a. A hollow clear plastic tube is pushed through the different layers to the bottom of the tank. When the tube is brought back up it retains a sample showing a cross-section of the inside of the tank.

b. The layers can also be measured using a long stick. To measure the scum layer using a stick, a 3 in. (8 cm) piece of wood is attached across the end of the stick to form a "foot," and the stick is pushed down through the scum to the liquid layer. When the stick is moved up, the foot meets resistance on the bottom of the scum layer. The stick is marked at the top of the layer. The distance between the mark and the foot on the end of the stick can be measured to determine the total thickness of the scum layer.

The solids layer can be measured by wrapping cloth around the bottom of the stick and lowering it to the bottom of the tank. Insert the stick either through a hole in the scum layer or through the baffle or tee, if possible, avoid getting scum on the cloth. Estimate the solids depth by the length of solids sticking to the cloth.

Table 10-1 Estimated Septic Tank Pumping Frequencies in Years

	Household Size (number of people)					
Tank Size (gallons)	**1**	**2**	**3**	**4**	**5**	**6**
500	5.8	2.6	1.5	1.0	0.7	0.4
750	9.1	4.2	2.6	1.8	1.3	1.0
900	11.0	5.2	3.3	2.3	1.7	1.3
1,000	12.4	5.9	3.7	2.6	2.0	1.5
1,250	15.6	7.5	4.8	3.4	2.6	2.0
1,500	18.9	9.1	5.9	4.2	3.3	2.6
1,750	22.1	10.7	6.9	5.0	3.9	3.1
2,000	25.4	12.4	8.0	5.9	4.5	3.7
2,250	28.6	14.0	9.1	6.7	5.2	4.2
2,500	31.9	15.6	10.2	7.5	5.9	4.8

(1) These figures assume no garbage disposal is in use.

Source: *Maintaining Your Septic System - A Guide for Homeowners*

10-3.4.1.4 Removal of Settleable Solids.

Pump solids out of the tank when the depth of solids is one-third or more of the liquid depth. When pumping the tank, remove all contents, including scum, liquid, and solids. Use only the access ports on the tank for cleaning; do not pump out the tank through the distribution box. Do not use toxic or hazardous chemicals for cleaning the tank and do not use organic chemical solvents or petroleum products for degreasing or declogging the system. These chemicals and products are harmful to the system and to the groundwater near the system.

10-3.4.1.5 Removal of Scum.

The tee shaped outlet prevents the scum from leaving the tank. Pump the tank whenever the bottom of the floating scum layer is within 6 inches (150 mm) of the bottom of the outlet tee or the top of the floating scum layer is within 12 inches (300 mm) of the outlet tee.

10-3.4.2 Effluent Disposal Systems.

Soil absorption systems, pressure distribution systems, mound systems, and holding tanks are used to dispose or store treated effluent. Do not allow vehicles to drive over effluent disposal systems. Do not plant trees, shrubs, or similar plants over the effluent disposal systems.

10-3.4.2.1 Soil Absorption System.

A gravity effluent leaching system consists of a distribution box or header pipe and a drain field. The drain field is a system of open-jointed or perforated piping that allows the wastewater effluent to be evenly distributed into the soil. Where groundwater levels are high, the elevation may be insufficient for a soil absorption system and an alternative system is used to dispose of treated effluent.

10-3.4.2.2 Soil Absorption System Maintenance.

Replacement is the only remedy for a leachate system that is not functioning. There are no conclusive data to support the premise that enzymes and chemical treatment can revitalize a drain field.

10-3.4.2.3 Mound Systems

Mound systems are generally used in areas with high groundwater levels or a minimum soil depth to bedrock. Mound systems are prohibited in flood hazard areas. Mound systems require a pump to deliver the effluent to the elevated leaching system. Electric controls and a power supply are required to operate the pump.

10-3.4.3 Effluent Screens.

Effluent screens enhance solids removal and clarify the septic tank effluent. Typically, effluent screens are attached to the outlet pipe inside the septic tank. In some cases, effluent screens may be placed in a filter chamber located outside of the septic tank on the outlet side of the septic tank. Effluent screens can assist in preventing blockages that could damage the drain field. In some cases, a biolayer may build up on the screen. The biolayer can help with the removal of viruses and pathogens. Review the state requirements for your location to see if an effluent screen is required. Refer to EPA 832-F-03-023 for additional guidance on effluent screens.

10-3.4.3.1 Effluent Screen Maintenance.

Effluent screens require regular cleaning to keep them operating efficiently and to prevent plugging. The frequency of cleaning depends on many factors, such as, environmental conditions, the material entering the septic tank, and the size of the screen. Some states require the use effluent screens.

10-3.5 Septic System Failures.

Several warning signs can indicate that a septic tank system is failing and that more than cleaning of the system is necessary:

- Obnoxious odors around the system or inside the building
- Soft ground or low spots around the system
- Grass growing faster or greener around the system
- Gurgling sounds in the plumbing or plumbing backups
- Sluggishness in the toilet when flushed
- Plumbing backups
- Tests showing the presence of bacteria in nearby well water

Table 10-2 shows possible causes of septic tank system failures and suggests remedial procedures.

Note: For the Air Force, **\1** AFMAN **/1/** 32-1067 provides additional requirements for septic systems.

10-4 GREASE TRAPS.

If grease traps are not properly maintained, slug loads of grease will interfere with the performance of both the collection and treatment system. There are two general types of grease traps, with the largest being inground grease traps that are usually located outside the food-service establishment in an underground tank with ground-level access. The second type is an under-sink unit. The under-sink units can be either passive, which captures the grease and requires an operator to remove the grease periodically or an automatic system that removes the grease as set by a timer to a separate container that the operator must empty periodically. Under-sink units are not recommended because they generally do not provide adequate grease removal. Where under-sink units are used, proper maintenance is especially critical because of the higher potential for release of slug loads of grease into the wastewater system.

10-4.1 Configuration.

Grease traps usually consist of an underground, watertight concrete tank with inlet and outlet piping. The outlet pipe has a tee that allows the internal discharge to be located within 12 in. (300 mm) of the tank bottom. The size of the grease trap depends on the anticipated flow rate, water temperature, and grease concentration. Access to the tank is typically through one or two manhole rings and covers.

10-4.2 Location.

Grease traps are located outside food-service buildings in an accessible location for inspection and maintenance.

Table 10-2 Septic System Failures

Possible Causes of Failure	Possible Remedial Procedures
Underdesign	
• Tank size insufficient for wastewater flow quantity and/or characteristics • Drain field too small	• Replace septic tank or add additional septic tank(s) in parallel. • Replace septic tank or add additional septic tank(s) in parallel.
Faulty Drain Field Installation	
• Plugged pipes • Insufficient stone in trenches • Uneven grades	• For plugged pipes, insufficient stone, and uneven grades, install a new drain field on top of existing field.
Poor Soil Conditions	
• High groundwater • Insufficient distance below drain field to bedrock • Relatively impervious soils	• Improve surface drainage, install curtain drains, elevate field, and/or reduce water consumption. • Elevate drain field and/or reduce water consumption. • Elevate drain field and/or reduce water consumption.
Overload	
• Excessive wastewater loading • Poor stormwater drainage away from system • Leaking plumbing fixtures • Wastewater flow quantity and/or characteristics greater than anticipated in design due to changes in use of building, garbage grinders, etc.	• Increase tank size or reduce water consumption. • Improve surface drainage. • Repair plumbing fixtures. • Remove garbage grinders; increase drain field.

Possible Causes of Failure	Possible Remedial Procedures
Lack of Tank Maintenance	
• Septic tanks not pumped out at sufficient intervals, causing solids to be discharged to drain field	• Pump out tank, construct new drain field on top of existing drain field, relieve drain field by draining into a pit and pumping out, and let field rest for a month.

Source: Adapted from *Wastewater Engineering Design for Unsewered Areas*

10-4.3 Discharges to Grease Traps.

Grease traps do not perform effectively if they receive discharges with elevated temperatures or high solids concentrations. It is not recommended for grease traps to receive discharges from garbage grinders or produce -preparation sinks. Discharges from mechanical dishwashers are also not recommended. However, the preflush or prescraping sinks that serve mechanical dishwashers may be connected to the grease trap, provided no garbage grinders are used at these sinks.

10-4.4 Maintenance Procedures.

The critical maintenance procedure for all grease traps is periodic removal of accumulated waste. If the responsibility and procedures for cleaning grease traps are not clearly identified and implemented, the traps are ineffective. It is recommended that waste be pumped out of the grease traps rather than dissolved with solvents. Grease and solvents may have a negative impact on the wastewater collection and treatment system. Recovered oil and grease from food-service operations typically can be sold to a local recycling company. If proper maintenance cannot be maintained, consider removing the grease trap and having the user separate the grease before discharging wastewater to the sanitary system.

Note: For the Army, AR 420-1 provides further guidance on grease trap maintenance.

10-4.4.1 Pump-Out Frequency.

The recommended pump-out frequency ranges depending on the waste characteristics of the establishment and the size of the grease trap. The necessary pump-out frequency can be determined by checking the grease retention capacity in the grease trap. Remove grease and accumulated wastes as often as necessary to maintain at least 50% of the grease retention capacity.

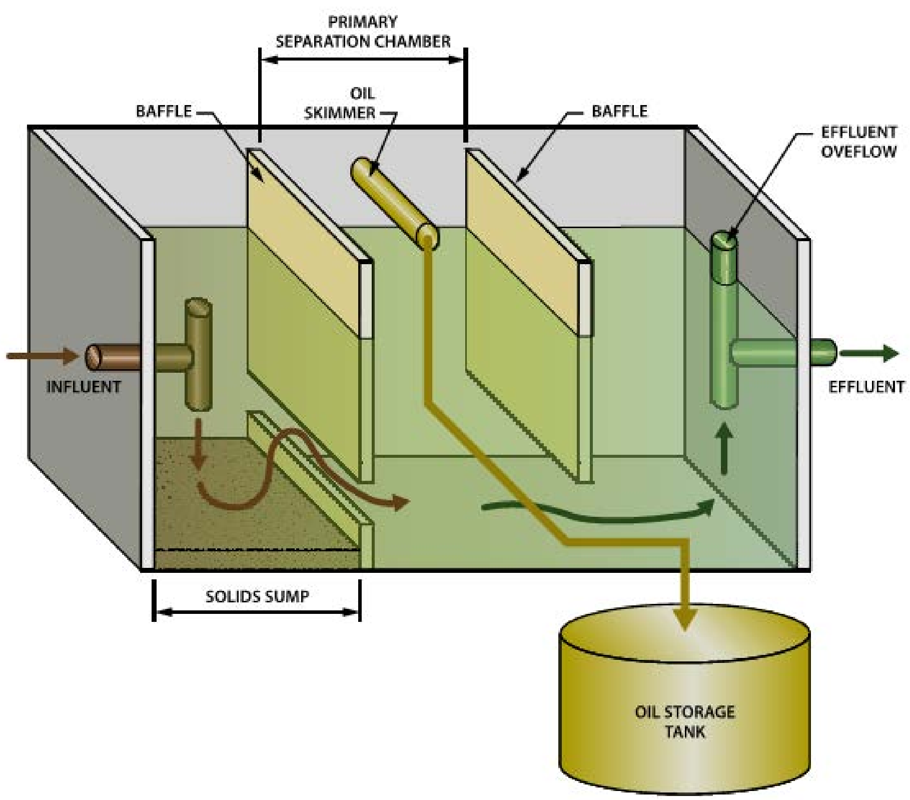
10-5 OIL/WATER SEPARATORS.

Oil-water separators are devices commonly used to separate oily waste products from wastewater streams. They are typically installed in industrial and maintenance areas to receive and separate oils at low concentrations from wastewater generated during industrial processes such as maintaining and washing aircrafts and vehicles. There are three predominant types of oil-water separators: conventional gravity separators, corrugated plate gravity separators, and flotation separators. Most oil-water separators used are conventional gravity separators. Most units, regardless of the type, are purchased as proprietary equipment from vendors.

10-5.1 Gravity Separators.

The process relies on the different densities of oil, water, and solids for successful operation. The wastewater is fed to a vessel sized to provide a quiescent zone of sufficient retention time to allow the oil to float to the top and the solids to settle to the bottom. Gravity oil-water separators come in two configurations: conventional gravity separators, such as those designed in accordance with guidelines established by the American Petroleum Institute (API) and corrugated plate interceptors (CPIs).

Conventional gravity separators are typically rectangular in-ground or above-ground tanks with maximum widths of 20 ft (6 m). A diagram of a typical conventional gravity separator is presented in Figure 10-3. Influent and effluent channels are normally located on opposite ends of the separator. The influent typically passes an inlet section that contains a slotted baffle to distribute influent evenly throughout the depth of the separator. For units without sludge collectors, there may also be a bottom baffle in the separator; this retains settled solids in the front part of the separator to reduce cleaning requirements. Other separators may have automatic sludge removal equipment that will rake accumulated sludge to a sludge hopper where it is pumped from the tank periodically.

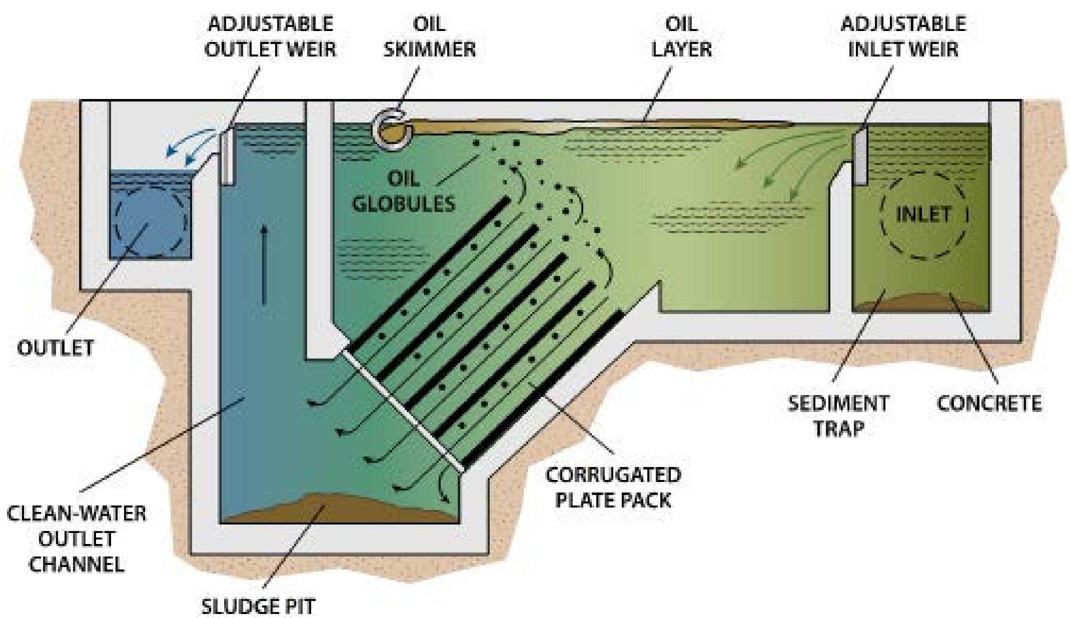


10-5.1.1 Sludge Level.

Monitor the sludge level routinely and remove sludge when it occupies 10% or more of the separator volume. All conventional gravity separators have a surface baffle at the Conventional Gravity Separator outlet end to retain floating oil and grease. The grease is removed by pumping or by activating a rotary drum or slotted pipe that allows the surface material to drain to a drum or oil holding tank. Regularly check the depth of the surface oil layer and conduct routine surface skimming. Experience gained from operating a conventional gravity separator in a specific application will indicate the required intervals for checking and skimming the oil layer. For example, although the oil layer might need to be checked and skimmed daily, this interval could range from several times per day to several times per month, depending on the rate of oil accumulation on the separator surface.

One criterion to use is monitoring the oil layer and skimming as often as necessary to prevent an excess amount of oil from being flushed through the separator by an unexpected hydraulic surge (e.g., rainfall). Thus, the frequency may also depend on the sensitivity of downstream processes to increased oil loading. The frequency will have to be determined by experience, but it likely will be such that the floating oil layer does not exceed about 2 in. (50 mm); some operators prefer that there be no floating oil layer on the separator.

Figure 10-2 Process Schematic of CPI Separator

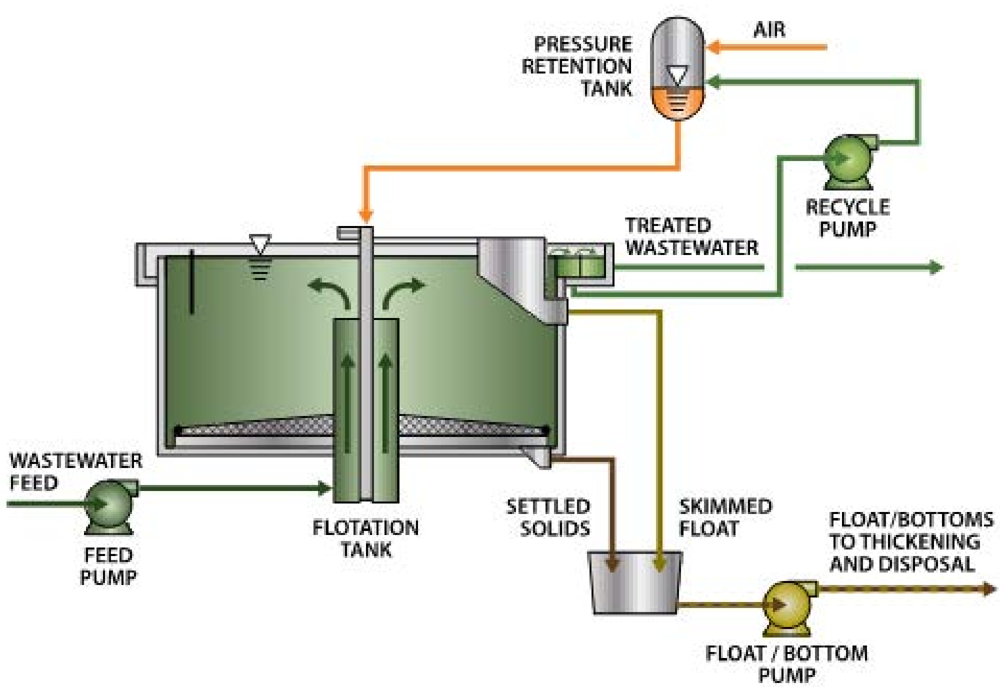


10-5.2 Corrugated Plate Interceptors.

CPIs are typically supplied by vendors and based on proprietary designs. A CPI consists of a tank containing parallel corrugated plates mounted from 0.8 to 1.6 in. (20 to 40 mm) apart and inclined at an angle to the horizontal. A diagram of a typical CPI is presented in Figure 10-4. Wastewater may flow either downward or upward between the plates. In the configuration shown, wastewater flows downward through the plates. As this happens, the oil droplets float upward and collect on the underside of adjacent plates where they coalesce. The coalesced oil droplets move up the plates and are retained in the separator to form a floating layer that is skimmed from the surface of the tank. Settled solids from the wastewater collect on the top side of adjacent plates, migrating down the plates and dropping into the bottom of the CPI vessel. In the diagram shown, treated water flows down through the plates and over a weir into an effluent flume. Some manufacturers use different configurations than the one shown.

CPI separators are smaller and easier to cover for controlling atmospheric emissions, and they may be less expensive than API-type separators. In practice, however, the smaller size has sometimes been a disadvantage because it may not provide sufficient volume to accommodate slugs of oil and it may not provide sufficient detention time for breaking emulsions. In some cases, the plate packs have become severely fouled. CPIs are usually drained and hosed down routinely to clean the plates. Operating experience over time will dictate how often this occurs, but a minimum interval of every 6 months is appropriate.

Figure 10-3 Process Schematic of Dissolved Air Flotation



10-5.3 Dissolved Air Flotation.

DAF is commonly used to remove oil, grease, and suspended solids from industrial wastewaters. A diagram of a typical DAF is presented on Figure 10-4. Typically, gravity oil-water separators are used in front of flotation units to remove the major fraction of free or floating oils; thus, flotation units usually are considered polishing units. The air bubbles can be added to the wastewater by a variety of means. Diffused air flotation and induced air flotation are the two most common types of DAF units. Both types incorporate a flotation vessel with a baffle to retain floated oil, an oil-skimming mechanism, and sometimes a bottom-scraping mechanism to remove heavy particles that do not float.

Significant mechanical equipment is associated with these systems and must be maintained according to manufacturer's directions. Flotation vessel surface skimming generally is continuous but settled sludge must be drawn off manually. The draw-off frequency will have to be determined by experience but could range from once daily to twice monthly, with weekly being a reasonable starting point.

10-5.4 Emulsified Oils.

The most common military applications seldom involve simple oil-and-water mixtures. Waste streams generated from military applications frequently contain significant quantities of dirt, cleaning aids (detergents, solvents), fuels, floatable debris, and various other items common to military equipment and activities. Oil-water separators are not designed to separate these other products. Improper use can result in oil passing through the oil-water separator. Misuse of these systems can upset treatment plants and exceed discharge requirements.

The following factors directly affect the efficiency, use, and management of oil-water separators: frequency and intensity of influent flow, design capacity, emulsifying agents, periodic maintenance practices, type of separator system, and other contaminants contained in the waste stream. Installation personnel must be familiar with these factors so they can operate and maintain these systems. A separator that is being used improperly must be reported to the environmental office.

10-5.4.1 Emulsifying Agents.

Emulsifying Agents, detergents, and soaps designed to remove oily grime from dirty weapon systems, vehicles, or other components can adversely affect oil-water separator operation. These agents are designed to increase solvency of oily grime in water. Hence, the oil droplets take longer to separate from water, reducing separation efficiency. Overzealous use of detergents can degrade efficiency by completely emulsifying oil in the wastewater stream, thus, allowing the oil to pass through an oil-water separator unaffected.

10-5.5 Frequency and Intensity of Flow.

The longer the residence time of the waste stream in the oil-water separator, the more efficient it will be at separating oil. Contaminated water enters a receiving chamber of the separator where the flow velocity of the wastewater is reduced, thereby allowing heavy solids to settle while larger oil droplets float to the top of the compartment. Further separation continues in a separation chamber where smaller droplets of oil separate from the water and join the larger droplets previously separated. The oil layer that has accumulated on the top of the water spills over an oil skimmer into a holding area; the wastewater then flows, or is pumped, to the stormwater or sanitary sewer system.

A longer separation time increases the efficiency of the oil-water separator by allowing a greater amount of oil to rise to the top of the wastewater. Therefore, restricting the wastewater to design flow rates will improve the efficiency of the separator.

10-5.6 Design Capacity.

An oil-water separator has a finite capacity for storing oils and sludges accumulated during its operation. Quite often, the oil-water separator holding compartments can become saturated or full of oils and sludges, allowing contamination to flow freely into the wastewater effluent exiting the separator system. Ensuring that the separator capacity meets the needs of the process will aid separation efficiency.

10-5.7 Operational Changes.

An oil-water separator designed and installed to a past mission requirement may not be suitable for a new mission. For example, a wash rack with an oil-water separator designed to capture contaminants from a small fighter aircraft will not handle larger wastewater volumes from a larger aircraft. Additionally, changes in mission can affect the effluent characteristics of the wastewater being discharged to an oil-water separator (i.e., wastewater with solvents or emulsions versus free floating oil). As missions evolve, the oil-water separator use must be re-evaluated to confirm continued suitability.

Mission conversions can necessitate modifying stormwater or wastewater drainage systems. Oil-water separators that do not have a stormwater diversion system can suffer from reduced removals from the hydraulic loading of stormwater that does not need to be treated. Thus, separator collection systems also must be reviewed for excessive stormwater flows.

10-5.8 Contaminants in Wastewater Stream.

Particulate heavy metals and solids in the wastewater will settle into the sludge at the bottom of the oil-water separator receiving compartments. The sludge could be regulated as a hazardous waste if levels exceed RCRA or state hazardous waste levels. Solvents or fuels also may be retained in oil-water separator sludge.

10-5.9 Evaluation of Need for Oil-Water Separators.

An oil-water separator may not be needed to meet pretreatment or discharge permit limits, coordinate with the Installation Environmental Program staff to see if the oil-water separator may be eliminated, see Figure 10-4. Operators should assist by knowing what is discharged to separators, educating others whose activities are generating the wastewater, and alerting Installation Environmental Program staff of any problems. Vehicle and equipment washrack wastewater typically contains oil and grease but have a relatively small amount of solids. Exterior washing of vehicles and equipment, particularly after field training exercises, can discharge large quantities of solids. At many installations, central vehicle wash racks are provided specifically for exterior washing.

Operators should assist Installation Environmental Program staff in evaluating the need for and effectiveness of existing oil-water separators. Consider the potential for emulsified oil. Example: Are high-pressure water or detergents being used. These practices increase emulsification and allow smaller oil droplets to pass through the oil-water separator.

10-5.10 Operation and Maintenance.

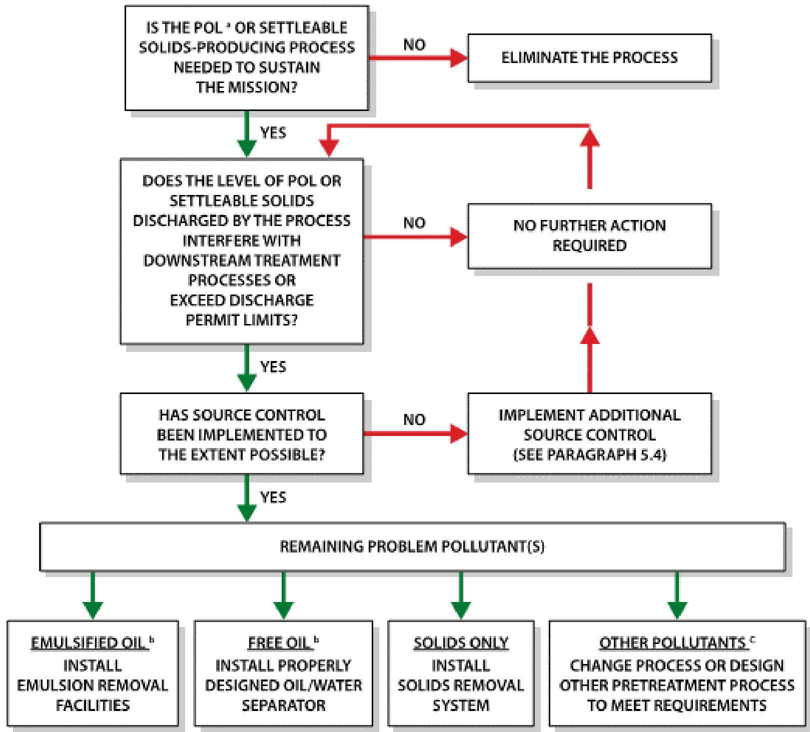
The ability of oil-water separators to function properly depends on the application of required routine service and maintenance.

Personnel using and maintaining the system are expected to understand the separation process and the components of the specific oil-water separator. Maintenance personnel are expected to be familiar with the piping and configuration of each separator for which they are responsible. Periodically inspect all parts of the separator and its draining system to prevent failures caused by operations, breaks, and mechanical settings. Items suggested for inspection and a recommended frequency for inspection are listed in Table 10-3. To determine requirements for periodic draining and cleaning, system users must be familiar with the capacity of the separator and holding tanks, uses of the system, and its potential misuses. Separator performance can be an important indicator of the mechanical condition of the device. Performance can be tracked by regular influent and effluent sampling and analysis.

Note: For the Air Force, **\1** AFMAN **/1/** 32-1067 provides additional requirements for oil-water separators.

Note: For the Army, PWTB 200-1-142 provides additional requirements for oil-water separators.

Figure 10-4 Decision Tree for Pretreatment of Oily Waste



LEGEND

a POL - PETROLEUM / OILS / LUBRICANTS

b SOME SOLIDS CAN ALSO BE REMOVED BY OIL REMOVAL PROCESS

c IF HAZARDOUS WASTE IS FOUND IN THE PROCESS DISCHARGE, THE HAZARDOUS WASTE MUST BE REMOVED FROM THE WASTE STREAM

10-5.10.1 Periodic Maintenance Practices.

Sludges and oils that are not periodically pumped from separator holding tanks can render the separator inoperative. Additionally, leaks from oil-water separators can result in environmental pollution that could require investigative studies and extensive cleanup. Regular equipment inspections and a preventive maintenance plan can prevent contaminated discharges from the oil-water separator system. Depending on the wastewater characteristics (e.g., low pH), what material the separator is made of, and the age of the facility, perform visual equipment inspections from once per week to once per month. Conduct more rigorous inspections two to four times per year. Focus inspections on areas below the water line, equipment construction joints, piping connections and interfaces, and other areas prone to wear, spills, or leaks.

Table 10-3 Recommended Inspection Frequency for Oil-Water Separators

Item	Suggested Frequency
Conventional Gravity Separator	
Flight mechanism: flights, chains, sprockets, rails, drive	Visual weekly; detailed annually
Sludge hopper valves: open/close freely, close tight	Weekly
Oil skimmer mechanism: moves freely, level, not plugged	Weekly
Skimming pump(s)	Weekly
Sludge pump(s)	Weekly
CPI Separator	
Parallel plates: fouling	Weekly
Skimmer weir: level	Annually
Skimming pump(s)	Weekly
Sludge pump(s)	Weekly
Flotation	
Surface skimmer mechanism: drive, flight, roller, beach	Visual weekly; detailed annually
Bottom rake: flight	Annually
Pressurization pump and tank	Weekly
Back pressure valve: holds recommended back pressure	Weekly
Sludge valve: operates freely, closes tightly	Weekly
Skimming/bottoms pump(s)	Weekly

10-5.10.2 Parameters of Concern.

Parameters of concern are those that would be expected to be removed or reduced across the separator: oil, grease, and TSS. Data may be plotted to help identify trends showing both influent and effluent concentrations. Compare effluent concentrations with influent concentrations to detect performance deterioration and with discharge permit limits obtained from the Installation Environmental Program staff to assess permit compliance. Frequency of separator effluent sampling is as required by the discharge permit. Influent sample frequency must be the same as effluent sampling frequency. At a minimum, twice monthly is recommended.

APPENDIX A BEST PRACTICES

A-1 PERMITS.

Coordinate with the Installation Environmental Program staff for permit renewal or changes. NPDES permit forms will vary, depending upon the primary agency, EPA or state, and the characteristics of the discharge. The EPA delegates permits to states with approved permitting programs. State and local agencies may have more stringent requirements. Permit forms may require historical plant operation data and much of the same information required for the Capacity Analysis and Operation and Maintenance reports. There is no fee required from the federal government, but state and local agencies may assess fees to process applications.

As part of the operating NPDES permit, WWTPs may be required to periodically submit operating data to the agency that issued the permit, including data to verify the WWTP is operating in accordance with its operating NPDES permit. This may include providing nutrient results of the wastewater treatment plant, sludge sample results and other items such as various flow meter calibration.

A-2 STORMWATER NPDES PERMITS.

Stormwater NPDES permits typically involve developing a stormwater pollution prevention plan, and routinely inspecting the stormwater system, monitoring runoff, and maintaining records on site.

A-3 CURRENT TRENDS AFFECTING WWTP OPERATIONS.

The regulatory agencies responsible for the issuance of discharge permits are implementing more comprehensive programs to ensure protection of the water quality standards of the state’s streams.

A-3.1 Water Quality-Based Effluent Limits.

Effluent limits contained in operating NPDES permits are developed by the permit writer and based on state water quality standards for the receiving stream. These effluent limits are called water quality-based effluent limits. Each stream in the state is classified in the water quality standards according to its existing or potential uses. Specific and general standards apply to each classification.

The inclusion of water quality-based effluent limits in the permit is based on a review of the effluent characterization presented in the discharger’s operating NPDES permit application. This review, conducted by the permit writer, assesses the presence of compounds that have the potential to violate the water quality standards.

A-3.2 Waste Load Allocation.

Most operating NPDES permits include limits on oxygen-demanding substances (such as CBOD and ammonia). Development of these limits typically is based on a waste load allocation for the receiving stream. Stream modeling is used to assess the assimilative capacity of the stream based on the applicable dissolved oxygen standard. This capacity is then allocated among all the dischargers in the area. Generally, some portion of the stream's capacity is reserved for future dischargers.

Waste load allocation modeling typically consists of a desk-top effort for small discharges and a calibrated and verified model based on field measurements for larger discharges. Modeling is performed by the discharger or by the state agency. Regardless of who performs the modeling, the results receive a detailed review by both the state and EPA. Typically, these results are put out for public comment. In many cases, the public comment period is concurrent with the public notice for the NPDES permit.

A-3.3 Chemical-Specific Criteria.

Water quality-based effluent limits is based on chemical-specific criteria from the water quality standards (such as for metals or toxics) or on general narrative criteria. Specific criteria are used in the development of effluent limits, and in many cases, an allowance for dilution in the receiving stream is provided.

Typically, some portion of the 7Q10 low-flow for the receiving stream is used for dilution purposes. 7Q10 is a hydrogeological determination of the lowest average flow over 7 consecutive days with an average recurrence frequency of once in 10 years. Consider background concentrations in the receiving stream when performing dilution calculations. Where the 7Q10 low-flow is zero, the criteria will apply at the point of discharge, prior to any dilution.

A-3.4 Aquatic Life Criteria.

For aquatic life criteria, acute or chronic values apply. The application of acute versus chronic criteria is dependent on many items, including the use classification and the available dilution in the receiving stream. Generally, if the available dilution is greater than 100 to 1, then the acute criteria apply.

A-3.5 General Narrative Criteria.

To address these narrative criteria, most states apply a whole-effluent toxicity requirement in the permit. The whole-effluent approach to toxics control for the protection of aquatic life involves the use of acute and/or chronic toxicity tests to measure the toxicity of wastewaters. The acute test assesses the lethality of the wastewater to the test organisms and is conducted based on the regulatory agencies' requirements. The chronic test assesses growth and reproduction in addition to lethality and is conducted based on the regulatory agencies' requirements. Whole-effluent toxicity tests use standardized surrogate freshwater or marine plants, invertebrates, and vertebrates. The test is run at the same dilution as is allowed for the wastewater in the receiving stream. Failure to meet the criteria results in the need to conduct a toxicity reduction evaluation on the discharge. If the plant is not yet built, the effluent standards are determined by using effluent standards from a similar type of facility. Additionally, permits consider the standards of the receiving stream.

Example of general narrative criteria:

Toxic substances must not be present in receiving waters, after mixing, in such quantities as to be toxic to human, animal, plant, or aquatic life or to interfere with the normal propagation, growth, and survival of the indigenous aquatic biota.

A-4 COLD WEATHER OPERATION.

Consider Tables A-1 for treatment process components subject to freezing problems.

Table A-1 Treatment Process Components Subject to Freezing Problems

Preliminary Treatment	Clarifiers	Biological Reactors	Solids Management	Disinfection
Pumping	Primary	Activated sludge	Digestion	Chlorination
Screens	Secondary	Extended aeration	Dewatering	
Grinders	Polishing ponds	Oxidation ditches	Disposal	
Grit chamber	Air flotation	Trickling filters		
Flow measurement	Thickeners	Rotary biological contactors		
Flow equalization		Aerated lagoons		
		Facultative lagoons		

Source: SR 85-11.

Consider Table A-2 for winter problems associated with preliminary treatment.

Table A-2 Winter Problems with Preliminary Treatment

Problem	Solution
Ice buildup in headworks area	Keep building heated above 50 ˚F (10 ˚C).
Icing of bar racks	Cover inlet channel. Flush with warm water. Weather-strip channels to reduce cold air entry into building. Clean by hand frequently.
Septage pumping lines freeze	Use heat tape on lines and valves. Use proper flushing after pumping truck. Use manhole to directly dump into plant. Do not handle septage in winter. Drain all lines.
Septage freezing in truck	Pass engine exhaust through truck tank to prevent freezing. Drain truck tank pipings and valves.
Collected grit freezes	Store dumpsters in heated building before emptying. Store truck inside. Remove no grit in winter.
Icing of grit dewatering equipment	Duct kerosene heater into area.
Grit machine freezes	Enclose unit.
Screened rags freeze	Remove regularly by hand.
Spiral lift pumps freeze	Run water on ice to reduce buildup.
Screw pumps freeze	Install timer to “bump” screw once per hour.
Valves and hoses freeze	Drain lines. Keep hoses on.

Automatic sampler freezes	Place sampler inside building. Do not use in severe cold. Build insulated structure heated with light bulb. Insulate suction lines. Purge lines after sample taken. Move sampler location to decrease exposure. Install suction lines to give a straight fall.
Flow measurement device freezes	Use heat tape and glass fiber insulation on flow transmitter. Insulate chamber and heat with one light bulb. Put heat tape on Parshall flume linkage.
Float for flow measurement freezes	Heat with light bulb and insulate. Add antifreeze to float box.
Grit removal bypass channel freezes	Temporarily switch flow to bypass channel, 30 minutes/day or more often if needed.
Water freezing at comminutor	Build Plexiglas structure to keep influent warm.
Doors frozen shut on screening enclosure because of condensation	Put heat tape around door enclosure.
Stairs above screw pumps are slippery from icing condensation	Plant policy requires all operators to keep one hand free at all times to use rails.

Source: SR 85-11.

Consider Table A-3 for winter problems associated with clarifiers.

Table A-3 Winter Problems with Clarifiers

Problem	Solution
Scum line freezes	Flush out with hot water. Use sewer bag to free blockages. Install automatic flushing mechanism.
Scum trough freezes	Cover exterior trough. Break ice into pieces and remove by hand. Install automatic flushing mechanism.
Scum freezes on beaching plate	Flush off with hot water. Discontinue scum removal in winter. Shovel and hose down by hand. If adjustable, decrease exposed plate area.
Ice on beaching plate hangs up collector arm and damages mechanism	Remove skimmer during winter. Remove ice by hand.
Scum freezes on outside ring of peripheral feed clarifier	Cover clarifier.
Scum solidifies, will not flow	Use warm water to flush.
Scum freezes at center feed	Install a warm water sprayer to keep scum moving toward skimmer.
Surface icing	Remove secondary arms to prevent damage. Keep clarifiers on 24 hours/day. Remove thick ice with long- armed backhoe. Shorten detention times.
Icing in idle units	Pump units dry routinely.
Icing in gear units	Install heat tapes on drain line. Drain water in bullgear after rain and when temperature rises.

Hoses and hydrants freeze	Leave lines on. Drain lines after use.
Traveling bridge controls ice-up	Build enclosure over controls.
Icing of bus bar for bridges	Install heat guns or warm air blower.
Switches on monorakes freeze	Shut off units in snow and ice to prevent freezing.
Accumulation of snow on monorake rails stops wheels	Shut down rake during snowstorms and remove snow.
Automatic sampler freezes	Build insulated boxes heated with a 100-watt light bulb.
Waste activated sludge lines freeze	Locate lines deeper. Install proper drainage.

Source: SR 85-11.

Consider Table A-4 for winter problems associated with biological systems.

Table A-4 Winter Problems with Biological Systems

Problem	Solution
Ice buildup on surface area	Remove by hand. Run on high speed for 15 minutes. Turn off for ½ hour, allow mixed liquor to warm aerator, and turn on high speed. Steam ice off. Bump aerator on and off carefully.
Impeller icing causing ponding on fixed shroud	Remove shroud. Ice will still build up, but aerator will not be damaged.
Ice buildup on supporting columns causing rotating shroud to pond on columns	Shorten detention times; run aerators on timers.
Cooling of mixed liquor	Install timers on aerators. Use diffused air instead of surface aeration. Remove some aerator blades.
Icing in idle tank damaging structure	Fill tank 1 foot above baffle. Install small sump pump to keep surface free of ice. Exercise units regularly during sunny days. Care must be taken not to damage units. Use inner tubes to absorb ice expansion. Bubble air to prevent freezing.
Ice buildup on splash guard, electrical conduit, and walkways	Use good snow and ice removal procedures, salt. Plant policy requires operators to keep one hand free to hold railing.
Decreased removal efficiencies	Increase MCRT, decrease food-to-microorganism ratio.

Source: SR 85-11.

Consider Table A-5 for winter problems associated with disinfection problems.

Table A-5 Winter Disinfection Problems

Problem	Solution
Feed lines freeze	Enclose all storage and pumping facilities in a heated building.
Hypochlorite solution crystallizes in pumps and pipes	Keep in heated room above 65 ˚F (18 ˚C).
Surface contact chamber freezes	Cover and insulate tanks.

Source: SR 85-11.

A-5 ODOR CONTROL SYSTEMS.

Each of the odor control systems require maintenance that is based on the air flow, constituents in the odorous air streams, and site conditions. These individual factors have effect on the amount and type of maintenance that each system requires.

A-6 CHEMICAL ODOR CONTROL SYSTEM.

Based on the data collected on the operation of the chemical odor control system, cleaning the plastic media in the system may be required. The media may be replaced or acid washed. Seven to 10 years is the normal expected frequency of cleaning or replacing the media.

A-7 BIOLOGICAL ODOR CONTROL SYSTEM.

Based on the data collected on the operation of the biological odor control system, replacing media in the biological odor control system may be required. Depending on the type of media, the expected life will vary. If the media are made of natural items (e.g., soil, wood chips), the media will need to be replaced every 2 to 3 years. If the media are manmade products, the media are expected to last 7 to 10 years.

A-8 MAINTENANCE.

While maintenance requirements for all the equipment is be completed as detailed in the manufacturer's equipment manual, there are other tests and observations an operator can complete to identify problems or extend the periodicity of the maintenance requirements.

Consider Table A-6 for winter problems associated with solids management.

Table A-6 Winter Problems with Solids Management

Problem	Solution
Unable to use solids drying beds in winter; beds freeze	Cover beds.
Not able to apply solids to land in winter	Stockpile solids in winter months.
Aerobic digester freezes if blower is shut off to allow thickening by decanting	Cover tank. Decant smaller amounts more often.
Solids mixture freezes in tank	Run mechanical agitator overnight.
Ice forms on digesters	Insulate better.
Icing in gravity thickener	Run final effluent to keep hydraulic loading higher.
Solids holding tank freezes	Take offline during winter.
Solids freeze on truck	Use truck body heated with exhaust gases.
Solids lines freeze; valves freeze	Drain lines correctly. Dismantle and thaw valve. Put heat tape on lines. Increase return rates.
Holding tanks too small to last winter	Use spare clarifier of oxidation ditch.
Extensive heat loss from anaerobic digester	Improve insulation.
Operating temperature could not be reached in a new compost pile	Cover pile and insulate. Mix solids and wood chips with hot compost. Blow hot exhaust from working pile into new pile.

Source: SR 85-11.

A-8.1 Predictive Maintenance.

Predictive maintenance is maintenance completed on a periodic basis. The results of predictive maintenance are used to determine (predict) when a piece of equipment is going to fail or to discover a problem in a piece of equipment before a failure occurs. Most predictive maintenance requires that the piece of equipment be running at its design point before testing starts and during testing.

The periodicity will need to be determined by the operator based on the criticality of the component to the wastewater treatment process, ease of completing the test, treatment plant operations, and budget. As an example, an influent pump cannot have vibration testing and thermal imaging completed during the summer when the pump will not run at full deign speed for long periods of time.

A-8.2 Vibration Testing.

Vibration testing is conducted on mechanical equipment to determine bearing failure. Vibration testing is conducted on both the machine bearings and its motor bearings. The results of the test can provide operators with information on bearing wear and allow the operator to replace or repair bearings prior to the bearing failing. If the bearing were to fail, it may cause equipment damage and result in a violation to the NPDES permit. Conduct vibration testing by a qualified person to ensure that the results are accurate and the test is done consistently each time.

Measure vibration displacement in inches or millimeters. In all cases, the vibration is the measure of the amplitude of the motion from the piece of machinery. If one of the values is known, it can be converted to another using one of the two equations below:

Equation A-1. Vibration Velocity

$$v = 2 * \pi * f * d$$

Where:
v = peak velocity (m/sec or in/sec)
f = cycles per second (hertz)
d = peak displacement (mm or in.)

Equation A-2. Vibration Acceleration

$$a = 2 * \pi * f * v$$

Where:

a = acceleration (g [m/sec^2] or in./sec^2)
f = cycles per second (hertz)
v = peak velocity (m/sec or in./sec)

A-8.3 Lubrication and Wear Particle Analysis.

Lubrication and wear particle analysis is a test that provides information about the condition of the lubricant itself that is provided by a testing laboratory. The analysis provides information on the amount of chemical contamination of the lubricant, the state of the lubricant additives, the molecular condition of the lubricant, and the amount of dissolve elements in the lubricant. The analysis also provides the amount of, makeup, shape, and size of the particles in the lubricant that come from the wear of the internal machinery components being lubricated.

The results of the lubrication and wear particle analysis can help operators adjust their lubrication schedule from the manufacturer's recommendations.

A-8.4 Thermographic Imaging.

Thermographic imaging is the measure of either the temperature or the difference in temperature of both mechanical and electrical components. When thermographic imaging is used, the equipment being checked must be operated at its designed operating point. Thermographic imaging can identify poor lubrication practices on pieces of equipment and poor alignment of the equipment. In electrical equipment, thermographic imaging can identify when equipment is overloaded, there are loose electrical fittings or poor electrical connections, and other potential failures.

A-8.5 Ultrasonic Analysis.

Ultrasonic analysis is used on bearings to determine when it must be greased and how much grease to add. Ultrasonic analysis must be done several times on a piece of equipment with normal lubrication conditions to establish a baseline sound signature, which is measured in decibels (dB). When the bearings sound signature changes by more than 8 dB from its baseline signature, correct the bearing by adding grease to it. If the bearings sound signature changes by more than 12 dB, the bearing is showing an indication of deterioration.

A-8.6 Electrical Surge Testing.

Electrical surge testing is the only testing that can be done on a motor to determine if the motor is deteriorating and may possibly fail. The testing tests the motor's winding for weakness in the turn to turn, coil to coil, and phase to phase insulation. The electrical surge testing looks for faults in the motor windings themselves. A megohm test also known as "meggering" can be performed on the motor windings. The megohm test only examines the motor windings insulation quality.

A-8.7 Motor Current Signature Analysis.

Motor signature analysis is used to detect both mechanical and electrical issues in equipment. This test uses the electrical amperage draw of the motor as load changes over time to provide an early warning of equipment or motor deterioration. Start the motor current signature when the piece of equipment is new to allow for a baseline signature to be developed. Compare the motor current signature to the base line and trend to identify the deterioration of the piece of equipment.

A-8.8 Bearing Greasing.

Bearings are required to be greased on a regular basis and measure the amount of grease added in ounces or grams. Measure the grease to be pumped in as each grease gun dispenses different amounts of grease per pump. Some larger bearings require periodic cleaning out of the bearing and repacking it with grease based on the bearing manufacturer's requirements.

It is common for equipment manufacturers to direct the operator to grease the motor bearings at set intervals. Review the motor greasing frequency. Consider the following items to determine the frequency of motor greasing:

- Motor frame size
- Motor speed
- Severity of service

A-8.9 Severity of Service.

Factors that affect the severity of service are the motor's daily hours of operation, the ambient temperature of the atmosphere around the motor, and the amount of dust in the atmosphere around the motor. In general, motors that are in warmer and dustier locations require greasing more often than motors operating inside a clean and cool room.

A-8.10 Lubricants.

Lubricants come with different options and have different operating ranges. Use the lubricant that is specified in the manufacturer's equipment manual. If the operator decides to change the lubricant type, consult a lubrication engineer and the equipment manufacturer to ensure the equipment is properly lubricated to prevent equipment damage.

The viscosity of lubricating oils will change because of freezing temperatures. The operator can either change the oil to suit the expected temperature range or use heat tape or immersion-type heaters to maintain higher oil temperatures. Sometimes multi-viscosity year-round synthetic oils may be appropriate. Gear boxes tend to collect moisture and condensate, which may either degrade lubrication oil or cause corrosion.

A-8.11 Painting and Coatings.

Maintenance of coating systems in wastewater treatment plants depends upon a number of factors:

- Knowing the specific coating systems that currently exist within the plant
- Implementing an active inspection program
- Providing a good maintenance painting program

Maintenance painting operations are different than new construction painting operations. With a proper maintenance painting program, total recoating is generally atypical rather than normal. In saltwater or coastal environments, painting frequency may need to be increased.

A-8.11.1 Inspection.

Routinely inspect all coating surfaces and be observant for the first signs of coating breakdown such as rust staining and streaking, blistering of coating, peeling of coating, and other signs of deterioration. Coatings on steel substrates generally will show the first signs of failure at sharp edges such as edges of structural steel, adjacent to welds, and around threads of bolts and edges of nuts. Failures on flat surfaces take longer to develop.

In immersion service, coating failures also develop first at edges but can also develop on flat surfaces because of imperfection/s and defects. Linings in tanks and vessels are especially critical.

A-8.11.2 Chemical Storage Areas.

Most chemical storage areas will have concrete containment walls to contain potential spills of the tank. Coat containment surfaces with a suitable coating system capable of withstanding the spilled chemical. Most monolithic (bonded) coatings will mirror any cracks that may develop in the concrete. Visually inspect these areas to detect any leaks or spills through the concrete.

A-8.11.3 Material Selection.

Much of a typical wastewater treatment plant consists of cast-in-place concrete structures. With a few exceptions, concrete performs well in the environments associated with wastewater treatment plants. Other common construction materials also do well but require careful selection and maintenance to achieve long-term service life. The wastewater associated with the wastewater treatment plants is usually not extremely aggressive unless the facility receives wastewater from certain industrial operations.

Hydrogen sulfide is ever present and must be recognized, especially in the vapor areas above the wastewater surface. Where the wastewater is agitated or falls over weirs, hydrogen sulfide is released. Any condensate formed will be acidic and therefore aggressive to concrete and unprotected carbon steel.

A-8.12 Corrosion.

Perform regular inspection of the concrete and steel surfaces in these aggressive areas and take appropriate action when significant corrosion becomes evident. Corrosion of metal surfaces usually occurs faster than on concrete surfaces. Take corrective action as soon as possible.

UFC 3-190-06 contains requirements for painting and coating various components in a wastewater treatment plant.

A-8.13 Maintenance Scheduling.

Follow the manufacturer's maintenance requirements at the recommended periodicities; however, each Installation should review their periodicities and adjust based on specific Installation requirements, experiences, or other considerations such as predictive maintenance results. If the Installation cannot complete all maintenance items, consider a tiered approach in which designated higher tier maintenance items are completed first. A recommended tiered approach would include the following levels:

- Operator-level maintenance
- Tier I
- Tier II
- Tier III
- Tier IV

If a maintenance item is in a lower tier and not completed over multiple cycles, failure to complete the maintenance may cause the piece of equipment to fail. Over time, lack of completion of lower-tier maintenance items will require that those items move up on the tier list. Failure to reassign maintenance completion priority may result in the system not operating as required to meet the wastewater treatment plant's permit requirements.

A-8.13.1 Operator-Level Maintenance.

The operator-level maintenance tier comprises maintenance items that are non-intrusive and normally take little time to complete. Examples of operator-level maintenance include:

- Instrumentation cleaning
- Monitoring equipment for abnormal noise, vibration, and lubricant leakage
- Equipment performance testing

A-8.13.2 Tier I Maintenance.

Tier I maintenance includes maintenance items that must be completed as required by the various operating permits of the wastewater treatment plant. Examples of Tier I maintenance items include:

- Flow meter calibration
- Laboratory instrumentation calibration
- Maintenance items required by the NPDES permit, equipment and system warranties, and performance guarantees

A-8.13.3 Tier II Maintenance.

The Tier II maintenance level includes maintenance items that are completed to keep the equipment running or to check equipment health. Examples of Tier II maintenance items include:

- Checking or changing oil in gearboxes
- Predictive maintenance on equipment
- Changing air filters for HVAC units

A-8.13.4 Tier III Maintenance.

The Tier III maintenance level includes maintenance items that result in major changes to the wastewater treatment process or require a large amount of manpower to complete. Examples of Tier III maintenance items include:

- Cleaning aeration grid air diffusers
- Most electrical system maintenance
- Checking and replacing wear part clearances

A-8.13.5 Tier IV Maintenance.

Tier IV maintenance level includes maintenance items that are required to be completed at infrequent intervals of the equipment's operation life. Examples of Tier IV maintenance items include:

- Rebuilding a pump or blower
- Cleaning or replacing media in an odor control system
- Replacing clarifier scrappers **\1**

A-8.14 Wastewater Collection.

Cleaning and inspecting sewers assists in maintaining sewer capacity and identifying repairs that may be needed. A site-specific maintenance plan for cleaning and inspecting wastewater collection systems should be prepared to assist in maintaining sewers. Include options and procedures for cleaning and inspecting sewers in the maintenance plan. The Installation should determine cleaning and inspection schedules based on the age of the sewer, sewer condition and availability of funding. Use WEF MOP FD-6 and EPA 832-F-99-031 for sewer cleaning and inspection guidance. **/1/**

A-9 O&M GUIDANCE DOCUMENTS.

The Sacramento series are the primary technical guidance references for the operation and maintenance of wastewater treatment systems. These references provide valuable training, operating, maintenance and troubleshooting techniques. These best practice references should be available to personnel operating and maintaining the WWTP.

A-10 OPERATOR TRAINING.

There are various methods of obtaining training for certification. State regulatory agencies or Association of Boards of Certification can help. The required training can be obtained from the following locations:

- The California State University, Sacramento, has correspondence courses available that provide the basics for most state examinations and certification processes.
- Water Environment Federation has wastewater courses both in printed and computer CD-ROM formats.
- Local, state, and national trade shows may have forums that can help meet the required training for the operator certification.
- Local and state classes for operator certification
- College level classes
- Approved equipment manufactures operation and maintenance training
- Approved consultant provided training

A-11 OPERATIONS OF EQUIPMENT AND SYSTEMS.

Consider the following items as part of equipment and system operations.

A-11.1 Starting, Stopping, and Changing Equipment.

Starting, stopping, and changing equipment and wastewater treatment plant processes should be done using site-specific O&M manuals, equipment manufacturer O&M manuals, and standard operating procedures.

A-11.2 Emergency Operating Requirements.

Make emergency generators available and always fueled to above the 75% level. There needs to be enough pumps and tankage available to meet design flow. Complete repairs to equipment that prevent meeting design flow/loads as soon as possible.

There will be specific emergency operating requirements for individual WWTPs. These specific requirements should be identified in the site-specific O&M manual.

A-11.3 Equipment Calibration and Field Checking.

Conduct instrument calibration frequently to have accuracy across readings. Take measurements, flows, and concentrations twice to check the accuracy of the measuring device.

It is useful to have portable field equipment to double-check the values/readings from permanently mounted monitoring instruments as a quality check for data and treatment process control.

A-11.4 Sampling and Process Data Review.

Review sampling and process data to identify trends. These trends can be utilized by the operators to improve the operation of the WWTP. Review plant-operating parameters that includes but is not limited to DO, RAS flow, and influent flow.

A-12 BEST PRACTICE REFERENCES

ENVIRONMENTAL PROTECTION AGENCY

https://www.epa.gov/

EPA/625/R-00/008, *Onsite Wastewater Treatment Systems Manual*, February 2002

EPA/625/R-92/013, *Control of Pathogens and Vector Attraction in Sludge*, July 2003

EPA 832-F-03-023, *Decentralized Systems Technology Fact Sheet; Septic Tank Effluent Screens*, September 2003

EPA 932-F-99-068, *Decentralized Systems Technology Fact Sheet; Septage Treatment/Disposal*, September 1999

NATIONAL SMALL FLOWS CLEARINGHOUSE

http://www.nesc.wvu.edu/pdf/ww/septic/pl_fall04.pdf

Maintaining Your Septic System - A Guide for Homeowners

OFFICE OF WATER PROGRAMS, CALIFORNIA STATE UNIVERSITY, SACRAMENTO, 3020 STATE UNIVERSITY DRIVE, MODOC HALL SUITE 1001, SACRAMENTO, CA 95819. 916-278-6142.

http://www.owp.csus.edu/courses/wastewater.php

Operation of Wastewater Treatment Plants, Volume 1, 2008

Operation of Wastewater Treatment Plants, Volume 2, 2007

Advanced Waste Treatment, 2006

APPENDIX B GLOSSARY

B-1 ACRONYMS

BOD_5	biochemical oxygen demand
CBOD	carbonaceous biochemical oxygen demand
CFR	Code of Federal Regulations
CPI	corrugated plate interceptor
DAF	dissolved air flotation
DoD	Department of Defense
EPA	Environmental Protection Agency
F:M	food to mass ratio
FGS	Final Governing Standards
HQUSACE	Headquarters, U.S. Army Corps of Engineers
HNFA	Host Nation Funded Construction Agreement
HVAC	heating, ventilation, and air conditioning
MCRT	mean cell residence time
MLSS	mixed liquor suspended solids
MLVSS	mixed liquor volatile suspended solids
NAVFAC	Naval Facilities Engineering Command
NPDES	National Pollutant Discharge Elimination System
OEBGD	Overseas Environmental Baseline Guideline Document
O&M	operations and maintenance
PAA	peracetic acid
RAS	return activated sludge
SBR	single batch reactor

SOFA	Status of Forces Agreement
SRT_a	aerobic solids retention time
TSS	total suspended solids
UFC	Unified Facilities Criteria
U.S.	United States
UV	ultraviolet
UVT	UV transmittance
WAS	waste activated sludge
WWTP	wastewater treatment plant

B-2 DEFINITION OF TERMS

Use WEF MOP 11 or the applicable industry standard for definition of terms.

APPENDIX C REFERENCES

DEPARTMENT OF THE AIR FORCE, AIR FORCE PUBLICATIONS DISTRIBUTION CENTER, 2800 EASTERN BOULEVARD, BALTIMORE, MD 21220-2896

http://www.wbdg.org/ffc/af-afcec/instructions-afi/.

AIR FORCE HANDBOOK

AFH 32-1290, *Cathodic Protection Field Testing*, 01 February 1999

AIR FORCE INSTRUCTION

\1\ /1/

\1 AFMAN **/1/** 32-1062*, Electrical Systems, Power Plants and Generators,* 15 January 2015

\1\ /1/

\1 AFMAN **/1/** 32-1067, *Water and Fuel Systems,* 04 February 2015

\1 AFMAN **/1/** 32-1068, *Heating Systems and Unfired Pressure Vessels,* 08 February 2017

AFI 32-7001, *Civil Engineering Environmental Management,* 23 August 2019

DEPARTMENT OF THE ARMY, U.S. ARMY CORPS OF ENGINEERS, 441 G STREET, NW, WASHINGTON, DC 20314-1000

https://www.wbdg.org

COLD REGIONS RESEARCH AND ENGINEERING LABORATORY

SR 85-11, Special Report, Prevention of Freezing and Other Cold Weather Problems at Wastewater Treatment Facilities, 1985

PUBLIC WORKS TECHNICAL BULLETIN

PWTB 200-1-142, *Application Guidelines for Water Reuse at Army Installations,* 30 June 2014

PWTB 420-49-29, *Operation and Maintenance of Cathodic Protection Systems,* 2 December 1999

TECHNICAL MANUAL

TM 5-682, *Facilities Engineering Electrical Facilities Safety*, 08 November 1999

TM 5-683, *Facilities Engineering Electrical Interior Facilities*, 30 November 1999

TM 5-684, *Facilities Engineering Electrical Exterior Facilities, 29 November 1996*

TM 5-685, *Operation, Maintenance and Repair of Auxiliary Generators*, 26 August 1996

TM 5-814-3*, Domestic Wastewater Treatment,* 31 August 1988

DEPARTMENT OF DEFENSE

http://www.dtic.mil/whs/directives/

DoD 4715.05-G, Overseas Environmental Baseline Guideline Document

DEPARTMENT OF DEFENSE INSTRUCTION

DoDI 4715.05, Environmental Compliance at Installations Outside the United States

DoDI 4715.06, Environmental Compliance in the United States

DoDI 4715.1E, Environment, Safety, and Occupational Health (ESOH)

DoDI 6055.1, DoD Safety and Occupational Health, 14 October 2014

DEPARTMENT OF THE NAVY, OFFICE OF THE CHIEF OF NAVAL OPERATIONS, 1200 NAVY PENTAGON, WASHINGTON, DC 20350-1200

http://www.public.navy.mil

OPNAVINST 5090.1D, *Environmental Readiness Program,* 10 January 2014

OPNAVINST 5100.23G, *Navy Occupational Safety and Health Program*

INTERNATIONAL CODE COUNCIL, 500 NEW JERSEY AVENUE, NW, 6TH FLOOR, WASHINGTON, DC 20001-2070

https://www.iccsafe.org/

IPC, International Plumbing Code

IPSDC, International Private Sewage Disposal Code

MARINE CORPS ORDER

MCO P5090.2A, *Environmental Compliance and Protection Manual*, 26 August 2013.

TECHNOMIC PUBLISHING CO INC, LANCASTER, PENNSYLVANIA

Wastewater Engineering Design for Unsewered Areas, by Rein Laak, 1986,

UNIFIED FACILITIES CRITERIA

https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc

UFC 1-200-01, DoD Building Code (General Building Requirements)

UFC 3-190-06, Protective Coatings and Paints

UFC 3-230-01, Water Storage and Distribution

UFC 3-230-02, Operation and Maintenance (O&M): Water Supply Systems

UFC 3-420-01, Plumbing Systems

UFC 3-540-07, Operation and Maintenance (O&M): Generators

UFC 3-550-07, Operation and Maintenance (O&M): Exterior Power Distribution Systems

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

UFC 3-570-06, O&M: Cathodic Protection Systems

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

UFC 3-600-02, Operations and Maintenance: Inspection, Testing, and Maintenance of Fire Protection Systems

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

WATER ENVIRONMENT FEDERATION
MCGRAW-HILL, TWO PENN PLAZA, NEW YORK, NY 10121-2298

WEF MOP 11*, Operation of Water Resources Recovery Facilities,* Manual of Practice No. 11, Seventh Edition, 2017

UFC 3-240-11
24 March 2021

UNIFIED FACILITIES CRITERIA (UFC)

LANDFILLS IN SUPPORT OF MILITARY OPERATIONS

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

UNIFIED FACILITIES CRITERIA (UFC)

LANDFILLS IN SUPPORT OF MILITARY OPERATIONS

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

U.S. ARMY CORPS OF ENGINEERS (Preparing Activity)

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER CENTER

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

Change No.	**Date**	**Location**

FOREWORD

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

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and the Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Defense agencies must contact the preparing Service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale must be sent to the respective service proponent office by the following electronic form: Criteria Change Request. The form is also accessible from the Internet site listed below.

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

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

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

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UNIFIED FACILITIES CRITERIA (UFC)
NEW SUMMARY SHEET

Document: UFC 3-240-11, *Landfills in Support of Military Operations*

Superseding: None

Description: This UFC provides guidance for planning, design, construction, and operation of landfills at contingency locations. This UFC describes appropriate practices for land disposal of non-hazardous solid waste. This UFC is applicable to contingency locations outside the United States.

Reasons for Document:

- This document provides guidance for military engineers to design and construct landfills at contingency locations or have the necessary landfill specifications available so a contracting officer can incorporate these specifications in contracts for landfill construction and operation during contingency operations.
- This document fills the need for UFC construction specifications for landfill facilities in support of contingency operations.

Impact:

- This document provides guidance that will protect force health by diverting solid waste from burn pits to landfills in contingency operations and avoid long-term health effects through best use of engineering principles.
- This document provides typical design specifications that can be tailored to fit site-specific needs and that will save repetitive costs for planning and designing landfills during contingency operations.
- This document provides guidance that will balance Service members' health and safety, environmental protection, and field-expedient practices.

Unification Issues: There are no unification issues.

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FIGURES

TABLES

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CHAPTER 1 INTRODUCTION

1-1 BACKGROUND.

1-1.1 General.

This UFC describes waste streams generated during contingency operations in theater and provides design guidance on landfill construction. Solid waste disposal can be a significant problem. Proper planning for and management of solid waste is critical to protect the health of Service members and the environment. Improper handling and disposal of solid waste can create unhealthy working conditions and impact mission accomplishment. Generated waste, if not dealt with properly, can contaminate food and water sources, contribute to spread of disease, cause varying degrees of harm to the environment, and generate ill feelings with the host nation (HN). Experiences in Iraq and Afghanistan have demonstrated some of the consequences when waste generation is not considered early in the planning phase or when DoD does not effectively respond to problems related to waste generation or disposal. These include health concerns associated with trash burning and the residual negative environmental impacts related to base camp transfers and closures.

The extent to which the environment can directly affect military operations and the resulting need to consider environmental considerations in its plans and operations depends on the specifics of the operation, including the situation on the ground, the military objectives, and the ultimate goals of the operation. Some information on this topic is available in DoDI 4715.22, *Environmental Management Policy for Contingency Locations*. ATP 3-34.5, *Environmental Considerations*, can also help commanders make informed decisions about environmental issues during a contingency operation. The longer forces must remain in the theater of operations, the more complex environmental issues can become.

1-1.2 Future Operations.

Recent experience suggests that ongoing and future contingencies will feature large stability, security, transition, and reconstruction (SSTR) components, will involve longer stays in theater, and require forces to perform functions that have historically been managed by U.S. government agencies, international organizations, or non-governmental organizations (NGO). These factors elevate the importance of treating environmental issues more explicitly and systematically in planning, operations, and training[1].

Future operational environments will likely be complex. Local or HN waste recycling, disposal, or treatment facilities (or services) may be nonexistent or beyond reach due to proximity, security, or political considerations. Thus, the burden for waste management falls on DoD. Commanders must consider the various operational impacts of waste generation early in the planning phase and throughout each phase of the operation. Commanders must also protect their Service members from long-term exposure to

[1] Mosher et al. 2008

waste, pollution, and diseases, whether those exposures are from conditions in the base camp or from conditions endemic to the area of operations. Consequently, it will be necessary to consider more comprehensive solutions to base camp wastes, disease vectors, and health protection for all on the base camp.

1-1.3 Concurrence with Integrated Solid Waste Management (ISWM) Program.

An integrated solid waste management (ISWM) program assesses various aspects of waste management, including the collection, storage, and disposal of waste, source reduction, recycling and composting, facility management, and budgeting and financing. It identifies existing waste systems, assesses needs, and sets forth the ways to design, implement, and monitor a more effective and sustainable waste management program. (See TM 3-34.56, *Waste Management for Deployed Forces*, for more information on ISWM program development.)

Since all methods of waste disposal can affect the environment to some degree, waste minimization should be of primary importance within every operation. Commanders should continually seek to reuse and recycle waste materials. Composting is one identified option that can also reduce materials that go into the landfill. Also evaluate reducing the amount of packaging materials sent into theater. Disposal of solid waste in a landfill is an option in ISWM programs. Current UFC construction specifications for landfills are designed to meet standards in CONUS; therefore, this UFC was developed to provide the necessary guidance for landfill construction in theater operations.

1-2 PURPOSE AND SCOPE.

1-2.1 Purpose.

This UFC describes appropriate practices for land disposal of non-hazardous solid waste during contingency operations for base camps with temporary and semi-permanent construction levels. (See UFC 1-201-01, *Non-Permanent DoD Facilities in Support of Military Operations*, for construction levels.) The goal is to balance Service members' health and safety, environmental protection, and field-expedient practices. If the HN does not have adequate infrastructure for managing solid waste, it is recommended that a contingency landfill be considered when a camp population is projected to grow to more than 500, when there is potential that the life expectancy of the base camp will be two years or more, and when, depending on combatant command (CCMD) policy, there are site conditions, resources, and logistics available to construct a landfill.

1-2.2 Scope.

This UFC covers land disposal of:

- Non-hazardous solid waste as defined below
- Non-hazardous byproducts of other waste management processes

This UFC does not cover:

- Management and disposal of hazardous waste (HW)
- Management and disposal of medical waste

For the purpose of this UFC, a contingency landfill is a landfill that accepts less than 20 tons per day of waste. This quantity of waste would be the maximum expected from a camp of 2000 people. Contingency landfills will only be developed in regions that experience less than 64 centimeters (cm) (25 inches [in.]) of rainfall each year.

1-2.3 Additional Information.

Refer to TM 3-34.56 for additional information on waste management for deployed forces. Chapter 5 of the TM details information on HW and special waste. This chapter also provides information on the six-step process to develop an HW and special waste management plan. Chapter 6 of the TM provides an overview of medical waste and describes some unique requirements that must be considered in developing a plan for collecting, storing, transporting, and disposing of medical waste.

1-3 APPLICABILITY.

This UFC is applicable to contingency locations outside the United States when a landfill is required and where other alternatives such as incineration or local hauling are not feasible.

1-4 WASTE MANAGEMENT OPTIONS.

Generated waste places a significant demand on a unit’s resources. Municipal waste disposal or treatment facilities will likely be nonexistent, incapacitated, substandard, or beyond reach due to security or logistical considerations. DoD is responsible for the entire waste management process. To reduce the amount of waste generated, it is essential to employ the principles of “reduce, reuse and recycle,” i.e., to manage daily operations to reduce the amount of waste generated.

1-4.1 Open-Air Burn Pit.

A burn pit is an area designated for burning trash in open air while not using an incinerator. DoD policy prohibits the use of open-air burn pits during contingency operations except in circumstances in which no alternative disposal method is feasible (see DoDI 4715.19, *Use of Open-Air Burn Pits in Contingency Operations*). Incinerators, engineered landfills, or other accepted solid waste management practices must be used whenever feasible. When open-air burn pits are used, they will be operated in a manner that prevents or minimizes risks to human health and safety of DoD personnel and, where possible, harm to the environment.

For each contingency operation, the operational commander must develop and approve an ISWM plan. The use of open-air burn pits is not allowed unless included within this plan. For additional information on procedures and minimum requirements for an open-air burn pit, refer to Section 3 of DoDI 4715.19.

1-4.2 Incineration.

A solid waste incinerator is any DoD-approved furnace used to burn solid waste for the purpose of destruction of and reduction of the volume of waste. Incineration is a waste treatment process that involves the combustion of organic substances (e.g., paper, plastic, wood, food) in waste materials. Incineration and other high-temperature waste treatment systems can be described as "thermal treatment." Incineration of waste material converts the waste into ash, flu gas, and heat. Solid waste incinerators are maintained and operated in accordance with the manufacturer's specifications. The majority of solid waste typically incinerated includes wastes from dining and life support area facilities and other non-recyclable materials including office waste and packaging waste. Incinerator operators must maintain a daily log and, at minimum, record the time, date, and amount of waste incinerated and the primary and secondary chamber temperatures during incineration. Consult command environmental staff for current requirements on air monitoring.

1-4.3 Composting.

Composting is nature's process of recycling decomposed organic materials into a rich soil known as compost. A large percentage of solid waste is organic, like packaging materials (cardboard and paper) and waste food. Four tasks are central to the design of a solid waste composting facility: collection, contaminant separation, sizing and mixing, and biological decomposition. Composting reduces the amount of materials that must be collected, transported, and disposed of in a landfill. It will also reduce fuel costs associated with burning solid waste if wet wastes are removed from the burn pit or incinerator.

1-4.4 Recycling.

Recycling is the process of converting waste materials into reusable objects to prevent waste of potentially useful materials, reduce the consumption of fresh raw materials, and reduce energy usage by decreasing the need for conventional waste disposal. Recycling also brings economic advantages, i.e., costs associated with solid waste disposal can be reduced if recycled materials can be sold. Examples of materials that can be recycled include plastics, cardboard, wood, mixed paper, aluminum cans, other metals, glass bottles and jars, and milk and juice cartons. Materials that have been sorted for recycling need to be stored in a facility so they do not create a fire, health, or safety hazard. These materials should also be bundled or contained to avoid spillage. Since recycling relies on the local economy, options might be limited in contingency operations.

1-4.5 Landfill.

Landfills are engineered disposal sites, designed to protect health and the environment. They are permanent facilities that will be in place for a long time; they require maintenance and may require long-term monitoring. While landfills may be preferable to burn pits, they should only be constructed where no other alternative is feasible, such as incineration or local hauling.

1-5 LAWS, REGULATIONS, AND POLICY.

Regulatory compliance may not seem relevant in many contingency operations, where U.S. laws do not apply, HN laws may be minimal or nonexistent, and local environmental conditions may be degraded. It is the commander's and leaders' responsibility at each contingency location to ensure ISWM is incorporated throughout all operations to minimize the harmful effects of waste on human health, the environment, and the mission. Even though U.S. regulations do not apply to contingency operations, similar environmental considerations, as reflected in the contingency location environmental standards (CLES), on properly managing and disposing waste can be applied in the operational area, to the extent practical, without impacting the mission. In contrast, units stationed at permanent bases overseas must comply with established final governing standards (FGS) that respect local HN laws.

1-5.1 Treaties, if Applicable.

Another body of laws that affect U.S. military forces are international treaties that govern armed conflict, known collectively as Environmental Laws of War (ELOW). Various international treaties, federal policies, and U.S. military Service regulations provide direction on conducting operations by preventing certain operations (such as environmental modification as prohibited by the Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques) and regulating others (such as cross-border movement of hazardous material regulated by the Basel Convention) (see ATP 3-34.5). According to the conventions, combatants are required to protect the natural environment against widespread, long-term, and severe damage during war.

1-5.2 DoDD 3000.10, Contingency Basing Outside the United States.

This directive establishes policy and assigns responsibilities for DoD contingency basing outside the United States. It states that it is DoD policy to pursue increased effectiveness and efficiency in contingency basing by promoting scalable interoperable capabilities that support joint, interagency, intergovernmental, and multinational partners. Use operational energy efficiently in accordance with DoD operational energy strategy and DoD directives, minimize waste, and conserve water and other resources. Minimize adverse impacts on local populations. Refer to Enclosure 2 of DoDD 3000.10 for an extensive list of responsibilities for various DoD organizations.

1-5.3 DoDI 4715.22, Environmental Management Policy for Contingency Locations.

This directive establishes policy, assigns responsibilities, and provides direction for environmental management at contingency locations in accordance with DoDD 4715.1E, *Environment, Safety, and Occupational Health (ESOH).* DoDI 4715.22 applies to all phases in the lifecycle of contingency locations, including planning and design, establishment, operation and management, and transition or closure. It establishes policy and provides oversight of a multi-DoD component work group to identify, develop, and revise the CLES as required. The CLES will include minimum environmental compliance standards and best management practices, including those that avoid or mitigate adverse effects.

1-5.4 Manuals.

For Army:

FM 3-34, *Engineer Operations*, provides overall doctrinal guidance and direction for conducting engineer activities. This FM provides information on engineer support to stability operations, which includes the task of constructing waste treatment and disposal facilities.

ATP 3-34.5, *Environmental Considerations*, serves as a guide for planners in identifying environmental-related issues as they pertain to operations and enables the integration of these issues into the operations planning process. Appendix B of this ATP provides information on international laws and treaties.

TM 3-34.56, *Waste Management for Deployed Forces*, gives guidance on planning and construction of waste management services and infrastructure. It covers expeditionary and large camps, and covers planning and roles and responsibilities.

1-5.5 DoDM 4715-05, Volumes 1–5, Overseas Environmental Baseline Guidance Document (OEBGD).

The primary purpose of DoD 4715-05G (OEBGD), composed of multiple volumes, is to provide standards to protect human health and the environment on enduring installations under DoD control outside the United States. The OEBGD is used by DoD lead environmental components (LEC) to establish and update FGS. The OEBGD establishes baseline environmental standards for installations in countries where an FGS is not required or has not been developed. While it does not technically apply to contingency locations, it still provides broad guidance on good environmental practices.

DoDM 4715.05, Volume 5, *Overseas Environmental Baseline Guidance Document: Waste*, contains definitions and criteria to ensure solid wastes are identified, classified, collected, transported, stored, treated, and disposed of safely and in a manner protective of human health and the environment. These criteria apply to residential and commercial solid waste generated at the installation level.

1-5.6 Summary.

Current policy regarding environmental issues impacts planning, design, construction, and operation and maintenance of contingency operations. DoDI 4715.22 establishes policy, assigns responsibilities, and provides direction for environmental management at contingency locations in accordance with DoDD 4715.1E and DoDD 3000.10. TM 3-34.56 provides guidance for conducting waste management operations while deployed on brigade level and below. In addition, standard operating procedures (SOP) are also available (e.g., Iraq, Afghanistan) that provide procedures for environmental compliance and guidance to the multi-national corps. These procedures are appropriate for use in the theater of operations.

1-6 GLOSSARY.

Appendix A contains acronyms, abbreviations, and terms.

1-7 REFERENCES.

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

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CHAPTER 2 PLANNING

2-1 WASTE REDUCTION.

Waste management operations involve collection, segregation, recycling, composting, reduction, transportation, and disposal of waste materials. Recycling and reuse programs should be initiated for plastics, cardboard, paper, batteries, tires, wood, aluminum cans, and other metals. This will require conducting source segregation, sorting, reuse, and a recycling program to make it effective. Sorting/source segregation of materials should be part of waste management from the beginning, even if the recycling program is not yet established. Especially sorting/segregation of demilitarized (DEMIL), HW, and medical waste must be in place from the very beginning as part of ISWM. Composting of food waste will also need to be considered, based on the size and volume of waste generated. Efforts should be made to reuse materials, such as construction materials, wood pallets, and packaging material, whenever possible. Reusable materials can be given away to locals at no cost, subject to the approval of the base commander or CCMD policy. Location of trash cans, recycle bins, and signs that explain separation of waste should be clear and simple to follow.

2-2 SOLID WASTE DISPOSAL DETERMINATION.

Following waste reduction measures, if disposal is required, determine if the HN has an existing landfill within reasonable distance with a capacity to accept additional solid waste. If the HN landfill can be used, an agreement must be developed for the terms, conditions, and requirements. If an HN landfill is not available and it is not possible to use an incinerator, identify a site that will host the new landfill. The site selection and planning processes will begin with a review of any existing environmental baseline survey (EBS) or environmental condition report (ECR); a review of local laws that might affect the construction of a landfill should also be conducted. Understanding the local geographic, geologic, hydrologic, environmental, and population conditions will significantly contribute to the planning process.

2-3 INTEGRATED SOLID WASTE MANAGEMENT PLAN

To achieve the best overall results, a camp should have an ISWM plan that identifies waste types and sources, recycling and recycling options, and safe treatment or disposal practices for all materials. At a minimum, this plan will describe the operation of the landfill, including procedures for excluding receipt of hazardous waste, PCBs, bulk liquid waste, and non-containerized liquids into the landfill.

2-4 ENVIRONMENTAL MANAGEMENT PLAN.

Develop a location-specific plan to identify potential environmental risks and associated resources needed to protect the environment and comply with applicable international agreements, DoD policy, and environmental compliance requirements, as appropriate.

2-5 DETERMINING SCOPE OF LANDFILL.

2-5.1 Primary Considerations.

There are five primary considerations when planning a landfill for in-theater operations.

- Feasibility
- Duration
- Capacity
- Sizing
- Future sizing

2-5.2 When to Construct a Landfill.

A decision by the lead Service or combatant commander to construct a landfill should be based on the definite advantages the landfill will bring to the deployed forces, whether those advantages are environmental, operational, or economical (i.e., cost-savings). Therefore, if the in-theater operations are expected to increase and a landfill is deemed necessary, a feasibility investigation should be conducted. Feasibility investigations assess projected future waste disposal demands and compare these demands with the current method of waste management. As stated in paragraph 1-6, it is recommended that a contingency landfill be considered when a camp population is projected to grow to more than 500, when there is a potential that the life expectancy of the base camp will be two years or more, and when, depending on CCMD policy, there are site conditions, resources, and logistics available to construct a landfill. The feasibility investigation should analyze and document existing conditions and final conditions; the topography at the proposed landfill site; surface drainage; quantity and location of cover material; supporting facility requirements; and recommended operational procedures. All of these aspects are outlined in this UFC.

The size of a landfill must be designed to accommodate the duration of the military operation and any future growth of the facilities it serves. The capacity of the landfill must meet the projected future demands of the base camp it is supporting. Capacity estimates should consider other waste management options such as recycling, volume reduction, and waste minimization. Equation 3-1 in Chapter 3 can be used to calculate the volume of a landfill; required area can be calculated once the landfill depth is determined based on site condition, including depth of groundwater table.

2-5.3 Waste Characteristics.

Data on the solid waste destined for disposal is needed for the accurate design of a landfill. That data includes the types of waste, amounts, and variations in delivery rates. For in-theater operations, that data can be estimated from an analysis of the population to be served and the operations conducted at a facility.

2-5.4 Mission Duration.

Consider the expected duration of the mission and nature of the operation. In addition, identify types and amounts of waste that will be generated (based on type, size, and function of units within the organization). The expected duration of the mission will determine appropriate design, performance, and construction standards. An analysis can be made of the population to be served and other major sources of solid waste.

2-5.5 Operational Methods.

The three most commonly used methods of operating a landfill are the area method, trench method, and ramp. Selecting the most appropriate method for a proposed landfill depends on local site conditions. Selection criteria, design, construction, and operation of all three methods are explained in Chapters 3, 4, and 5.

2-5.6 Operational Equipment.

Determine the types of operational equipment needed to collect, deliver, and operate the landfill. The equipment needed is determined by the projected types and estimated quantity of solid waste being disposed of in the proposed landfill. The capabilities of the equipment must be considered in evaluating factors such as access roads, grades, drainage, operation in severe climates, and feasibility of operation in a war zone. Generally, a waste-hauling truck, tracked or wheeled tractor with dozer, front-end loader, and trash blade are needed for daily operations of the landfill. A wheeled compactor and scraper also add value to the daily operations of a landfill. The specific equipment requirement will be mostly dictated by the site condition and availability of equipment in theater.

2-5.7 Closure.

Planning the closure of the landfill is a critical step when developing the design and operations of a landfill. This includes selecting the leachate collection and gas collection systems (if dictated) and final cover material as well as any maintenance that might need to be conducted after closure. Closure activities must begin soon after the last load of waste is received.

2-6 SITE SELECTION.

Landfills are site-specific and their design must take into consideration the unique environmental and land use qualities of a region. Additionally, the landfill site selection process should include careful planning that takes into account minimizing hauling distances while maximizing distances from bed-down areas and other inhabited locations in addition to locating the landfill away from living quarters, airfields, helipads, and access control points. Site selection should also consider the climate and environmental attributes of a location to ensure the landfill is properly designed to meet those conditions. The first stage in site selection is determining where a landfill should be optimally located. A landfill must be located downwind and downward from the bed-down area and dining facility. A safe distance must be maintained from all other activities of the base camp in accordance with a theater-specific SOP. In absence of theater-specific guidance, a distance of 400 meters (m) (1,312 feet [ft]) must be maintained downwind from the nearest bed-down area. Table 2-1 lists other landfill standoff distances that must be maintained[2]. No landfill should be constructed within a floodplain of major rivers, a 100-year floodplain area, or within 90 m (295 ft) of a navigable river or stream.

Table 2-1 Landfill Standoff Distances

Sensitive Areas	Distance m (ft)
Lake or pond	300 (984)
River	90 (295)
Highway	300 (984)
Public park	300 (984)
Water well	365 (1198)

2-6.2 Solid Waste Types and Quantities.

Estimate the types of waste and quantities expected for the life of the landfill operations. This estimate will determine the size of the landfill and scope of the operations.

2-6.3 Cover.

There should be a sufficient quantity of on-site soil suitable for use as cover material for the duration of landfill operations at the selected site.

2-6.4 Existing Site Utilities.

Sites with underground pipes or conduits (e.g., sewage, stormwater) must be rejected. If no other site is available, the underground infrastructure must be relocated before landfill construction.

2-6.5 Access.

Sites that can be directly accessed by existing all-weather roads are preferred. Direct routes to the landfill provide time and cost savings. Routes that use primary roads, go through residential areas, or cross major highways create safety hazards and should be avoided.

2-6.6 Agricultural Land.

If possible, locate landfills away from agricultural land.

[2] Bagchi, A. 1994

2-6.7 Airports.

All parts of a landfill complex must be located away from airports so the landfill does not pose a bird hazard to aircraft. A theater-specific SOP must be followed to identify a safe distance for the landfill site from the airports. If possible, follow UFC 3-260-01, *Airfield and Heliport Planning and Design*, which prescribes a lateral clearance zone of 152 m (500 ft) on both sides of the runway and a clear zone (CZ) of 915 m (3,000 ft) from the end of the runway with a 60-m (200-ft) approach/departure clearance. In general, for airports used by turbojet aircraft, the landfill must be 3 kilometers (km) (10,000 ft) from the end of the runway. For airports used only by piston-type aircraft, the landfill should not be closer than 1.5 km (5,000 ft) from the end of the runway. If a landfill site under consideration is within 8 km (5 miles) of any runway end, the commander or his/her representative must notify the affected airport authority.

2-6.8 Environmental Considerations.

The location of a landfill determines its level of environmental impact. Locations with features favorable to landfill design are more acceptable. Favorable features that might contribute to less-engineered landfill designs include naturally occurring clay soils, deep groundwater levels, remote or absent surface water sources, and limited surface run-off. Other environmental factors to consider are:

- Ground and surface water conditions
- Geology
- Soils
- Topographic features
- Floodplains
- Permafrost
- Cultural sites (Cultural property will be respected during armed conflict in accordance with the 1954 Hague Convention as ratified by the U.S. Senate in 2009.)
- Critical habitats of endangered species
- Aesthetic impacts

Environmentally sensitive areas such as wetlands, 100-year floodplains, permafrost areas, critical habitats of endangered species, and recharge zones of sole source aquifers should be classified as lowest-level priority for siting in-theater landfills.

2-6.8.1 Wetlands.

In theater, avoid all wetlands and wetlands buffer areas.

2-6.8.2 Unstable Areas.

Avoid karst terrain and other unstable areas.

2-7 CLIMATE.

The effects of heavy rains or snow should be considered and their effects on operations analyzed. Other factors to consider are litter problems and dust blowing from mounds of cover material. If the site is in an area where freezing temperatures will inhibit excavation, space for storing cover material needs to be incorporated into the facility. If adverse weather will disrupt operations, a landfill should not be constructed.

2-7.1 Cold Weather.

Extremely cold weather can greatly reduce the biological activity in a landfill. In areas where winter temperatures are lower than -34 °C (-30 °F), only minimal waste stabilization occurs. Frozen soil is another serious problem. In cold climates, excavate fill during the summer season and stockpile cover material to be used during the winter.

2-7.2 Hot Weather.

Extremely hot weather has no real adverse effects on landfill operations.

2-7.3 Wet Weather.

A major problem during wet weather is maintaining maneuverability of vehicles and equipment used to handle solid waste. Selecting a site that is well drained and has soil that provides adequate vehicle handling helps mitigate problems during wet weather. It may be necessary to import gravel to maintain roadways.

2-7.4 Dry Weather.

Dry weather does not cause operational problems at landfills although extremely dry weather limits the amount of biological activity taking place. Blowing refuse should be controlled by promptly covering waste materials and by erecting portable fences downwind of the working face, which is where waste is being dumped into the landfill and compaction and covering are ongoing.

CHAPTER 3 DESIGN GUIDELINES

3-1 GENERAL.

The proper design of a landfill that is adequate to the conditions in a theater environment is a challenging task because every site location is different and, in most cases, unfamiliar to the designer. An appropriate design that meets the site-specific need for disposal of solid waste generated at the contingency base while protecting human health and environment is the key. If needed, add additional protective measures, depending on site-specific requirements, topography, and geology and if required by the combatant commander. As a basis for the design of the landfill, review available information including, but not limited to, topographic maps, geological information, floodplain area, wetlands, faults, seismic impact zones, unstable areas, and surrounding area land use, including airports and helipads in the vicinity. In addition, verify the contingency operation cooperates with HN officials where applicable, to the extent possible in the ISWM planning process. Important factors to consider while designing the landfill are:

- Contingency operations
- Number of personnel
- Security of forces leaving the secured contingency operation
- Vehicles used for hauling waste
- Access road to the landfill
- Land area to be used for landfilling
- Landfilling method: area method, ramp method, or trench method, depending on the terrain
- Surface drainage to divert runoff water
- Protection of surface and groundwater
- Landfill gas and leachate

3-2 HEALTH AND SAFETY CONSIDERATIONS.

3-2.1 Landfill Workers.

Landfill workers face health and safety risks throughout the life of the landfill and even into closure. To minimize risks, depending on site-specific conditions, the design of the landfill will take into consideration the following hazards:

- Construction hazards
- Traffic accidents (e.g., rollovers during ramp or trenched operations)
- Heavy equipment operations during construction, operation, and closure
- Workers’ exposure to:

- ○ Waste material
- ○ Dangerous gases
- ○ Unknown chemicals
- ○ Disease vectors, including birds
- ○ Austere environment
- ○ Noise

Appropriate personal protective equipment (PPE) must be provided to landfill workers as the contingency situation permits, including clothing, steel-toe working boots, air-filtering headgear, and puncture-proof hand gloves.

3-2.2 Neighboring Inhabitants.

A landfill design that does not threaten the health and safety of nearby inhabitants in general precludes the following:

- Pollution of surface and groundwater from landfill-generated leachate
- Air pollution from dust or smoke
- Infestation by rats, flies, or other vermin
- Other nuisance factors, such as odors and noise
- Fires and combustion of refuse materials
- Explosives hazards from methane gas generated within the landfill
- FOD (foreign object debris) and bird strike hazard to aircraft
- Uncontrolled traffic from landfill construction/operation

3-3 SITE LAYOUT.

3-3.1 Road Access.

Although the siting of the landfill is influenced by many factors and in many cases will be dictated by the contingency location and mission type, the design must take into consideration the convenience and safety of the collection vehicles. The landfill must be easily accessible by an all-weather road with the shortest hauling distance possible considering other factors. The access road plan must also be aligned with existing terrain to minimize new construction and avoid the path of the natural drainage system.

3-3.2 Buffer Zones.

A buffer zone is the separation distance (both horizontal and vertical) between the landfill and any sensitive areas including, but not limited to, drinking water sources, Service members' bed-down areas, critical habitats, and historic and archeological sites. Buffer zones provide several benefits, including:

- Preventing migration of contamination off-site from accidental release
- Protecting drinking water sources
- Minimizing health effects on Service members and other contingency location residents

3-3.3 Fencing.

The landfill design may include a perimeter fence. The contingency location standard must be followed for type and height of the fence. In absence of a contingency standard, at a minimum, a 1.8-m (6-ft) -high chain link fence may be installed to catch blowing litter, prevent unauthorized landfill use, and maintain security.

3-4 LANDFILLING METHODS.

Generally, there are three methods used for solid waste landfilling—trench/cell method, area method, and ramp method—depending on site topography, geology, availability of land, groundwater level, availability of cover material, and any other site-specific condition.

3-4.1 Trench Method.

The trench or cell method is suited where the groundwater table is deeper and excavated soil can be used as cover material (Figures 3-1 and 3-2). Excavated trenches can be square or rectangular, depending on the site-specific condition and soil types, and will be constructed as mission requirements dictate to minimize earthwork. Trench cells should be separated by a 1- to 1.5-m (3- to 5-ft) path to ensure wall stability, surrounded by a movable fence to prevent littering caused by blowing waste. Table 3-1 lists recommended design criteria for trench cells. It is especially important in contingency operations to only dig as the mission requires to economize earthwork, considering the demand of solid waste generation.

Figure 3-1 Layout of a Trench Landfill

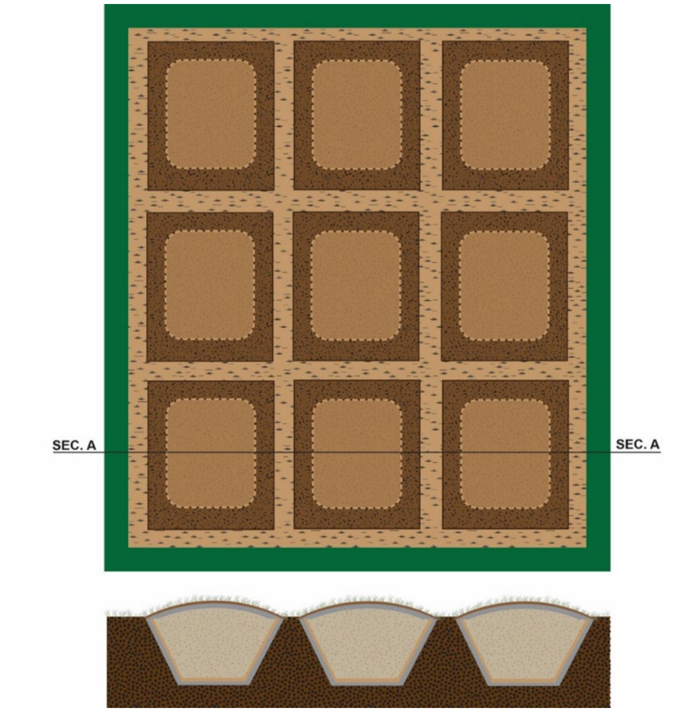


Figure 3-2 Trench Method of Burying Waste

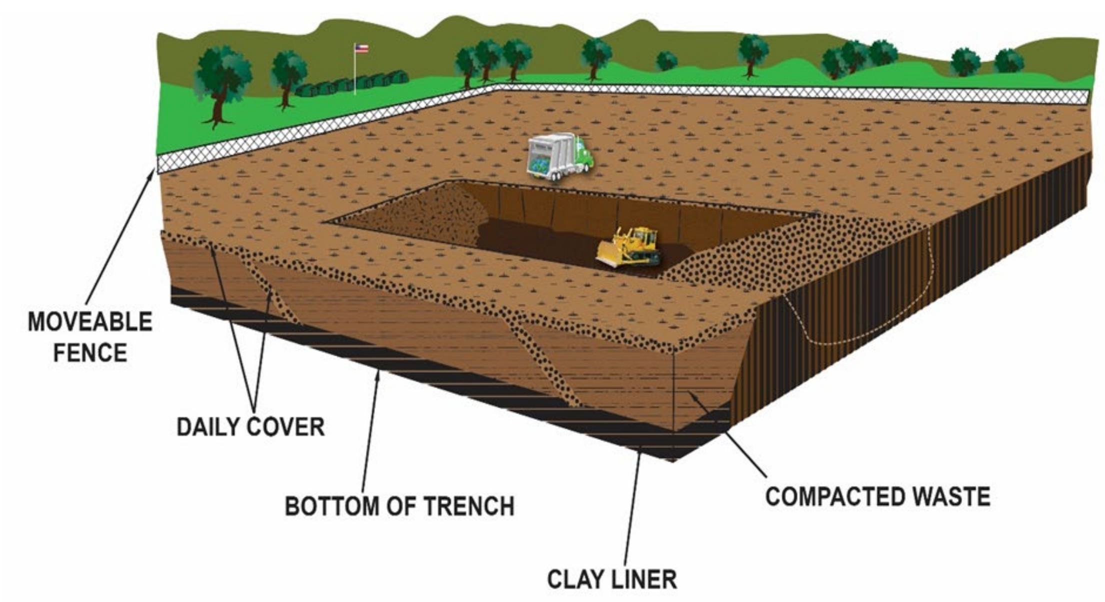


Table 3-1 Trench Landfill Design Factors

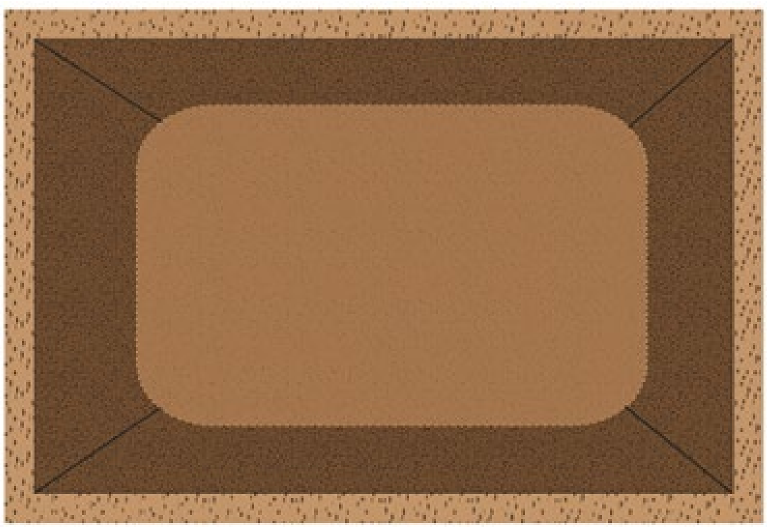
Parameter	Cell Criteria
Daily waste generation	7.2 kg (16 lb) per person[3]
Side slope	1.5 – 3:1
Depth (max)	6 m (20 ft)
Width (max)	6 m (20 ft)
Width (max)	As needed
Compaction	356 kg/m^3 (600 lb/yd^3)

Source: EM 1110-3-177

3-4.2 Area Method.

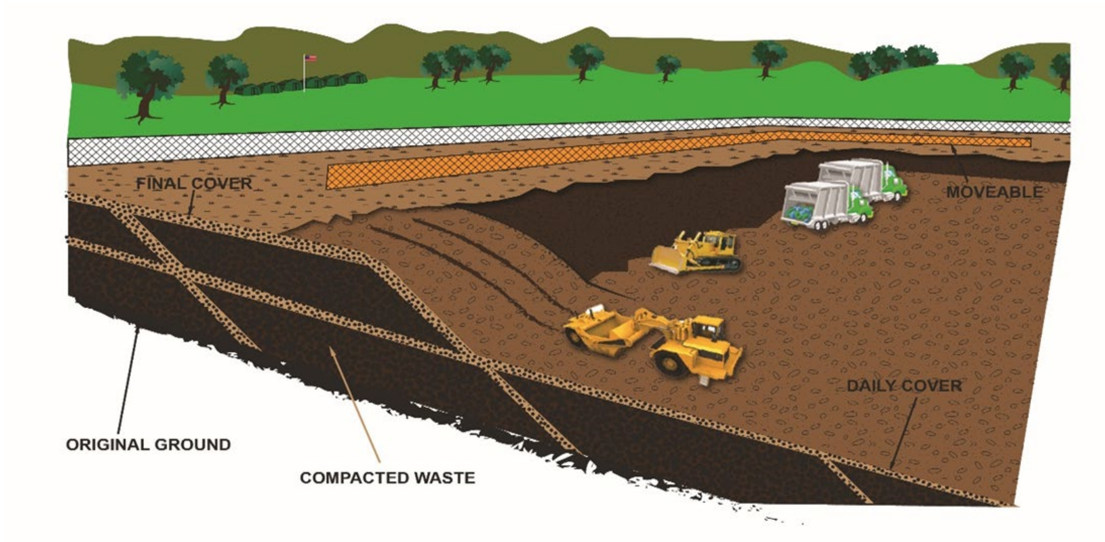
The area method is used where the terrain is not suitable for deep digging due to the presence of a high groundwater table or when encountering bedrock. Depending on the site-specific condition, the area method may or may not require excavation to meet the requirement to maintain a 150-cm (59-in.) buffer zone between the bottom of the landfill and highest seasonal groundwater level (Figures 3-3 and 3-4). However, the cover material may be hauled in or be collected from a nearby borrow pit. Using this method, the total area required for the landfill is estimated based on the current contingency population and the operational life of the landfill, based on the need to serve the current and projected contingency population.

Figure 3-3 Layout of the Area Method



[3] Cosper et al., 2013

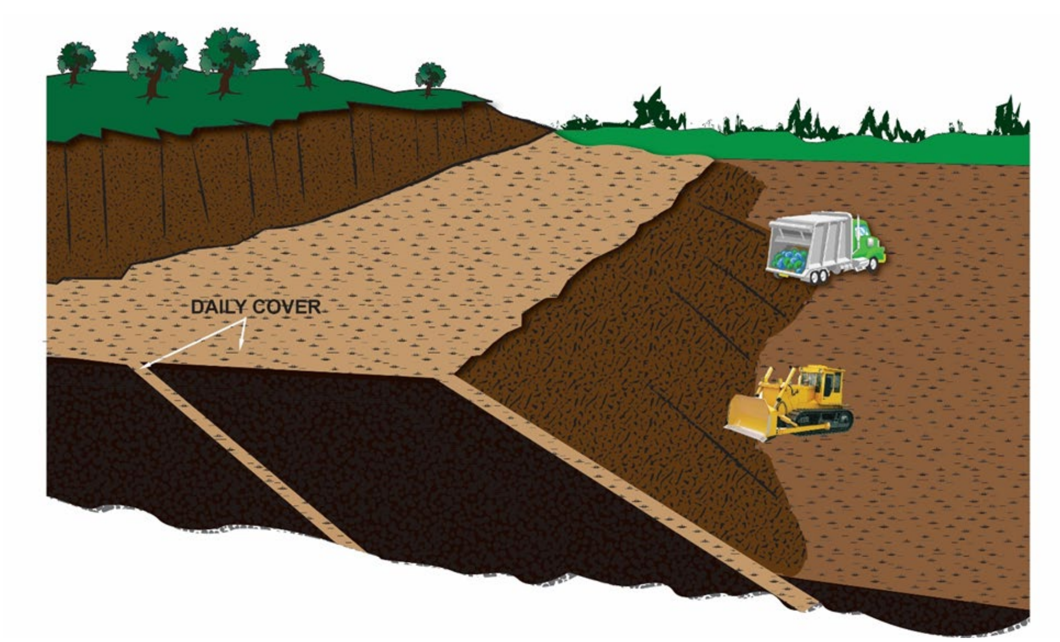
Figure 3-4 Area Method of Burying Waste



3-4.3 Ramp Method.

The ramp/canyons or ravines method is suitable for mountainous or hilly areas or rolling land with progressive slope. Old borrow pits/quarries also fit this category. When using this method, cover material is obtained from the daily working face and compacted. The procedures to place daily waste and compact it may vary, depending on the site condition. Site geology and hydrogeology and the need to control surface drainage, place leachate, and collect gas (if required) may further complicate site development in a contingency situation using the ramp method; therefore, landfilling using the ramp method is the least-preferable method in a contingency situation.

Figure 3-5 Ramp Method of Burying Waste



3-5 LANDFILL DESIGN.

3-5.1 Capacity.

Daily per capita solid waste generation must be known or estimated to calculate the required landfill volume. In current theaters, daily per capita solid waste generation varies from 4.5 to 9 kilograms (kg) (10 to 20 pounds [lb]), depending on contingency site locations and time of the year. However, for simplicity of the design for a contingency landfill, a total of 9 kg/day/capita (20 lb/day/capita) solid waste generation is recommended to be used as the planning factor to calculate the number of tons to be disposed of at a proposed landfill. Appropriate compacting equipment may not always be available in a contingency situation; therefore, a lower value of 240 kg (529 lb) of waste per cubic meter (m^3) (35 cubic feet [ft^3]) of density is recommended to calculate the total volume required for a landfill. The following equation can be used to calculate the required volume of landfill space for any size population.

Equation 3-1. Required Volume of Landfill Space

$$Q = Peck/d$$

Where:
Q = cubic meter (m^3)/year
P = population of the base (person)
e = ratio (cover material to compacted solid waste, 1.25)
c = per capita waste generation rate, kg/day/person
k = number of days in a year, 365 day/year
d = compacted waste density, kg/m^3

For example, a base with a population of 2,000, including Service members and contractors, will require a landfill space of about 34,000 m^3 (1,200,699 ft^3) per year.

P = 2,000
e = 1.25
c = 9 kg/day
k = 365 day/year
d = 240 kg/m^3
Q = (2,000 x 1.25 x 9 kg/day x 365 days/year)/240 kg/m^3 = 34,218 m^3/year

3-5.2 Landfill Liners.

Solid waste landfills require a lining system installed on the side slopes and floor of the landfill to provide a protective layer for the environment, including the soil and surface and groundwater. The selected lining system must be compatible not only with the expected waste to be disposed of but also the surrounding area. Typical lining systems are constructed of either compacted clay or a synthetic material such as high-density polyethylene (HDPE). If a locally sourced natural clay of low permeability is not available and a synthetic liner cannot be obtained and installed, landfilling should not be considered as an option for solid waste disposal.

3-5.2.1 Compacted Clay Liners

Constructing the landfill liner from a natural clay (i.e., clay, silty clay, clayey silt) is most economical and advantageous for contingency locations. This preferred option allows the use of locally available material for construction of the liner. Laboratory measurements, including particle size and Atterberg limits, should be conducted to investigate the suitability of the local soil as the liner material prior to constructing the liner. The constructed liner should have a hydraulic conductivity of less than or equal to 1×10^{-9} meters per second (m/s) (3.9×10^{-8} inches per second [in./s]). The total thickness of the liner should be no less than 1 m (3 ft), placed in 250-millimeter (mm) (10-in.) compacted lifts. Table 3-2 lists recommended design criteria and soil specifications.

Table 3-2 Specification for Clay Liners

Criteria	Value	Standard
Liner thickness	1 m (3 ft)	
Lift thickness	250 mm (10 in.)	
Hydraulic conductivity	1×10^{-9} m/s (3.9×10^{-8} in./s)	ASTM D5084
Soil specifications		
% passing No 200 sieve[4] Clay content	> 50% > 10%	ASTM D2487
Atterberg limits:[5] Plasticity index Liquid limit	 10% to 30% > = 30%	ASTM D4318

3-5.2.2 Synthetic Liners

If site conditions do not favor the use of a compacted clay liner, the use of a synthetic liner should be investigated. The manufacturer of the synthetic liner must be consulted regarding the compatibility of the liner to the waste, soil conditions, and the potential extreme weather conditions present in theater as well as the possibility for delivery and support of the installation of the liner at the site. It is recommended that the synthetic liner have a thickness of 1 to 2 mm (40 to 80 mil).

The subsurface of the soil will need to be carefully prepared and free from rocks to prevent damage to the liner. A leachate collection system will also be required for all synthetically lined landfills. Contact your Service-specific subject matter expert for support in leachate collection system design.

[4] Daniel and R. M. Koerner 1993 (EPA/600/R-93/182)
[5] Ibid.

3-5.3 Final Cover.

The final cover of the landfill consists of 45 cm (18 in.) of compacted earthen material with a hydraulic conductivity less than 10^{-7} centimeters per second (cm/s) (10^{-7} 3.937 in./s) with 15 cm (6 in.) of earthen material capable of sustaining native plant growth and be graded with 2 percent slope top to form a crown. The landfills must be kept as dry as possible to minimize leachate and gas formation. To minimize infiltration of rainwater into the landfill, the final cover must not be less permeable than the bottom liner. In accordance with EM 1110-3-177, *Sanitary Landfill - Mobilization Construction*, slopes longer than 7.5 m (25 ft) may require additional erosion-control measures, such as construction of horizontal terraces. The final soil cover on a completed landfill disposal facility must be seeded or otherwise vegetated to minimize erosion.

3-5.4 Ultimate Use of a Landfill Site.

It is up to the combatant commander (CCDR) to decide how the land of a closed landfill will be used once it is closed in accordance with the closure plan. Typically, a closed landfill is off limits to heavy vehicles. Also, other agreements with the HN like a SOFA may play a critical role in decisions regarding the ultimate use of a closed landfill site. A closure plan must be developed early in the life of the landfill—potentially during the design or site development phase.

3-5.5 Access Road.

An access road must lead to the main access control point of the landfill from the public road system. The road must be capable of carrying the load of the collection trucks in all weather conditions and should consist of a minimum of two lanes, 7.5 m (25-ft) wide, for two-way traffic. The slope of the road should be no more than the design specification of service vehicles or any other equipment that will use the road. The access road may also lead to the vicinity of the working area; however, the access road should not cross completed cells.

Secondary or branch roads are used to deliver wastes to the working face from the access road due to the fact that working faces are continuously changing. A secondary or branch road is temporary and will be used only until the area or cell is filled. Therefore, a secondary or branch road can be constructed by compacting natural soil and topping it with gravel, crushed stone, crushed concrete, or asphalt binder, depending on the site condition and availability of the material.

3-6 LEACHATE CONTROL.

3-6.1 General.

Landfill leachate is the liquid that percolates through the strata of solid waste deposited in the landfill. The source of water to form leachate comes from either infiltration of water through the refuse or groundwater movement through the landfill. Landfill refuse will absorb a certain amount of water and remaining water will percolate through the liner out to the environment. If the landfill is located on or near a drinking water source then management of leachate is critical to protect both surface and groundwater.

3-6.2 Composition of Leachate.

Table 3-3 lists characteristics of common leachate constituents from a typical municipal solid waste landfill[6]. The composition of the leachate can vary considerably based on the type of waste buried, amount of infiltration, and age of the landfill. The composition of the leachate varies from landfill to landfill and mostly depends on what type of waste is buried in the landfill. A non-hazardous solid waste landfill will produce leachate mostly consisting of organic content (carbon and hydrogen).

Table 3-3 Leachate Characteristics and Average Values of Common Constituents

Constituents (in mg/L except pH)	Average Concentration in Newer Landfills (in mg/L except pH)	Average Concentration in Older Landfills (in mg/L except pH)
pH	6	8
Biological oxygen demand (BOD_5)	13,000	180
Chemical oxygen demand (COD)	22,000	3,000
Calcium	1,200	60
Iron	780	15
Ammonia	740	740
Total phosphorus	6	6
Chloride	2120	2120

3-6.3 Leachate Collection.

A landfill carefully constructed using a clay liner should not require a leachate collection system. The landfill site should be carefully selected to ensure the bottom of the landfill is 1.5 m (5 ft) above the highest seasonal groundwater level and not located on top of a groundwater aquifer or nearby surface water that serves as a source of potable water for local inhabitants. Note that geotechnical expertise is required to make this determination.

3-6.4 Leachate Treatment.

When landfill leachate is collected, it should be treated onsite in a wastewater treatment lagoon or wastewater collection system. If onsite treatment is not available, offsite treatment of the collected leachate should be considered. In an arid region, build an evaporation bed for disposal of collected leachate. Excavate the top 7.5 cm (3 in.) of the evaporation bed quarterly and use as daily cover in the landfill. In other regions or in

[6] Kjeldsen et al. 2002

any other situation, discharge leachate to the local municipal wastewater plant, with prior approval. Final disposal of the leachate through a contractor should not be considered until all the options described above are evaluated.

3-7 METHANE GAS CONTROL.

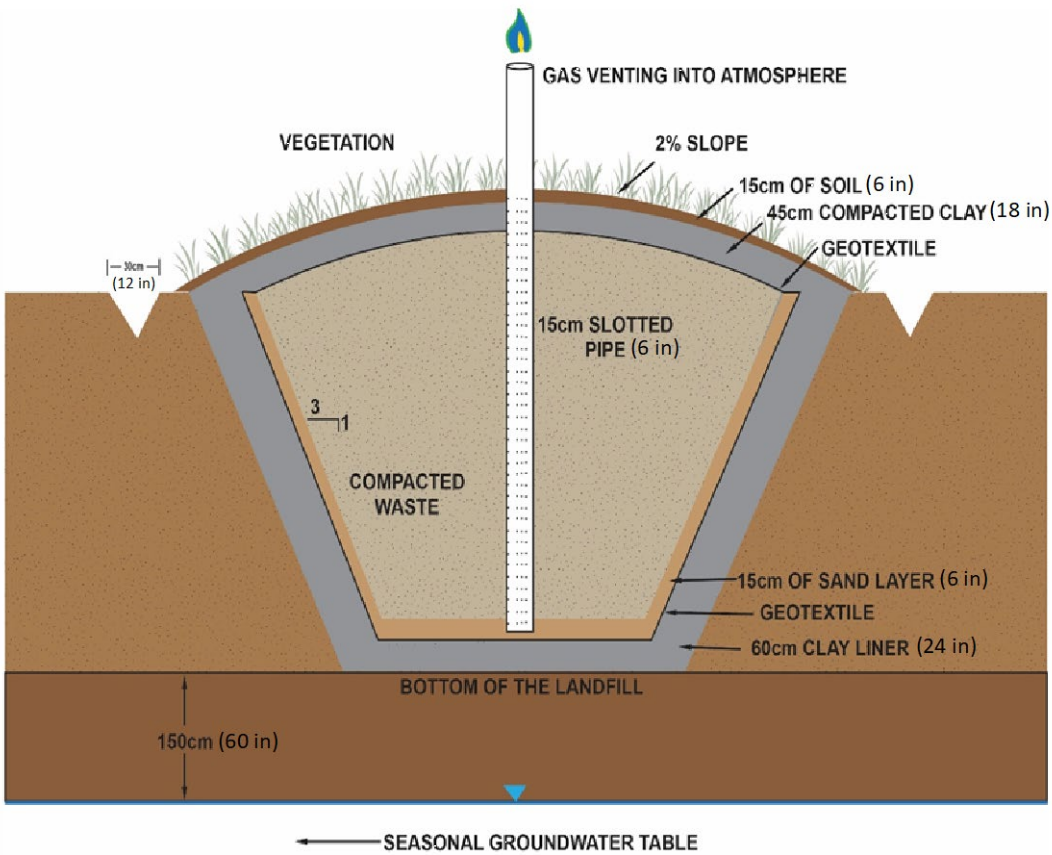
3-7.1 Production.

Methane gas production in a landfill is part of the natural process. Initially, the waste decomposes aerobically, depletes the available oxygen in the refuse, and produces carbon dioxide. Later in the process, in absence of oxygen, an anaerobic condition is created and methane gas is produced. Carbon dioxide and methane are two major gases produced from the decomposition of solid waste in landfills. The volume of gas generated depends on the quantity and quality of the waste disposed. Minimization of gas production must be the goal of the landfill designer. Gas reduction can be accomplished by controlling moisture in wastes. Anaerobic bacteria require nutrients and moisture to produce methane gas. Consider minimizing infiltration of runoff water into the solid waste through better compaction and slope, which will reduce gas generation. The drier the waste, the less amount of gas will be produced. Methane gas collection should not be the goal in a contingency situation unless otherwise directed by the CCDR.

3-7.2 Gas Disposal.

Consider a system to vent gas to the atmosphere through passive venting. Install a venting pipe with a perforated bottom through the waste depth at time of landfill closure up through the clay liner of the landfill to release gas into the atmosphere. One vent per 7,645 m^3 (10,000 cubic yards [yd^3]) of waste or approximately one vent for every 1,400 m^2 (⅓ acre) of land area may be needed to release gas into the environment. See Figure 3-6 for diagram. An observation monitor may be used at the landfill boundary to monitor methane concentration. The methane concentration should not exceed the lowest explosive limit (LEL) of 5 percent in facility structures on the landfill perimeter or at the landfill property boundary. The preventive medicine (PM) team should monitor LEL or any other health effects of landfill gas at least quarterly.

Figure 3-6 Design for Passive Gas Venting



3-8 STORMWATER CONTROL.

Controlling run-off water at a landfill site is critical to prevent environmental contamination and damage to the landfill structure. Specifically, runoff water can carry siltation to the working face of the landfill, add additional moisture to the refuse, and cause excessive leachate and increase gas generation. The landfill final cover must be compacted and sloped to the maximum extent to prevent infiltration of precipitation and minimize leachate and gas generation. The final soil cover on completed portions of the landfill must be seeded or otherwise vegetated to minimize erosion. A stormwater control system must be in place to prevent surface water run-on discharge into the working face of the landfill using berms, dikes, or ditches. Such structures must be designed to protect the landfill from a 24-hour, 25-year storm.

3-9 SUPPORT FACILITIES.

Support facilities required for support of landfill operations will vary, depending on contingency location, operation of the landfill, and availability of resources. The requirement will be different if a landfill is operated by Service members versus operated by a contractor. For example, if the landfill is contractor operated, a scale will be required if the contract is based upon the quantity of the disposed solid waste. The facilities described in the following sections may be required to operate and maintain a landfill.

3-9.1 Administration Facility.

A building or semi-portable containerized unit with a sanitary system will be required on the perimeter of the landfill to manage and run day-to-day operations of the landfill.

3-9.2 Control Facility.

A control facility should be located at the entrance of the landfill at a strategic location for truck inspection. Any unwanted materials should be denied entry at this point.

3-9.3 Sort and Separation Buildings.

All solid waste must be brought to a central location for manual sort and separation before going to the landfill. A manual sort and separation must be conducted to remove any sensitive materials such as ammunition even if the refuse is source separated.

3-9.4 Truck Scales (If Required).

If there is a need for the waste to be weighed, a truck scale must be located next to the control room.

3-9.5 Utilities.

Power, potable water, shower, and latrines are recommended for the landfill workers, as appropriate. A fire hydrant or other means of fire control should be available near the landfill.

3-9.6 Processing Equipment.

An equipment shed or facility should be centrally located for all equipment used for major operations involved in spreading waste after dumping, compacting waste, and spreading and compacting daily and final cover. Generally, a front-end loader, waste transportation truck, dozer, and compactor are needed for landfill operations. The dozer can serve as a compactor.

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CHAPTER 4 CONSTRUCTION

4-1 GENERAL.

Engineering plans will be developed based on technical specifications following the design criteria in Chapter 3. The first cell and half of the second cell will be excavated at the outset of the project, which minimizes the amount of initial excavation. As one cell is filled with waste, the next cell will be partially excavated; the excavated soil will then be used to support construction of the cap system over the filled cells. This process will continue throughout the life of the landfill.

4-2 TRENCH METHOD.

Before excavation, the area for the landfill should be cleared of all trees, shrubs, and grass. The topsoil should be removed and stockpiled for future use. Excavation using heavy equipment will follow the specifications identified in the engineering plans. The landfill cell should be sufficiently over-excavated to accommodate the compacted clay liner. Throughout the excavation process, rocks, gravel, and other soil and materials not suitable for the landfill should be removed.

During the excavation process, soils should be segregated and stockpiled based on their properties, paying close attention to segregate the soil layer identified in the technical specifications to be used for the clay liner. Prior to the installation of the liner, clay, or synthetic, the subgrade should be free from large clods and soft spots.

Trenches should be aligned perpendicular to the prevailing wind; this orientation can greatly reduce the amount of blowing litter. Refer to Figure 3-1 for layout of the trench method and Figure 4-1 for construction and operation of the trench and area methods of landfill.

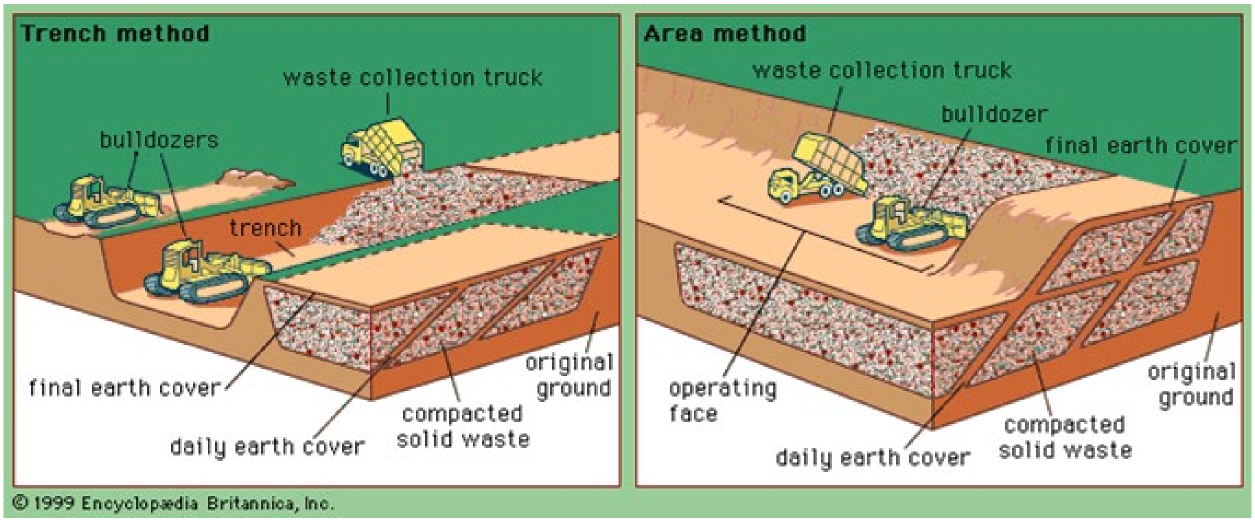
4-3 AREA METHOD.

The area method is used when the terrain is unsuitable for the excavation of trenches in which to place the solid waste and/or when the groundwater table is close to the ground surface. In this method, the waste is spread and compacted on the natural surface of the ground and cover material is spread and compacted over it. The area method is used on flat or gently sloping land and requires the least excavation. Daily cover soil may be available onsite or it may be hauled in and stockpiled from offsite sources. The filling operation is usually started by building an earthen levee against which wastes are placed in thin layers and compacted. The length of the uploading varies with site conditions and size of the operation. The width over which the wastes are compacted varies from 2.5 m to 6 m (8 ft to 20 ft), depending on the terrain (see TM 5-634, *Solid Waste Management*, paragraphs 4.2.7.2 and 4.2.7.3).

4-4 RAMP METHOD.

In this method, solid wastes are placed and compacted as described for the area method and partially or wholly covered with earth scraped from the base of the ramp. This technique makes a pit in which to place the next day’s waste. Additional soil must be hauled in as in the area method. Due to the increasing costs and problems associated with obtaining usable cover material, the use of the ramp method must be based on an economic feasibility study and may not be a suitable method for a contingency operation.

Figure 4-1 Trench and Area Methods



The designer of a landfill should prescribe the method of construction and the procedure to be followed for solid waste disposal, as there is no “best method” for all sites. The method selected depends on the physical conditions and the amount and type of solid waste to be handled.

The cell is the building block common to both the trench and the area method. All solid waste received is spread and compacted in layers within a confined area. The dimensions of the cell are determined by the volume of the compacted waste, which in turn depends on the density of the in-place solid waste. Cells should be divided by berms or other means and stormwater should be eliminated from the working portion of the landfill.

4-5 CONSTRUCTION PRACTICES.

There are several important things to consider during construction.

- Depending on site-specific conditions, compacted clay is recommended to use as liner material
- All soil and layers on waste must be pushed ahead of equipment as operations progress. Even foot traffic should be kept to a minimum on liners.
- A good access road must be provided and maintained in the trench, with additional subbase installed.
- Access roads must be designed to support the anticipated volume of truck traffic.

- Grades should not exceed equipment limitations.
- If membrane liners are used, it is noted that they are highly susceptible to expansion and contraction during temperature changes and must be laid in such a way as to avoid stress on the seams.
- Liners should be held in place by anchor trenches, sand bags, or soil cover.
- Anchor trenches are commonly used at the top of the side slopes but should not be firmly compacted.
- It is better for the liner to slip slightly than to cause stress.
- If it is anticipated that a liner will be excavated and extended to cover a new cell at a later date, a minimum of 1.5 m (5 ft) edge of liner material should be protected to provide a clean, smooth surface for future seaming.
- Seaming of wet membrane surfaces is not allowed.

4-6 CONSTRUCTION QUALITY ASSURANCE.

The construction quality assurance program should describe expected performance by the closure contractor, such as removal or demolition of onsite structures, installation of fencing, repair or construction of sediment ponds, litter pick-up, etc. All piping systems (if any) and compacted clay liner must be inspected. If a membrane liner is used, the construction contractor must be required to submit field installation directions for the flexible membrane liner, in addition to manufacturer quality control guidelines. In addition, the gas generated within the landfill should be monitored. The quantity of gas generated depends on waste volume, waste composition, and time since deposition of waste in the landfill. Gas pressure, stress on vegetation, and toxicity of the gas are some of the venting issues that should be considered. Passive or active venting systems can be installed, which consist of a series of isolated gas vents.

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CHAPTER 5 OPERATION AND MAINTENANCE

5-1 LANDFILL OPERATIONS.

This chapter provides information to guide landfill construction and operation. Landfill operating procedures are determined by many site variables. The operational plan provides the landfill's technical details and procedures for constructing various engineered elements. The landfill could potentially be operated for months to years as needed during the contingency operation; therefore, personnel need to consult the plan to ensure long-term conformance. If necessary, methods can be used to extend the useful life of a landfill. Such methods include reducing the volume of materials before placing them in landfills and finding more efficient methods for depositing waste in landfills. Methods of operating a landfill could have an effect on landfill design; therefore, the desired method of operation should be reviewed before design commences.

5-1.1 Restrictions.

In general, only wastes for which the facility has been specifically designed will be accepted for disposal. Other waste types may be accepted if it has been demonstrated that they can be satisfactorily disposed of within the design capability of the landfill or after appropriate modifications have been made.

5-1.2 Cover Requirements.

Volume requirements for cover material depend on the surface area of waste to be covered and the thickness of soil needed to perform particular functions. Cell configuration can greatly affect the volume of cover material needed; therefore, the surface area needed should be kept to a minimum. Most soil materials can satisfy the purpose of cover soil. However, if minimization of infiltration is necessary, relatively low-permeability cover material should be used and placed at the steepest allowable grade to encourage runoff. Low-permeability soils will remain effective only if the soil has a low shrink-swell potential or if the soil moisture can be maintained to prevent cracks from shrinking and swelling. Design specifications in Chapter 3 should be followed for placing cover material. In addition, cells that will not have additional wastes placed on them for three months or more should be covered with 30 cm (12 in.) of cover material. Cover material minimizes fire hazards, reduces odors, controls blowing litter, and discourages scavenging. Covers also reduce exposure to birds, insects, and rodents, which can transmit human disease.

5-1.3 Working Face.

The working face is an area of active waste placement. The slope of the working face controls area to volume of the landfill and compaction of waste. The daily and intermittent cover should be obtained from the adjacent cell under construction. The waste should always be placed at the toe of the working face. Uncompacted waste will be spread in layers no more than 1 m (3 ft) thick before compacting. Once compacted, another layer of waste can be added and compacted so the waste cell will be several meters/feet thick before the daily soil cover is added. The working face should have a 20 percent to 30 percent slope and be as narrow as feasible to accommodate the number of trucks using the landfill.

Several layers may be compacted on top of one another. Each layer of waste may be spread with a thickness of no more than 0.5 m to 1 m (1.5 ft to 3 ft) and then compacted. The compacted waste occupies about one-quarter of its original loose volume. At the end of each day's operation, the waste is covered with a daily layer of 15 cm (6 in.) soil to eliminate windblown litter, odors, and insect or rodent problems. Thus, one cell contains a daily volume of compacted solid waste and soil cover. There are three basic methods of burying the waste: trench, area, and ramp. All three methods involve shaping one day's waste into a cell by spreading and compacting it in layers. Chapter 3 provides design specifications for these methods.

5-1.4 Entry Control.

Public access to landfills must be controlled by artificial and/or natural barriers to prevent unauthorized vehicular traffic and illegal waste dumping. A fence can be used to control or limit access. A wooden fence may be used to screen the operation from view. Litter fences or movable fences are used to control blowing paper in the immediate vicinity of the working face. Generally, trench operations require less litter fencing as the solid waste tends to be confined within the walls of the trench. At a windy trench site, a 1.5-m (5-ft) fence will usually suffice. When blowing paper is more of a problem in an area operation, higher litter fences are often needed. Gates that can be locked when the site is unsupervised will also control access.

5-1.5 Prohibited Items.

In general, only wastes for which the facility has been specifically designed should be accepted for disposal. Specific waste types that have chemical, biological, or physical characteristics that are not compatible with disposal site design, location, or operation; that pose an unacceptable environmental or health effect; or pose a threat to the safety of personnel or users of the facility should be prohibited from acceptance for disposal. A container holding liquid wastes cannot be placed in a landfill.

There must be a systematic process to exclude unauthorized wastes from the landfill. This will include:

- Random inspections of incoming loads
- Records of inspection
- Training for operators
- Notifying the chain of command if hazardous waste, PCBs, bulk liquids, or non-containerized liquids are discovered

5-1.6 Landfill Inspection Program.

One of the most important considerations is to design the system to facilitate inspection and maintenance. There should be access to all parts of the system to facilitate inspection. The landfill should be inspected for signs of erosion, cracking, or sloughing. The landfill should also be inspected for birds, insects, and rodents. Ensure entry roads are safe and provide all-weather access. Chapter 3 outlines procedures for operation and maintenance of leachate and landfill gas.

5-1.7 Groundwater Monitoring.

The groundwater around the perimeter of the landfill must be monitored, at least quarterly, to ensure the landfill is not leaking. It requires an expert to determine the number and location of groundwater wells to install and monitor. Table 3-3 lists some constituents that could signal the presence of leachate. Values must be compared to background groundwater levels.

5-2 OPERATING RECORDS AND CONTROLS.

The landfill operating record must be maintained and must include the types and amount of waste being buried, a topographical map, and documentation of the dimensions of the area being used for landfill.

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CHAPTER 6 CLOSURE

6-1 FINAL COVER.

Installing the final cover is as important as installing the liner at the base of the landfill. The main purpose of the final cover is to minimize the infiltration of water from precipitation or surface runoff; therefore, the final cover should be installed in the shortest possible time. As outlined in paragraph 3-5, the final cover of the landfill consists of 45 cm (18 in.) of compacted clay with a hydraulic conductivity less than 10^{-7} cm/sec ($4x10^{-8}$ in/s) plus 15 cm (6 in.) of earthen material capable of sustaining native plant growth; the final cover must be graded with a 2 percent slope at the top to form a crown. The clay liner compaction should be done at optimum moisture with uniform distribution of moisture. A clay cover should be installed when each cell of the landfill is completed. Restrict the travel of heavy equipment over the closed landfill once the final cover installation is complete.

6-2 MAINTAIN FENCES.

A security fence should be maintained at the closed landfill to control or limit access and discourage vandalism and trespassing. Digging by unauthorized personnel may compromise the integrity of the landfill cover and may initiate erosion of the final cover.

6-3 SIGNS IN LOCAL LANGUAGE.

Warning signs must be posted at the perimeter in both English and the local language, with a letter size in compliance with the contingency location standards. At a minimum, the sign should say “Warning: Landfill - No Unauthorized Access.” In addition, the sign should state the landfill closure date if the landfill is closed.

6-4 POST-CLOSURE CARE.

A properly designed and constructed landfill should require minimal post-closure maintenance. It is important to periodically inspect the cap for integrity and erosion. A closure plan must be prepared outlining the necessary steps to close a landfill unit, especially the installation and maintenance of the final cover. The closure plan must ensure the site is not disturbed as long as the site is controlled by the United States. Also, the closure plan may be beneficial when handing the landfill over to the HN to give them a starting point along with an environmental condition report. The main objective of a closure plan is to ensure a closed landfill does not affect public health and the local environment. A closure plan should include instructions for post-closure care and maintenance, including a groundwater, leachate, and gas-monitoring program, instructions for maintaining the final cover, a point of contact for the closed landfill, and a description of post-closure use of the land. These inspections and monitoring must continue as long as the US controls the site. Once the landfill is closed, the site must be identified on a contingency area map and must be recorded in the closure document when the base camp is closed. As part of the SOFA or any other agreement with the HN, the post-closure care and maintenance plan may transfer to the HN.

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APPENDIX A GLOSSARY

A-1 ACRONYMS.

°C	Degree Celsius
°F	Degree Fahrenheit
AFI	Air Force Instruction
ATP	Army Techniques Publication
BOD	Biochemical Oxygen Demand
BUMEDINST	Bureau of Medicine and Surgery Instruction (Navy)
CCDR	Combatant Commander
CCMD	Combatant Command
CLES	Contingency Location Environmental Standards
cm	Centimeter
cm/s	Centimeter per Second
CONUS	Continental United States
DoD	Department of Defense
DoDD	Department of Defense Directive
DoDI	Department of Defense Instruction
DoDM	Department of Defense Manual
EM	Army Engineering Manual
FGS	Final Governing Standards
FM	Field Manual
ft	Foot
ft^3	Cubic Foot
HN	Host Nation
HW	Hazardous Waste
in.	Inch

in./s	Inch per Second
ISWM	Integrated Solid Waste Management
kg	Kilogram
kg/m^3	Kilogram per Cubic Meter
km	Kilometer
lb	Pound
lb/yd^3	Pound per Cubic Yard
m	Meter
m/s	Meter per Second
m^2	Square Meter
m^3	Cubic Meter
mg/L	Milligram per Liter
mm	Millimeter
PCB	Polychlorinated Biphenyls
pH	Measure of the acidity or basicity of aqueous solutions
SOFA	Status of Forces Agreement
SOP	Standard Operating Procedure
TM	Army Technical Manual
UFC	Unified Facilities Criteria
yd^3	Cubic Yard

A-2 DEFINITION OF TERMS.

A-2.1 Waste.

Any discarded material. Waste is generally categorized as nonhazardous solid waste, hazardous waste (HW), or medical waste. Nonhazardous solid waste includes items such as food waste, discarded paper, cardboard, plastic, wood, construction debris, and glass.

A-2.2 Hazardous Waste (HW).

Any solid waste listed under the Resource Conservation and Recovery Act (RCRA), 40 CFR 261, as hazardous waste or exhibits any of the four hazardous characteristics of toxicity, reactivity, ignitability, or corrosivity. HW items include used solvents, contaminated fuel, petroleum-contaminated soils, paint waste, and batteries. HW management and disposal is outside the scope of this UFC.

A-2.3 Medical Waste

Any waste that is generated in diagnosis, treatment, or immunization of human beings or animals, that is capable of causing disease, or that, if not handled properly, poses a risk to individuals or a community. Medical waste requires special precautions due to its unique characteristics and potential to cause infection. Management of medical waste is outside the scope of this UFC. Refer to Service public health staff and the following publications:

- U.S. Army Medical Command Regulation 40-35, *Management of Regulated Medical Waste (RMW)*, provides information on management of regulated medical waste.

- AFI 41-201, *Managing Clinical Engineering Programs*, gives basic guidance on appropriate handling of medical waste in paragraph 5.16.

- BUMEDINST 6280.1C, *Management of Regulated Medical Waste,* gives detailed instructions on medical waste handling and disposal.

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FM 3-34, *Engineer Operations*, https://usacac.army.mil/sites/default/files/misc/doctrine/CDG/cdg_resources/manuals/fm/fm3_34.pdf

MEDCOM Regulation 40-35, *Management of Regulated Medical Waste (RMW),* https://www.qmo.amedd.army.mil/riskmgt/MEDCOM_Reg_40_35.pdf

TM 3-34.56, *Waste Management for Deployed Forces*, https://armypubs.army.mil/ProductMaps/PubForm/Details.aspx?PUB_ID=1006600

TM 5-634, *Solid Waste Management*, https://armypubs.army.mil/ProductMaps/PubForm/Details.aspx?PUB_ID=5253

AIR FORCE

AFI 41-201, *Managing Clinical Engineering Programs*, https://www.e-publishing.af.mil/

ASTM INTERNATIONAL

https://www.astm.org/

ASTM D2487, *Standard Practice for Classification of Soils for Engineering Purposes*

ASTM D4318, *Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils*

ASTM D5084, *Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter*

DEPARTMENT OF DEFENSE

DoDD 3000.10, *Contingency Basing Outside the United States*, https://www.esd.whs.mil/Directives/issuances/dodd/

DoDD 4715.1E, *Environment, Safety, and Occupational Health (ESOH)*, https://www.esd.whs.mil/Directives/issuances/dodd/

DoDI 4715.19, *Use of Open-Air Burn Pits in Contingency Operations*, https://www.esd.whs.mil/Directives/issuances/dodi/

DoDI 4715.22, *Environmental Management Policy for Contingency Locations*, https://www.esd.whs.mil/Directives/issuances/dodi/

DoDM 4715.05, Volumes 1–5, *Overseas Environmental Baseline Guidance Document*, https://www.esd.whs.mil/Directives/issuances/dodm/

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UFC 3-250-01
14 November, 2016

UNIFIED FACILITIES CRITERIA (UFC)

PAVEMENT DESIGN FOR ROADS AND PARKING AREAS

UNIFIED FACILITIES CRITERIA (UFC)

PAVEMENT DESIGN FOR ROADS AND PARKING AREAS

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING COMMAND (Preparing Activity)

AIR FORCE CIVIL ENGINEER CENTER

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

Change No.	**Date**	**Location**

This UFC supersedes UFC 3-250-01FA, dated January, 2004 and UFC 3-230-06A dated January 2004.

FOREWORD

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

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale should be sent to the respective service proponent office by the following electronic form: Criteria Change Request. The form is also accessible from the Internet sites listed below.

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

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

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

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UNIFIED FACILITIES CRITERIA (UFC)
REVISION SUMMARY SHEET

Document: UFC 3-250-01, *PAVEMENT DESIGN FOR ROADS AND PARKING AREAS*

Superseding: This UFC supersedes UFC 3-250-01FA, dated January, 2004 and UFC 3-230-06A dated January 2004.

Description: This revision provides pavement design procedures and requirements for the pavement design of roads and parking areas worldwide. It clarifies when State pavement design procedures may be used and when Pavement-Transportation Computer Assisted Structural Engineering (PCASE) is required.

Reasons for Document:

- This UFC updates the guidance and requirements for specialized pavement design and underdrain design in two existing criteria documents and efficiently consolidates them into a single UFC.

- Provides consistency in applying pavement design requirements for projects with standard vehicle types, particularly with regard to using State pavement design procedures.

Impact:

This unification effort will result in less cost to maintain DoD criteria and a more efficient pavement design in the following ways:

- By relying on State pavement design procedures for standard vehicle types that typically travel local roads.
- Reduction in the number of references used for military construction provides a clear and efficient guidance for the design and construction of DoD pavements.
- Reduction in ambiguity and the need for interpretation reduces the potential for design and construction conflicts.

Unification Issues:

None.

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FIGURES

TABLES

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CHAPTER 1 INTRODUCTION

1-1 PURPOSE AND SCOPE.

This UFC provides minimum criteria for the design procedures and requirements for the pavement design of roads and parking areas. It clarifies when State pavement design procedures may be used and when Pavement-Transportation Computer Assisted Structural Engineering (PCASE) is required. Pavement design engineers must use this minimum criteria when making decisions and determining an acceptable pavement design procedure.

1-2 APPLICABILITY.

This UFC applies to all military service elements and contractors involved in the planning, design, and construction of DoD facilities worldwide.

1-3 GENERAL BUILDING REQUIREMENTS.

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

1-4 REFERENCES.

Appendix A contains a list of references used in this document. The publication date of the code or standard is not included in this document. In general, the latest available issuance of the reference is used.

1-5 GLOSSARY.

Appendix C contains acronyms, Unified Soil Classification System (USCS) soil types, units of measure, definition of terms and referenced figures.

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CHAPTER 2 PRELIMINARY SOIL INVESTIGATION

2-1 GENERAL.

Soil subgrades provide a foundation for supporting pavements. The strength and uniformity of the subgrade will affect the required pavement thickness and the performance of the pavement during its design life. Conduct a thorough investigation of the subgrade to determine soil characteristics. Soil uniformity and moisture conditions under the pavement are especially important with respect to frost action.

2-2 INVESTIGATION OF SITE.

Characteristics of subgrade soils must be known to predict pavement performance. Determine the general suitability of the subgrade soils based on classification of the soil, moisture-density relationship, degree to which the soil can be compacted, expansion characteristics, susceptibility to pumping, and susceptibility to detrimental frost action. Factors such as groundwater, surface infiltration, soil capillarity, topography, rainfall, and drainage conditions will also affect the future support rendered by the subgrade by increasing its moisture content and thereby reducing its strength.

2-2.1 Preliminary Site Analysis of Subgrade Conditions.

Before planning field explorations, conduct a general survey of the topographic and subsurface soil conditions at the site. Investigate previous performance of existing pavements, minimum of five years, on similar local subgrades to assist in evaluating subsurface conditions. Sources of data should include the landforms, soil conditions in ditches, and cuts and tests of representative soils in the site. Augment the survey with existing soil and geological maps. Sources of information include earlier subsurface investigations near the site, United States Geological Survey maps, and soil survey maps. Evaluate surface drainage at the site and subsurface drainage of the subgrade.

2-2.2 Subsurface Explorations.

Conduct subsurface explorations to test each type of soil identified in the preliminary site analysis. Test pits and soil borings may be used for subsurface investigations. The spacing of subsurface explorations along roadways depends on the variability of the existing soil conditions. When preliminary site analysis substantiates soil uniformity, use a maximum spacing of 400 ft (120 m). Make additional subsurface explorations when the preliminary site analysis indicates unusual or potentially troublesome subgrade conditions. When subsurface explorations have previously been conducted to the required depth and those subsurface explorations confirm soil uniformity, the spacing may be increased to a maximum of 1500 ft (450 m) as long as the subsurface explorations results continue to confirm soil uniformity.

The depth of subsurface explorations must extend beyond the frost penetration depth as determined from Chapter titled Seasonal Frost Conditions and be no less than 6 ft (2 m) below finished grade. Depth requirements stated above are measured from the pavement surface.

2-2.3 Dynamic Cone Penetrometer.

The Dynamic Cone Penetrometer (DCP) test can be used to determine design California Bearing Ratio (CBR) values. When using the DCP to determine CBR values in shallow pavement applications, perform test in accordance with ASTM D6951/D6951M.

2-2.4 Soil Classification.

Classify soil samples from the subsurface explorations according to the USCS in ASTM D2487.

2-2.5 Soil Evaluation

Use the subsurface exploration samples to compute soil properties, prepare soil profiles and to select soils for further testing. To help identify soft layers in the soil, evaluations must include moisture content.

2-3 BORROW AREAS.

Perform preliminary subsurface explorations in areas where material is to be borrowed from adjacent areas. Extend subsurface explorations to a minimum depth of 2 to 4 ft (0.6 to 1.2 m) below the anticipated depth of borrow. Use the preliminary samples to classify soils, compute moisture content, and determine compaction characteristics.

CHAPTER 3 TECHNICAL REQUIREMENTS

3-1 SELECTION OF PAVEMENT TYPE.

Use rigid pavements or composite pavements with a rigid overlay for the following areas:

- Vehicle Maintenance Areas.
- Pavements for All Vehicles with Non-pneumatic Tires.
- Open Storage Areas with Materials Having Non-pneumatic Loadings in Excess of 200 psi (1.38 MPa), covered or uncovered.
- Hardstands (Organizational Vehicle Parking Areas, Motor Pool, Unit's Equipment Parking).
- Pavements Supporting Tracked Vehicles.
- Vehicle Wash Racks.
- Vehicle Fueling Pads.

Exception: For architectural or special operational requirements design pavements based upon life-cycle cost analysis.

3-2 DESIGN VARIABLES.

The prime factor influencing the structural design of a pavement is the required load-carrying capacity. The thickness of pavement necessary to provide the desired load-carrying capacity is a function of the following variables:

- Vehicle gross loads and wheel configurations.
- Volume of traffic during the design life of pavement.
- Soil strength.
- Modulus of rupture (flexural strength).

3-3 RIGID PAVEMENTS.

The rigid pavement design procedures presented in this UFC are based upon the critical tensile stresses produced within the pavement by the vehicle loading. Correlation between theory, small-scale model studies, and full-scale accelerated traffic tests show that maximum tensile stresses in the pavement occur when the vehicle wheels are tangent to a free or unsupported edge of the pavement. Stresses for the condition of the vehicle wheels tangent to a longitudinal or transverse joint are less severe because of the use of load-transfer devices and aggregate interlock in these joints to transfer a portion of the load across the joint. Because of their cyclic nature, other stresses are, at times, additive to the vehicle load stresses. These other stresses include restraint stresses resulting from thermal expansion and contraction of the pavement and warping stresses resulting from moisture and temperature gradients within the pavement. Provision for those stresses not induced by wheel loads is included in design factors developed empirically from full-scale accelerated traffic tests and from the observed performance of pavements under actual service conditions.

3-4 FLEXIBLE PAVEMENTS.

The design procedure used by DoD to design flexible pavements for roads and parking areas is referred to as the Beta Criteria design procedure. This procedure requires that each layer be thick enough to distribute the stresses induced by traffic so that when such stresses reach the underlying layer they will not overstress the underlying layer causing excessive shear deformation. The Beta Criteria is used to sketch the design curves contained in Appendix E. Besides the determination of layer thicknesses, adequately compact each layer so that traffic does not induce excessive settlement. Use ASTM D1557 compaction effort procedures to design against consolidation under traffic.

3-5 MANDATORY USE OF PCASE.

PCASE is mandatory for the design of roads and parking areas trafficked by special military vehicles and for all vehicle types outside of the United States and its territories and possessions. Refer to UFC 3-201-01 for the types of vehicles characterized as special military vehicles.

PCASE is also mandatory for the design of organizational vehicle parking areas.

3-5.1 Pavement-Transportation Computer Assisted Structural Engineering.

PCASE is a computer program developed by the United States Army Corps of Engineers (USACE), Engineer Research and Development Center (ERDC), is available for use by the public. PCASE can be used to determine pavement thickness and compaction requirements. The computer program runs on the Microsoft Windows™ operating systems or Windows™ compatible systems. PCASE may be obtained electronically from the following:

- https://transportation.wes.army.mil/pcase or http://www.pcase.com
- A compact disk (CD) is also available from the U.S. Army Corps of Engineers, Transportation Systems Center, 1616 Capitol Avenue, Omaha, NE 68102-4901.

3-6 MATERIALS.

Materials for pavements designed in accordance with this UFC and PCASE must conform to requirements set forth in this and the Unified Facility Guide Specifications (UFGS). To the greatest practical extent, specify local materials that meet requirements of the Department of Transportation in the State in which the project is located, and are in accordance to UFC requirements. Only the materials should be changed in the UFGS, all other requirements such as general requirements, tolerances, and execution requirements should stay the same. The construction materials for pavements designed using state Department of Transportation (DoT) thickness design criteria must conform to the DoT material specifications. The construction execution procedure for physically determining acceptable conditions, preparation, installation, field quality control and inspection must conform to the UFGS.

3-7 DRAINAGE SYSTEMS.

Pavement subdrainage systems are covered in this UFC. Refer to UFC 3-201-01 for criteria on storm drainage systems (e.g. surface drainage, underground drainage systems, stormwater management facilities, erosion and sediment control). Refer to UFC 3-210-01 for criteria on low impact development.

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CHAPTER 4 PAVEMENT DESIGN

For the design of pavements traveled by standard American Association of State Highway and Transportation Officials (AASHTO) vehicles or vehicles not characterized as special military vehicles in UFC 3-201-01, in the United States, the State pavement design procedure may be used, except that the use of keyed joint, if allowed by the State, must not be used on pavement thinner than 9 inches. When using the State pavement design procedure, use the pavement design criteria and procedures recognized by the Department of Transportation (DoT) in the state in which the project is located. Refer to UFC 3-201-01, paragraph titled “Design Traffic” to predict average daily traffic (ADT) when using a State pavement design procedure.

4-1 EFFECT OF VEHICULAR TRAFFIC ON PAVEMENT DESIGN.

Design pavement thickness to withstand the anticipated traffic, categorized by type and weight of vehicles, and number of passes of each type for the design life of the pavement. For most pavements, the magnitude of the axle load is of greater importance than the gross weight of pneumatic-tired vehicles because axle spacing is generally so large that there is little interaction between the wheel loads of one axle and the wheel loads of the other axles. Thus, for the case of pneumatic-tired vehicles having equal axle loads, the increased severity of loading imposed by conventional four or five axle trucks as compared with that imposed by two or three axle trucks is largely a fatigue effect resulting from an increased number of load repetitions per vehicle operation. For forklift trucks where the loading is concentrated largely on a single axle and for tracked vehicles where the loading is evenly divided between the two tracks, the severity of the vehicle loading is a function of the gross weight of the vehicle and the frequency of loading. Relations between load repetition and required rigid pavement thickness developed from accelerated traffic tests of full-scale pavements have shown that, for any given vehicle, increasing the gross weight by as little as 10 percent can be equivalent to increasing the volume of traffic by as much as 300 to 400 percent. Therefore, for rigid pavements, the magnitude of the vehicle loading must be used as a more significant factor in the design of pavements than the number of load repetitions.

4-2 EQUIVALENT SINGLE AXLE LOAD (ESAL).

The ESAL used in this UFC is not the ESAL as computed by the AASHTO Guide for Design of Pavement Structures. In PCASE, the equivalency used is based on mixed traffic and the CBR Beta design model. Direct comparison or equivalence between AASHTO and PCASE ESAL is not straightforward since the ESAL computation in each methodology derives from specific models, assumptions, and design procedures. The conversion of each vehicle to ESALs is based on research done by the USACE, ERDC.

4-3 PAVEMENT DESIGN.

Unless specified otherwise in the project specific requirements, design pavement based upon anticipated vehicles and loadings for a 25 year life; however, sections must not be less than the minimums indicated in UFC 3-201-01. Pavements design is based on loads and the total number of passes during the life of the pavement for the expected vehicles. Typically, traffic is counted in terms of ADT. This ADT value should take into consideration the type, numbers of passes, and load for each of the vehicles in the mix. The ADT in the daily traffic distribution is converted to total number of passes for the desired pavement design life.

For example, if a road is to be designed for an average of 10 passes per day of a 5 axle truck, then the total design passes for a 25 year life will be 10 passes/day × 365 days/year × 25 years = 91,250 total passes. Design charts have been prepared using PCASE and can be used in lieu of PCASE. These charts are for flexible and rigid pavements use required thickness and total number of passes for various vehicles and are provided in Appendix E, and Appendix F, respectively. When designing for a mix of vehicles (mixed traffic), the concept of an equivalent vehicle is used. In this procedure each vehicle is converted to a critical or controlling vehicle, which in turn represents the cumulative effect of all vehicles in the mix. This procedure is the same procedure used to convert mixed traffic to an equivalent number of passes of an 18,000 lb (8,200 kg) single-axle, dual load ESAL. Use the number of ESALs to compute the minimum pavement layer thicknesses and compaction requirements.

4-3.1 Vehicle Wander Width.

As vehicles travel down a road, there is a natural tendency for the vehicles to wander from side to side. This lateral wander determines the actual number of load or stress repetitions applied to a given point on the pavement. This effect is accounted for in pavement design by the wander width, which is defined as the total width of pavement over which the centerline of a vehicle is distributed 75 percent of the time symmetrically around the mean. Traffic studies have indicated that the wander width for roads is about 33 in (850 mm) assuming a statistical normal distribution of traffic. This means that a vehicle would deviate laterally from its centerline a maximum distance of 165 in (420 mm) from its line of travel. The pavement design charts presented in this UFC are based on these assumptions.

4-3.2 Location of Critical Loads.

In roads with 12 ft (4 m) wide lanes, the location where the maximum loads are applied is about 0 to 3 ft (0 to 1 m) from the pavement edge. If no mechanisms are provided to transfer tire load to the adjacent shoulders, a condition of zero load transfer occurs at the pavement edge. This has a marked impact on the stresses that a concrete slab will be subjected to. In rigid pavements, the Westergaard theoretical analysis for edge stresses is used to compute these critical stresses and no reduction due to load transfer is performed. In flexible pavements, the concept of cumulative damage associated with each vehicle is used to account for the lateral wander and vertical stress applied to the subgrade.

4-3.3 Mixed Traffic.

The examples included in Appendix G illustrate the procedure for handling mixed traffic for either flexible or rigid pavements. The mixed traffic procedure performs an equivalency between vehicles by calculating the thickness requirements of each vehicle for the specified number of passes and subgrade CBR. The vehicle with the largest required thickness then becomes the controlling vehicle and the other vehicles converted to it by the procedure described in the examples. The calculations are based on the thickness requirements of each individual vehicle; therefore the resulting controlling vehicle for flexible and rigid pavements may be different. Since subgrade conditions may vary along a road, mixed traffic calculations use a representative subgrade strength category instead of a specific value. These representative subgrade categories are shown in Table 4-1. However, when the final mixed traffic equivalency has been finished in terms of the equivalent passes of the controlling vehicle, the design CBR or k value will be used to obtain the required pavement thickness above the subgrade.

Table 4-1 Representative Subgrade Categories

Subgrade Category	Flexible Pavements, CBR Range	Representative CBR Value	Rigid Pavements k-value Range psi/in[1]	Representative k-value, psi/in[1]
A	CBR ≥ 13	15	k ≥ 442	552.6
B	8 < CBR <13	10	221 < k < 442	294.7
C	4 < CBR ≤ 8	6	92 < k ≤ 221	147.4
D	CBR ≤ 4	3	k ≤ 92	73.7
[1] kPa/mm = psi/in ÷ 0.271				

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CHAPTER 5 FLEXIBLE PAVEMENT SUBGRADES

5-1 FACTORS TO BE CONSIDERED.

Consider the following primary factors regarding subgrades for flexible pavement design:

- The general characteristics of the subgrade soils (e.g. soil classification, limits).
- Depth to bed rock.
- Depth to groundwater table (including perched groundwater table).
- The attainable compaction in the subgrade and the adequacy of the existing density in the layers below the zone of compaction requirements
- The CBR that the compacted subgrade and un-compacted subgrade will have under local environmental conditions.
- The presence of weak soft layers in the subsoil.
- Susceptibility to detrimental frost action.
- Expansion potential

5-2 COMPACTION.

The natural density of the subgrade must be sufficient to resist densification under traffic or the subgrade must be compacted during construction to a depth where the natural density will resist densification under traffic. Table 5-1 shows the depth, measured from the pavement surface, at which a given percent compaction is required to prevent densification under traffic. Subgrades in cuts must have natural densities equal to or greater than the values shown in Table 5-1. Where such is not the case, compact the subgrade from the surface to meet the tabulated densities, or remove and replace the subgrade, in which case the requirements for fills apply. As another option, cover the subgrade with sufficient selected material, subbase, and base so that the un-compacted subgrade is at a depth where the in place densities are satisfactory. In fill areas, place cohesionless soils at no less than 95 percent of ASTM D1557 maximum density and cohesive fills at less than 90 percent of ASTM D1557 maximum density.

Table 5-1 Depth of Compaction for Select Materials and Subgrades (CBR[1] ≤ 20)

Equivalent Passes of an 18,000-lb (8,200-kg) ESAL		Depth of Compaction[2] or Percent Compaction Shown, in									
Type of Pavement		**Cohesive Soils PI>5; LL>25**					**Cohesionless Soils PI≤ 5, LL≤ 25**				
Flexible	**Rigid**	**100**	**95**	**90**	**85**	**80**	**100**	**95**	**90**	**85**	**80**
< 15,500	< 1,300	3	7	10	14	17	7	13	19	25	33
< 67,500	< 1,500	4	8	12	16	20	8	15	22	29	38
< 295,000	< 34,000	4	9	14	18	23	9	17	25	33	43
< 1.3 million	< 343,000	5	11	16	21	26	11	20	28	37	48
< 5.7 million	< 2.1 million	6	12	18	23	28	12	22	31	40	53
< 25 million	< 9.2 million	7	14	19	25	31	14	24	35	44	58
< 112 million	< 37 million	7	15	21	28	34	15	26	38	48	63
< 500 million	< 105 million	8	16	23	30	37	16	29	41	52	68
< 2,200 million	< 290 million	9	18	25	32	40	18	31	44	56	74
≥ 2,200 million	≥ 290 millions	10	20	28	35	43	20	34	47	59	77

[1] California Bearing Ratio (ASTM D4429).
[2] Depth of compaction is measured from pavement surface.

5-3 COMPACTION EXAMPLES.

Appendix G includes two examples illustrating the application of subgrade compaction requirements

5-4 SELECTION OF DESIGN CBR VALUES.

Flexible pavements may be designed using the laboratory soaked CBR, the field in-place CBR, the CBR from the Dynamic Cone Penetrometer as described in ASTM D6951/D6951M or the CBR from undisturbed samples as described in ASTM D1883 or ASTM D 4429. For the design of flexible pavements in areas where no previous experience regarding pavement performance is available, the laboratory soaked CBR is normally used. Where an existing pavement is available at the site that has a subgrade constructed to the same standards as the job being designed, in-place tests or tests on undisturbed samples may be used in selecting the design CBR value. In-place tests are used when the subgrade material is at the maximum water content expected in the prototype and frost is not expected to penetrate the subgrade. Contrarily, tests on undisturbed samples are used where the material is not at the maximum water content and thus soaking is required. Sampling involves considerably more work than in-place tests and undisturbed samples tend to be slightly disturbed. Therefore, in-place tests should be used where possible. Guides for determining when in-place tests can be used are given in details of the CBR test in ASTM D4429.

CHAPTER 6 FLEXIBLE PAVEMENT SELECT MATERIALS AND SUBBASE COURSES

6-1 GENERAL.

This UFC designates layers between the subgrade and base course as selected materials or subbases. Select materials are those with design CBR values equal to or less than 20; subbases are those with CBR values above 20. Minimum thicknesses of pavement and base have been established to eliminate the need for subbases with design CBR values above 50. Where the design CBR value of the subgrade without processing is in the range of 20 to 50, select materials and subbases may not be needed. However, the subgrade cannot be assigned design CBR values of 20 or higher unless it meets the gradation and plasticity requirements for subbases.

6-2 MATERIALS.

Use the soils investigations described in Chapter titled Preliminary Soils Investigation to determine the location and characteristics of suitable soils for select material and subbase construction.

6-2.1 Select Materials.

The subbase materials for each CBR value must conform to the quality and gradations requirements given in the guide specifications so that they will develop the needed strengths. Select materials are normally locally available coarse-grained soils (gravel: GW, GP, GM, GC, or sand: SW, SP, SM, SC), although fine-grained soils in the ML and CL groups may be used in certain cases. Consider limerock, coral, shell, ashes, cinders, caliche, disintegrated granite, and other such materials when they are economical. Recommended plasticity requirements are listed in Table 6-1. A maximum aggregate size of 3 in (80 mm) is suggested to aid in meeting grading requirements. Select material subbases are typically only used with subgrade CBR values less than 4 and large ESAL traffic volumes. Where frost is expected to penetrate the material, the subbase course must also meet the frost criteria in paragraph titled Free-Draining Material Directly Beneath Bound Base Or Surfacing Layer for free-draining material that contain 2.0 percent or less, by weight, of grains that can pass the No. 200 sieve.

6-2.2 Subbase Materials.

Subbase materials may consist of naturally occurring coarse-grained soils or blended and processed soils. Materials such as limerock, coral, shell, ashes, cinders, caliche, and disintegrated granite may be used as subbases when they meet the requirements described in Table 6-1. The existing subgrade may meet the requirements for a subbase course or it may be possible to treat the existing subgrade to produce a subbase. However, use native or processed materials only when the unmixed subgrade meets the liquid limit and plasticity index requirements for subbases. Do not “cut” plasticity by mixing subgrade. Material stabilized with commercial additives may be economical as a subbase. Portland cement, lime, fly ash, or bitumen and combinations thereof are commonly used for this purpose. Also, it may be possible to decrease the plasticity of some materials by use of lime or Portland cement in sufficient amounts to make them suitable as subbases. When using ash or cinders, the free lime content must be less than 5% and the material must be volumetrically stable.

6-3 COMPACTION.

Compaction of subbases will be 100 percent of ASTM D1557 density except where it is known that a higher density can be obtained, in which case the higher density should be required. Compaction of select materials and subgrades will be as shown in Table 5-1 except that in no case will cohesionless fill be placed at less than 95 percent or cohesive fill at less than 90 percent.

6-4 DRAINAGE.

Subbase drainage is an important aspect of design and is discussed in Chapter titled Design of Subsurface Pavement Drainage Systems.

6-5 SELECTION OF DESIGN CBR VALUES.

During the design phase where the materials have normally not been selected for construction, the design CBR values should be selected based on the gradations recommended in Table 6-1 and the cost of the materials available. The select material or subbase is generally uniform, and the problem of selecting a limiting condition, as described for the subgrade, does not ordinarily exist. Tests are usually made on remolded samples; however, where existing similar construction is available, CBR tests may be made in place on material when it has attained its maximum expected water content or on undisturbed soaked samples. The procedures for selecting CBR design values described for subgrades apply to select materials and subbases. CBR tests on gravelly materials in the laboratory tend to give CBR values higher than those obtained in the field. The difference is attributed to the processing necessary to test the sample in the 6 in (150 mm) mold, and to the confining effect of the mold. Therefore, the CBR test is supplemented by gradation and Atterberg limits requirements for subbases, as shown in Table 6-1. Suggested limits for select materials are also indicated. In addition to these requirements, the material must also show in the laboratory tests a CBR equal to or higher than the CBR assigned to the material for design purposes.

Table 6-1 Maximum Permissible Design Values for Subbases and Select Materials

Material	Design CBR	Size in	Gradation Requirements,* % passing		Liquid Limit	Plasticity Index
			No. 10	No. 200		
Subbase	50	3	50	15	25	5
Subbase	40	3	80	15	25	5
Subbase	30	3	100	15	25	5
Select material	20	*3	…	**25	**35	**12

* Cases may occur in which certain natural materials that do not meet the gradation requirements may develop satisfactory CBR values in the prototype. Exceptions to the gradation requirements are permissible when supported by adequate in-place CBR tests on construction that has been in service for several years. The CBR test is not applicable for use in evaluating materials stabilized with additives.
** Suggested limits.

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CHAPTER 7 FLEXIBLE PAVEMENT BASE COURSES

7-1 MATERIALS.

Use high-quality materials in base courses of flexible pavements. These high-quality materials provide resistance to the high stresses that occur near the pavement surface. Guide specifications for graded crushed aggregate, limerock, and stabilized aggregate may be used without qualification for design of roads and parking areas. Guide specifications for dry- and water-bound macadam base courses may be used for design of pavements only when the cost of the dry- or water-bound macadam base does not exceed the cost of stabilized-aggregate base course, and the ability of probable bidders to construct pavements with dry- or water-bound macadam base to the required surface smoothness and grade tolerances has been proved by experience in the area.

7-2 COMPACTION.

Compact base courses for flexible pavements sections to the maximum density practicable, but never less than 100 percent of ASTM D1557 maximum density. Generally, the base course will be compacted to a minimum of 100 percent of ASTM D1557 maximum density.

7-3 DRAINAGE.

Drainage design for base courses is discussed in Chapter titled Design of Subsurface Pavement Drainage Systems.

7-4 SELECTION OF DESIGN CBR.

Because of the effects of processing samples for the laboratory CBR tests and because of the effects of the test mold, do not use the laboratory CBR test to determine CBR values of base courses. Instead, assign selected CBR ratings as shown in Table 7-1. These ratings have been based on service behavior records and, where pertinent, on in-place tests made on materials subjected to traffic. Materials must conform to the quality requirements given in the guide specifications to develop the needed strengths. To obtain an 80 CBR for No. 6 Aggregate Base Coarse, the material must have 50 percent crushed particles and be graded, but the No. 1 Graded-Crushed Aggregate Base Coarse material has a higher 90 percent of crushed material.

7-5 MINIMUM THICKNESS.

Refer to UFC 3-201-01 for minimum thickness requirements where the State pavement design procedure is used. Where the use of PCASE is mandatory, the minimum allowable thickness of base course is shown in Table 7-2. The total thickness of pavement plus base for roads and parking areas must not be less than 6 in (150 mm) or the frost penetration depth as determined from Chapter titled Seasonal Frost Conditions except where a surface treatment is applied. Where frost is expected to penetrate the base material, the base course must also meet the frost criteria in paragraph titled Free-Draining Material Directly Beneath Bound Base Or Surfacing Layer for free-draining material that contain 2.0 percent or less, by weight, of grains that can pass the No. 200

sieve. The drainage criteria in Chapter titled Design of Subsurface Pavement Drainage Systems, requires a minimum of 4 in (100 mm) of drainage layer and 4 in (100 mm) of subbase (separation) course for most pavements. When a pavement design requires 12 in (300 mm) or more of granular material above the subgrade, add base course. For pavements requiring less than 12 in (300 mm) of granular material above the subgrade, evaluate the drainage requirements in Chapter titled Design of Subsurface Pavement Drainage Systems to determine a cost effective system of granular materials. Placing an asphalt surface directly on a drainage layer (without a base course) can be accomplished under certain conditions.

Table 7-1 Design CBR Values

No.	Type	Design CBR
1	Graded crushed aggregate	100
2	Water-bound macadam	100
3	Dry-bound macadam	100
4	Bituminous binder and surface courses, central plant, hot mix	100
5	Limerock	80
6	Aggregate	80

Table 7-2 Minimum Thickness of Flexible Pavement Sections

Equivalent Passes of an 8,164-kg (18,000-lb) ESAL	Minimum Base Course CBR								
	100			80			50		
	Surface[1] in	Base in	Total in	Surface[1] in	Base in	Total in	Surface[1] in	Base in	Total in
≤ 20,000	ST[3]	4	4.5	MST[4]	4	4.5	2	4	6
20,001 to 150,000	2	4	6	2	4	6	2.5	4	6.5
150,001 to 500,000	2	4	6	2.5	4	6.5	3.5	4	7.5
500,001 to 2 Million	2.5	4	6.5	3	4	7	N/A[2]		
>2 Million to 7 Million	3.5	4	7.5	3.5	4	7.5			
> 7 Million	3.5	4	7.5	4	4	8			

Conversion Factor: millimeters = 25.4 × inches

Symbols: ≤ less than or equal to, < less than, > greater than, ≥ greater than or equal to

[1] Use a minimum surface pavement thickness of 3 in (75 mm) for any vehicle with a tire pressure ≥ 100 psi.

[2] 50-CBR base course is restricted to roads and parking areas with less than or equal to 500,000 ESALs.

[3] Bituminous surface treatments (spray application).

[4] Multiple bituminous surface treatments (spray application).

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CHAPTER 8 BITUMINOUS PAVEMENT

8-1 GENERAL.

The bituminous materials used in paving are asphaltic or tar products as listed in UFC 3-250-03. Although asphalts and tars resemble each other in general appearance, they do not have the same physical or chemical characteristics. Tars are affected to a greater extent by temperature changes and weather conditions; however, they tend to have better adhesive and penetrating properties than asphalts. Generally, asphalt surface courses are preferred to tar surface courses. The selection of the type of bituminous material (asphalt or tar) should normally be based on economy.

8-2 CRITERIA FOR BITUMINOUS PAVEMENTS.

The basic criteria for selection and design of bituminous pavements are contained in UFC 3-250-03 which includes the following criteria:

- Selection of bitumen type;
- Selection of bitumen grade;
- Aggregate requirements;
- Quality requirements;
- Types of bituminous pavements.

8-3 MINIMUM THICKNESS.

Refer to UFC 3-201-01 for minimum thickness requirements where the State pavement design procedure is used. Where the use of PCASE is mandatory, the minimum thickness of bituminous materials varies with the strength of the underlying base course and is given in Table 7-2.

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CHAPTER 9 FLEXIBLE PAVEMENT DESIGN

9-1 GENERAL.

Flexible pavement designs must provide the following:

- Sufficient compaction of the subgrade and of each layer during construction to prevent objectionable settlement under traffic.
- Adequate drainage of base course.
- Adequate thickness above the subgrade and above each layer together with adequate quality of the select material, subbase, and base courses to prevent detrimental shear deformation under traffic and, when frost conditions are a factor, to control or reduce to acceptable limits effects of frost heave or permafrost degradation.
- A stable, weather-resistant, wear-resistant waterproof, non-slippery pavement.

9-2 DESIGN PROCEDURE.

9-2.1 Conventional Flexible Pavements.

In designing conventional flexible pavement structures, apply the design values assigned to the various layers to the curves and criteria presented in this UFC. As several designs are generally possible for a specific site, select the most practical and economical design meeting the minimum design requirements. Since the decision on the practicability of a particular design may be largely a matter of judgment, include full particulars regarding the selection of the final design (including cost estimates) in the design analysis.

Refer to UFC 3-201-01 for permeable pavement criteria.

9-2.2 Stabilized Soil Layers.

Flexible pavements containing stabilized soil layers are designed through the use of equivalency factors. A conventional flexible pavement is first designed and the equivalency factors applied to the thickness of the layer to be stabilized. When stabilized materials meeting all gradation, durability, and strength requirements indicated in UFC 3-250-11, and Chapter titled Seasonal Frost Conditions are used in pavement structures, an appropriate equivalency factor may be applied. Soils which have been mixed with a stabilizing agent and which do not meet the requirements for a stabilized soil are considered modified and are designed as conventional pavement layers. When Portland cement is used to stabilize base course materials in DoD pavements, the treatment level must be maintained below about 4 percent by weight to minimize shrinkage cracking which will reflect through the bituminous concrete surface course. In this case, the base course will, in most instances, be modified rather than stabilized. In addition, when unbound granular layers are used between two bound layers (e.g., an unbound base course between an asphalt concrete (AC) surface course and a stabilized subbase course), provide adequate drainage to the unbound layer to prevent entrapment of excessive moisture in the layer. Additional criteria on soil stabilization may be obtained from UFC 3-250-11.

9-2.3 All-Bituminous Concrete.

All-bituminous concrete pavements are also designed using equivalency factors. See paragraph titled Equivalency Factors below. The procedure is the same as for stabilized soil layers discussed above.

9-3 DESIGN TRAFFIC.

The design of flexible pavements for roads and parking areas will be based on the actual traffic expected to use a flexible pavement during its service life and the procedures described in Chapter titled Vehicular Traffic. The designer is cautioned that in selecting the design traffic, consideration must be given to traffic which may use the pavement structure during various stages of construction and to other foreseeable exceptional use.

9-4 THICKNESS CRITERIA FOR CONVENTIONAL FLEXIBLE PAVEMENTS.

For roads and parking areas, obtain the required thickness of flexible pavements from the design charts presented in Appendix E. The charts in Appendix E were developed using thickness design requirements and are given in terms of subgrade CBR. If the design includes vehicles not covered Appendix E, PCASE must be used. Minimum thickness requirements are shown in Table 7-2. For frost condition design, thickness requirements will be determined from Chapter titled Seasonal Frost. In regions where the annual precipitation is less than 15 in (380 mm) and the groundwater table (including perched groundwater table) is at least 15 ft (4.6 m) below the finished pavement surface, the danger of high moisture content in the subgrade is reduced. Where in-place tests on similar construction in these regions indicate that the water content of the subgrade will not increase above the optimum, the total pavement thickness, as determined by CBR tests on soaked samples, may be reduced by as much as 20 percent. The minimum thickness of pavement and subbase must still be met; therefore the reduction will be affected in the subbase course immediately above the subgrade. When only limited rainfall records are available, or the annual precipitation is close to the 15 inch criterion, give careful consideration to the sensitivity of the subgrade to small increases in moisture content before any reduction in thickness is made.

Appendix G includes an example of thickness design for conventional flexible pavements.

9-5 THICKNESS CRITERIA-STABILIZED SOIL LAYERS.

9-5.1 Equivalency Factors.

The use of stabilized soil layers within a flexible pavement provides the opportunity to reduce the overall thickness of pavement structure required to support a given load. The design of pavement containing stabilized soil layers requires the application of equivalency factors to a layer or layers of a conventionally designed pavement. To qualify for application of equivalency factors, the stabilized layer must meet appropriate strength and durability requirements set forth in UFC 3-250-11. An equivalency factor represents the number of inches (millimeters) of a conventional base or subbase which can be replaced by 1 in (25 mm) of stabilized material. Equivalency factors for stabilized materials are determined as shown in Table 9-1. The cement content must be limited to 4 percent by weight or less to prevent excessive reflective cracking. Selection of an equivalency factor from the tabulation is dependent upon the classification of the soil to be stabilized.

Table 9-1 Equivalency Factors for Stabilized Material

Material	Equivalency Factors	
	Base	Subbase
Asphalt-stabilized		
All-bituminous concrete	1.15	2.30
GW, GP, GM, GC	1.00	2.00
SW, SP, SM, SC	*	1.50
Cement-stabilized		
GW, GP, SW, SP	1.15	2.30
GM, GC	1.00	2.00
ML, MH, CL, CH	*	1.70
SC, SM	*	1.50
Lime-stabilized		
ML, MH, CL, CH	*	1.00
SC, SM, GM, GC	*	1.10
Lime, Cement, Fly ash Stabilized		
ML, MH, CL, CH	*	1.30
SC, SM, GM, GC	*	1.40
Unbound crushed stone	1.00	2.00
Unbound aggregate	*	1.00
* Not used for base course material.		

9-5.2 Minimum Thickness.

Apply the minimum thickness requirements to the standard pavement before determining the stabilized layer thicknesses. However for pavements with stabilized layers, the minimum thickness requirement for the asphalt layer is the same as shown in Table 7-1 for conventional pavements.

9-6 EXAMPLE THICKNESS DESIGN-STABILIZED SOIL LAYERS.

The equivalency factors require that a conventional flexible pavement be designed to support the design load conditions. If it is desired to use a stabilized base or subbase course, divide the thickness of conventional base or subbase by the equivalency factor for the applicable stabilized soil. Two examples for the application of the equivalency factors are included in Appendix G.

9-7 SHOULDERS AND SIMILAR AREAS.

These areas are provided only for the purpose of minimizing damage to vehicles which use them accidentally or in emergencies; therefore, they are not considered normal vehicular traffic areas. Provide paved shoulders for high volume roads. Others will be surfaced with soils selected for their stability in wet weather and will be compacted as required. Dust and erosion control will be provided by vegetative cover, anchored mulch, coarse-graded aggregate or liquid palliatives UFC 3-260-17. Shoulders will not block base course drainage, particularly where frost conditions are a factor.

9-8 BITUMINOUS SIDEWALKS, CURBS, AND GUTTERS.

Refer to UFC 3-201-01 for criteria on bituminous sidewalks, curbs and gutters.

9-9 FLEXIBLE OVERLAY DESIGN.

For the design of flexible pavement overlays, see Chapter titled Pavement Overlays.

9-10 FLEXIBLE PAVEMENT DESIGN CURVES.

Appendix E contains the flexible pavement design curves of vehicles commonly included in the design traffic mix. If a design curve for a vehicle not included in Appendix E, the U.S. Army Corps of Engineers, Transportation Systems Center, 1616 Capitol Avenue, Omaha, NE 68102-4901 may be contacted.

CHAPTER 10 RIGID PAVEMENT DESIGN

10-1 SOIL CLASSIFICATION AND TESTS.

All soils should be classified according to the USCS as given in ASTM D2487. There have been instances in construction specifications where the use of such terms as "loam," "gumbo," "mud," and "muck" have resulted in misunderstandings. These terms are not specific and are subject to different interpretations throughout the United States. Such terms should not be used. Sufficient investigations should be performed at the proposed site to facilitate the description of all soils that will be used or removed during construction in accordance with ASTM D 2487; any additional descriptive information considered pertinent should also be included. If Atterberg limits are a required part of the description, as indicated by the classification tests, the test procedures and limits should be referenced in the construction specifications.

10-2 COMPACTION.

10-2.1 General.

Compaction improves the stability of the subgrade soils and provides a more uniform foundation for the pavement. The ASTM D1557 soil compaction test conducted at several moisture contents is used to determine the compaction characteristics of the subgrade soils. The range of maximum densities normally obtained in the compaction test on various soil types is listed in UFC 3-260-02. This test method should not be used if the soil contains particles that are easily broken under the blow of the tamper unless the field method of compaction will produce a similar degradation. Certain types of soil may require the use of a laboratory compaction control test other than the soil compaction test. The unit weight of some types of sands and gravels obtained using the compaction method above may be lower than the unit weight that can be obtained by field compaction; hence, the method may not be applicable. In those cases where a higher laboratory density is desired, compaction tests are usually made under some variation of the ASTM D1557 method, such as vibration or tamping (alone or in combination) with a type hammer or compaction effort different from that used in the test.

10-2.2 Requirements.

For all subgrade soil types, compact the subgrade under the pavement slab or base course to a minimum depth of 6 in (150 mm). If the densities of the natural subgrade materials are equal to or greater than 90 percent of the maximum density from ASTM D1557, no rolling is necessary other than that required to provide a smooth surface. Compaction requirements for cohesive soils (Liquid Limit (LL) > 25; Plasticity Index (PI) > 5) are 90 percent of maximum density for the top 6 in (150 mm) of cuts and the full depth of fills. Compaction requirements for cohesionless soils (LL<25: PI<5) are 95 percent for the top 6-in of cuts and the full depth of fills. Compaction of the top 6 in (150 mm) of cuts may require the subgrade to be scarified and dried or moistened as necessary and re-compacted to the desired density.

10-2.3 Special Soils.

Although compaction increases the stability and strength of most soils, some soil types show a marked decrease in stability when scarified, worked, and rolled. Also, expansive soils shrink excessively during dry periods and expand excessively when allowed to absorb moisture. When soils of these types are encountered, special treatment will usually be required. For nominally expansive soils, water content, compaction effort, and overburden should be determined to control swell. For highly expansive soils, replacement to depth of moisture equilibrium, raising grade, lime stabilization, pre-wetting, or other acceptable means of controlling swell should be considered.

10-3 TREATMENT OF UNSUITABLE SOILS.

Soils not suitable for subgrade use, as specified in UFC 3-260-02, should be removed and replaced, covered with soils which are suitable or treated. The depth to which such adverse soils should be removed, covered, or treated depends on the soil type, drainage conditions, and depth of freezing temperature penetration and should be determined by the engineer on the basis of judgment and previous experience, with due consideration of the traffic to be served and the costs involved. Where freezing temperatures penetrate a frost-susceptible subgrade, follow the design procedures outlined in Chapter titled Seasonal Frost Conditions. In some instances, unsuitable or adverse soils may be improved economically by stabilization with such materials as cement, fly ash, lime, or certain chemical additives, whereby the characteristics of the composite material become suitable for subgrade purposes. Criteria for soil stabilization are in UFC 3-250-11. However, subgrade stabilization should not be attempted unless the costs reflect corresponding savings in base course, pavement, or drainage facilities construction. Highly expansive subgrades are typically removed and replaced with suitable soil, compacted at a moisture content and unit weight that will minimize expansion, or chemically treated. Care should be taken when using calcium-based materials such as lime and Portland cement to chemically treat clay soils with soluble sulfates. The combination of calcium-based stabilizer, water, and clay with soluble sulfates will produce calcium-aluminate-sulfate-hydrate minerals with very large expansion potential. An adequate amount of water and mellowing time is required to allow formation of the expansive minerals before compaction.

10-4 DETERMINATION OF MODULUS OF SUBGRADE REACTION.

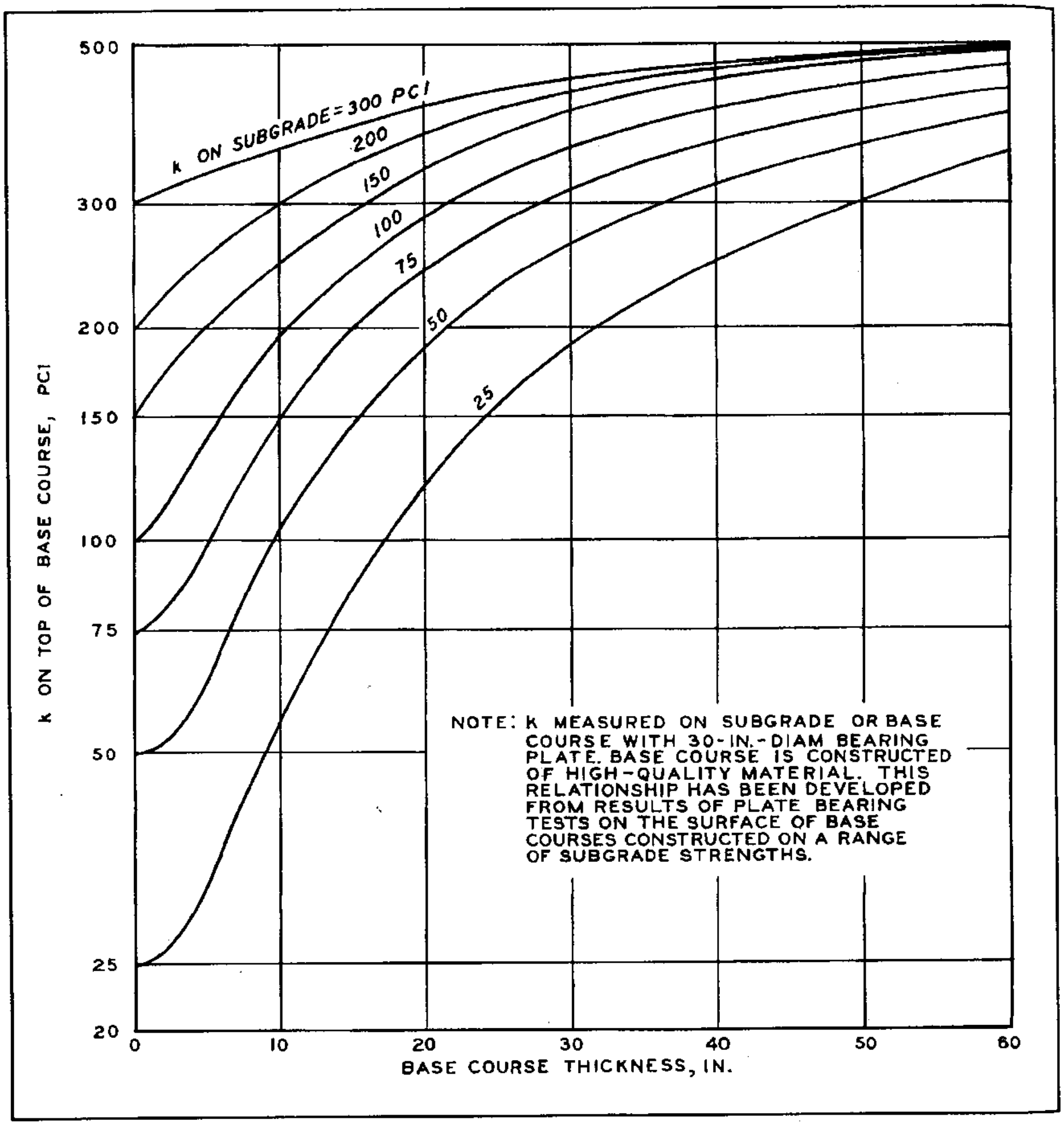
For the design of rigid pavements in those areas where no previous experience regarding pavement performance is available, determine the modulus of subgrade reaction **k** for design purposes by the field plate-bearing test. Where performance data from existing rigid pavements are available, adequate values for **k** can usually be determined on the basis of consideration of soil type, drainage conditions, and frost conditions that prevail at the proposed site. Table 10-1 presents typical values of **k** for various soil types and moisture conditions as a function of base course thickness. Consider these values as a guide only and their use in place of the field plate-bearing test, although not recommended, is left to the discretion of the engineer. Where a base course is used under the pavement, the **k** value on top of the base (also known as the effective k value) is used to determine the pavement thickness. The plate-bearing test may be run on top of the base, or Figure 10-1 may be used to determine the modulus of soil reaction on top of the base. It is good practice to confirm adequacy of the **k** on top of the base from Figure 10-1 by running a field plate-load test.

Table 10-1 Modulus of Soil Reaction (psi/in)*

Type of Material	Moisture Content Percentage							
	1 to 4	5 to 8	9 to 12	13 to 16	17 to 20	21 to 24	25 to 28	Over 28
Silts and clays, LL greater than 50 (OH, CH, MH)		175	150	125	100	75	50	25
Silts and clays, LL less than 50 (OL, CL, ML)		200	175	150	125	100	75	50
Silty and clayey sands (SM and SC)	300	250	225	200	150			
Sand and gravelly sands (SW and SP)	350	300	250					
Silty and clayey gravels (GM and GC)	400	350	300	250				
Gravel and sandy gravels (GW and GP)	500	450						

*Typical values of k in pounds per cubic inch for rigid pavement design.
Conversion factor: kPa/mm = psi/in ÷ 0.271.
Notes:
1. Values of k shown are typical for materials having dry densities equal to 90 to 95 percent of the maximum. For materials having dry densities less than 90 percent of the maximum, values should be reduced by 50 pounds per cubic inch (psi/inch), except that a k of 25 psi/inch will be the minimum used for design.
2. Values shown may be increased slightly if density is greater than 95 percent of the maximum, except that a k of 500 psi/in will be the maximum used for design.
3. Frost area k values are given in Chapter titled Seasonal Frost Conditions.

Figure 10-1 Effect of Base Course Thickness on Modulus of Soil Reaction for Non-frost Conditions



CHAPTER 11 RIGID PAVEMENT BASE COURSES

11-1 GENERAL REQUIREMENTS.

Base courses may be required under rigid pavements for replacing soft, highly compressible or expansive soils and for providing the following:

- Additional structural strength;
- More uniform bearing surface for the pavement;
- Protection for the subgrade against detrimental frost action;
- Drainage;
- Suitable surface for the operation of construction equipment, especially slip form pavers.

Use of base courses under a rigid pavement to provide structural benefit should be based on economy of construction. Thick base courses have often resulted in lower maintenance costs since the thick base course provides stronger foundation and therefore less slab movement. Provide a minimum base-course thickness of 4 in (100 mm) over subgrades that are classified as OH, CH, CL, MH, ML, and OL to provide protection against pumping. In certain cases of adverse moisture conditions (high groundwater table or poor drainage), SM and SC soils also may require base courses to prevent pumping. The designer is cautioned against the use of fine-grained material for leveling courses or choking open-graded base courses since this may create a pumping condition. Positive drainage should be provided for all base courses to ensure groundwater is not trapped directly beneath the pavement since saturation of these layers will cause the pumping condition that the base course is intended to prevent. The base course material and drains must meet the drainage criteria listed in Chapter titled Design of Subsurface Pavement Drainage Systems.

11-2 MATERIALS.

If conditions indicate that a base course is desirable under a rigid pavement, a thorough investigation should be made to determine the source, quantity, and characteristics of the available materials. A study should also be made to determine the most economical thickness of material for a base course that will meet the requirements. The base course may consist of natural, processed, or stabilized materials. The material selected should be the one that best accomplishes the intended purpose of the base course. In general, the base course material should be a well-graded, high-stability material. In this connection, all base courses to be placed beneath concrete pavements for roads and parking areas should conform to the following requirements:

- Percent passing No. 10 sieve: not more than 85.
- Percent passing No. 200 sieve: not more than 15.
- Plasticity index: not higher than 6.

- Where local experience indicates their desirability, other control limitations such as limited abrasion loss may be imposed to ensure a uniform high-quality base course.

11-3 COMPACTION.

Where base courses are used under rigid pavements, the base course material should be compacted to a minimum of 95 percent of the maximum density. The engineer is cautioned that it is difficult to compact thin base courses to high densities when they are placed on yielding subgrades.

11-4 FROST REQUIREMENTS.

In areas where subgrade soils are subjected to seasonal frost action detrimental to the performance of pavements, use the requirements for base course thickness and gradation outlined in Chapter titled Seasonal Frost Conditions.

CHAPTER 12 CONCRETE PAVEMENT

12-1 MIX PROPORTIONING AND CONTROL.

Proportioning of the concrete mix and control of the concrete for pavement construction is in accordance with UFC 3-250-04. Normally, a design flexural strength at a 28-day age is used for the pavement thickness determination. When it is necessary to use the pavements at an earlier age, consideration should be given to the use of a design flexural strength at the earlier age or to the use of high early strength cement, whichever is more economical. Fly ash gains strength more slowly than cement. If used it may be desirable to select a strength value at a period other than 28 days if time permits. Refer to UFC 3-201-01 for minimum flexural strength criteria.

12-2 TESTING.

The flexural strength of concrete and lean concrete base is determined in accordance with ASTM C78/C78M.

12-3 SPECIAL CONDITIONS.

Mix proportion or pavement thickness may require adjustment due to results of concrete tests. When tests results are less than predicted or a retrogression in strength, then the minimum pavement section must be increased. If the concrete strength is higher than predicted, then the thickness may be reduced. Rather than changing the thickness required as a result of tests on the concrete, the mix proportioning can be changed to increase or decrease the concrete strength, thereby not changing the thickness. If using the local state DoT specifications for the construction, verify that the specifications are compatible with lump sum bidding and that alkali-silica reaction (ASR) has adequately been addressed in your area.

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CHAPTER 13 PLAIN CONCRETE PAVEMENT DESIGN

13-1 GENERAL.

Rigid pavements for roads and parking areas must be plain (non-reinforced) concrete except for those conditions listed in Chapter titled Reinforced Concrete Pavements or unless otherwise approved by the Government Civil Engineer. Non-reinforced pavement design requires a minimum of 0.05 percent steel in odd-shaped slabs and mismatched joints. Refer to UFC 3-201-01 for permeable pavement criteria.

13-2 ROLLER-COMPACTED CONCRETE PAVEMENTS.

Roller-compacted concrete pavements (RCCP) are plain concrete pavements constructed using a zero-slump Portland Cement Concrete (PCC) mixture that is placed with an AC paving machine and compacted with vibratory and rubber-tired rollers. The design of RCCP is presented in Chapter titled Roller-Compacted Concrete Pavements.

13-3 DESIGN PROCEDURE.

For roads and parking areas, obtain the required thickness of plain and roller-compacted concrete pavements from the design charts presented in Appendix F. Parking areas assume that only a few vehicles will apply loads close to the edge of pavement and therefore, the pavement is designed assuming 25 percent joint load transfer. Use Appendix F to determine the thickness of concrete in parking areas, divide the design concrete flexural strength by 0.75 (i.e., Flexural Strength ÷ 0.75). This is equivalent to reducing the edge stress (multiplying the edge stress by 0.75) to account for joint load transfer. For example, if a flexural strength of 600 psi is selected for the design of a parking area, then the flexural strength to be used in the design charts is 600 ÷ 0.75 = 800 psi. The net result is a thickness that is less than the road design. These design charts are graphical representations of the relationship between flexural strength, modulus of subgrade reaction *k*, pavement thickness, and repetitions of a vehicle. If the design includes vehicles not covered in Appendix F, PCASE must be used. These design charts are based on the theoretical stress analyses of Westergaard (New Formulas for Stresses in Concrete Pavements of Airfields, American Society of Civil Engineers Transactions), supplemented by empirical modifications determined from accelerated traffic tests and observations of pavement behavior under actual service conditions. Enter the design charts using the 28-day flexural strength of the concrete. Make a horizontal projection to the right to the design value for *k*. Make a vertical projection to the appropriate pass level line. Make a second horizontal projection to the right to intersect the scale of pavement thickness. The guidelines shown on the curves are an example of the correct usage of the curves. When the final pavement thickness obtained from the design curve indicates a fractional value, round up in 0.5 in (10 mm) increments. All plain concrete pavements must be uniform in cross-sectional thickness. Thickened edges are not normally required on roads since the design is for free edge stresses. Only use thickened edges where the road layout requires repeated wheel loads across the free edge of the pavement. The minimum thickness of plain concrete is 6 in (150 mm). These charts also assume that the vehicle loadings traverse very close to the edge of the pavement and there is very little load transfer between the road slabs and the shoulders. Consequently, the computed edge stress is not reduced before it is used to check for maximum allowable edge stress values.

13-4 DESIGN PROCEDURE FOR STABILIZED FOUNDATIONS.

The thickness requirements for a plain concrete pavement on a modified soil foundation must be designed as if the layer is unbound using the *k* value measured on top of the modified soil layer. For stabilized soil layers, consider the treated layer to be a low-strength base pavement and the thickness determined using the following modified partially bonded overlay pavement design equation:

$$h_o = \sqrt[1.4]{h_d^{1.4} - \left(0.0063 \sqrt[3]{E_f}\ h_s\right)^{1.4}} \quad \text{(eq. 13-1)}$$

Where:

h_o=thickness of plain concrete pavement overlay required over the stabilized layer, inches;

h_d=thickness of plain concrete pavement from design charts based on k value of unbound material, inches;

E_f=flexural modulus of elasticity of the stabilized soil. The modulus value for stabilized soils is determined according to the procedures in Appendix H;

h_s=thickness of stabilized layer, inches;

The coefficient 0.0063 derives from $\left(\frac{1}{\mathrm{E_c}}\right)^{\frac{1}{3}}$ where E_c represents the concrete modulus of elasticity, usually assumed being equal to 4,000,000 psi.

For additional information on stabilization and mix proportioning see UFC 3-250-11.

13-5 DESIGN EXAMPLES.

Appendix G contains two design examples of rigid pavement design

13-6 CONCRETE SIDEWALKS, CURBS AND GUTTERS.

Refer to UFC 3-201-01 for criteria on concrete sidewalks, curbs and gutters.

13-7 RIGID PAVEMENT DESIGN CURVES.

Appendix F contains the rigid pavement design curves of vehicles commonly included in the design traffic mix. If a design curve for a vehicle not included in Appendix F, the U.S. Army Corps of Engineers, Transportation Systems Center, 1616 Capitol Avenue, Omaha, NE 68102-4901 may be contacted.

CHAPTER 14 REINFORCED CONCRETE PAVEMENTS

14-1 APPLICATION.

Under certain conditions, concrete pavement slabs may be reinforced with welded wire fabric or formed bar mats arranged in a square or rectangular grid. The advantages of using steel reinforcement include a reduction in the required slab thickness, greater spacing between joints, and reduced differential settlement due to non-uniform support or frost heave. Figure C14-1, Figure C14-3, Figure C14-4, and Figure C14-5 show the typical details for the design and construction of reinforced concrete pavements.

14-1.1 Subgrade Conditions.

Reinforcement may reduce the damage resulting from cracked slabs. Cracking may occur in rigid pavements founded on subgrades where differential vertical movement is a definite potential. An example is a foundation with definite or borderline frost susceptibility that cannot feasibly be made to conform to conventional frost design requirements.

14-1.2 Economic Considerations.

In general, reinforced concrete pavements are not economically competitive with plain concrete pavements of equal load-carrying capacity, even though a reduction in pavement thickness is possible. Alternate bids, however, should be invited if reasonable doubt exists on this point.

14-1.3 Plain Concrete Pavements.

In plain concrete pavements, steel reinforcement should be used for the following conditions:

14-1.3.1 Odd-Shaped Slabs.

Odd-shaped slabs should be reinforced in two directions normal to each other using a minimum of 0.05 percent of steel in both directions. The entire area of the slab should be reinforced. An odd-shaped slab is one in which the longer dimension exceeds the shorter dimension by more than 25 percent or a slab which essentially is neither square nor rectangular, or has unmatched joints with an adjacent slab. Refer to Figure C14-1 (Appendix C).

Reinforcement of slabs is required where the joint patterns of abutting pavements or adjacent paving lanes do not match, unless the pavements are positively separated by an expansion joint or slip-type joint having not less than 0.25 in (6.4 mm) bond-breaking medium. The pavement slab directly opposite the mismatched joint should be reinforced with a minimum of 0.05 percent of steel in directions normal to each other for a distance of 3 ft (1 m) back from the juncture and for the full width or length of the slab in a direction normal to the mismatched joint. Mismatched joints normally occur at intersections of pavements or between pavement and fillet areas.

14-1.4 Other Uses.

Reinforced concrete pavements may be considered for reasons other than those described above provided that a report containing a justification of the need for reinforcement is prepared and submitted for approval to the Government Civil Engineer.

14-2 DESIGN PROCEDURE.

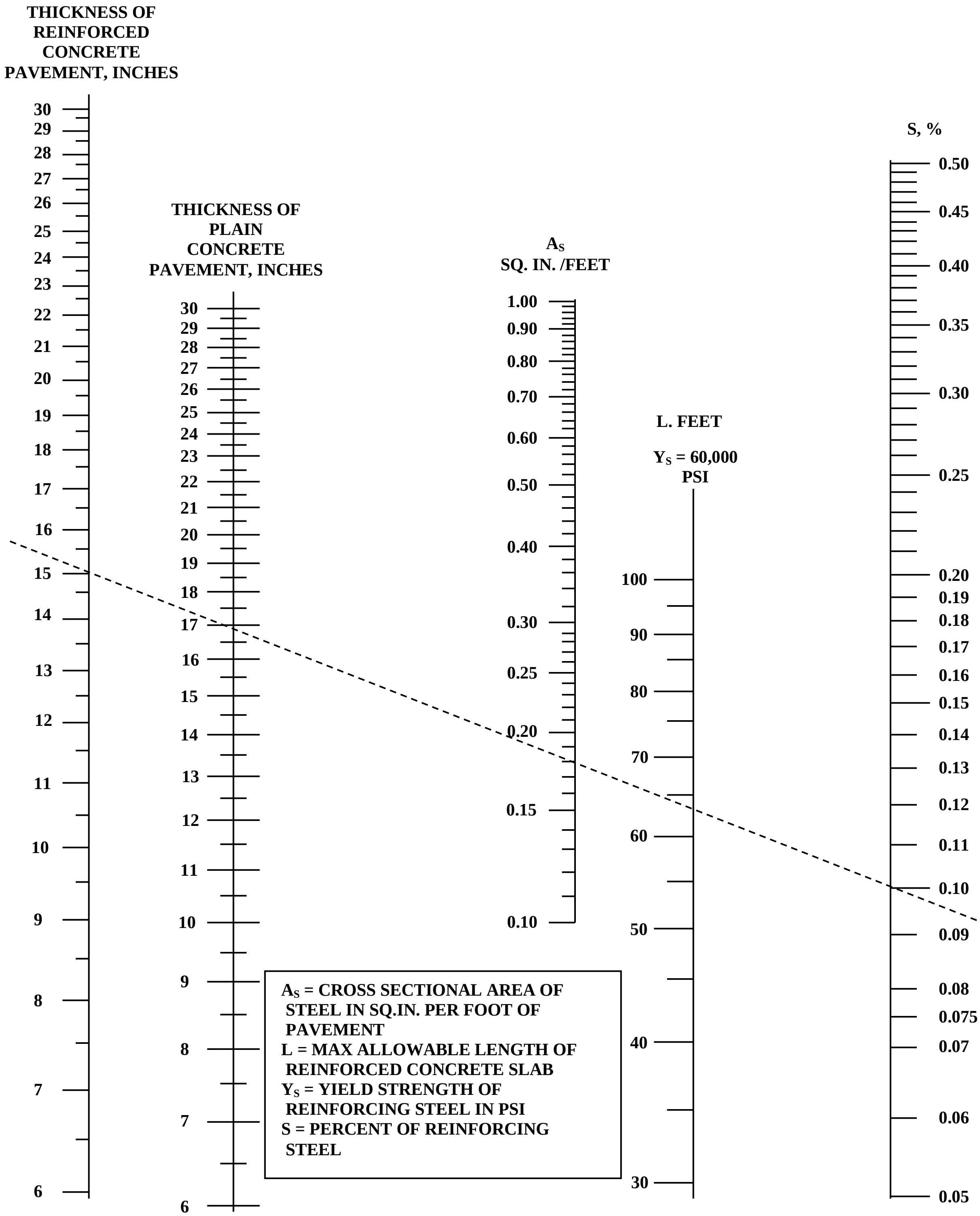
14-2.1 Thickness Design on Unbound Base or Subbase.

The design procedure for reinforced concrete pavements uses the principle of allowing a reduction in the required thickness of plain concrete pavement due to the presence of the steel reinforcing. The design procedure has been developed empirically from a limited number of prototype test pavements subjected to accelerated traffic testing. Although some cracking occurs in the pavement under the design traffic loadings, the steel reinforcing holds the cracks tightly closed. The reinforcing prevents spalling or faulting at the cracks and provides a serviceable pavement during the anticipated design life. Essentially, the design method consists of determining the percentage of steel required, the thickness of the reinforced concrete pavement, and the minimum allowable length of the slabs. Figure 14-1 presents a graphic solution for the design of reinforced concrete pavements. Since the thickness of a reinforced concrete pavement is a function of the percentage of steel reinforcing, the designer may determine either the required percentage of steel for a predetermined thickness of pavement or the required thickness of pavement for a predetermined percentage of steel. In either case, it is necessary first to determine the required thickness of plain concrete pavement by the method outlined previously in Chapter titled Plain Concrete Pavement Design. Enter the nomograph in Figure 14-1 using the plain concrete pavement thickness h_d (to the nearest 0.1 in (3 mm)). Then draw a straight line from the value of h_d to the value selected for either the reinforced concrete pavement thickness h_r or the percentage of reinforcing steel S. Note that the S value indicated by Figure 14-1 is the percentage to be used in the longitudinal direction only. For normal designs, the percentage of steel used in the transverse direction is one half of that used in the longitudinal direction. In fillets, the percent steel is the same in both directions. Once the h_r and S values have been determined, obtain the maximum allowable slab length L from the intersection of the straight line and the scale or L. Difficulties may be encountered in sealing joints between very long slabs because of large volumetric changes caused by temperature changes.

14-2.2 Thickness Design on Stabilized Base or Subgrade.

To determine the thickness requirements for reinforced concrete pavement on a stabilized foundation, first determine the thickness of plain concrete pavement required over the stabilized layer using procedures set forth in Chapter titled Plain Concrete Pavement Design. Then use this thickness of plain concrete with Figure 14-1 to design the reinforced concrete pavement in the same way discussed above for non-stabilized foundations.

Figure 14-1 Reinforced Rigid Pavement Design



14-3 LIMITATIONS.

The design criteria for reinforced concrete pavement for roads and parking areas are subject to the following limitations.

- No reduction in the required thickness of plain concrete pavement should be allowed for percentages of longitudinal steel less than 0.05 percent.
- No further reduction in the required thickness of plain concrete pavement should be allowed over that indicated in Figure 14-1 for 0.5 percent longitudinal steel, regardless of the percentage of steel used.
- The maximum length L of reinforced concrete pavement slabs should not exceed 75 ft (25 m) regardless of the percentage of longitudinal steel, yield strength of the steel, or thickness of the pavement. When long slabs are used, special consideration must be given to joint design and sealant requirements.
- The minimum thickness of reinforced concrete pavements should be 6 in (150 mm) and the minimum thickness for reinforced overlays over rigid pavements will be 4 in (100 mm).

14-4 DESIGN EXAMPLE.

Appendix G includes a design example for a reinforced concrete pavement.

14-5 TYPICAL DETAILS.

Figure C14-3, Figure C14-4 and Figure C14-5 (Appendix C) show typical details for a reinforced concrete pavement.

CHAPTER 15 PAVEMENT OVERLAYS

15-1 GENERAL.

Normally, overlays of existing pavements are used to increase the load-carrying capacity of an existing pavement or to correct a defective surface condition on the existing pavement. Of these reasons, the first requires a structural design procedure for determining the thickness of overlay; whereas the second requires only a thickness of overlay sufficient to correct the surface condition, and no increase in load-carrying capacity is considered. The design method for overlays included in this chapter determines the thickness required to increase load-carrying capacity. These methods have been developed from a series of full-scale accelerated traffic tests on various types of overlays and are, therefore, empirical. These methods determine the required thickness of overlay that, when placed on the existing pavement, will be equivalent in performance to the required design thickness of a new pavement placed on subgrade.

15-2 PREPARATION OF EXISTING PAVEMENT.

Exploration and tests of the existing pavement should be made to locate all areas of distress in the existing pavement and to determine the cause of the distress. Areas showing extensive and progressive cracking, rutting, and foundation failures should be repaired before the overlay. Such repair is especially needed in areas where excessive pumping, bleeding of groundwater at joints or cracks, excessive settlement in foundation, subgrade rutting, surface rutting, and slides have occurred. If testing of the existing pavement indicates the presence of voids beneath a rigid pavement, they should be filled by grouting before the overlay. The properties of the existing pavement and foundation such as the modulus of subgrade reaction, CBR, thickness, condition index, and flexural strength should be determined. The exact properties to be determined depend upon the type of overlay to be used. The surface of the existing pavement should be conditioned for the various types of overlays as follows.

15-2.1 Rigid Overlay.

Overlay thickness criteria are presented for three conditions of bond between the rigid overlay and existing rigid pavement: fully bonded, partially bonded, and non-bonded. The fully bonded condition exists when the concrete is cast directly on concrete and special efforts are made to obtain bond. The partially bonded condition exists when the concrete is cast directly on concrete with no special efforts to achieve or destroy bond. The non-bonded condition exists when the bond is prevented by an intervening layer of material. When using a fully bonded or partially bonded rigid overlay, clean the existing rigid pavement of all foreign matter (such as oil and paint), spalled concrete, extruded joint seal, bituminous patches, or anything else that would act as a bond-breaker between the overlay and existing rigid pavement. In addition, for the fully bonded overlay, prepare the surface of the existing pavement according to the recommendation in UFC 3-250-04. Apply a sand-cement grout or an epoxy grout to the cleaned surface immediately prior placement of the concrete overlay. When using a non-bonded rigid overlay, clean the existing rigid pavement of all loose particles and cover with a leveling or bond-breaking course of bituminous concrete, sand asphalt, heavy building paper, polyethylene, or other similar stable material. The bond-breaking medium generally should not exceed a thickness of about 1 in (25 mm) except in the case of leveling courses where greater thicknesses may be necessary. When applying a rigid overlay to an existing flexible pavement, clean the surface of the existing pavement of loose materials, and repair any potholing or unevenness exceeding about 1 in (25 mm) by cold planning, localized patching or the application of a leveling course using bituminous concrete, sand-asphalt, or a similar material.

15-2.2 Flexible Overlay.

When using a flexible overlay, no special treatment of the surface of the existing rigid pavement is required, other than the removal of loose material. When the flexible overlay is over bituminous concrete, clean the surface of the existing rigid pavement of all foreign matter, spalled concrete, fat spots in bituminous patches, and extruded soft or spongy joint seal material. Fill joints or cracks less than 1 in (25 mm) wide in the existing rigid with joint sealant. Clean joints or cracks that are 1 in (25 mm) or greater in width and fill with an acceptable bituminous mixture (such as sand asphalt) which is compatible with the overlay. Use leveling courses of bituminous concrete to bring the existing rigid pavement to the proper grade when required. Before placing the all-bituminous concrete, apply a tack coat to the surface of the existing pavement.

15-3 CONDITION OF EXISTING RIGID PAVEMENT.

15-3.1 General.

The support that the existing rigid pavement provides to an overlay is a function of its structural condition just before the overlay. In the overlay design equations, the structural condition of the existing rigid pavement is assessed by a condition factor C. Select the value of C based upon a condition survey of the existing rigid pavement. Use an interpolation of C values between those shown if it is considered necessary to define more accurately the existing structural condition.

15-3.2 Plain Concrete Overlay.

The following values of C are assigned for the following conditions of plain and reinforced concrete pavements.

15-3.2.1 Condition of Existing Plain Concrete Pavement:

C=1.00 - Pavements are in good condition with little or no structural cracking due to load.

C=0.75 - Pavements exhibit initial cracking due to load but no progressive cracking or faulting of joints or cracks.

C=0.35 - Pavements exhibit progressive cracking due to load accompanied by spalling, raveling, or faulting of cracks and joints.

15-3.2.2 Condition of Existing Reinforced Concrete Pavement.

C=1.00 - Pavements are in good condition with little or no short-spaced transverse 12 in (300 mm) to 24 in (600 mm) cracks, no longitudinal cracking, and little spalling or raveling along cracks.

C=0.75 - Pavements exhibit short-spaced transverse cracking but little or no interconnecting longitudinal cracking due to load and only moderate spalling or raveling along cracks.

C=0.35 - Pavements exhibit severe short-spaced transverse cracking and interconnecting longitudinal cracking due to load, severe spalling along cracks, and initial punch-out type failures.

15-3.3 Flexible Overlay.

The following values of C are assigned for the following conditions of plain and reinforced concrete pavement.

15-3.3.1 Condition of Existing Plain Concrete Pavements.

C=1.00 - Pavements are in good condition with some cracking due to load but little or no progressive-type cracking.

C=0.75 - Pavements exhibit progressive cracking due to load and spalling, raveling, and minor faulting at joints and cracks.

C=0.50 - Pavements exhibit multiple cracking along with raveling, spalling, and faulting at joints and cracks.

15-3.3.2 Condition of Existing Reinforced Concrete Pavement.

C=1.00 - Pavements are in good condition but exhibit some closely spaced load-induced transverse cracking, initial interconnecting longitudinal cracks, and moderate spalling or raveling of joints and cracks.

C=0.75 - Pavements in trafficked areas exhibit numerous closely spaced load-induced transverse and longitudinal cracks, rather severe spalling or raveling, or initial evidence of punch-out failures.

15-4 RIGID OVERLAY OF EXISTING RIGID PAVEMENT.

15-4.1 General.

There are three basic equations for the design of rigid overlays which depend upon the degree of bond that develops between the overlay and existing pavement: fully bonded, partially bonded, and non-bonded. Use the fully bonded overlay equation when special care is taken to provide bond between the overlay and the existing pavement. Use the partially bonded equation when the rigid overlay is to be placed directly on the existing pavement and no special care is taken to provide bond. Use a bond-breaking medium and the non-bonded equation when a plain concrete overlay is used to overlay an existing reinforced concrete pavement or an existing plain concrete pavement that has a condition factor $C \leq 0.35$. Also use these equations when matching joints in a plain concrete overlay with those in the existing plain concrete pavement causing undue construction difficulties or resulting in odd-shaped slabs.

15-4.2 Plain Concrete Overlay.

15-4.2.1 Thickness Determination.

The required thickness h_o of plain concrete overlay is determined from the following applicable equations:

Fully bonded

$$h_o = h_d - h_E \qquad \text{(eq. 15-1)}$$

Partially bonded

$$h_o = \sqrt[1.4]{h_d^{1.4} - C\left(\frac{h_d}{h_e} \times h_E\right)^{1.4}} \qquad \text{(eq. 15-2)}$$

Non-bonded

$$h_o = \sqrt{h_d^{2} - C\left(\frac{h_d}{h_e} \times h_E\right)^{2}} \qquad \text{(eq. 15-3)}$$

where h_d is the design thickness of plain concrete pavement determined from Appendix F using the design flexural strength of the overlay and h_e is the design thickness of plain concrete pavement using the measured flexural strength of the existing rigid pavement, the modulus of soil reaction **k** of the existing rigid pavement foundation, and the design traffic needed for overlay design. The use of fully bonded overlay is limited to existing pavements having a condition index of 1.0 and to overlay thickness of 2.0 in (50 mm) to 5.0 in (125 mm). The fully bonded overlay is used primarily to correct a surface problem such as scaling rather than as a structural upgrade. The factor h_E represents the thickness of the existing plain concrete pavement or the equivalent thickness of plain concrete pavement having the same load-carrying capacity as the existing pavement. If the existing pavement is reinforced concrete, h_E is determined from Figure 14-1 using the percent reinforcing steel S and design thickness h_e. The minimum thickness of plain concrete overlay is 2 in (50 mm) for a fully bonded overlay and 6 in (150 mm) for a partially bonded or non-bonded overlay. When the final pavement thickness obtained from the design curve indicates a fractional value, round up in 0.5 in (10 mm) increments. See paragraph titled Overlay Design Example for an example.

15-4.2.2 Jointing.

For all partially bonded and fully bonded plain concrete overlays, provide joints in the overlay to coincide with all joints in the existing rigid pavement. It is not necessary for joints in the overlay to be of the same type as joints in the existing pavement. When it is impractical to match the joints in the overlay to joints in the existing rigid pavement, either use a bond-breaking medium and design the overlay as a non-bonded overlay or reinforce the overlay over the mismatched joints. Should the mismatch of joints become severe, consider a reinforced concrete overlay design as an economic alternative to the use of a non-bonded plain concrete overlay. For non-bonded plain concrete overlays, the design and spacing of transverse contraction joints is in accordance with requirements for plain concrete pavements. For both partially bonded and non-bonded plain concrete overlays, dowel the longitudinal construction joints using the dowel size and spacing discussed in Chapter titled Rigid Overlay Of Existing Flexible Or Composite Pavements. Do not use dowels and load-transfer devices in fully bonded overlays. Joint sealing for plain concrete overlays must conform to the requirements for plain concrete pavements.

15-4.3 Reinforced Concrete Overlay.

A reinforced concrete overlay may be used to strengthen either, an existing plain concrete pavement, or an existing reinforced concrete pavement. Generally, the overlay will be designed as a partially bonded overlay. Use the non-bonded overlay design only when a leveling course is required over the existing pavement. Design the reinforcement steel for reinforced concrete overlays and place in accordance with reinforced concrete pavements.

15-4.3.1 Thickness Determination.

Determine the required thickness of reinforced concrete overlay using Figure 14-1 after determining the thickness of plain concrete overlay from the appropriate overlay equation. Then, using the value for the thickness of plain concrete overlay, select either the thickness of reinforced concrete overlay and determine the required percent steel or select the percent steel and determine the thickness of reinforced concrete overlay from Figure 14-1. The minimum thickness of reinforced concrete overlay must be 6 in (150 mm).

15-4.3.2 Jointing.

Whenever possible, the longitudinal construction joints in the overlay should match the longitudinal joints in the existing pavement. Dowel all longitudinal joints dowel size and spacing designated in Chapter titled Joints For Plain Concrete using the thickness of reinforced concrete overlay. It is not necessary for transverse joints in the overlay to match joints in the existing pavement; however, when practical, match the joints. Determine the maximum spacing of transverse contraction joints in accordance with equation 17-1, but do not exceed 75 ft (25 m) regardless of the thickness of the pavement or the percent steel used. Joint sealing for reinforced concrete pavements must conform to the requirements for plain concrete pavements.

15-5 RIGID OVERLAY OF EXISTING FLEXIBLE OR COMPOSITE PAVEMENTS.

15-5.1 Flexible Pavements.

Design a rigid overlay of an existing flexible pavement in the same way as a rigid pavement on grade. Determine a modulus of subgrade reaction **k** by a plate-bearing test performed on the surface of the existing flexible pavement. If it is not practical to determine **k** from a plate-bearing test, use Figure 10-1 to determine an approximate value. Figure 10-1 yields an effective **k** value at the surface of the flexible pavement as a function of the subgrade **k** and thickness of base and subbase above the subgrade. When using Figure 10-1, consider the bituminous concrete to be unbound base course material. Using this **k** value and the concrete flexural strength, determine the required thickness of plain concrete overlay from the charts in Appendix F. However, the following limitations should apply:

- In no case should a **k** value greater than 500 pci (140 KPa/mm) be used.
- Perform the plate-bearing test to determine the **k** value on the flexible pavement at a time when the temperature of the bituminous concrete is within five degrees of the ambient temperature of the hottest period of the year in the locality of the proposed construction.

15-5.2 Composite Base Pavements.

Two conditions of composite pavement are possible when considering a rigid overlay. When the composite pavement is composed of a rigid base pavement with less than 4 in (100 mm) of all-bituminous overlay, determine the required thickness of rigid overlay using the non-bonded overlay equation. If the composite pavement is composed of a rigid base pavement with 4 in (100 mm) or more of either all bituminous or bituminous with base course overlay, determine the required thickness of overlay by paragraph titled Flexible Pavements above. The same limitations for maximum **k** value and temperature of pavement during testing apply.

15-6 FLEXIBLE OVERLAY OF FLEXIBLE PAVEMENT.

Overlays are used for strengthening or rehabilitation of an existing pavement. Strengthening is required when heavier loads are introduced or when a pavement is no longer capable of supporting the loads for which it was designed. Rehabilitation may include sealing or resealing of cracks, patching, limited reconstruction before an overlay, restoration of the surface profile, improvement of skid resistance by a friction course, or improvement of the surface quality. When it has been determined that strengthening is required, design the overlay by designing a new pavement and comparing its thickness with the thickness of the existing pavement. The difference between these two pavements is the thickness of overlay required to satisfy design requirements. Overlays may be all-bituminous concrete or asphalt concrete and base course. The flexible pavement, after being overlaid, must meet all compaction requirements of a new pavement. Where the existing construction is complex, consisting of several layers, and especially where there are semi-rigid layers, such as soil cement, cement-stabilized soils, or badly cracked PCC, exercise careful judgment to evaluate the existing materials. UFC 3-260-03 provides criteria for evaluating existing construction.

15-7 FLEXIBLE OVERLAY OF RIGID BASE PAVEMENT.

15-7.1 Design Procedure.

The design procedure presented determines the thickness of flexible overlay necessary to increase the load-carrying capacity of existing rigid pavement. This method is limited to the design of the two types of flexible overlay, the all-bituminous and the bituminous with base course. The selection of the type of flexible overlay to be used for a given condition is dependent only on the required thickness of the overlay. Normally, use the bituminous with base course overlay when the required thickness of overlay is sufficient to incorporate a minimum 4 in (100 mm) compacted layer of high quality base course material plus the required thickness of bituminous concrete surface courses. For lesser thicknesses of flexible overlay, use the all-bituminous overlay. The method of design is referenced to the deficiency in thickness of the existing rigid base pavement and assumes that a controlled degree of cracking takes place in the rigid base pavement during the design life of the pavement.

15-7.2 Thickness Determination.

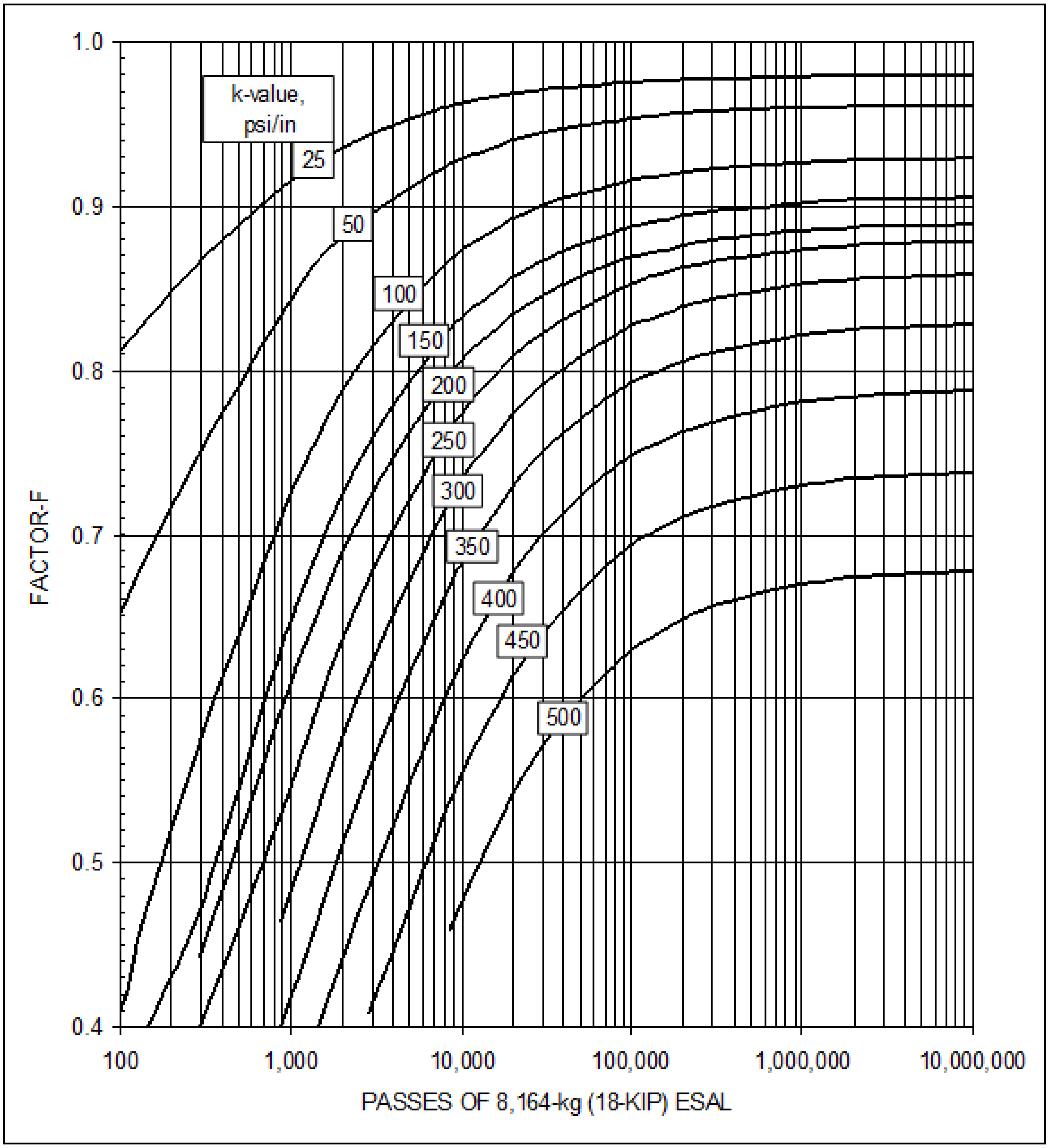
Regardless of the type of non-rigid overlay, determine the thickness by

$$t_o = 3.0\left(Fh_d - Ch_E\right) \text{(eq. 15-4)}$$

where h_d is the design thickness of plain concrete pavement from the charts in Appendix F; the factor h_e represents the thickness of plain concrete pavement equivalent in load-carrying capacity to the thickness of existing rigid pavement. If the existing rigid pavement is plain concrete, then the equivalent thickness equals the existing thickness. If the existing rigid pavement is reinforced concrete, determine the equivalent thickness from Figure 14-1. F is a factor, determined from Figure 15-1, that projects the cracking expected to occur in the base pavement during the design life of the overlay. C is a coefficient from paragraph titled Condition of Existing Pavement based upon the structural condition of the existing rigid pavement.

Round the computed overlay thickness up using 0.5 in (10 mm) increments. To reduce reflective cracking, the minimum thickness of all-bituminous overlay used for strengthening purposes will be 4 in (100 mm). No limitation is placed on the minimum thickness of an all-bituminous overlay when used for maintenance or to improve pavement surface smoothness. In certain instances, the flexible overlay design equation may indicate thickness requirements less (sometimes negative values) than the minimum values. In such cases use the minimum thickness requirement. When strengthening existing rigid pavements that exhibit low flexural strength (less than 500 psi (3.5 MPa)) or that are constructed on high-strength foundation (k exceeding 200 pci (50 kPa/mm)), it is possible that the flexible pavement design procedure in this UFC indicates a lesser required overlay thickness than the overlay design formula. For these conditions, determine the overlay thickness by both methods, and use the lesser thickness for design. For the flexible pavement design procedure, consider the existing rigid pavement an equivalent thickness of high quality crushed aggregate base (CBR = 100), and determine the total pavement thickness based upon the subgrade CBR. Consider any existing base or subbase layers as corresponding layers in the flexible pavement. The thickness of required overlay is then the difference between the required flexible pavement thickness and the combined thicknesses of existing rigid pavement and any base or subbase layers above the subgrade.

Figure 15-1 Factor for Projecting Cracking in a Flexible Pavement



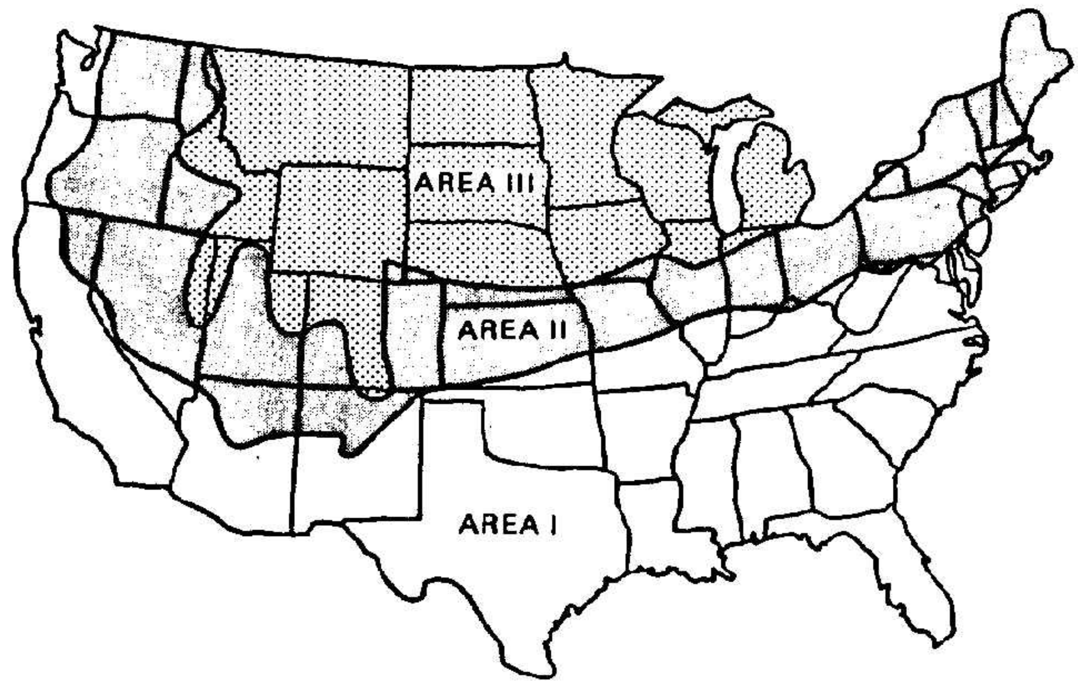
15-7.3 Jointing.

Normally, joints, other than those required for construction of a bituminous concrete pavement, are not required in flexible overlays of existing rigid pavements. It is good practice to try to layout paving lanes in the bituminous concrete to prevent joints in the overlay from coinciding with joints in the rigid base pavement. Movements of the existing rigid pavement, both from contraction and expansion and deflections due to applied loads, cause high concentrated stresses in the flexible overlay directly over joints and cracks in the existing rigid pavements. These stresses may result in cracking, often referred to as reflection cracks, in the overlay. The severity of this type of cracking depends, in part, upon the type of rigid pavement. For example, a plain concrete pavement normally has closely spaced joints and may result in reflection cracks over the joints, but the cracks are fairly tight and less likely to ravel. Nevertheless, reinforced concrete pavements normally have joints spaced farther apart, which in turn experience larger movements. The reflection cracks over these joints are more likely to ravel and spall. Likewise, either existing plain concrete or reinforced concrete pavements may have expansion joints that experience rather large movements, and consideration should be given to provide an expansion joint in the flexible overlay to coincide with the expansion joint in the existing pavement. No practical method has been developed to absolutely prevent reflective cracking in flexible overlays; however, experience shows that the degree of cracking is related to the thickness of the overlay, with the thinner overlays exhibiting the greater tendency to crack.

15-8 USE OF GEOTEXTILES TO RETARD REFLECTIVE CRACKING.

Geotextiles are effective in retarding reflective cracking in some areas of the United States, as shown in Figure 15-2. When using geotextiles under an asphalt concrete pavement, the existing pavement should be relatively smooth with all cracks larger than 0.25 in (6 mm) sealed. A leveling course is also recommended before application of the fabric to ensure a suitable surface. A tack coat is also required immediately before placement of the geotextile. The minimum overlay thickness is shown in Figure 15-2. When using geotextiles under a flexible pavement overlay, the geotextiles can be used as a membrane strip or a full-width application. The existing pavement should be stable with negligible movement under loads and all joints and cracks larger than 0.25 in (6 mm) sealed. With the strip method, apply the geotextile directly on the concrete joints and cracks and then overlay. With the full-width method, apply the geotextile directly to the existing pavement or place on a leveling course. In flexible overlays, the lower viscosity (or higher penetration grade) asphalts are less likely to experience reflective cracking. Therefore, use the lowest viscosity grade asphalt that provides sufficient stability during high temperatures.

Figure 15-2 Location Guide for the Use of Geotextiles in Retarding Reflective Cracking



AREA I – GEOTEXTILES ARE RECOMMENDED WITH MINIMUM OVERLAY THICKNESS OF 2 IN.
AREA II – ARE RECOMMENDED WITH OVERLAY THICKNESS OF 3-4 IN.
AREA III – GEOTEXTILES ARE NOT RECOMMENDED

15-9 OVERLAYS IN FROST REGIONS.

Whenever the subgrade is susceptible to differential heaving or weakening during the frost-melt period, the overlay design should meet the requirements for frost action as given in Chapter titled Seasonal Frost Conditions. When it is determined that distress in an existing pavement has been caused by differential heaving due to frost action, an overlay may not correct the condition unless the combined thickness of the pavement is sufficient to prevent substantial frost penetration into the underlying frost-susceptible material.

15-10 OVERLAY DESIGN EXAMPLE.

Appendix G includes examples of design for bonded, partially bonded, unbounded rigid overly and flexible overlay design.

CHAPTER 16 JOINTS FOR PLAIN CONCRETE

16-1 ROADWAYS

A typical layout and cross section of a roadway is presented in Figure C16-1 (Appendix C) and shows the location of various types of joints. Figure C16-2, Figure C16-3, Figure C16-4, Figure C16-5, and Figure C16-6 (Appendix C) show the associated details for the design and construction of plain concrete pavements. Figure C14-1 (Appendix C) presents a layout of joints at intersections of plain concrete pavements. Figure C16-2 (Appendix C) shows the layout of joints for plain concrete parking areas. Joints for roller compacted concrete pavements (RCCP) are discussed in Chapter 18.

16-2 JOINT TYPES AND USAGE.

Joints are provided to permit contraction and expansion of the concrete resulting from temperature and moisture changes, to relieve warping and curling stresses due to temperature and moisture differentials, to prevent unsightly irregular breaking of the pavement, and as a construction expedient, to separate sections or strips of concrete placed at different times. The three general types of joints are contraction, construction, and expansion and are shown in Figure C16-7 (Appendix C).

16-2.1 Contraction Joints.

Weakened-plane contraction joints control cracking in the concrete and limit curling or warping stresses resulting from drying shrinkage and contraction, and from temperature and moisture gradients in the pavement, respectively. Shrinkage and contraction of the concrete causes slight cracking and separation of the pavement at the weakened planes, which provides some relief from tensile forces resulting from foundation restraint and compressive forces caused by subsequent expansion. Contraction joints are required transversely and may be required longitudinally depending upon pavement thickness and spacing of construction joints. UFC 3-250-04 contains instructions for the use of sawcuts or preformed inserts to form the weakened plane.

16-2.1.1 Width and Depth of Weakened Plane Groove.

The width of the weakened plane groove must be a minimum of 1/8 in (3 mm) and a maximum equal to the width of the sealant reservoir. The depth of the weakened plane groove must be great enough to cause the concrete to crack under the tensile stresses resulting from the shrinkage and contraction of the concrete as it cures. Experience, supported by analyses, indicates that this depth should be at least one-fourth of the slab thickness for pavements 12 in (300 mm) or less, and 3 in (75 mm) for pavements greater than 12 in (300 mm) and less than 18 in (450 mm) in thickness. In no case is the depth of the groove less than the maximum nominal size of aggregate used. Concrete placement conditions may influence the fracturing of the concrete and dictate the depth of groove required. For example, concrete placed early in the day, when the air temperature is rising, may experience expansion rather than contraction during the early life of the concrete with subsequent contraction occurring several hours later as the air temperature drops. The concrete may have attained sufficient strength before the contraction occurs so that each successive weakened plane does not result in fracturing of the concrete. As a result, an excessive opening may result where fracturing does occur. To prevent such an opening, increase the depth of the groove to one-third of the slab thickness to assure the fracturing and proper functioning of each of the scheduled joints.

16-2.1.2 Width and Depth of Sealant Reservoir.

The dimensions of the sealant reservoir are critical to satisfactory performance of the joint sealing materials. The minimum width is 3/4-in (19 mm) and the minimum depth is 1.0 – 1.5 times the width.

16-2.1.3 Spacing of Transverse Contraction Joints.

Transverse contraction joints must be constructed across each paving lane perpendicular to the center line. The spacing between transvers contraction joints is generally 10 ft (3 m). If possible the slabs should be close to square or the joint spacing should equal the paving width. In regions where the design freezing index is 1,800 or more degree days the maximum spacing should be 20 ft (6 m). The joint spacing must be uniform throughout any major paved area, and each joint must be straight and continuous from edge to edge of the paving lane and across all paving lanes for the full width of the paved area. Staggering of joints in adjacent paving lanes can lead to sympathetic cracking and is not permitted unless reinforcement is used or separated by a thickened edge expansion joint. The maximum spacing of transverse joints that effectively control cracking varies appreciably depending on pavement thickness, thermal coefficient and other characteristics of the aggregate and concrete, climatic conditions, and foundation restraint. It is impractical to establish limits on joint spacing that are suitable for all conditions without making them unduly restrictive. The joint spacing in Table 16-1 give satisfactory control of transverse cracking in most instances, subject to modification based on available information regarding the performance of existing pavements in the vicinity or unusual properties of the concrete. Experience shows that oblong slabs, especially in thin pavements, tend to crack into smaller slabs of nearly equal dimensions under traffic. Therefore, it is desirable, insofar as practicable, to keep the length and width dimensions as nearly equal as possible. In no case should the length dimension (in the direction of paving) exceed the width dimension more than 25 percent. Use joint spacing as indicated in Table 16-1 or as approved by the Government Civil Engineer. Requests must indicate local conditions and justification for the proposed change in joint spacing.

Table 16-1 Allowable Spacing of Longitudinal and Transverse Contraction Joints

Pavement Thickness, in (mm)	Spacing of Joint, ft (m)
Less than 9 (225)	10 to 15 (3.0 to 4.6)
9 to 12 (225 to 300)	15 to 20 (4.6 to 6.1)
Over 12 (300)	20 (6.1)*
* The maximum spacing of transverse contraction joints for DoD pavements is 20 ft (6.1 m).	

16-2.1.4 Spacing of Longitudinal Contraction Joints.

Contraction joints must be placed along the centerline of paving lanes that have a width greater than the determined maximum spacing of transverse contraction joints in Table 16-1. These joints may also be required in the longitudinal direction for overlays, regardless of overlay thickness, to match joints existing in the base pavement unless a bond-breaking medium is used between the overlay and base pavement or the overlay pavement is reinforced. Normally, the contractor should be given the option to used construction joints in the longitudinal paving direction to permit smaller paving equipment to be used.

16-2.1.5 Doweled and Tied Contraction Joints.

16-2.1.5.1 Transverse Joints.

Dowels are required in transverse contraction joints for plain concrete pavements for roads and parking areas that use slab lengths greater than those in Table 16-1. Dowels are recommended in the last joint at ends of long paving lanes such as large storage and parking areas. Doweled transverse contraction joints in plain concrete pavement are required to ensure joint load transfer under heavy, repeated loads and reduce slab pumping and faulting. Doweled transverse contraction joints provide a smoother driving surface across the joint. Doweled transverse contraction joints in reinforced concrete pavements are required to ensure good joint transfer where conventional contraction joints may have inadequate load transfer because of excessive joint opening. Table 16-2 presents the size and spacing of dowels. Because of inadequate thermal expansion and contraction capability, not more than two consecutive joints must be constructed with tied bars. Smooth dowel must be used in every other joint.

Table 16-2 Dowel Size and Spacing for Construction, Contraction, and Expansion Joints

Pavement Thickness, in (mm)	Minimum Dowel Length, in (mm)	Max Dowel Spacing, in (mm)	Dowel Diameter and Type
Less than 8 (200)	16 (400)	12 (300)	.75 in (20 mm) bar
8 to 11 (200 to 275)	16 (400)	12 (300)	1 in (25 mm) bar
12 to 15 (300 to 380)	20 (510)	15 (375)	1 in (25 mm) to 1.25 in (32 mm) bar, or 1 in (25 mm) extra strength pipe*
* Extra strength pipe will be filled or plugged when used.			

16-2.1.5.2 Longitudinal Joints

For plain concrete pavements, deformed tie bars are required in longitudinal contraction joints that fall 15 ft (4.6 m) or less from the free edge of paved areas that are 100 ft (30.5 m) or greater in width. The deformed tie bars must be 30 in (750 mm) long, and spaced on 30 in (750 mm) centers. In addition, longitudinal contraction joints placed along the center line of paving lanes that have a width greater than the maximum spacing of transverse contraction joints must be tied using tie bars of the dimensions shown in Figure C16-3 (Appendix C).

16-2.2 Construction Joints.

Construction joints may be required in both the longitudinal and transverse directions. Longitudinal construction joints, generally spaced 10 to 25 ft (3.0 to 7.6 m) apart but which may reach 50 ft (15.2 m) apart, depending on construction equipment capability, must be provided to separate successively placed paving lanes. Transverse construction joints must be installed at the end of each day's paving operation and at other points within a paving lane where the placing of concrete is discontinued a sufficient length of time for the concrete to start to set. All transverse construction joints should be located in place of other regularly spaced transverse joints (contraction or expansion types). There are several types of construction joints available for use, as described below. The selection of the type of construction joint depends on such factors as the concrete placement procedure (formed or slip formed) and foundation conditions. Make longitudinal changes in grade at a joint if slip formed paving is permitted. Spacing between longitudinal joints in parking areas should be as uniform as possible to minimize contractor downtime required to adjust paver width.

16-2.2.1 Doweled Joint.

The doweled joint is the best joint for providing load transfer and maintaining slab alignment. It is a desirable joint for the most adverse conditions such as heavy loading, high traffic intensity, and lower strength foundations. However, because the alignment and placement of the dowel bars are critical to satisfactory performance, this type of joint is difficult to construct, especially for slip formed concrete. However, the doweled joint is required for all transverse construction joints in plain concrete pavements.

16-2.2.2 Thickened-Edge Joint.

Thickened-edge type joints may be used instead of other types of joints using load transfer devices. When the thickened-edge joint is constructed, the thickness of the concrete at the edge is increased to 125 percent of the design thickness. The thickness is then reduced by tapering from the free-edge thickness to the design thickness at a distance of 5 ft (1.5 m) from the longitudinal edge. For pavement thickness less than 12 in (300 mm), the taper distance can be reduced to 3 ft (0.9 m) at the designer’s option. The thickened-edge joint is considered adequate for the load-induced concrete stresses. However, the inclusion of a key in the thickened-edge joint Figure C16-4 (Appendix C) provides some degree of load transfer in the joint and helps to maintain slab alignment; although not required, it can be used for pavement constructed on low- to medium-strength foundations. The thickened-edge joint may be used at free edges of paved areas to accommodate future expansion of the facility or where wheel loadings may track the edge of the pavement. The use of this type joint is contingent upon adequate base course drainage meeting requirements of UFC 3-250-04.

16-2.2.3 Keyed Joint.

The keyed joint is the most economical method, from a construction standpoint, for providing load transfer in the joint. The key or keyway can be satisfactorily constructed using either formed or slip formed methods. The required dimensions of the joint can best be maintained by forming or slip forming the keyway rather than the key. The dimensions and location of the key are critical to its performance. Deviations exceeding the stated tolerances can result in failure in the joint. Keyed joints should not be used in rigid pavements that are less than 9 in (225 mm) in thickness. Tie bars in the keyed joint limit opening of the joint and provide some shear transfer that will improve the performance of the keyed joints. However, tying all joints in pavement widths of more than 75 ft (25 m) can result in excessive stresses and cracking in the concrete during contraction.

16-2.3 Expansion Joints.

Expansion joints must be used at all intersections of pavements with structures or with other concrete pavements where paving lanes are perpendicular to each other, and they may be required within the pavement features. The types of expansion joints are the thickened-edge joint, the thickened-edge slip joint, and the doweled type joint. Refer to Figure C16-5 and Figure C16-6 (Appendix C). Filler material for the thickened-edge and doweled type expansion joint must be a non-extruding type. The type and thickness of filler material and the way of its installation will depend upon the particular case. Usually, a preformed material of 3/4-in (19 mm) thickness is adequate; however, in some instances, a greater thickness of filler material may be required. Filler material for slip joints must be either a heavy coating of bituminous material not less than 1/16 in (1.5 mm) in thickness when joints match or a normal non-extruding-type material not less than 1/4 in (6 mm) in thickness when joints do not match. Where large expansions may have a detrimental effect on adjoining structures, such as at the juncture of rigid and flexible pavements, consider expansion joints in successive transverse joints back from the juncture. The depth, length, and position of each expansion joint must be sufficient to form a complete and uniform separation between the pavements or between the pavement and the structure concerned.

16-2.3.1 Between Pavement and Structures.

Expansion joints must be installed to surround, or to separate from the pavement, any structures that project through, into, or against the pavements, such as at the approaches to buildings or around drainage inlets. The thickened edge expansion joint is generally best suited for these places. Refer to Figure C16-5 (Appendix C).

16-2.3.2 Within Pavements and at Pavement Intersections.

Expansion joints within pavements are difficult to construct and maintain and often contribute to pavement failures. Keep their use to the absolute minimum necessary to prevent excessive stresses in the pavement from expansion of the concrete or to avoid distortion of a pavement through the expansion of an adjoining pavement. Determine the need for and spacing of expansion joints based upon pavement thickness, thermal properties of the concrete, prevailing temperatures in the area, temperatures during the construction period, and the experience with concrete pavements in the area. Unless needed to protect abutting structures, omit expansion joints in all pavements 10 in (250 mm) or more in thickness and also in pavements less than 10 in (250mm) thickness when the concrete is placed during warm weather since the initial volume of the concrete on hardening will be at or near the maximum. However, for concrete placed during cold weather, expansion joints may be used in pavements less than 10 in (250 mm) thick.

16-2.3.2.1 Longitudinal Joints

Longitudinal expansion joints within pavements must be of the thickened-edge type, refer to Figure C16-5 (Appendix C). Dowels are not permitted in longitudinal expansion joints because differential expansion and contraction parallel with the joints may develop undesirable localized strains and cause failure of the concrete, especially near the corners of slabs at transverse joints. Expansion joints are not required between two adjoining pavements where paving lanes of the two pavements are parallel.

16-2.3.2.2 Transverse Joints

Transverse expansion joints in roads are typically not needed since the initial volume of concrete hardening will be at or near the maximum. Transverse expansion joints in roads and parking areas can progressively close up over the years, allowing adjacent contraction joints to open more. The result is increased infiltration of fines and loss of load transfer in the adjacent contraction joints. Transverse expansion joints are required at bridge approach slabs. Thickened edge expansion joints may be used in roads and parking areas which do not require doweled contraction joints. Transverse expansion joints may be considered when pavement is constructed at low temperature or using materials that in the past have shown high expansion characteristics.

16-2.3.2.3 Slip Joints

A special expansion joint, the slip joint, is required at pavement intersections.

16-3 DOWELS.

The important functions of dowels or any other load-transfer device in concrete pavements are to help maintain the alignment of adjoining slabs and to transfer some stresses from loads to the adjacent slab, thereby limiting or reducing stresses in the loaded slab. Specify different sizes of dowels for different thicknesses of pavements as indicated in Table 16-2. When extra strength pipe is used for dowels, fill the pipe with either a stiff mixture of sand-asphalt or Portland cement mortar or plug the ends of the pipe. If the ends of the pipe are plugged, the plug must fit inside the pipe and be cut off flush with the end of the pipe so that there will be no protruding material to bond with the concrete and prevent free movement of the dowel. All dowels must be straight, smooth, and free from burrs at the ends. One end of the dowel will be painted and oiled to prevent bonding with the concrete. Dowels used at expansion joints must be capped at one end, in addition to being painted and oiled, to permit further penetration of the dowels into the concrete when the joints close.

16-4 SPECIAL PROVISIONS FOR SLIP FORM PAVING.

Make provisions for slip form pavers when there is a change in longitudinal joint configuration. The thickness may be varied without stopping the paving train, but the joint configuration cannot be varied without changing the side forms, which normally require stopping the paver and installing a header. The following requirements apply at a pavement transition area.

16-4.1 Header.

The header may be set on either side of the transition slab with the transverse construction joint doweled, as required. The dowel size and location in the transverse construction joint should be commensurate with the thickness of the pavement at the header.

16-4.2 Transition Between Different Joints.

When there is a transition between a doweled longitudinal construction joint and a keyed longitudinal construction joint, the longitudinal construction joint in the transition slab may be either keyed or doweled. The size and location of the dowels or keys in the transition slabs should be the same as those in the pavement with the doweled or keyed joint, respectively.

16-4.3 Transition Between Two Keyed Joints.

When there is a transition between two keyed joints with different dimensions, the size and location of the key in the transition slab should be based on the thickness of the thinner pavement.

16-5 JOINT SEALING.

All joints will be sealed to prevent infiltration of surface water and solid substances. Use a jet fuel resistant sealant, either poured or preformed, in the joints of hardstands, wash racks, and other paved areas where fuel or other lubricants may be spilled during the operation, parking, maintenance, and servicing of vehicles. Poured joint sealant must conform to UFGS 32 01 19 and preformed joint seals must conform to UFGS 32 13 73. Use sealants that are not fuel resistant in joints of all other pavements. Compress preformed sealants 45 to 85 percent of their original width. Base the selection of poured or preformed sealant upon economics. Compression-type preformed sealants are recommended when the joint spacing exceeds 25 ft (7.6 m). For many projects the cold applied (silicone) sealants have the best life-cycle cost.

16-6 SPECIAL JOINTS AND JUNCTURES.

Situations can develop where special joints or variations of the more standard type joints are needed to accommodate the movements that occur and to provide a satisfactory operational surface. Some of these special joints or junctures are as follows:

16-6.1 Slip-Type Joints.

At the juncture of two pavement facilities, expansion and contraction of the concrete may result in movements that occur in different directions. Such movements may create detrimental stresses within the concrete unless provision is made to allow the movements to occur. At such junctures, a thickened-edge slip joint must be used to permit the horizontal slippage to occur. The design of the thickened-edge slip joint is similar to the thickened-edge construction joint. Refer to Figure C16-6 (Appendix C). The bond-breaking medium must be either a heavy coating of bituminous material not less than 1/16 in (1.5 mm) in thickness when joints match or a normal non-extruding type expansion joint material not less than 1/4 in (6 mm) in thickness when joints do not match. The 1/16 in (1.5 mm) bituminous coating may be either a low penetration (60 to 70 grade asphalt) or a clay-type asphalt-base emulsion similar to that used for roof coating and must be applied to the face of the joint by hand brushing or spraying.

16-6.2 Joints Between New and Existing Pavements.

A special thickened-edge joint design, refer to Figure C16-4 (Appendix C), must be used at the juncture of new and existing pavements for the following conditions:

- When load-transfer devices (keyways or dowels) or a thickened edge are not provided at the free edge of the existing pavement.
- When load-transfer devices or a thickened edge is provided at the free edge of the existing pavement, but neither meet the design requirements for the new pavement.
- For transverse contraction joints, when removing and replacing slabs in an existing pavement.
- For longitudinal construction joints, when removing and replacing slabs in an existing pavement if the existing load-transfer devices are damaged during the pavement removal.
- Any other location where it is necessary to provide load transfer for the existing pavements. The special joint design may not be required if a new pavement joins an existing pavement that is grossly inadequate to carry the design load of the new pavement or if the existing pavement is in poor structural condition. If the existing pavement can carry a load that is 75 percent or less of the new pavement design load, special efforts to provide edge support for the existing pavement may be omitted and the alternate thickened-edge joint used as shown in Figure C16-4 (Appendix C); however, if omitted, the existing pavement may experience accelerated failures. Design the new pavement with a thickened edge at the juncture. Use any load-transfer devices in the existing pavement at the juncture to provide as much support as possible to the existing pavement. Consider drilling and grouting dowels in the existing pavement for edge support as an alternate to the special joint; however, use a thickened-edge design for the new pavement at the juncture.

CHAPTER 17 JOINTS FOR REINFORCED CONCRETE

17-1 REQUIREMENTS.

The exceptions for joint requirements and types of reinforced concrete pavements are the same as for plain concrete pavements except as listed below.

Figure C17-1, Figure C17-2 and Figure C17-3 (Appendix C) show the associated details for the design and construction of joints for reinforced concrete pavements.

17-1.1 Unscheduled Joints.

All joints falling at a point other than a regularly scheduled transverse contraction joint must be doweled with the exception of the thickened-edge type. One end of the dowel must be painted and oiled to permit movement at the joint.

17-1.2 Thickened-Edge-Type Joints.

Thickened-edge-type joints must not be doweled. Thicken the edge to 125 percent of the design thickness.

17-1.3 Transverse Construction Joint.

When a transverse construction joint is required within a reinforced concrete slab unit not at a regularly scheduled contraction joint location, carry the reinforcing steel through the joint. In addition, use dowels meeting the size and spacing requirements of Table 16-2 for the design thickness in the joint.

17-1.4 Transverse Contraction Joints.

Transverse contraction joints in reinforced concrete pavements should be constructed across each paving lane, perpendicular to the pavement center line, and at intervals of not less than 25 ft (7.6 m) nor more than 75 ft (25 m). The maximum allowable slab width or length for reinforced concrete pavements is a function of the effective frictional restraint developed at the interface between the slab and subgrade, the percentage of steel reinforcing used in the slab, and the yield strength of the steel reinforcing. Allowable slab widths or lengths can be determined directly from Figure 14-1 for yield strengths of 60,000 psi (410 MPa). If it is desired to use reinforcing steel having a yield strength other than this value, determine the maximum allowable slab width or length from the following equation:

Equation 17-1 $$L = \left[0.00047 \cdot h_r \cdot \left(f_s \cdot S\right)^2\right]^{\frac{1}{3}}$$

where

h_r=thickness of reinforced concrete pavement, in

f_s=yield strength of reinforcing steel, psi

S=percent of reinforcing steel

17-1.5 Two Traffic Lanes.

For reinforced concrete pavements where two traffic lanes are placed as a single paving lane, provide a longitudinal contraction joint at the center line of the paving lane to control cracking. In these joints, carry the reinforcing steel through the joint. Tie bars are not required.

17-1.6 Pavement Center Line.

Tied longitudinal contraction joints are also required at the center line of reinforced concrete pavements when the width of the pavement exceeds the allowable length of slab L for the percentage of steel reinforcement being used. When such joints are required, break the steel reinforcement at the joint, and use 5/8-in (16-mm) diameter tie bars 30 in (750 mm) long and spaced 30 in (750 mm) center to center.

17-2 JOINT SEALING.

Joint sealing for reinforced concrete pavements must be the same as for plain concrete pavements (see paragraph 15-5). Use preformed compression sealants when the joint spacing exceeds 50 ft (15.2 m).

CHAPTER 18 ROLLER-COMPACTED CONCRETE PAVEMENTS

18-1 INTRODUCTION.

RCCP is a zero-slump PCC mixture that is placed with an asphalt concrete paving machine and compacted with vibratory and rubber-tired rollers. Mixture proportions and most engineering properties of RCCP are similar to those of conventional plain concrete pavements. The mixture proportions of RCCP are not appreciably different than those used in conventional concrete; flexural strengths of beams taken from RCCP facilities and test sections routinely exceed 650 psi (4.5 MPa) at 28 days. Limited tests show that the fatigue characteristics of RCCP mixtures are similar to those of conventional concrete pavement mixtures. In Canada under moderately severe environmental and heavy loading conditions, RCCP hardstands have performed well for over 10 years alongside conventional concrete hardstands. Therefore, it may be assumed that the same rationale applied to the thickness design for plain non-reinforced concrete pavement thickness may also be applied to the design of RCCP.

18-2 LOAD TRANSFER.

A major difference exists in the assumptions of load transfer at joints made for plain concrete pavements and RCCP, which directly affects the design stress and therefore the thickness of the pavement. RCCP has typically been allowed to crack naturally, and spacing between these cracks is usually irregular, ranging from 40 to 70 ft (12 to 21 m) apart. Although, spacing between cracks have been reported much greater than and lower than this range. Consequently, the width of the crack opening will be greater and the load transfer developed from aggregate interlock at the cracks will be highly variable, if not totally lost. Limited tests at Fort Hood, TX and Fort Stewart, GA have revealed average load transfer at transverse contraction cracks of 18.6 percent (standard deviation of 6.7 percent) and longitudinal cracks of 16.7 percent (standard deviation of 5.9 percent), respectively. Tests on longitudinal and transverse cold (construction) joints revealed even less load transfer. Therefore, the assumption of 25 percent load transfer at joints constructed of plain concrete would not be valid for RCCP thickness design. Therefore, base the thickness design of RCCP on no load transfer at the joints, (i.e. assuming all joints and cracks to be a free edge condition).

18-3 THICKNESS DESIGN.

Use the thickness design curves shown in Appendix F to determine thickness requirements for RCCP. These curves are the same as used for plain concrete roads and parking areas.

18-4 MULTILIFT PAVEMENTS.

The maximum lift thickness that can be placed at an acceptable grade and smoothness and compacted to a uniform density is about 10 in (250 mm). Therefore, if the RCCP design thickness is greater than 10 in (250 mm), two or more lifts will be necessary to achieve the design thickness. If possible, the upper lift should be of minimal thickness, preferably one-third of the total pavement thickness (but no less than 4 in (100 mm)), to aid in creating a smoother surface finish. The type of bond achieved between the lifts is a function of the construction sequence and timing and will govern the method of thickness design used for multi-lift RCCP. The three types of bonding conditions to be considered in RCCP thickness design are full bond, partial bond, and no bond.

18-4.1 Full Bond.

Full bond may be assumed between adjacent lifts if they are placed and compacted within 1 hour of each other, or if a thin grout is placed between the upper and lower lifts. The surface of the lower lift must be kept clean and moist until the upper lift is placed and should not be rolled with the rubber-tired roller. If the full bond condition is achieved, the thickness should be determined as if a monolithic slab were used, with no consideration for the joint between lifts in the thickness design calculations.

18-4.2 Partial Bond.

Partial bond should be assumed between subsequent lifts if they are placed and compacted more than 1 hour apart. Keep the surface of the lower lift clean and moist until the upper lift is placed. The thickness should be designed as a rigid overlay of a rigid base pavement with partial bonding according to the guidance in Chapter titled Pavement Overlays.

18-4.3 No Bond.

Assume no bond between adjacent lifts if some type of bond breaker is used between the lifts, such as a curing compound or asphalt emulsion sprayed on the surface of the lower lift. Design the thickness as a rigid overlay of a rigid base pavement with no bond, according to the guidance in Chapter titled Pavement Overlays.

18-5 JOINT TYPES FOR RCCP.

18-5.1 Expansion Joints.

Expansion joints, within an area paved with RCCP, are not required except to protect facilities located within the paved area.

18-5.2 Contraction Joints.

Generally, longitudinal contraction joints are not required in RCCP. However, most RCCP pavement to date has been allowed to crack naturally in the transverse direction. These cracks usually occur randomly at 40 to 70 ft (12 to 21 m) spacings, and have performed well, with little raveling or faulting. The natural cracks are typically not sealed; however, it is recommended that all cracks be routed and sealed in areas where the pavement may be susceptible to frost damage. Sawing of contraction joints is recommended at spacing of 50 to 75 ft (15 to 23 m), providing the sawing can be accomplished in the first 24 hours without excessive raveling. Determine the optimum time for sawing and optimum transverse joint spacing during the test section construction. Depth of sawcut should be one-third of the pavement thickness. For multi-lift pavements, make the sawcut one-third the pavement depth if full bond conditions are used. If partial bond or no bond conditions are used, make the sawcuts in each lift in coinciding locations to one-third the lift thickness (the sawcuts in the lower lifts may be made 1 hour after compaction). The longitudinal and transverse cold joints for each lift should always coincide. Seal all sawed joints.

18-5.3 Construction Joints.

Currently, there are two types of construction joints in RCCP; fresh and cold. When fresh concrete can be placed and compacted against in-place concrete before initial set (usually within 90 min), consider the juncture or joint to be a fresh joint requiring no special treatment. For the construction of a fresh joint, the edge of the in-place concrete is left un-compacted and rolled after the adjoining concrete has been placed. When the in-place RCCP has stiffened significantly before the adjoining fresh concrete can be placed (usually around 90 min), consider the resulting juncture a cold construction joint. The in-place concrete must be fully compacted and then the edge trimmed back to solid concrete to form a near vertical face. If the required density or smoothness is not obtained, then remove the in-place concrete. Immediately before placement of the adjoining concrete, dampen the vertical edge. After placement of the fresh concrete, the excess which spills onto the compacted material should be pushed back to the edge of the fresh concrete before rolling. No effort will be made to achieve load transfer at the cold joint. Make every effort to keep cold longitudinal construction joints spaced at least 50 to 75 ft (15 to 23 m).

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CHAPTER 19 SEASONAL FROST CONDITIONS

19-1 GENERAL.

This chapter presents criteria and procedures for the design and construction of pavements placed on subgrade or base course materials subject to seasonal frost action. The most prevalent modes of distress in pavements and their causes are listed in Table 19-1. The detrimental effects of frost action in subsurface materials are manifested by non-uniform heave of pavements during the winter and by loss of strength of affected soils during the ensuing thaw period. This is accompanied by a corresponding increase in damage accumulation and a more rapid rate of pavement deterioration during the period of weakening. Other related detrimental effects of frost and low temperatures are possible loss of compaction, development of permanent roughness, restriction of drainage by the frozen strata, and cracking and deterioration of the pavement surface. Hazardous operating conditions, excessive maintenance, or pavement destruction may result. Except when other criteria are specifically established, pavements should be designed so that there will be no interruption of traffic at any time due to differential heave or to reduction in load-supporting capacity. Pavements should also be designed so that the rate of deterioration during critical periods of thaw weakening and during cold periods causing low-temperature cracking will not be so high that the useful life of the pavements will be less than that assumed as the design objective.

19-2 FROST-SUSCEPTIBILITY CLASSIFICATION.

For frost design purposes, soils are divided into eight groups as shown in Table 19-2. The first four groups are generally suitable for base course and subbase course materials, and any of the eight groups may be encountered as subgrade soils. Soils are listed in approximate order of decreasing bearing capacity during periods of thaw. There is also a tendency for the order of the listing of groups to coincide with increasing order of susceptibility to frost heave, although the low coefficients of permeability of most clays restrict their heaving potential. The order of listing of subgroups under groups F3 and F4 does not necessarily indicate the order of susceptibility to frost heave of these subgroups. There is some overlapping of frost susceptibility between groups. Soils in group F4 are of especially high frost susceptibility.

19-2.1 S1 and S2 Groups.

The S1 group includes gravelly soils with very low to medium frost-susceptibility classifications that are considered suitable for subbase materials. They generally exhibit less frost heave and higher strength after freeze-thaw cycles than similar PI group subgrade soils. The S2 group includes sandy soils with very low to medium frost-susceptibility classifications that are considered suitable for subbase materials. Due to their lower percentages of finer than 0.02 mm grains than similar F2 groups subgrade soils, they generally exhibit less frost heave and higher strength after freeze-thaw cycles.

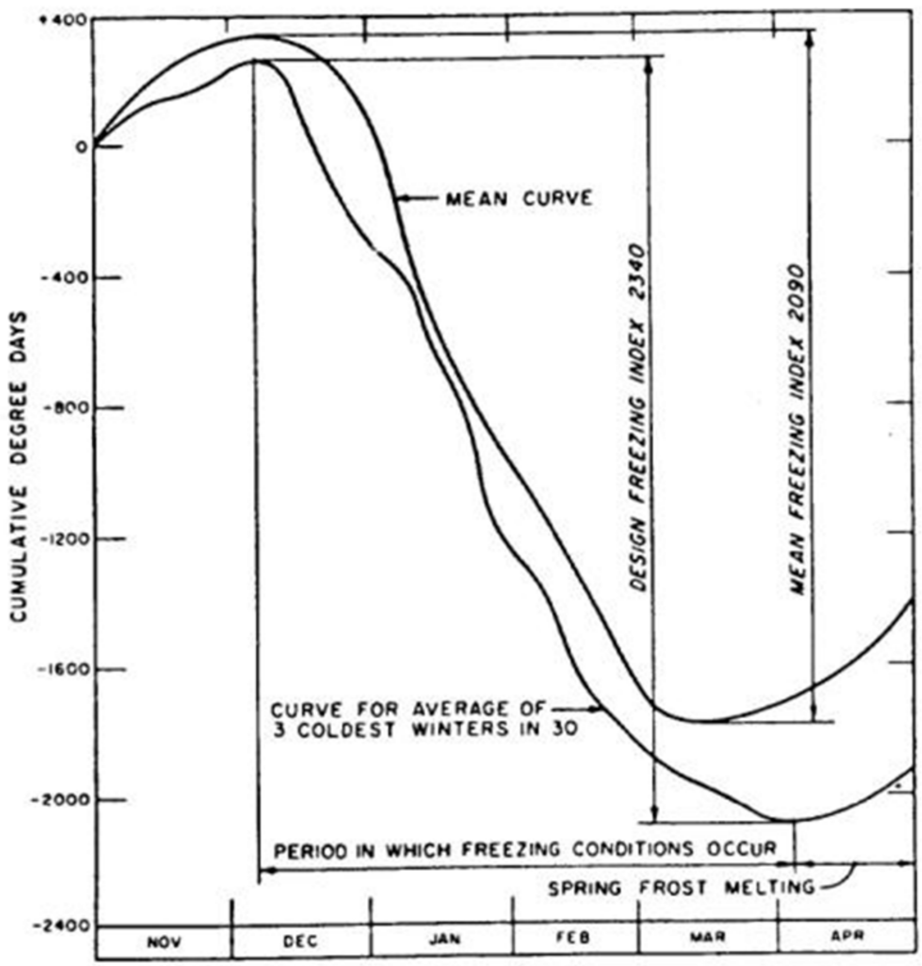
Table 19-1 Modes of Distress in Pavements

Distress Mode	General Cause	Specific Causative Factor
Cracking	Traffic-load associated	Repeated loading (fatigue) Slippage (resulting from braking stresses)
	Non-traffic-associated	Thermal changes Moisture changes Shrinkage of underlying materials (reflection cracking, which may also be accelerated by traffic loading)
Distortion (may also lead to cracking)	Traffic-load associated	Rutting, or pumping and faulting (from repetitive loading) Plastic flow or creep (from single or comparatively few excessive loads)
	Non-traffic-associated	Differential heave Swelling of expansive clays in subgrade Frost action in subgrades or bases Differential settlement Permanent, from long-term consolidation in subgrade Transient, from reconsolidation after heave (may be accelerated by traffic) Curling of rigid slabs, from moisture and temperature differentials
Disintegration	May be advanced stage of cracking mode of distress or may result from detrimental effects of certain materials contained within the layered system or from abrasion by traffic. May also be triggered by freeze-thaw effects.	

19-2.2 F1 and F2 Groups.

The F1 group includes frost-susceptible gravelly soils that in the normal unfrozen condition have traffic performance characteristics of GM, GW GM, and GP GM type materials with the noted percentage of fines. The F2 group includes frost-susceptible soils that in the normal unfrozen condition have traffic performance characteristics of GM, GW GM, GP GM, SM, SW SM, or SP SM type materials with fines within the stated limits. Occasionally, GC or SC materials may occur within the F2 group, although they normally fall into the F3 category. The basis for division between the F1 and F2 groups is that F1 materials are expected to show higher bearing capacity than F2 materials during thaw, even though both may have experienced equal ice segregation.

Figure 19-1 Determination of Freezing Index



19-2.3 Varved Clays.

Varved clays consisting of alternating layers of silts and clays are likely to combine the undesirable properties of both silts and clays. These and other stratified fine-grained sediments may be hard to classify for frost design. Since such soils are likely to heave and soften more readily than homogeneous soils with equal average water contents, the classification of the material of highest frost susceptibility should be adopted for design. Usually, this will place the overall deposit in the F4 category.

Table 19-2 Frost Design Soil Classification*

Frost Group	Kind of Soil		Percentage Finer than 0.02 mm by Weight*	Typical Soil Types Under Unified Soil Classification System
NFS**	(a)	Gravels	0-1.5	GW, GP
		Crushed stone		
		Crushed rock		
	(b)	Sands	0-3	SW, SP
PFS***	(a)	Gravels	1.5-3	GW, GP
		Crushed stone		
		Crushed rock		
	(b)	Sands	3-10	SW, SP
S1		Gravelly soils	3-6	GW, GP, GW-GM, GP-GM
S2		Sandy soils	3-6	SW, SP, SW-SM, SP-SM
F1		Gravelly soils	6 to 10	GM, GW-GM, GP-GM
F2	(a)	Gravelly soils	10 to 20	GM, GW-GM, GP-GM
	(b)	Sands	6 to 15	SM, SW - SM, SP-SM
F3	(a)	Gravelly soils	Over 20	GM, GC
	(b)	Sands, except very fine silty sands	Over 15	SM, SC
	(c)	Clays, PI > 12	- -	CL, CH
F4	(a)	All silts	- -	ML, MH
	(b)	Very fine silty sands	Over 15	SM
	(c)	Clays, PI > 12	- -	CL, CL-ML
	(d)	Varved clays and other fine-grained, banded sediments	- -	CL, CL-ML
				CL and ML; CL, ML, and SM; CL, CH, and ML; CL, CH, ML and SM

* 25.4 mm = 1 in
** Non-frost susceptible.
*** Possibly frost-susceptible, but requires laboratory test to determine frost design soils classification.

19-2.4 Special Conditions.

Under special conditions the frost group classification adopted for design may differ from that obtained by application of the above frost group definitions when the difference is not greater than one frost group and complete justification for the variation is presented and approved by the Government Civil Engineer. Such justification may take into account special conditions of subgrade moisture or soil uniformity, in addition to soil gradation and plasticity, and should include data on performance of existing pavements near those proposed to be constructed.

19-3 ALTERNATIVE METHODS OF THICKNESS DESIGN.

The thickness design process is the determination of the required thickness for each layer of a pavement system and of the combined thickness of all layers above the subgrade. Its objective is to determine the lowest-cost pavement system whose rate of deterioration under traffic loads and environmental conditions will be acceptably low. In seasonal frost areas, the thickness design process must include the effects of frost action. Two methods are prescribed for determining the thickness design of a pavement that will have adequate resistance to distortion by frost heave and cracking and distortion under traffic loads as affected by seasonal variation of supporting capacity, including possible severe weakening during frost-melting periods.

19-3.1 Limited Subgrade Frost Penetration Method.

The first method is directed specifically to the control of pavement distortion caused by frost heave. It requires a sufficient thickness of pavement, base, and subbase to limit the penetration of frost into the frost-susceptible subgrade to an acceptable amount. This method also includes a design approach to determine the thickness of pavement, base, and subbase necessary to prevent the penetration of frost into the subgrade. Prevention of frost penetration into the subgrade is nearly always uneconomical and unnecessary, and will not be used to design pavements to serve conventional traffic, except when approved by the Government Civil Engineer.

19-3.2 Reduced Subgrade Strength Method.

The second method does not seek to limit the penetration of frost into the subgrade, but it determines the thickness of pavement, base, and subbase that will adequately carry traffic loads over the design period of years, each of which includes one or more periods during which the subgrade supporting capacity is sharply reduced by frost melting. This approach relies on uniform subgrade conditions, adequate subgrade preparation techniques, and transitions for adequate control of pavement roughness resulting from differential frost heave.

19-4 SELECTION OF DESIGN METHOD.

In most cases the choice of the pavement design method will be the one that gives the lower cost. Exceptions dictating the choice of the limited subgrade frost penetration method, even at higher cost, include pavements in locations where subgrade soils are so extremely variable (as, for example, in some glaciated areas) that the required subgrade preparation techniques could not be expected to provide sufficient protection against differential frost heave. In other cases special operational demands on the pavement might dictate unusually severe restrictions on tolerable pavement roughness, requiring that subgrade frost penetration be strictly limited or even prevented. If the use of limited subgrade frost penetration method is not required, preliminary designs must be prepared by both methods for comparison of costs. A preliminary design must also be prepared following the NFS criteria, since the thickness requirements under NFS criteria must be met in addition to the frost design requirements.

19-5 LIMITED SUBGRADE FROST PENETRATION.

Use this method of design for seasonal frost conditions where it requires less thickness than the reduced subgrade strength method. Its use is likely to be economical only in regions of low design freezing index.

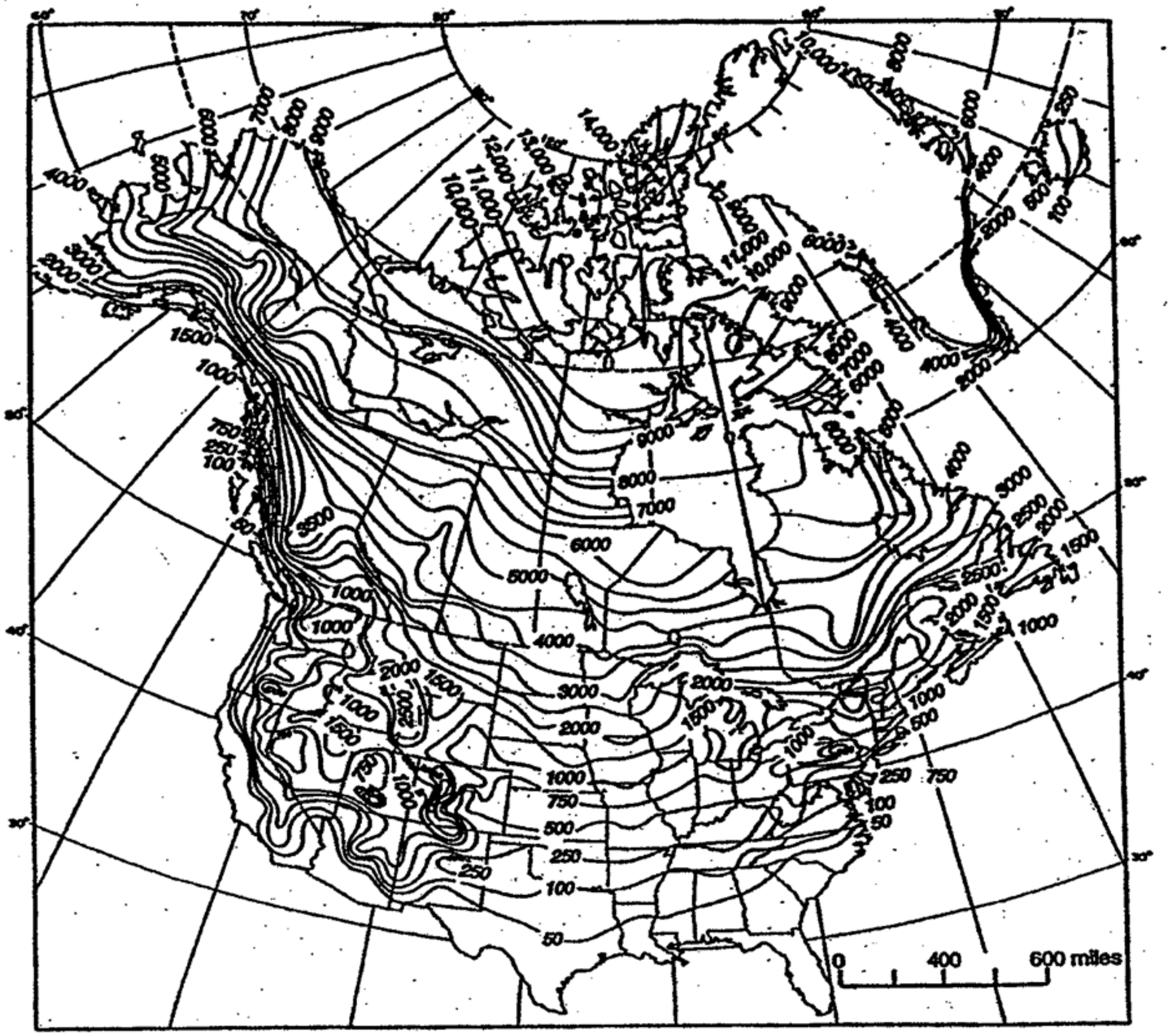
19-5.1 Air Freezing Index.

Air freezing index values should be based on actual air temperatures obtained from the meteorological station closest to the construction site. This is desirable because differences in elevation or topographical position, or nearness to bodies of water, cities, or other sources of heat may cause considerable variation in air freezing indexes over short distances. These variations are of greater relative importance in areas of design freezing index of less than 1,000 degree Fahrenheit days (i.e., mean air freezing index of less than about 500 degree Fahrenheit days) than they are in colder climates. The daily maximum, minimum, and mean monthly air temperature records for all stations that report to the U.S. National Weather Service are available from Weather Service Centers. One of these centers is generally located in each state. The mean air freezing index may be based on mean monthly air temperatures, but computation of values for the design freezing index may be limited to only the coldest years in the desired cycle. These years may be selected from the tabulation of average monthly temperatures for the nearest first-order weather station. A local climatological data summary containing this tabulation for the period of record is published annually by the National Weather Service for each of the about 350 U.S. first-order stations. If the temperature record of the station closest to the construction site is not long enough to determine the mean or design freezing index values, the available data should be related, for the same period, to that of the nearest station or stations of adequate record. Site air freezing index values can then be computed based on this established relation and the indexes for the more distant station or stations.

19-5.2 Design Freezing Index.

The design freezing index should be used in determining the combined thickness of pavement, base, and subbase required to limit subgrade frost penetration. As with any natural climatic phenomenon, winters that are colder than average occur with a frequency that decreases as the degree of departure from average becomes greater. A mean freezing index cannot be computed where temperatures in some of the winters do not fall below freezing. A design method has been adopted that uses the average air freezing index for the three coldest years in a 30 year period (or for the coldest winter in 10 year of record) as the design freezing index to determine the thickness of protection that will be provided. A distribution of design freezing indexes for North America and Northern Eurasia are shown in Figures 19-2 and 19-3 and are to be used as a guide only.

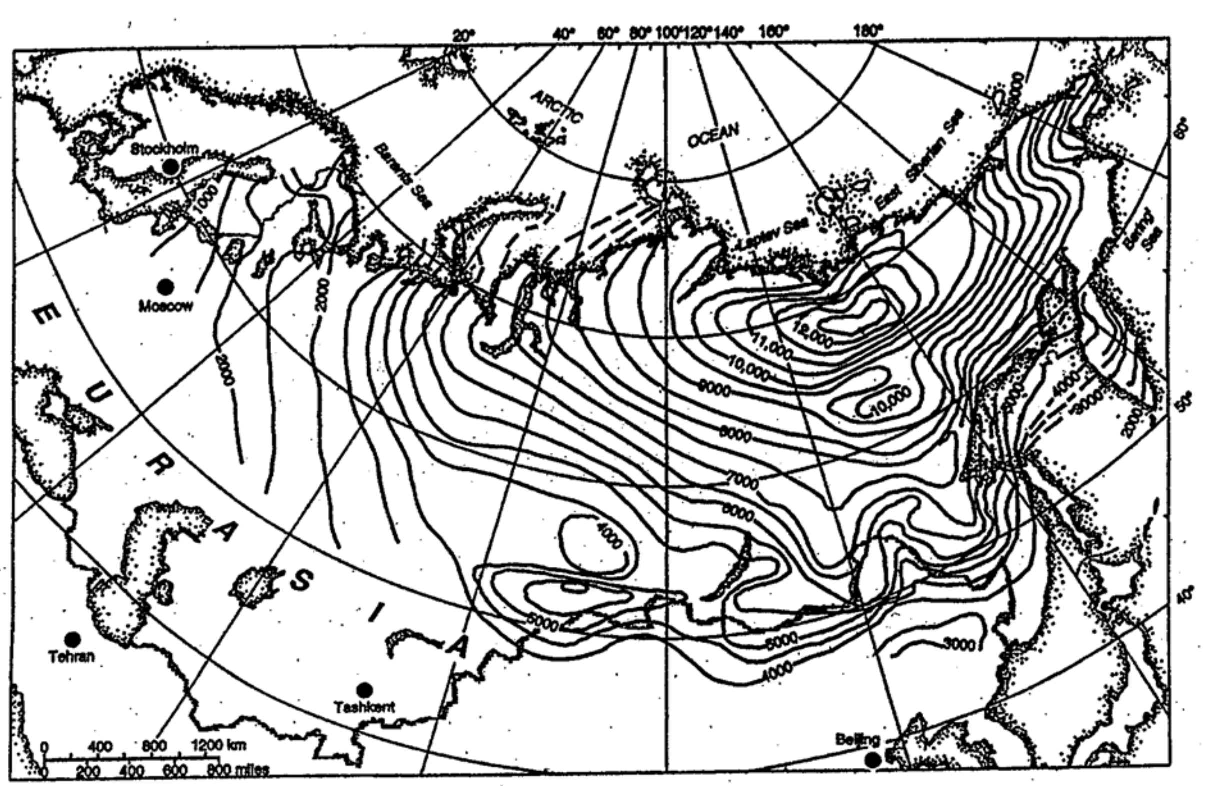
Figure 19-2 Distribution of Design Freezing Indexes in North America



CONVERSION FACTORS

°C - HOURS = 13.33 x °F DAYS

Figure 19-3 Distribution of Mean Freezing Indexes in Northern Eurasia



19-5.3 Design Method.

The design method permits a small amount of frost penetration into frost-susceptible subgrades for the design freezing index year. The procedure is described in the following subparagraphs.

Estimate average moisture contents in the base course and subgrade at start of freezing period, and estimate the dry unit weight of base. The moisture content of the base is generally affected by the moisture content of the subgrade, drainage, precipitation, and depth to groundwater table. As the base course may, in some cases, comprise successive layers containing substantially different fine contents, the average moisture content and dry unit weight should be weighted in proportion to the thickness of the various layers. Alternatively, if layers of bound base course and granular unbound base course are used in the pavement, the average may be assumed to be equal to the moisture content and dry unit weight of the material in the granular unbound base course.

From Figure 19-4, determine frost penetration depth (a). These frost penetration depths are based on modified Berggren formula and computational procedures. Frost penetration depths are measured from pavement surface. Depths are computed on a 12 in (300 mm.) rigid pavement kept free of snow and ice, and are good approximations for bituminous pavements over 6 to 9 in (150 to 225 mm.) of high-quality base. Computations also assume that all soil beneath pavements within depths of frost penetration are granular and NFS. It was assumed in computations that all soil moisture freezes at 32 degrees Fahrenheit (0 degrees Celsius). Use straight line interpolation where necessary. For rigid pavements greater than 12 in (300 mm) thick, deduct 10 degree s Fahrenheit days for each 1 in (25 mm) increment of pavement exceeding 12 in (300 mm) from the design freezing index before entering Figure 19-4 to determine frost penetration depth (a). Then add extra concrete pavement thickness to the determined frost penetration.

Compute thickness of unbound base C (Figure 19-5) required for zero frost penetration into the subgrade as follows:

$$C = a - p$$

Where

a = frost penetration depth

p = thickness of PCC or bituminous concrete

Compute ratio $$r = \frac{\text{water content of subgrade}}{\text{water content of base}}$$

Enter Figure 19-5 with C as the abscissa and, at the applicable value of r, find on the left scale the design base thickness b that will result in the allowable subgrade frost penetration shown on the right scale. If r is greater than 3.0 use 3.0.

19-5.4 Thickness.

The above procedure results in a thickness of material between the frost-susceptible subgrade and the pavement so that for average field conditions subgrade frost penetration of the amount s should not cause excessive differential heave of the pavement surface during the design freezing index year.

19-5.5 Controlling Thickness.

If the combined thickness of pavement and base required by the NFS criteria exceeds the thickness given by the limited subgrade frost penetration procedure of design, adopt the greater thickness given by the NFS criteria as the design thickness.

19-5.6 Effects of Non-frost Susceptible Criteria.

Rigorously follow the base course composition requirements of this chapter. The design base thickness is the total thickness of filter layers, granular unbound base and subbase, and any bound base. For flexible pavements, the thickness of the asphalt surfacing layer and of any bound base, as well as the CBR requirements of each layer of granular unbound base, must be determined using NFS criteria. The thickness of rigid pavement slab must also be determined from NFS criteria.

Figure 19-4A Frost Penetration Beneath Pavements

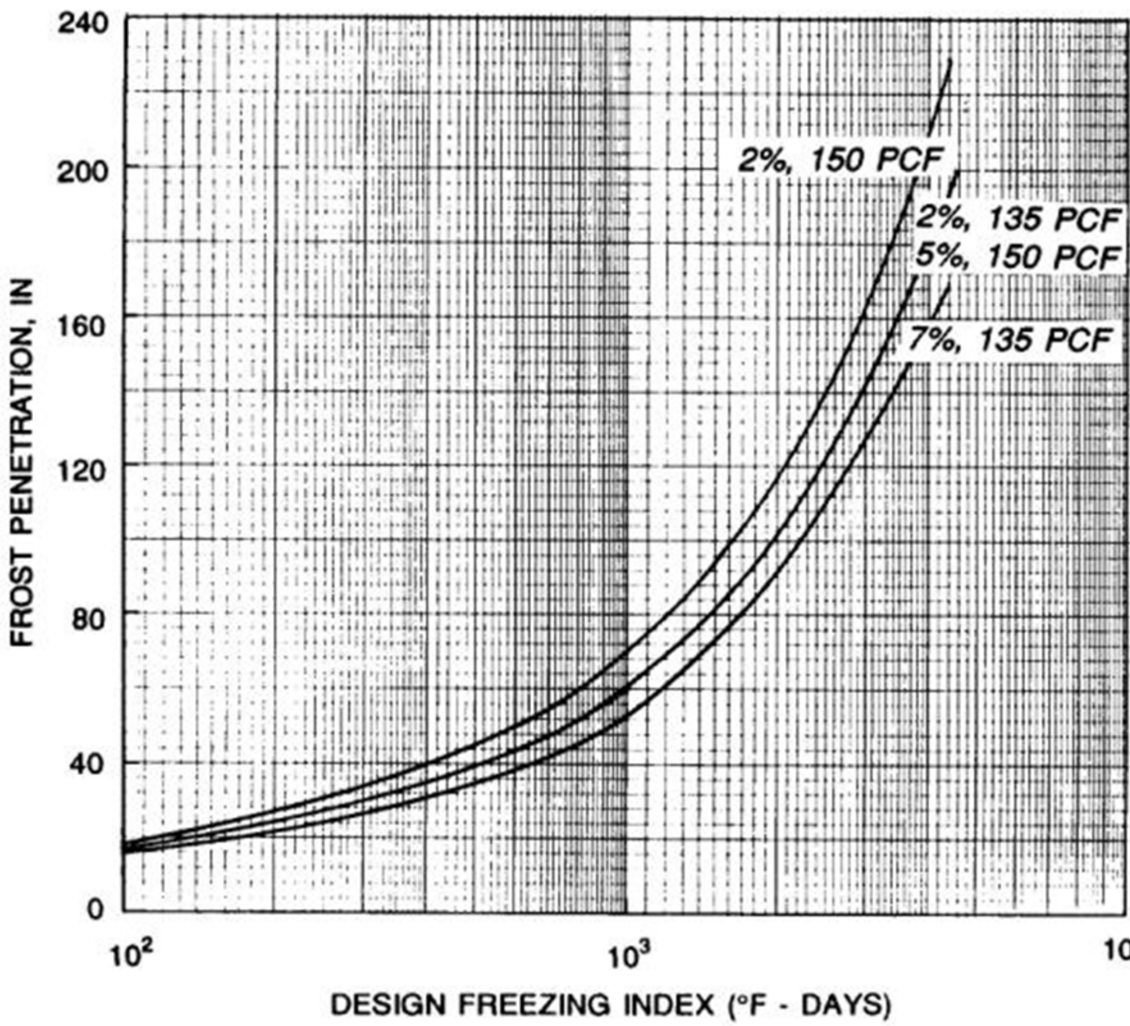


Figure 19-4B Frost Penetration Beneath Pavements

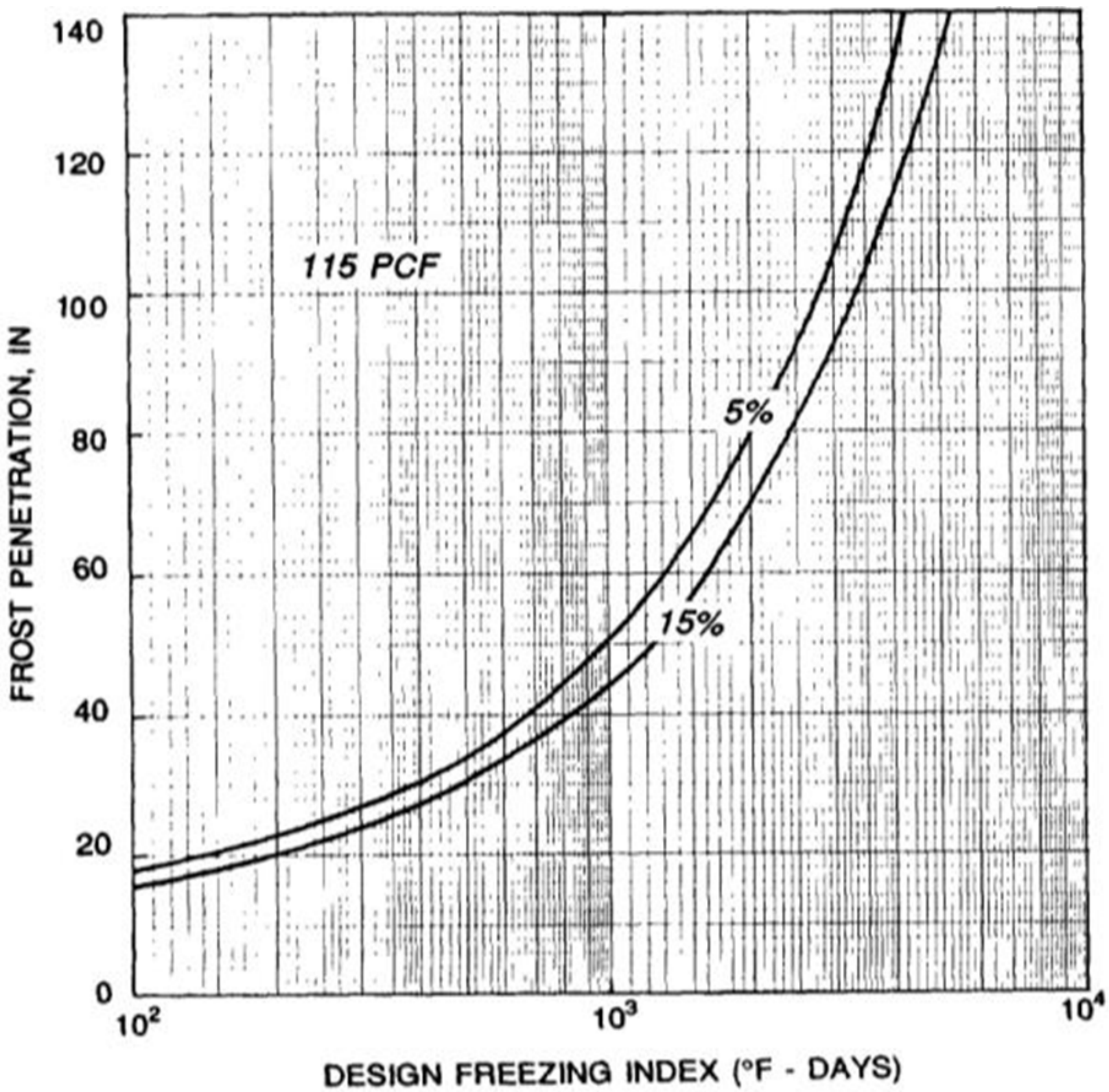


Figure 19-4C Frost Penetration Beneath Pavements

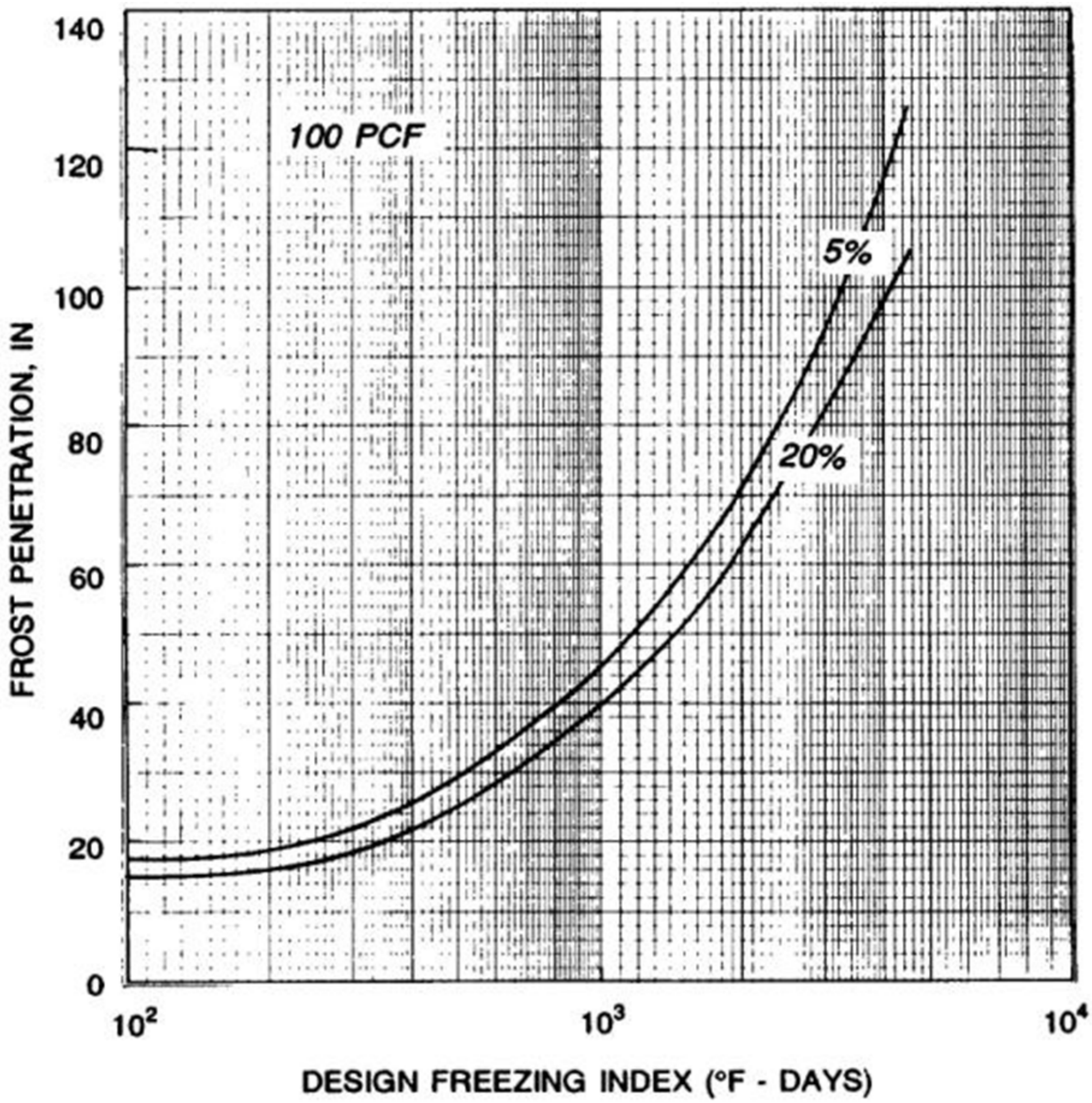
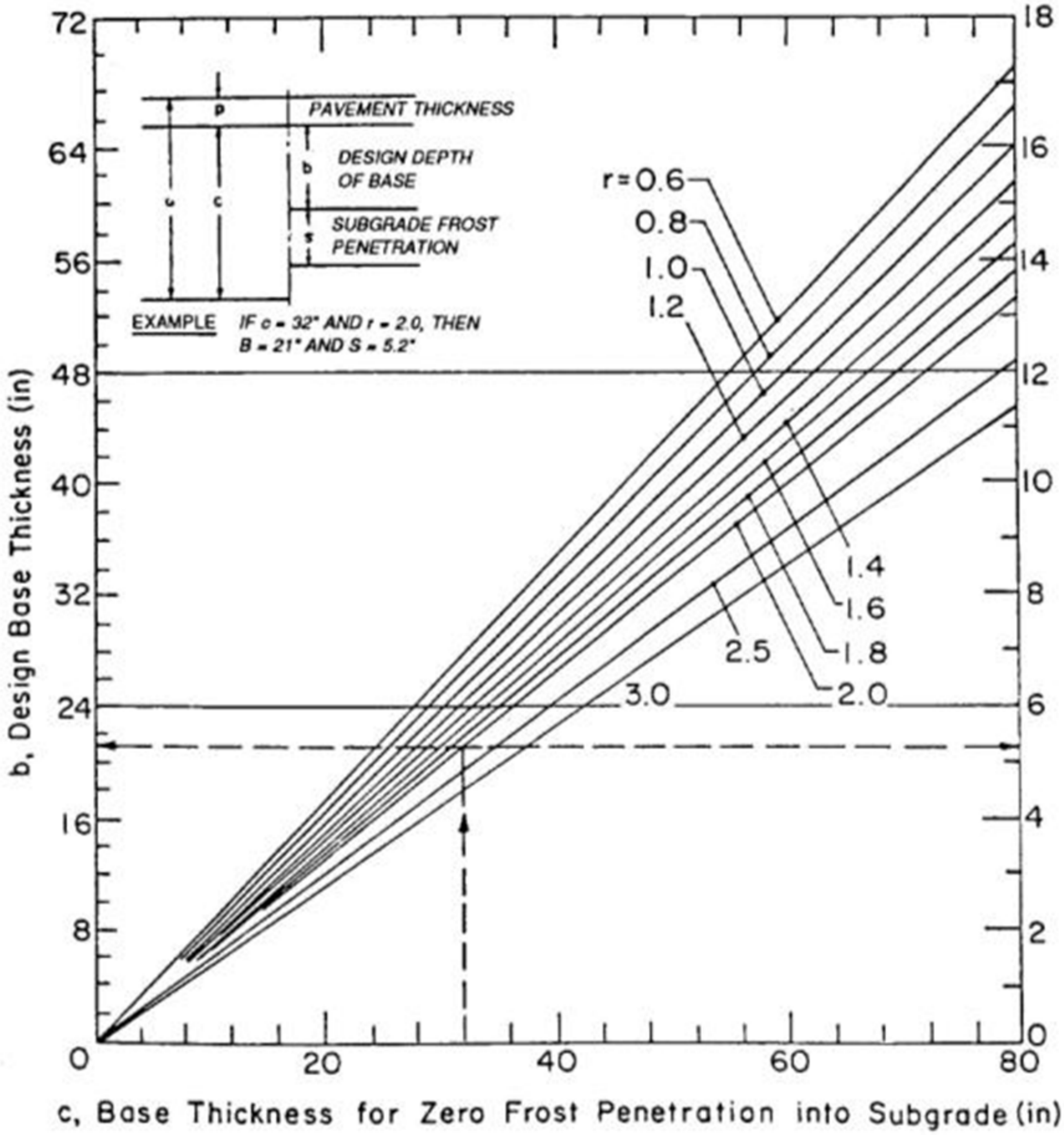


Figure 19-5 Design Depth of Non-frost Susceptible Base for Limited Subgrade Frost Penetration



19-6 REDUCED SUBGRADE STRENGTH.

Thickness design may also be based on the seasonally varying subgrade support that includes sharply reduced values during thawing of soils that have been affected by frost action. Except for pavement projects that are located in regions of low design freezing index, this design procedure usually requires less thickness of pavement and base than that needed for limited subgrade frost penetration. The method may be used for both flexible and rigid pavements wherever the subgrade is reasonably uniform or can be made reasonably horizontally uniform by the required techniques of subgrade preparation. This will prevent or minimize significant or objectionable differential heaving and resultant cracking of pavements. When the reduced subgrade strength method is used for F4 subgrade soils, unusually rigorous control of subgrade preparation must be required. When a thickness determined by the reduced subgrade strength procedure exceeds that determined for limited subgrade frost penetration, the latter smaller value must be used, provided it is at least equal to the thickness required for NFS conditions. In situations where use of the reduced subgrade strength procedure might result in objectionable frost heave, but use of the greater thickness of base course indicated by the limited subgrade frost penetration design procedure is not considered necessary, intermediate design thickness may be used. However, these must be justified on the basis of frost heaving experience developed from existing pavements where climatic and soil conditions are comparable.

19-6.1 Thickness of Flexible Pavements.

In the reduced subgrade strength procedure for design, the design curves in Appendix E should be used for road, street, and parking area design. Do not enter the curves with subgrade CBR values determined by tests or estimates, but instead with the applicable frost-area soil support index from Table 19-3. Frost-area soil support indexes are used as if they were CBR values; the term CBR is not applied to them, however, because being weighted average values for an annual cycle, their value cannot be determined by CBR tests. The soil support index for S1 or S2 material meeting current specifications for base or subbase are determined by conventional CBR tests in the unfrozen state.

General field data and experience indicate that on the relatively narrow embankments of roads and parking areas, reduction in strength of subgrades during frost melting may be less in substantial fills than in cuts because of better drainage conditions and less intense ice segregation. If local field data and experience show this to be the case, then a reduction in combined thickness of pavement and base for frost conditions of up to 10 percent may be permitted for substantial fills.

Flexible pavement criteria for NFS design should also be used to determine the thickness of individual layers in the pavement system, and to ascertain whether it will be advantageous to include one or more layers of bound base in the system. The base course composition requirements set forth must be followed rigorously.

Table 19-3 Frost-Area Soil Support Indexes for Subgrade Soils for Flexible Pavement Design

Frost Group of Subgrade Soil	Frost-Area Soil Support Index
F1 and S1	9.0
F2 and S2	6.5
F3 and F4	3.5

19-6.2 Thickness of Rigid Pavements.

Where frost is expected to penetrate into a frost-susceptible subgrade beneath a rigid pavement, it is good practice to use a NFS base course at least equal in thickness to the slab. Experience has shown, however, that rigid pavements with only a 4 in (100 mm) base have performed well in cold environments with relatively uniform subgrade conditions. Accordingly, where subgrade soils can be made reasonably uniform by the required procedures of subgrade preparation, the minimum thickness of granular unbound base may be reduced to a minimum of 4 in (100 mm). The material must meet the requirements set forth below for free-draining material as well as the criteria for filter under pavement slab. If it does not also meet the criteria for filter over subgrade, a second 4 in (100 mm) layer meeting that criterion must be provided.

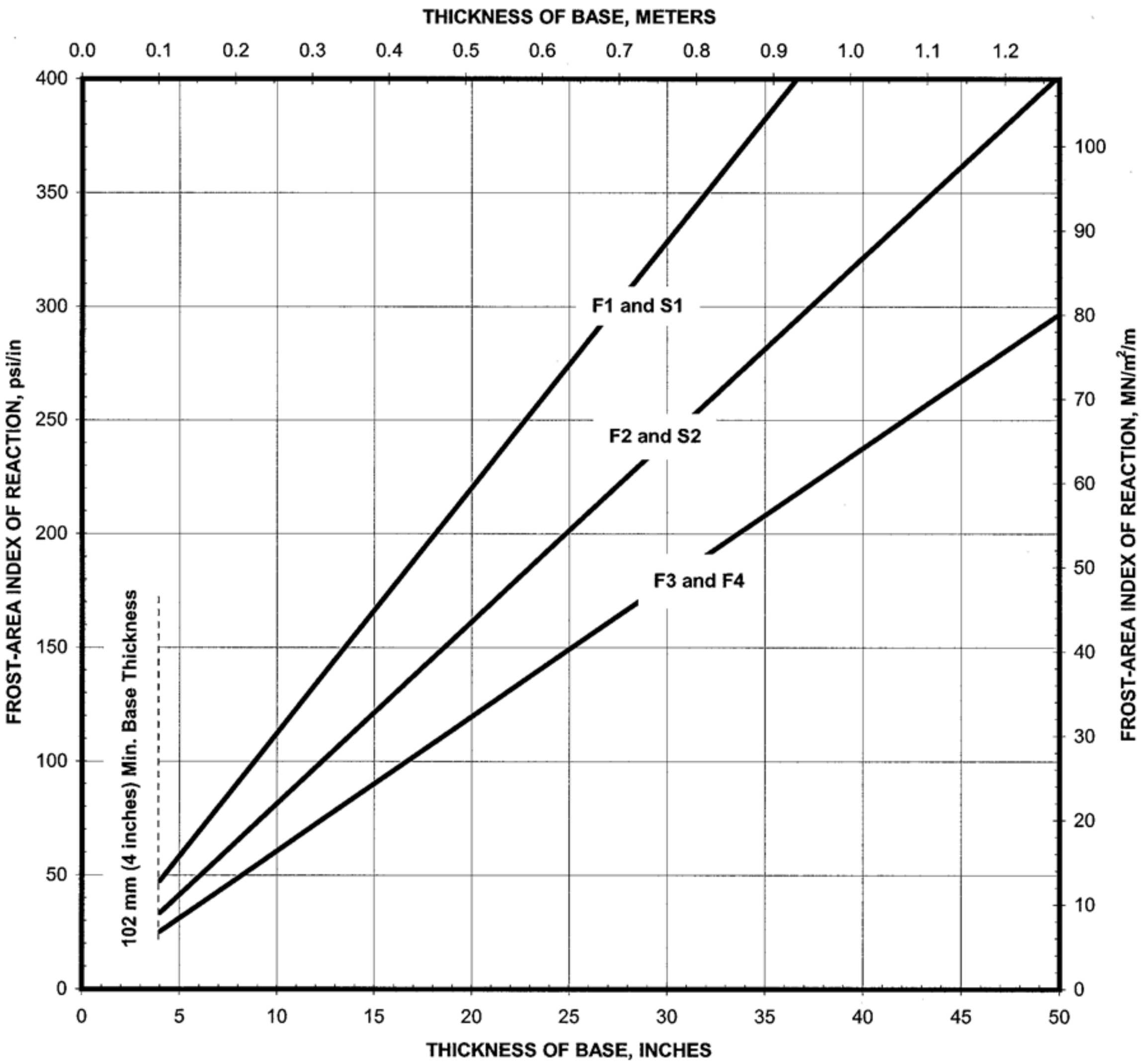
Additional granular unbound base course, giving a thickness greater than the minimum specified above, improves pavement performance, giving a higher frost-area index of reaction on the surface of the unbound base Figure 19-6 and permitting a pavement slab of less thickness. Bound base also has significant structural value, and may be used to effect a further reduction in the required thickness of rigid pavement slab. Criteria for determining the required thickness of rigid pavement slabs in combination with a bound base course are contained in Chapter titled Plain Concrete Pavement Design. The requirements for granular unbound base as drainage and filter layers are still applicable.

The thickness of concrete pavement must be determined in accordance with Chapter titled Plain Concrete Pavement Design, using the frost-area index of reaction determined from Figure 19-6. This figure shows the equivalent weighted average index of reaction values for an annual cycle that includes a period of thaw-weakening in relation to the thickness base. Frost-area indexes of reaction are used as if they were moduli of reaction, k, and have the same units. The term modulus of reaction is not applied to them because being weighted average values for an annual cycle, they cannot be determined by a plate-bearing test. If the modulus of reaction, k, determined from tests on the equivalent base course and subgrade, but without frost melting, is numerically smaller than the index of reaction obtained from Figure 19-6, the test value must govern the design.

19-7 FREE-DRAINING MATERIAL DIRECTLY BENEATH BOUND BASE OR SURFACING LAYER.

Base courses may consist of either granular unbound materials or bound base materials or a combination of the two. However, do not place cement or lime bound base directly beneath bituminous pavement unless approved by the Government Civil Engineer. Also, do not place an unbound course between two relatively impervious bound layers. If the combined thickness, in inches, of pavement and contiguous bound base courses is less than 0.09 multiplied by the design air freezing index (this calculation limits the design freezing index at the bottom of the bound base to about 20 degrees Fahrenheit days), not less than 4 in (100 mm) of free-draining material must be placed directly beneath the lower layer of bound base or, if there is no bound base, directly beneath the pavement slab or surface course. The free-draining material must contain 2.0 percent or less, by weight, of grains that can pass the No. 200 sieve, and to meet this requirement, it probably will have to be screened and washed. If the structural criteria for design of the pavement do not require granular unbound base other than the 4 in of free-draining material, then the material in the 4 in (100 mm) layer must be checked for conformance with the filter requirements below. If it fails the test for conformance, an additional layer meeting those requirements must be provided. When using a drainage layer, the drainage layer must extend to an open ditch or subdrain. Pavement drainage is discussed in Chapter titled Design Of Subsurface Pavement Drainage Systems.

Figure 19-6 Frost-Area Index of Reaction for Design of Rigid Roads and Parking Areas



19-8 SOIL STABILIZATION.

19-8.1 Bound Base.

Soils containing only lime as the stabilizer are generally unsuitable for use as base course layers in the upper layers of pavement systems in frost areas. Lime, cement, and a pozzolanic material such as fly ash may be used in some cases to produce a cemented material of high quality that is suitable for upper base course and that has adequate durability and resistance to freeze-thaw action. Soil stabilization mixture design will be based on the procedures set forth in UFC 3-250-11 with the additional requirement that the mixture, after freeze-thaw testing as set forth below, should meet the weight-loss criteria specified in UFC 3-250-11 for cement-stabilized soil. The procedures in ASTM D560/560M should be followed for freeze-thaw testing, except that the specimens should be compacted in a 6 in (150 mm) diameter mold in five layers with a 10 lb (4.5 kg) hammer having an 18 in (450 mm) drop, and that the preparation and curing of the specimens should follow the procedures indicated in UFC 3-250-11 for unconfined compression tests on lime-stabilized soil.

19-8.2 Stabilization with Lime.

If it is economical to use lime-stabilized or lime-modified soil in lower layers of a pavement system, a mixture of adequate durability and resistance to frost action is still necessary. In addition to the requirements for mixture design of lime-stabilized and lime-modified subbase and subgrade materials set forth in UFC 3-250-11, cured specimens should be subjected to the 12 freeze-thaw cycles in ASTM D560/560M (but omitting wire-brushing) or other applicable freeze-thaw procedures. This should be followed by determination of frost-design soil classification by standard laboratory freezing tests. For lime-stabilized or lime-modified soil used in lower layers of the base course, the frost susceptibility, determined after freeze-thaw cycling, should meet the requirements set forth for base course in Chapter titled Flexible Pavement Select Materials And Subbase Courses. If lime-stabilized or lime-modified soil is used as subgrade, its frost susceptibility, determined after freeze-thawing cycling, should be used as the basis of the pavement thickness design if the reduced subgrade strength design method is applied.

19-8.3 Stabilization with Portland Cement.

Cement-stabilized soil meeting the requirements set forth in UFC 3-250-11, including freeze-thaw effects tested under ASTM D560/560M, may be used in frost areas as base course or as stabilized subgrade. Cement-modified soil conforming with the requirements in UFC 3-250-11 also may be used in frost areas. However, in addition to the procedures for mixture design specified in UFC 3-250-11, cured specimens of cement-modified soil should be subjected to the 12 freeze-thaw cycles in ASTM D560/560M (but omitting wire-brushing) or other applicable freeze-thaw procedures. This should be followed by determination of frost design soil classification by standard laboratory freezing tests. For cement-modified soil used in the base course, the frost susceptibility, determined after freeze-thaw cycling, should meet the requirements set forth for base course in Chapter titled Flexible Pavement Select Materials And Subbase Courses. If cement-modified soil is used as subgrade, its frost susceptibility, determined after freeze-thaw cycling, should be used as the basis of the pavement thickness design if the reduced subgrade design method is applied.

19-8.4 Stabilization with Bitumen.

Many different types of soils and aggregates can be successfully stabilized to produce a high quality bound base with a variety of types of bituminous material. In frost areas the use of tar as a binder should be avoided because of its high temperature susceptibility. Asphalts are affected to a lesser extent by temperature changes, but a grade of asphalt suitable to the prevailing climatic conditions should be selected. Excepting these special conditions affecting the suitability of particular types of bitumen, the procedures for mixture design set forth in UFC 3-250-11 and UFC 3-250-03 will ensure that the asphalt-stabilized base will have adequate durability and resistance to moisture and freeze-thaw cycles.

19-9 SUBGRADE REQUIREMENTS.

It is a basic requirement for all pavements constructed in frost areas, that subgrades in which freezing will occur, must be prepared to achieve uniformity of soil conditions by mixing stratified soils, eliminating isolated pockets of soil of higher or lower frost susceptibility, and blending the various types of soils into a single, relatively homogeneous mass. It is not intended to eliminate from the subgrade those soils in which detrimental frost action will occur, but to produce a subgrade of uniform frost susceptibility and thus create conditions tending to make both surface heave and subgrade thaw-weakening as uniform as possible over the paved area. In fill sections the least frost-susceptible soils must be placed in the upper portion of the subgrade by temporarily stockpiling the better materials, cross-hauling, and selective grading. If the upper layers of fill contain frost-susceptible soils, then the finished fill section must be subjected to the subgrade preparation procedures required for cut sections. In cut sections the subgrade must be scarified and excavated to a prescribed depth, and the excavated material must be windrowed and bladed successively until thoroughly blended. The depth of subgrade preparation, measured downward from the top of the subgrade, must be 24 in (600 mm) or two-thirds of the frost penetration less the actual combined thickness of pavement, base course, and subbase course, whichever is less. The prepared subgrade must meet the designated compaction requirements for NFS areas. The construction inspection personnel should be alert to verify that the processing of the subgrade will yield uniform soil conditions throughout the section. To achieve uniformity in some cases, it will be necessary to remove highly frost susceptible soils or soils of low frost susceptibility. In that case, the pockets of soil to be removed should be excavated to the full depth of frost penetration and replaced with material surrounding the frost-susceptible soil being removed.

19-9.1 Exception Conditions.

Exceptions to the basic requirement for subgrade preparation are subgrades known to be NFS to the depth prescribed for subgrade preparation and known to contain no frost-susceptible layers or lenses, as demonstrated and verified by extensive and thorough subsurface investigations and by the performance of nearby existing pavements. Also, fine-grained subgrades containing moisture well in excess of the optimum for compaction, without drainage or other means for reducing the moisture content, and which consequently it is not possible to scarify and re-compacted, are also exceptions.

19-9.2 Treatment of Wet Fine-Grained Subgrades.

If wet fine-grained subgrades exist at the site, it is necessary to achieve frost protection with fill material. This may be done by raising the grade by an amount equal to the depth of subgrade preparation that otherwise would be prescribed, or by undercutting and replacing the wet fine-grained subgrade to that same depth. In either case the fill or backfill material may be NFS material or frost-susceptible material meeting specified requirements. If the fill or backfill material is frost susceptible, it should be subjected to the same subgrade preparation procedures prescribed above.

19-9.3 Cobbles or Boulders.

A critical condition requiring the attention of inspection personnel is the presence of cobbles or boulders in the subgrades. All stones larger than about 6 in (150 mm) in diameter should be removed from fill materials for the full depth of frost penetration, either at the source or as the material is spread in the embankments. Any such large stones exposed during the subgrade preparation work also must be removed, down to the full depth to which subgrade preparation is required. Failure to remove stones or large roots can result in increasingly severe pavement roughness as the stones or roots are heaved gradually upward toward the pavement surface. They eventually break through the surface in extreme cases, necessitating complete reconstruction.

19-9.4 Changes in Soil Conditions.

Abrupt changes in soil conditions must not be permitted. Where the subgrade changes from a cut to a fill section, a wedge of subgrade soil in the cut section with the dimensions shown in Figure C19-7 (Appendix C) should be removed and replaced with fill material. Tapered transitions also are needed at culverts beneath paved areas, but in such cases the transition material should be clean, NFS granular fill. Other pipes under pavement should be similarly treated, and perforated-pipe underdrains should be constructed. These and any other discontinuities in subgrade conditions require the most careful attention of construction inspection personnel, as failure to enforce strict compliance with the requirements for transitions may result in serious pavement distress.

19-9.5 Wet Areas.

Careful attention should be given to wet areas in the subgrade, and special drainage measures should be installed as required. The need for such measures arises most often in road construction, where it may be necessary to provide intercepting drains to prevent infiltration into the subgrade from higher ground adjacent to the road.

19-9.6 Rock Excavation.

In areas where rock excavation is required, consider the character of the rock and seepage conditions. In any case, the excavations should be made so that positive transverse drainage is provided, and no pockets are left on the rock surface that permit ponding of water within the depth of freezing. The irregular groundwater availability created by such conditions may result in markedly irregular heaving under freezing conditions. It may be necessary to fill drainage pockets with lean concrete. At intersections of fills with rock cuts, the tapered transitions mentioned above Figure C19-7 (Appendix C) are essential. Rock subgrades where large quantities of seepage are involved should be blanketed with a highly pervious material to permit the escape of groundwater. Often, the fractures and joints in the rock contain frost-susceptible soils. These materials should be cleaned out of the joints to the depth of frost penetration and replaced with NFS material. If this is impractical, it may be necessary to remove the rock to the full depth of frost penetration.

19-9.7 Rock Subgrades.

An alternative method for treatment of rock subgrades, in-place fragmentation, has been used effectively in road construction. Blast holes 3 to 6 ft (0.9 to 1.8 m) deep are commonly used. They are spaced suitably for achieving thorough fragmentation of the rock to permit effective drainage of groundwater through the shattered rock and out of the zone of freezing in the subgrade. A tapered transition should be provided between the shattered rock cut and the adjacent fill.

19-10 OTHER MEASURES TO REDUCE HEAVE.

Other possible measures to reduce the effects of heave are the use of insulation (Appendix D) to control depth of frost penetration and the use of steel reinforcement to improve the continuity of rigid pavements that may become distorted by frost heave. Reinforcement does not reduce heave nor prevent the cracking resulting from it, but it helps to hold cracks tightly closed and thus reduce pumping through these cracks. Transitions between cut and fill, culverts and drains change in character or stratification of subgrade soils. Subgrade preparation and boulder removal should also receive special attention in field construction control.

19-11 PAVEMENT CRACKING ASSOCIATED WITH FROST HEAVE.

One of the most detrimental effects of frost action on a pavement is surface distortion as the result of differential frost heave or differential loss of strength. These may also lead to random cracking. Deterioration and spalling of the edges of working cracks are causes of uneven surface conditions and sources of debris. Cracking may be reduced by control of such elements as base composition, uniformity and thickness, slab dimensions, subbase and subgrade materials, uniformity of subsurface moisture conditions, and, in special situations, by use of reinforcement and by limitation of pavement type. The importance of uniformity cannot be overemphasized. Where unavoidable discontinuities in subgrade conditions exist, gradual transitions are essential.

19-12 COMPACTION.

Subgrade, subbase, and base course materials must meet the applicable compaction requirements for NFS materials.

19-13 USE OF INSULATION MATERIALS IN PAVEMENTS.

The use of synthetic insulating material within a pavement cross section must have written approval by the Government Civil Engineer, which can also provide advice and assistance in regard to the structural analysis. Criteria for design of pavements containing insulating layers are contained in Appendix D.

19-14 DESIGN EXAMPLE HEAVILY TRAFFICKED ROAD.

Appendix G includes examples of design for flexible and rigid pavements in an environment subjected to seasonal frost.

19-15 ALTERNATIVE DESIGNS.

Besides the two methodologies in dealing with seasonal frost, investigate other design alternatives using stabilized layers, including aggregate base course pavements, to determine whether they are more economical than the designs presented above.

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CHAPTER 20 DESIGN OF SUBSURFACE PAVEMENT DRAINAGE SYSTEMS

20-1 GENERAL.

In recent years subsurface drainage has received increasing attention, particularly in the area of highway design. A number of studies have been conducted by State Highway Agencies and by the Federal Highway Administration that have resulted in a large number of publications on the subject of subsurface drainage. Appendix A contains a list of publications which contain information pertaining to the design of subsurface drainage for pavements.

20-1.1 Effects of Water on Pavements and Subgrade.

Water has a detrimental effect on pavement performance, primarily by either weakening subsurface materials or erosion of material by free water movement. For flexible pavements the weakening of the base, subbase or subgrade when saturated with water is one of the main causes of pavement failures. In rigid pavement, free water trapped between the concrete surface and an impermeable layer directly beneath the concrete, moves due to pressure caused by loadings. This movement of water, referred to as pumping, erodes the subsurface material creating voids under the concrete surface. In frost areas water contributes to frost damage by heaving during freezing and loss of subgrade support during thawing. Poor subsurface drainage can also contribute to secondary damage such as ‘D’ cracking or swelling of subsurface materials.

20-1.2 Traffic Effects.

The type, speed and volume of traffic will influence the criteria used in the design of pavement drainage systems. For rigid pavements pumping is greatly increased as the volume and speed of the traffic increases. For flexible pavements the buildup of pore pressures as a result of high volume, high speed traffic is a primary cause of the weakening of the pavement structure.

20-1.3 Sources of Water.

The two sources of water to be considered are from infiltration and subterranean water. Infiltration is the most important source of water and is the source of most concern in this document. Subterranean water is important in frost areas and areas of very high groundwater table or areas of artesian water. In many areas, perched groundwater may develop under pavements due to a reduced rate of evaporation of the water from the surface. In frost areas, free water collects under the surface by freeze-thaw action.

20-1.3.1 Infiltration.

Infiltration is surface water which enters the pavement from the surface through cracks or joints in the pavement, through the joint between the pavement and shoulder, through pores in the pavement, and through shoulders and adjacent areas. Since surface infiltration is the principal source of water, it is the source needing greatest control measures.

20-1.3.2 Subterranean Groundwater.

Subterranean groundwater can be a source of water from a high groundwater table, capillary forces, artesian pressure, and freeze-thaw action. Groundwater tables rise and fall depending upon the relation between infiltration, absorption, evaporation and groundwater flow. Seasonal fluctuations are normal because of differences in the amount of precipitation and maybe relatively large in some localities. Prolonged drought or wet periods will cause large fluctuations in the groundwater level. Subterranean source of water is particularly important in areas of frost action when large volumes of water can be drawn into the pavement structure during the formation of ice lenses. For large paved areas the evaporation from the surface is greatly reduced which causes saturation of the pavement structure by capillary forces. Also, if impervious layers exist beneath the pavement, perched groundwater can be present or develop from water entering the pavement through infiltration. This perched groundwater then becomes a subterranean source of water. In general, the presence of near surface subterranean water must be identified during soil exploration and drainage facilities designed to mitigate the influence of subterranean water.

20-1.3.3 Freeze-Thaw.

Freeze-thaw action can result in large amounts of groundwater being drawn into the pavement structure. In freeze-thaw conditions, groundwater flows to the freeze front by capillary action. Repeated cycles of freeze-thaw result in the growth of ice lenses that can cause heave in the pavement structure. Heaves in soils as great as 60 percent are not uncommon and under laboratory conditions, heaves of as much as 300 percent have been recorded. The formation of ice lenses in the pavement structure affects the structural integrity of the pavement structure in two very detrimental ways. One effect is the formation of the ice lenses causes a loss of density of the pavement materials resulting in strength loss of the pavement materials. A second effect is thawing of the ice results in a large volume of free water that must be drained from the pavement. Because thawing usually occurs simultaneously from both the top and bottom of the pavement structure, the free water can be trapped within the pavement structural. Providing adequate drainage minimizes pumping and promotes the restoration of pavement strength. In the design of sub-drain systems in frost areas, free water in both the upper and lower sections of the pavement must be considered.

20-1.4 Classification of Subdrain Facilities

Subdrain facilities can be categorized into two functional categories, one to control infiltration, and one to control groundwater. An infiltration control system is designed to intercept and remove water that enters the pavement from precipitation or surface flow. An important function of this system is to keep water from being trapped between impermeable layers. A groundwater control system is designed to reduce water movement into subgrades and pavement sections by controlling the flow of groundwater or by lowering the water table. Often, subdrains are required to perform both functions, and the two subdrain functions can be combined into a single subdrain system. Figure C20-1 and Figure C20-2 (Appendix C) illustrate examples of infiltration and groundwater control systems.

20-1.5 Subsurface Drainage Requirements.

The determination of the subsurface soil properties and water condition is a prerequisite for the satisfactory design of a subsurface drainage system. Field explorations and borings made in connection with the project design should include the following investigations pertinent to subsurface drainage. A topographic map of the proposed area and the surrounding vicinity should be prepared indicating all streams, ditches, wells, and natural reservoirs. The analysis of aerial photographs of the areas selected for construction may furnish valuable information on general soil and groundwater conditions. An aerial photograph presents a graphic record of the extent, boundaries, and surface features of soil patterns occurring at the surface of the ground. The presence of vegetation, the slopes of a valley, the colorless monotony of sand plains, the farming patterns, the drainage pattern, gullies, eroded lands, and evidences of the works of man are revealed in detail by aerial photographs. The use of aerial photographs may supplement both the detail and knowledge gained in topographic survey and ground explorations. The sampling and exploratory work can be made more rapid and effective after analysis of aerial photographs has developed the general soil features. The location and depth of permanent and perched groundwater tables may be sufficiently shallow to influence the design. The season of the year and rainfall cycle will measurably affect the depth to the groundwater table. In many locations, information may be obtained from residents of the surrounding areas regarding the behavior of wells and springs and other evidences of surface or subsurface water. The soil properties investigated for other purposes in connection with the design will supply information that can be used for the design of the drainage system. It may be necessary to supplement these explorations at locations of subsurface drainage structures and in areas where soil information is incomplete for design of the drainage system.

20-1.6 Laboratory Tests.

The design of subsurface drainage structures requires knowledge of the following soil properties: strength, compressibility, swell and dispersion characteristics, the in situ and compacted unit dry weights, the coefficient of permeability, the in situ water content, specific gravity, grain-size distribution, and the effective void ratio. These soil properties may be satisfactorily determined by experienced soil technicians through laboratory tests. The final selected soil properties for design purposes may be expressed as a range, one extreme representing a maximum value and the other a minimum value. The true value should be between these two extremes, but it may approach or equal one or the other, depending upon the variation within a soil stratum.

20-1.7 Drainage of Water from Soil.

The quantity of water removed by a drain varies depending on the type of soil and location of the drain with respect to the groundwater table. All the water contained in a given specimen cannot be removed by gravity flow since water retained as thin films adhering to the soil particles and held in the voids by capillarity do not drain. Consequently, to determine the volume of water that can be removed from a soil in a given time, the effective porosity as well as the permeability must be known. Limited effective porosity test data for well-graded base course materials, such as bank-run sands and gravels, indicate a value for effective porosity of not more than 0.15. Uniformly graded soils such as medium coarse sands, may have an effective porosity of not more than 0.25. Open graded aggregate used for drainage layers will have an effective porosity of between 0.25 and 0.35.

20-2 PRINCIPLES OF PAVEMENT DRAINAGE.

20-2.1 Flow of Water Through Soils.

The flow of water through soils is expressed by Darcy's empirical law which states that the velocity of flow (v) is directly proportional to the hydraulic gradient (i). This law can be expressed as:

Equation 20-1 $$v = k \times i$$

Where k is the coefficient of proportionality known as the coefficient-of-permeability, Equation 20-1 can be expanded to obtain the rate of flow through an area of soil (A). The equation for the rate of flow (Q) is:

Equation 20-2 $$Q = k \times i \times A$$

According to Darcy's law, the velocity of flow and the quantity of discharge through a porous media are directly proportional to the hydraulic gradient. For this condition to be true, flow must be laminar or non-turbulent. Investigations have found that Darcy's law is valid for a wide range of soils and hydraulic gradients. However, in developing criteria for subsurface drainage, liberal margins have been applied to allow for turbulent flow. The criteria and uncertainty depend heavily on the permeability of the soils involved in the pavement structure. It is therefore useful to examine the influence of various factors on the permeability of soils. In examining permeability of soils in regard to pavement drainage, the materials of most concern are base and subbase aggregate and aggregate used as drainage layers.

20-2.2 Factors Affecting Permeability.

20-2.2.1 Coefficient of Permeability.

The value of permeability depends primarily on the characteristics of the permeable materials, but it is also a function of the properties of the fluid. An equation (after Taylor) demonstrating the influence of the soil and pore fluid properties on permeability was developed based on flow through porous media similar to flow through a bundle of capillary tubes. This equation is as follows:

Equation 20-3 $$k = D_s^2 \cdot C \cdot \left(\frac{\gamma \cdot e^3}{\mu \cdot (1-e)} \right)$$

where

k=the coefficient of permeability

D_s=Hazen's effective particle diameter

C=shape factor

γ=unit weight of pore fluid

μ=viscosity of pore fluid

e=void ratio

20-2.2.2 Effect of Pore Fluid and Temperature.

In the design of subsurface drainage systems for pavements, the primary pore fluid of concern is water. Therefore, when permeability is mentioned in this chapter, water is assumed to be the pore fluid. Equation 20-3 indicates that the permeability is directly proportional to the unit weight of water and inversely proportional to the viscosity. The unit weight of water is essentially constant, but the viscosity of water will vary with temperature. Over the widest range in temperatures ordinarily encountered in seepage problems, viscosity varies about 100 percent. Although this variation seems large, it can be insignificant when considered in the context of the variations which can occur with changes in material properties.

20-2.2.3 Effect of Grain Size and Void Ratio.

It is logical that the smaller the grain size the smaller the voids that constitute the flow channels, and hence the lower the permeability. Equation 20-3 suggests that permeability varies with the square of the effective particle diameter and the cube of the void ratio. Since the void ratio is, for the most part a function of the material gradation, the influence of effective particle diameter will be magnified. Consider that when the effective particle size increases from No. 200 (0.08 mm) to No. 16 (1.2 mm) the permeability, according to equation 20-3, would increase by a factor of about 250. Assuming the increase in effective particle size would result in an increase in the void ratio by a minimum of two times then the permeability due to the increase in void ratio would be by a factor of 8. Thus the total increase in permeability due to the increase in the effective particle size and increase in void ratio would be by a factor of about 2000. Also, the shape of the void spaces has a marked influence on the permeability. As a result, the relationships between grain size, void ratio and permeability are complex. Intuition and experimental test data suggest that the finer particles in a soil have the most influence on permeability. The coefficient of permeability of sand and gravel materials, graded between limits usually specified for pavement bases and subbases, depends principally upon the percentage by weight of particles passing the No. 200

sieve. Table 20-1 provides estimates of the permeability for these materials for various amounts of material finer than the No. 200 sieve.

Table 20-1 Coefficient of Permeability for Sand and Gravel Materials (Coefficient of 55)

Percent by Weight Passing No. 200 Sieve	Permeability for Remolded Samples	
	mm/sec	ft/min
3	5×10^{-1}	10^{-1}
5	5×10^{-2}	10^{-2}
10	5×10^{-3}	10^{-3}
15	5×10^{-4}	10^{-4}
20	5×10^{-5}	10^{-5}

The volume of water that a soil mass is capable of holding is directly related to the void ratio. Not all water contained in a soil can be drained by gravity flow since water retained as thin films adhering to the soil particles and held by capillarity do not drain. Consequently, to determine the volume of water that can be removed from a soil the effective porosity (n_e) must be known. The effective porosity is defined as the ratio of the volume of the voids that can be drained under gravity flow to the total volume of soil, and can be expressed mathematically as

Equation 20-4 $$n_e = 1 - \frac{\gamma_d}{G_S \times \gamma_W}\left(1 + G_S \times W_e\right)$$

where

γ_d=dry density of the soil

G_S=specific gravity of solids

γ_W=unit weight of water

W_e=effective water content (after the soil has drained) expressed as a decimal fraction relative to dry weight

Limited effective porosity test data for well-graded base course materials, such as bank-run sands and gravels, indicate a value for effective porosity of not more than 0.15. Uniformly graded medium or coarse sands, may have an effective porosity of not more than 0.25 while for a uniformly graded aggregate, such as would be used in a drainage layer, the effective porosity may be above 0.25.

20-2.2.4 Effect of Structure and Stratification.

Generally, in situ soils show a certain amount of stratification or a heterogeneous structure. Water deposited soils usually exhibit a series of horizontal layers that vary in grain-size distribution and permeability, and generally these deposits are more permeable in the horizontal than in the vertical direction. In pavement construction the subgrade, subbase, and base materials are placed and compacted in horizontal layers which result in having a different permeability in the vertical direction than in the horizontal direction. The vertical drainage of water from a pavement can be disrupted by a single relatively impermeable layer. For most pavements the subgrades have a very low permeability compared to the base and subbase materials. Therefore, water in the pavement structure can best be removed by horizontal flow. For a layered pavement system the effective horizontal permeability is obtained from a weighted average of the layer permeability by the formula.

Equation 20-5 $$k = \frac{(k_1 \times d_1 + k_2 \times d_2 + k_3 \times d_3 + ...)}{(d_1 + d_2 + d_3 + ...)}$$

Where:

k = the effective horizontal permeability

$k_1, k_2, k_3 ...$ = the coefficients of horizontal permeability of individual layers

$d_1, d_2, d_3 ...$ = thicknesses of the individual layers

When a drainage layer is used in the pavement section, the permeability of the drainage material will likely be several orders of magnitude greater than the other materials in the section. Since water flow is proportional to permeability, the flow of water from the pavement section can be computed based only on the characteristics of the drainage layer.

20-2.3 Quantity and Rate of Subsurface Flow.

20-2.3.1 General.

Water flowing from the pavement section may come from infiltration through the pavement surface, groundwater or both. Normally groundwater flows into collector drains from the subgrade and will be an insignificant flow compared to the flow coming from infiltration. The computation of the groundwater flow is beyond the scope of this UFC. The volume of surface water infiltration flowing into the pavement depends on factors such as type and condition of surface, length, intensity of rainfall, properties of the drainage layer, hydraulic gradient, time allowed for drainage and the drained area. Consider all these factors in the design of the subsurface drainage system.

20-2.3.2 Effects of Pavement Surface.

The type and condition of the pavement surface has considerable influence on the volume of water entering the pavement structure. In the design of surface drainage facilities, assume all rain falling on paved surfaces to be runoff. For new well designed and constructed pavements, the assumption of 90 percent runoff is probably a good conservative assumption for the design of surface drainage facilities. For design of the subsurface drainage facilities, the design should be based on the infiltration rate for a deteriorated pavement. Studies have shown that for badly deteriorated pavements well over 50 percent of the rainfall can flow through the pavement surface. Since it is almost impossible to completely maintain a pavement over its life and since water may also enter from the shoulders, the infiltration rate for a deteriorated pavement must be used.

20-2.3.3 Effects of Rainfall.

The volume of water entering the pavement is directly proportional to the intensity and length of the rainfall. Relatively low intensity rainfalls can be used for designing the subsurface drainage facilities because high intensity rainfalls do not greatly increase the adverse effect of water on pavement performance. The excess rainfall would, once the base and subbase are saturated, run off as surface drainage. For this reason a seemingly non-conservative design rainfall can be selected.

20-2.3.4 Capacity of Drainage Layers.

If water enters the pavement structure at a greater rate than the discharge rate, the pavement structure becomes saturated. The design of horizontal drainage layers for the pavement structure is based, in part, on the drainage layer serving as a reservoir for the excess water entering the pavement. The capacity of the drainage layer as a reservoir is a function of the storage capacity of the drainage layer plus the amount of water which drains from the layer during a rain event. The storage capacity of the drainage layer is a function of the effective porosity of the drainage material and the thickness of the drainage layer. The storage capacity of the drainage layer q_s in terms of depth of water per unit area is computed by:

Equation 20-6 $$q_s = n_e \times h$$

where

n_e=the effective porosity

h=the thickness of the drainage layer

In the equation the dimensions of the q_s will be the same as the dimensions of the h. If all the water does not drain from the drainage layer, then the storage capacity is reduced by the amount of water in the layer at the start of the rain event. The criterion for design of the drainage layer calls for 85 percent of the water to be drained from the drainage layer within 24 hours; therefore it is conservatively assumed that only 85 percent of the storage volume will be available at the beginning of a rain event. To account for the possibility of water in the layer at the beginning of a rain event, equation 20-6 is modified to be:

Equation 20-7 $$q_s = 0.85 \times n_e \times h$$

The amount of water (q_d) which will drain from the drainage layer during the rain event may be estimated using the equation

Equation 20-8 $$q_d = \frac{t \times k \times i \times h}{2 \times L}$$

Where:

t = duration of the rain event

L = length of the drain path

k = permeability of the drainage layer

i = slope of the drainage layer

h = thickness of the drainage layer

In these equations the dimensions of q_s, q_d, t, k, h and L should be consistent. The total capacity (q) of the drainage layer will be the sum of q_s and q_d resulting in the following equation for the capacity

Equation 20-9 $$q = (0.85 \cdot n_e \cdot h) + \left(\frac{t \cdot k \cdot i \cdot h}{2 \cdot L} \right)$$

Knowing the intensity of water entering the pavement, equation 20-9 can be used to estimate the thickness of the drainage layer such that the drainage layer will have the capacity for a given design rain event. For most situations the amount of water draining from the drainage layer is small compared to the storage capacity. Therefore, in most cases, equation 20-7 can be used in estimating the thickness required for the drainage layer. For most highway designs a 4 in (100 mm) thick drainage layer will be sufficient.

20-2.3.5 Time for Drainage.

It is desirable that the water be drained from the base and subbase layers as rapidly as possible. The time for drainage of these layers is a function of the effective porosity, length of the drainage path, thickness of the layers, slope of the drainage path, and permeability of the layers, refer to Figure C20-3 (Appendix C) for pavement geometry. Until 1994, criteria specified that the base and subbase obtain a degree of 50 percent drainage within 10 days. The equation for computing time for 50 percent drainage is:

Equation 20-10 $$T_{50} = \frac{\left(n_e \times D^2\right)}{\left(2 \times k \times H_o\right)}$$

Where:

T_{50} = time for 50 percent drainage

n_e = effective porosity of the soil

k = coefficient of permeability

D, H_o and H = base and subbase geometry dimensions as shown in Figure C20-3 (Appendix C).

The dimensions of time *k, H*

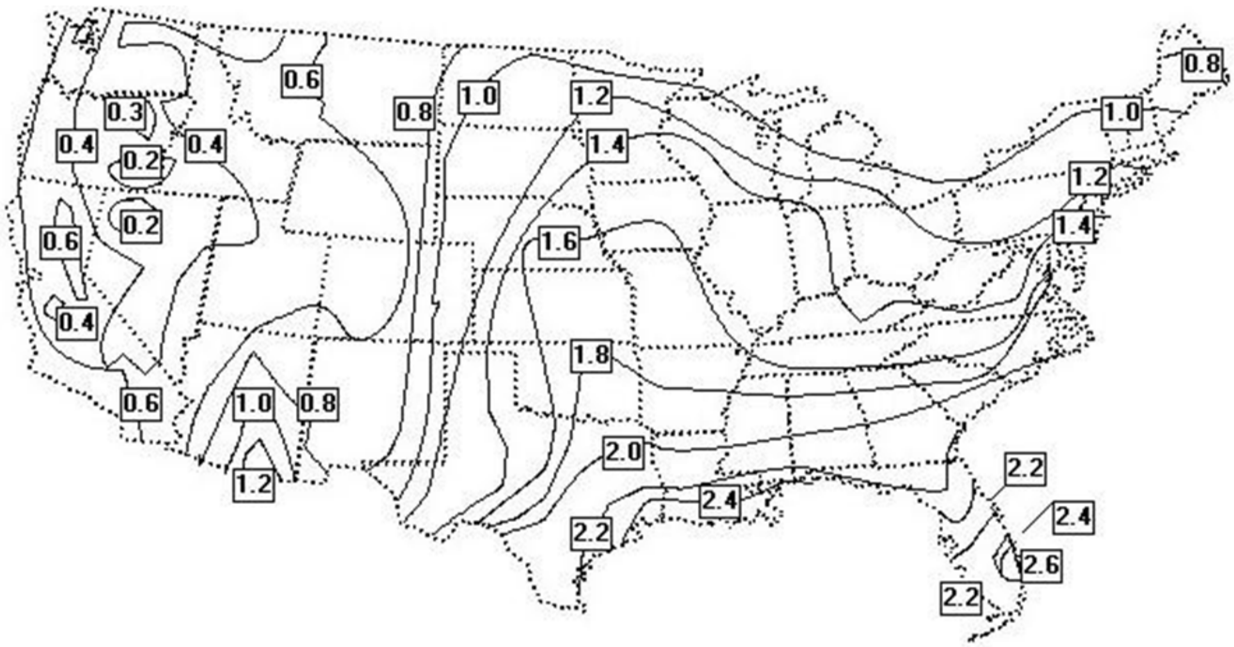
The dimensions of time k, H_o, H and D must be consistent. If In Figure C20-3 (Appendix C) the thickness of the drainage layer is small compared the length of the drainage path, the slope of the drainage path (i) can represent the value of $\left(\frac{H_o}{D}\right)$ therefore equation 20-10 can be written

Equation 20-11 $$T_{50} = \frac{n_e \times D}{2 \times i \times k}$$

Experience has shown that base and subbase materials, when compacted to densities required in pavement construction, seldom have sufficient permeability to meet the 10 day drainage criterion. In such pavements the base and subbase materials become saturated causing a reduced pavement life. When a drainage layer is incorporated into the pavement structure to improve pavement drainage, the criterion for design of the drainage layer must be that the drainage layer must reach a degree of drainage of 85 percent within 24 hr. The time for 85 percent drainage is about twice the time for 50 percent drainage. The time for 85 percent drainage (T_{85}) is computed by

Equation 20-12 $$T_{85} = \frac{n_e \times D}{i \times k}$$

Figure 20-1 Design Storm Index (in/hour), 1-hr Rainfall Intensity-Frequency Data for Continental United States Excluding Alaska



20-2.3.6 Length and Slope of the Drainage Path.

As can be seen in equation 20-10, the time for drainage is a function of the square of the length of drainage path. For this reason and the fact that for most pavement designs the length of the drainage path can be controlled, the drainage path length is an important parameter in the design of the drainage system. The length of the drainage path (L) may be computed from the following equation

Equation 20-13 $$L = \frac{L_t \times \sqrt{i_t^2 + i_e^2}}{i_t}$$

Where:

L_t = the length of the transverse slope of the drainage layer

i_t = the transverse slope of the drainage layer

i_e = the longitudinal slope of the drainage layer

The slope of the drainage path (i) is a function of the transverse slope and longitudinal slope of the drainage layer and is computed by the equation

Equation 20-14 $$i = \sqrt{i_t^2 + i_e^2}$$

20-2.3.7 Rate of Flow.

The edge drains for pavements having drainage layers must be designed to handle the maximum rate of flow from the drainage layer. This maximum rate of flow will be obtained when the drainage layer is flowing full and may be estimated using equation 20-2.

20-2.4 Use of Drainage Layers.

20-2.4.1 Purpose of Drainage Layers.

Special drainage layers may be used to promote horizontal drainage of water from pavements, prevent the buildup of hydrostatic water pressure, and facilitate the drainage of water generated by cycles of freeze-thaw.

20-2.4.2 Placement of Drainage Layers.

In rigid pavements the drainage layer will generally be placed directly beneath the concrete slab. In this location, the drainage layer will intercept surface water entering through cracks and joints, and permit rapid drainage of the water away from the bottom of the concrete slab. In flexible pavements the drainage layer will normally be placed beneath the base. In placing the drainage layer beneath the base the stresses on the drainage layer are reduced to an acceptable level and drainage is provided for the base course. Placement of the drainage layer in areas of frost penetration requires special consideration, in that, during the thaw it is likely that free water will be generated as the thaw front advances up from the bottom as well as down from the top. For frost areas it is possible that the drainage layer is best placed beneath any good draining NFS material. Another consideration in the design of subsurface drainage systems in frost areas is that it is possible for the drains to become blocked by snow and ice.

20-2.4.3 Permeability Requirements for the Drainage Layer.

The material for drainage layers in pavements must be of sufficient permeability to provide rapid drainage and rapidly dissipate water pressure and yet provide sufficient strength and stability to withstand load induced stresses. There is a trade-off between strength or stability and permeability; therefore the material for the drainage layers should have the minimum permeability for the required drainage application. For most applications a material (referred to as a rapid draining material) with a permeability of 1,000 ft/day (300 m/day) will provide sufficient drainage.

20-2.5 Use of Filters.

20-2.5.1 Purpose of Filters in Pavement Structures.

The purpose of filters in pavement structures is to prevent the movement of soil (piping) yet allow the flow of water from one material to another. The need for a filter is dictated by the existence of water flow from a fine grain material to a coarse gain material generating a potential for piping of the fine grain material. The principal location in the pavement structure where a flow from a fine grain material into a coarse grain material is water flowing from the base, subbase, or subgrade into the coarse aggregate surrounding the drain pipe. Thus, the principal use of a filter in a pavement system is to prevent piping into the drain pipe. Although rare, the possibility exists for hydrostatic head forcing a flow of water upward from the subbase or subgrade into the pavement drainage layer. For such a condition it is necessary to design a filter to separate the drainage layer from the finer material.

20-2.5.2 Piping Criteria.

The criteria for preventing movement of particles from the soil or granular material to be drained into the drainage material are:

$$\frac{\text{15 percent size of drainage or filter material}}{\text{85 percent size of material to be drained}} \leq 5$$

and

$$\frac{\text{50 percent size of drainage or filter material}}{\text{50 percent size of material to be drained}} \leq 25$$

The criteria given above are used when protecting all soils except clays without sand or silt particles. For these soils, the 15 percent size of drainage or filter material may be as great as 0.4 mm and the d_{50} criteria will be disregarded.

20-2.5.3 Permeability Requirements.

To assure that the filter material is sufficiently permeable to permit passage of water without hydrostatic pressure buildup, the following requirement should be met:

$$\frac{\text{15 percent size of filter material}}{\text{15 percent size of material to be drained}} \geq 5$$

20-2.6 Use of Separation Layers.

When drainage layers are used in pavement systems, the drainage layers must be separated from fine grain subgrade materials to prevent penetration of the drainage material into the subgrade or pumping of fines from the subgrade into the drainage layer. The separation layer is different from a filter in that there is no requirement, except during frost thaw, to protect against water flowing from the subgrade through the layer into the drainage layer.

20-2.6.1 Requirements for Separation Layers.

The main requirements of the separation layer are that the material for the separation layer have sufficient strength to prevent the coarse aggregate of the drainage layer from being pushed into the fine material of the subgrade and that the material have sufficient permeability to prevent buildup of hydrostatic pressure in the subgrade. To satisfy the strength requirements the material of the separation layer should have a minimum CBR of 50. To allow for release of hydrostatic pressure in the subgrade, the separation layer should have a higher permeability than that of the subgrade. This would not normally be a problem because the permeability of subgrades are orders of magnitude less than the permeability of a 50 CBR material but to ensure sufficient permeability the permeability requirements of a filter would apply.

20-2.7 Use of Geotextiles.

20-2.7.1 Purpose of Geotextiles.

Geotextiles (engineering fabrics) may be used to replace either the filter or the separation layer. The principal use of geotextiles is the filter around the pipe for the edge drain. Although geotextiles can be used as a replacement for the separation layer, geotextile adds no structure strength to the pavement; therefore this practice is not recommended.

20-2.7.2 Requirements of the Geotextiles for Filters.

When geotextiles are to serve as a filter lining the edge drain trench, the most important function of the filter is to keep fines from entering the edge drain system. For pavement systems having drainage layers there is little requirement for water flow through the fabric; therefore for most applications, it is better to have a heavier fabric than would normally be used as a filter. Since drainage layers have a very high permeability, geotextile fabric should never be placed between the drainage layer and the edge drain. The permeability of geotextiles is governed by the size of the openings in the fabric which is specified in terms of the apparent opening size (AOS) in millimeters. For use as a filter for the trench of the edge drain the AOS of the geotextile should always be equal to or less than 0.212 mm. For geotextiles used as filters with drains installed to intercept groundwater flow in subsurface aquifers the geotextile should be selected based on criteria similar to the criteria used to design a granular filter.

20-2.7.3 Requirements for Geotextiles Used for Separation.

Geotextiles used as separation layers beneath drainage layers should be selected based primarily on survivability of the geotextiles with somewhat less emphasis placed on the AOS. When used as a separation layer the geotextile survivability should be rated very high by the rating scheme given by AASHTO M 288. This ensures the survival of the geotextiles under the stress of traffic during the life of the pavement. To ensure that fines will not pump into the drainage layer yet allow water flow to prevent hydrostatic pressure the AOS of the geotextile must be equal to or less than 0.212 mm and also equal to or greater than 0.125 mm.

20-3 DESIGN OF THE PAVEMENT SUBSURFACE DRAINAGE SYSTEM.

20-3.1 General.

Provide a pavement subsurface drainage system for the rapid removal of surface water and water generated by freeze-thaw action. Although the primary emphasis will be on removing water from under the pavement, there may be occasions when the system will also serve as interceptor drain for groundwater.

20-3.2 Methods.

For most pavement structures, water is to be removed by the use of a special drainage layer which allows the rapid horizontal drainage of water. The drainage layer must be designed to handle surface infiltration from a design storm and withstand the stress of traffic. A separation layer must be provided to prevent intrusion of fines from the subgrade or subbase into the drainage layer and facilitate construction of the drainage layer. The drainage layers should feed into a collection system consisting of trenches with a drain pipe, backfill, and filter. The collection system must be designed to maintain progressively greater outflow capabilities in the direction of flow. The outlet for the subsurface drains should be properly located or protected to prevent backflow from the surface drainage system. Some pavements may not require a drainage system in that the subgrade may have sufficient permeability for the water to drain vertically into the subgrade. In addition, some pavements designed for very light traffic, may not justify the expense of a subsurface drain system. Even for the pavements designed for very light traffic care must be taken to insure that base and subbase material are free draining and that water will be not trapped in the pavement structure. For pavements not having collection systems the base and subbase must daylight at the shoulders.

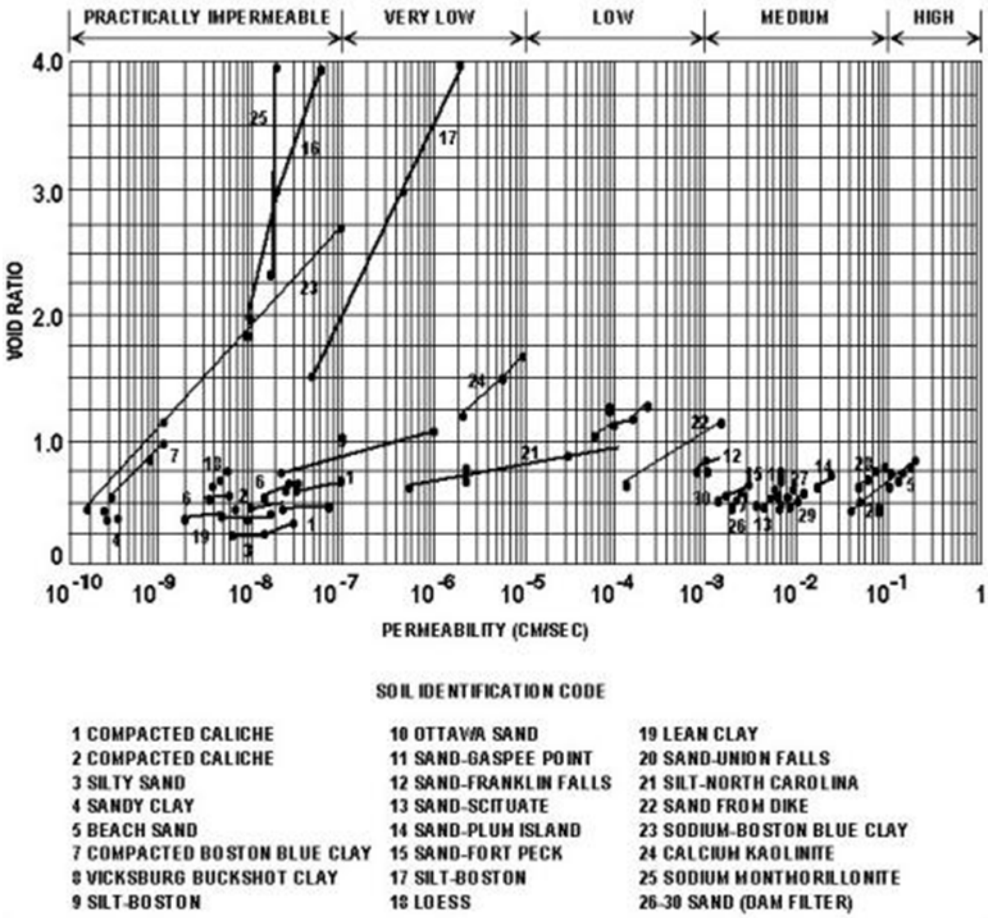
20-3.3 Design Prerequisites.

For the satisfactory design of a subsurface drainage system, the designer must have an understanding of environmental conditions, subsurface soil properties and groundwater conditions.

20-3.3.1 Environmental Conditions.

Temperature and rainfall data applicable to the local area should be obtained and studied. The depth of frost penetration is an important factor in the design of a subsurface drainage. For most areas the approximate depth of frost penetration can be determined by referring to UFC 3-260-02 or by using the computer program for frost analysis. Rainfall data are used to determine the volume of water to be handled by the subsurface drainage system. The data can be obtained from local weather stations or by the use of Figure 20-1.

Figure 20-2 Permeability Test Data (from Lambe and Whitman, With Permission)



20-3.3.2 Soil Properties.

In most cases the soil properties investigated for other purposes in connection with the pavement design will supply information that can be used for the design of the subsurface drainage system. The two properties of most interest are the coefficient of permeability and the frost susceptibility of the pavement materials.

20-3.3.3 Coefficient of Permeability.

The coefficient of permeability of the existing subsurface soils determines the need for special horizontal drainage layers in the pavement. For pavements having subgrades with a high coefficient of permeability the water entering the pavement will drain vertically and therefore horizontal drainage layers will not be required. For pavements having subgrades with a low coefficient of permeability the water entering the pavement must be drained horizontally to the collector system or to edge drains.

20-3.3.4 Frost Susceptible Soils.

Soils susceptible to frost action are those that have the potential of ice formation occurring when they are subjected to freezing conditions with water available. Ice formation takes place at successive levels as freezing temperatures penetrate into the ground. Soils having a high capillary rate and low cohesive nature act as a wick in feeding water to ice lenses. Soils are placed into groups according to the degree of frost susceptibility as shown in Table 20-2. Because a large volume of free water is generated during the thawing of ice lenses, horizontal drainage layers are required to permit the escape of the water from the pavement structure and thus facilitate the restoration of the pavement strength.

Table 20-2 Frost Susceptible Soils

Typical Soil			
Frost Group	**Type of Soil**	**Percent Finer than 0.02 mm by Weight**	**Types Under Unified Soil Classification System**
F1	Gravelly Soils	6-10	GW-GM, GP-GM, GW-GC, GP-GC
F2	(a) Gravelly Soils (b) Sands	10-20 6-15	GM, GC, GM-GC SM, SC, SW-SM, SP-SM, SW-SC, SP-SC, SM-SC
F3	(a) Gravelly Soils (b) Sands, except very fine silty sands (c) Clays (PI > 12)	> 20 > 15 --	GM, GC, GM-GC SM, SC, SM-SC CL, CH, ML-CL
F4	(a) Silts (b) Very fine sands (c) Clays (PI < 12) (d) Varved clays and other fine grained, with banded sediments	-- > 15 -- --	ML, MH, ML-CL SM, SC, SM-SC CL, ML-CL CL or CH layered ML, MH, SM, SC SM-SC or ML-CL

20-3.3.5 Sources for Data

The field explorations made in connection with the project design should include a topographic map of the proposed pavement facility and surrounding vicinity indicating all streams, ditches, wells, and natural reservoirs. An analysis of aerial photographs should be conducted for information on general soil and groundwater conditions. Borings taken during the soil exploration must provide depth to groundwater tables and subgrade soil types. Typical values of permeability for subgrade soils can be obtained from Figure 20-2. Although the value of permeability determined from Figure 20-2 must be considered only an estimate, the value should be sufficiently accurate to determine if subsurface drainage is required for the pavement.

For the permeability of granular materials, estimates of the permeability may be determined from the following equations:

Equation 20-15
$$k = \frac{217.5 \times (D_{10})^{1.478} \times (n)^{6.654}}{(P_{200})^{0.597}} \text{ (mm/sec)}$$

or

Equation 20-16
$$k = \frac{(6.214 \times 10^{5}) \times (D_{10})^{1.478} \times (n)^{6.654}}{(P_{200})^{0.597}} \text{ (ft/day)}$$

Where:

n = porosity $= 1 - \frac{\gamma_d}{\gamma_w \cdot G}$

G = specific gravity of solids (assumed 2.7)

γ_d = dry density of material

γ_w = density of water

D_{10} = effective grain size at 10 percent passing in millimeters

P_{200} = percent passing No. 200 (0.08 mm) sieve

For the most part the permeability needed for design of the drainage layer will be assigned based on the gradation of the drainage material. In some cases, laboratory permeability tests may be necessary, but it is cautioned that the permeability of very open granular materials is very sensitive to test methods, methods of compaction and gradation of the sample. Therefore, conservative drainage layer permeability values should be used for design.

20-3.4 Criteria for Subsurface Drain Systems.

Not all pavements require a subsurface drain system either because the subgrade is sufficiently permeable to allow vertical drainage of water into the subgrade or the pavement structure does not justify the expense of a subsurface drain system. For pavements having a subgrade with permeability greater than 20 ft/day (6 m/day), one can assume that the vertical drainage is sufficient to not require a drainage system. In addition to the above exemption for the requirement for drainage systems, flexible pavements having total thickness of structure above the subgrade of 8 in (200 mm) or less are not required to have a drainage system. All pavements not meeting the above criteria are required to have a subsurface drainage system. Even if a pavement meets the exemption requirements, a drainage analysis should be conducted for possible benefits for including the drainage system. For rigid pavements in particular, care should be taken to ensure water is drained rapidly from the bottom of the slab and that the material directly beneath the concrete slab is not susceptible to pumping.

20-3.4.1 Surface Water Inflow.

The subsurface drainage of the pavement is to be designed to handle surface water infiltrated from a design storm of 1 hour duration at an expected return frequency of 2 yr. The design storm index for different parts of the U.S. can be obtained from Figure 20-1. Determine the inflow by multiplying the design storm index (R) times an infiltration coefficient (F). The infiltration coefficient varies over the life of the pavement depending on the type of pavement, surface drainage, pavement maintenance, and structural condition of the pavement. Since the determination of a precise value of the infiltration coefficient for a particular pavement is very difficult, a value of 0.5 may be assumed for design.

20-3.4.2 Length and Slope of Drainage Path.

The length of the drainage path is measured along the slope of the drainage layer from the crest of the slope to where the water will exit the drainage layer. In simple terms, the length of the drainage path is the maximum distance water will travel in the drainage layer. The length of the drainage path (L) in feet (meters) is to be computed by equation 20-13, where and the slope (i) of the drainage path is to be computed by equation 20-14.

20-3.4.3 Thickness of Drainage Layer.

The thickness of the drainage layer is computed such that the capacity of the drainage layer is equal to or greater than the infiltration from the design storm. When the length of the drainage path (L) is in feet (meters), the design storm index (R) is in feet/hour (meters/hour), the permeability of the drainage layer (k) is in feet/hour (meters/hour), and the length of the design storm (t) is in hours, the equation for computing the thickness (H) in feet (meters) is

Equation 20-17
$$H = \frac{2 \times F \times R \times L \times t}{(1.7 \times n_e \times L) + (k \times i \times t)}$$

The effective porosity (n_e), the infiltration coefficient (F) and the slope of the drainage path (i) are non-dimensional. If the term ($k\ i\ t$) is small compared to the term ($1.7\ n_e\ L$) which would be the case for long drainage paths, i.e., for drainage paths longer than about 20 ft (6 m), then the required thickness of the drainage layer can be estimated by deleting the term ($k\ i\ t$) from equation 7-17 or

Equation 20-18
$$H = \frac{F \times R \times t}{0.85 \times n_e}$$

where the units are the same as in equation 20-17.

20-3.4.4 Drainage Criteria.

The subsurface drainage criteria for roadways require the drainage layer to become saturated. The drainage layer should be capable of attaining 85 percent drainage within 24 hours. For pavement areas receiving only low volume, low speed traffic the time for 85 percent drainage is 10 days. The time for 85 percent drainage is computed by the equation

Equation 20-19 $$T_{85} = \frac{n_e \times L}{i \times k}$$

where the dimensions of (T_{85}) will be in days when (L) is in feet (meters) and (k) is in feet/day (meters/day). The time of drainage may be adjusted by changing the drainage material, the length of the drainage path or the slope of the drainage path. Changing the drainage material changes both the effective porosity and the permeability but the effective porosity changes, at the most, by a factor of 3, whereas the permeability may change by several orders of magnitude. Thus, providing a more open drainage material decreases the time for drainage but more open materials are less stable and more susceptible to rutting. It is therefore desirable to keep the drainage material as dense as possible. The drainage layer of a pavement is usually placed parallel to the surface; therefore in most cases the slope of the drainage path is governed by the geometry of the pavement surface. For large paved areas such as vehicle parking areas, the time for drainage is best controlled by designing the collection system to minimize the length of the drainage path. For edge drains along roads and parking areas, it may be difficult to reduce the length of the drainage path without resorting to placing drains under the pavement. Pavements having long longitudinal slopes may require transverse collector drains to prevent long drainage paths. Thus, designing the subsurface drainage system to meet the criteria for time of drainage involves matching the type of drainage material with the drainage path length and slope.

20-3.5 Placement of Subsurface Drainage System.

20-3.5.1 Rigid Pavements.

In the case of rigid pavements the drainage layer, if required, must be placed directly beneath the concrete slab. In the structural design of the concrete slab the drainage layer along with any granular separation layer must be considered a base layer, and structural benefit may be realized from the layers.

20-3.5.2 Flexible Pavements.

In the case of flexible pavements the drainage layer should be placed either directly beneath the surface layer or beneath a graded crushed aggregate base course. If the required thickness of granular subbase is equal to or greater than the thickness of the drainage layer plus the thickness of the separation layer, the drainage layer is placed beneath the graded crushed aggregate base. Where the total thickness of pavement structure is less than 12 in (300 mm), the drainage layer may be placed directly beneath the surface layer and the drainage layer used as a base. When the drainage layer is placed beneath an unbound aggregate base, care must be taken to limit the material passing the No. 200 (0.08 mm) sieve in the aggregate base to 8 percent or less.

20-3.5.3 Separation Layer.

The drainage layer must be protected from contamination of fines from the underlying layers by a separation layer to be placed directly beneath the drainage layer. In most cases the separation layer should be a graded aggregate material meeting the requirements of a 50 CBR subbase and can be considered as part of the subbase. For design situations where a firm foundation already exists and thickness of the separation layer is not needed in the structure for protection of the subgrade, a filter fabric may be substituted for the granular separation layer. In frost areas the separation layer should be NFS.

20-3.6 Material Properties for Drainage Layers.

The material for a drainage layer should be a hard, durable crushed aggregate to withstand degradation under construction traffic as well as in service traffic. The gradation of the material should be such that the material has sufficient stability for the operation of construction equipment. While it is desirable for strength and stability to have the well-graded aggregate, the permeability of the material must be maintained. For most drainage layers, the drainage materials should have a minimum permeability of 1,000 ft/day (300 m/day). Two materials, a rapid draining material (RDM) and an open graded material (OGM), have been identified for use in drainage layers. The RDM is a material having a sufficiently high permeability (1,000 ft/day to 5,000 ft/day (1,500 m/day)) to serve as a drainage layer and will also have the stability to support construction equipment and the structural strength to serve as a base or a subbase. The OGM is a material having a very high permeability (greater than 5,000 ft/day) which can be used for a drainage layer. The OGM will normally require stabilization for construction stability and for structural strength to serve as a base in a flexible pavement. Gradation limits for the two materials are given in Table 20-3 and the design properties are given in Table 20-4. The gradations given in Table 20-3 provide very wide bands and it is possible to produce gradations within these bands that may not be sufficiently stable for construction without the use of chemical stabilization. Table 20-5 provides the gradation specifications for three aggregate materials each of which will meet the criteria for stability. These gradations were developed to produce the maximum density given maximum aggregate sizes of 1-1/2 in (38 mm), 1 in (25mm), and 3/4 in (19mm) and a maximum of 8 percent passing the number 16 sieve. For drainage layer thicknesses less than 6 in (150 mm). gradations number 1 or 2 may be used. For drainage layers 6 in. or more in thickness any of the three gradations may be used but the gradations having the larger size aggregates will produce the more stable aggregate. Each of the gradations would produce a drainage layer having a permeability of about 1000 ft/day.

20-3.6.1 Aggregate for Separation Layer.

The separation layer prevents fines from infiltrating or pumping into the drainage layer and provides a working platform for construction and compaction of the drainage layer. The material for the separation layer should be a graded aggregate meeting the requirements of a 50 CBR subbase as given in Chapter titled Flexible Pavement Select Materials and Subbase Courses except that the maximum aggregate size should not be greater than 1/4 the thickness of the separation layer. The permeability of the separation layer should be greater than the permeability of the subgrade, but the material should not be so open as to permit pumping of fines into the separation layer. To prevent pumping of fines the ratio of d_{15} of the separation layer to d_{85} of the subgrade must be equal to or less than 5. The material property requirements for the separation layer are given in Table 20-6.

Table 20-3 Gradations of Materials for Drainage Layers and Choke Stone

Drainage Layer Material			
Sieve Designation (in)	**Rapid Draining Material**	**Open Graded Material**	**Choke Stone**
1-1/2 in (38 mm)	100	100	100
1 in (25 mm)	70-100	95-100	100
3/4 in (19 mm)	55-100	--	100
1/2 in (13 mm)	40-80	25-80	100
3/8 in (10 mm)	30-65	--	80-100
No. 4 (5 mm)	10-50	0-10	10-100
No. 8 (2 mm)	0-25	0-5	5-40
No. 16 (1 mm)	0-5	--	0-10

Table 20-4 Properties of Materials for Drainage Layers

Property	Rapid Draining Material	Open Graded Material
Permeability in feet/day (m/sec)	1,000-5,000 (300-1,500)	> 5,000 (> 1,500)
Effective Porosity	0.25	0.32
Percent Fractured Faces (COE method)	90% for 80 CBR 75% for 50 CBR	90% for 80 CBR 75% for 50 CBR
C_v	> 3.5	--
LA Abrasion	< 40	< 40
Note: C_v is the uniformity coefficient = D60/D10.		

Table 20-5 Material Gradations for Drainage Layers

Sieve Size	Gradation No. 1 3/4 in (19 mm) max.		Gradation No. 2 1 in (25 mm) max.		Gradation No. 3 1-1/2 in (38 mm)max	
	Percent Passing	Tolerance	Percent Passing	Tolerance	Percent Passing	Tolerance
1-1/2 in (38 mm)					100	-5
1 in (25 mm)			100	-5	79	±8
3/4 in (19 mm)	100	-5	85	±8	66	±8
1/2 in (13 mm)	78	±8	65	±8	52	±8
3/8 in (10 mm)	63	±8	53	±8	42	±8
No. 4 (5 mm)	38	±8	32	±6	25	±6
No. 8 (2 mm)	19	±6	16	±6	12	±4
No. 16 (1 mm)	4	±4	4	±4	4	±4

Table 20-6 Criteria for Granular Separation Layer

Maximum Aggregate Size	Lesser of 2 in (50 mm) or 1/4 of layer thickness
Maximum CBR	50
Maximum Percent Passing No. 10 (2 mm)	50
Maximum Percent Passing No. 200 (0.08 mm)	15
Maximum Liquid Limit	25
Maximum Plasticity Index	5
d_{15} of Separation Layer to d_{85} of Subgrade	$\leq$ 5

20-3.6.2 Filter Fabric for Separation Layer.

Although filter fabric provides protection against pumping, it does not provide extra stability for compaction of the drainage layer. Therefore, fabric should be selected only when the subgrade provides adequate support for compaction of the drainage layer. The important characteristics of the fabric are strength for surviving construction and traffic loads, and AOS to prevent pumping of fines into the drainage layer. Filter fabric for separation must be a nonwoven needle punched fabric meeting the criteria given in Table 20-7.

Table 20-7 Criteria for Filter Fabric to be Used as a Separation Layer

	Criteria	ASTM Test Method
50 Percent or Less Passing No. 200 Sieve	AOS (mm) < 0.6 mm Greater than No. 30 sieve	D4751
Greater Than 50 Percent Passing No. 200 Sieve	AOS (mm) < 0.297 Greater than No. 50 sieve	D4751
Minimum Grab Strength in lb (kN) at 50% Elongation	0.8 (180)	D4632/D4632M
Minimum Puncture Strength in lb (kN)	0.35 (80)	D4833/D4833M

20-4 STABILIZATION OF DRAINAGE LAYER.

Stabilization of OGM is normally required for stability and strength, and to prevent degradation of the aggregate in handling and compaction. Stabilization may also be used when high quality crushed aggregate is not available and there may even be occasions when stabilization of RDM is necessary. Stabilization may be accomplished mechanically by use of a choke stone or by the use of a binder such as asphalt or Portland cement.

20-4.1 Choke Stone Stabilization.

A choke stone is a small size stone used to stabilize the surface of an OGM. The choke stone should be a hard, durable, crushed aggregate having 90 percent fractured faces. The ratio of d_{15} of the coarse aggregate to the d_{15} of the choke stone must be less than 5, and the ratio of the d_{50} of the coarse aggregate to d_{50} of the choke stone must be greater than 2. The gradation range for acceptable choke stone is given in Table 20-3.

20-4.2 Asphalt Stabilization.

Stabilize the drainage material with asphalt by using only enough asphalt to coat the aggregate. Take care to not fill the voids with excess asphalt. Asphalt grade used for stabilization should be AC20 or higher. For stabilization of OGM, 2 to 2-1/2 percent asphalt by weight should be sufficient to coat the aggregate. Higher rates of application may be necessary when stabilization of less open aggregate such as RDM is necessary.

20-4.3 Cement Stabilization.

As with asphalt stabilization, Portland cement stabilization should only use enough cement paste to coat the aggregate, and take care to not fill the voids with excess paste. The amount of Portland cement required should be about 2 bags/yd^3 (170 kilograms per cubic meter) depending on the gradation of the aggregate. The water-cement ratio should be just sufficient to provide a paste which will adequately coat the aggregate.

20-5 COLLECTOR DRAINS.

20-5.1 Design Flow.

Provide collector drains to collect and transport water from under the pavement. For pavements having drainage layers, provide the drainage layers with a means for water to drain either with a collector or ditches. The collector system should have the capacity to handle the water from the drainage layer plus water from other sources. The water entering the collector system from the drainage layer is computed assuming the drainage layer is flowing full. Thus, the volume of water (*Q*) in cubic feet per day per foot (cubic millimeters per second per meter) of length of collector pipe (assuming the drainage layer is only on one side of the collector) would be

Equation 20-20 $$Q = 1000 \times H \times i \times k \text{ in cubic mm per second per meter}$$

or

Equation 20-21 $$Q = H \times i \times k \text{ in cubic ft per day per foot}$$

where

H=thickness of the drainage layer, ft (mm)

i=slope of the drainage layer

k=permeability of the material in the drainage layer, ft/day (mm/sec)

If the collector system has water entering from both sides, the volume of water entering the collector would be twice that given by equation 20-20.

20-5.2 Design of Collector Drains.

20-5.2.1 Drain System Layout.

Normally, the collector drains are equally spaced along the shoulder of the pavement. The system consists of the drain pipe, flushing and observation risers, manholes, discharge laterals, filter fabric, and trench backfill. Since placement of subsurface drains under pavements may be a source of differential settlement or heave, this should be avoided when possible. The drainage system for large areas of pavement may require placement of subsurface drains under the pavement. For these cases the subsurface drains should be placed to avoid high traffic areas. In areas of extreme cold temperatures and heavy snow buildup laterals must be placed to reduce the probability of the laterals or outlets becoming clogged with ice or snow. Also in areas of extreme cold temperatures it may not be possible to place the collector drains below the depth of frost penetration therefore it is possible that the collector pipe may be filled with ice while thawing is occurring near the surface. For this case provisions must be made to drain the upper portion of the pavement either by day-lighting the drainage layer or providing special laterals to drain the drainage layer.

20-5.2.2 Collector Pipe.

The collector pipe may be perforated flexible, Acrylonitrile-Butadiene-Styrene, corrugated polyethylene (CPE) or smooth rigid polyvinyl chloride pipe (PVC). Pipe must conform to the appropriate AASHTO Specification. Most State Highway Agencies use either CPE or PVC. For CPE pipe, AASHTO specification M 252 “Corrugated Polyethylene Drainage Tubing” is suggested, while for PVC pipe, AASHTO Specification M 278, “Class PC 50 PVC Pipe,” is recommended. It is recommended that asphalt stabilized material not be used as backfill around pipe, but, if it is to be used, then the pipe should be PVC 90 degrees C electric plastic conduct, EPC40 or EPC80 conforming to the requirements of National Electrical Manufacturers Association Specification TC2. Geocomposite edge drains (strip drains) may be used in special situations but only with the approval of the Government Civil Engineer. Geocomposite edge drains should only be considered for pavements not having a drainage layer.

20-5.2.3 Pipe Size and Slopes.

The pipe must be sized, according to equations 20-22 or 20-23, to have a capacity sufficient to collect the peak flow from under the pavement. Equations 20-22 and 20-23 are Manning equations for computing the capacity of a full flowing circular drain. The equation for flow (*Q*) in cubic feet per second is:

Equation 20-22 $$Q = \frac{1.486}{n} \cdot (A) \cdot \left[\frac{d}{4}\right]^{2/3} \cdot \left(s^{1/2}\right)$$

where

n = coefficient of roughness for the pipe
A = area of the pipe, ft^2
d = pipe diameter, ft
s = slope of the pipe invert

For metric units the equation for flow in cubic meters per second is:

Equation 20-23 $$Q = \frac{1.0}{n} \cdot (A) \cdot \left[\frac{d}{4}\right]^{2/3} \cdot \left(s^{1/2}\right)$$

where

n and s are as defined in equation 20-22
A = pipe area, m^2
d = pipe diameter, m

The coefficient of roughness for different pipe types can be obtained from Table 20-8 Except for long intercepting lines and extremely severe groundwater conditions, 6 in (150 mm) diameter drains should be satisfactory for most subsurface drainage installations. The minimum size pipe recommended for all collector drains is a 6 in (150 mm) diameter pipe. The recommended minimum slope for subdrains is 0.15 percent.

Table 20-8 Coefficient of Roughness for Different Types of Pipe

Type of Pipe	Coefficient of Roughness, *n*
Clay, concrete, smooth-wall plastic, and Asbestos-cement	0.013
Bituminous-coated, non-coated corrugated metal pipe or corrugated metal pipe	0.024

20-5.3 Placement of the Drainage Layer and Collector Drains.

20-5.3.1 Design.

In general the drainage layer is placed below the concrete surface in the case of rigid pavement and below the base course for a flexible pavement as illustrated in Figure C20-7, Figure C20-8, and Figure C20-9 (Appendix C). In most cases the trench for the collector drains should be constructed of sufficient width to provide 6 in (150 mm) clearance on each side of the pipe. The depth of the trench must be sufficient to provide a minimum 12 in (300 mm) from the top of the pavement subgrade to the center of the pipe plus 3 in (75 mm) clearance beneath the pipe. In frost areas extra care must be used in placing subsurface drains. For F3 and F4 subgrades a collector pipe will always be placed such that there will be positive drainage for the drainage layer and any NFS fill. If possible the drains should be placed below the depth of frost penetration. For many locations it will not be economically possible to place drains below the depth of frost penetration and therefore the drains and backfill will be subject to freezing. In areas where the depth of frost penetration is greater than 4 ft (1.2 m) below the bottom of the drainage layer, the top of the pipe need not be located deeper than 4 ft (1.2 m) below the bottom of the drainage layer. In frost areas where differential heave will cause pavement problems, the sides of the trench must be sloped not steeper than 1 vertical on 10 horizontal for the depth of frost penetration. At the edge of the pavement, where the pavement will not be subjected to traffic, the sides of the trench may be sloped at a slope of 1 vertical on 4 horizontal. The sloping of the trench sides is not required for the parts of the trench in NFS materials or for F1 or S1 soils unless the pavement over the trench is subjected to high speed traffic. The placement of collector drains under the interior portion of a pavement in frost areas is a special case where the collector drain is not directly connected to the drainage layer by an OGM or a RDM. This case is illustrated in Figure C20-7, Figure C20-8, and Figure C20-9 (Appendix C). The interior designs are based on the premise that NFS fill will have sufficient permeability to allow vertical drainage of the drainage layer into the collector pipes. Another premise is that the filter fabric will have sufficient area as not to impede the flow of water from the NFS fill to the collector pipe. The exception to the minimum requirement for the depth of the collector pipe below the surface of the subgrade is the interior case in a frost area for an F3 or F4 subgrade when the collection pipe is in above the depth of frost penetration. For this case the depth of the pipe below the surface of the subgrade is to be kept to a minimum.

20-5.3.2 Backfill.

Backfill the trench with a permeable material to rapidly convey water to the drainage pipe. The backfill material may be OGM, RDM, or other uniform graded aggregate. Place a minimum of 3 in (75 mm) of aggregate beneath the drainage pipe. Proper compaction or chemical stabilization of the backfill is necessary to prevent settlement of the fill. In placing the backfill, compact the backfill in lifts not exceeding 6 in (150 mm). When geocomposites are used in place of pipe, place the geocomposites against the material to be drained and thus the backfill is not expected to convey water. For this reason the backfill for the geocomposites will not require the high permeability required for the backfill around the pipe drains. However, since the backfill for the geocomposites will be against the side of the trench, the backfill should meet the requirements of a granular filter.

20-5.3.3 Geotextiles in the Trench.

Provide the trench with a geotextile filter fabric. Place the filter fabric to separate the permeable backfill of the trench from the subgrade or subbase materials. The filter fabric must not be placed so as to impede the flow of water from the drainage layer to the drain pipe. The filter fabric must also protect from the infiltration of fines from any surface layer. This is particularly important for drains placed outside the pavement area where surface water can enter the drain through a soil surface. The filter fabric for the trench must be a nonwoven needle punched fabric meeting the criteria given in Table 20-9.

Table 20-9 Criteria for Fabrics Used in Trench Construction

	ASTM Test Method	Criteria
Soil With 50 Percent or Less Passing No. 200 Sieve	D 4751	AOS < Sieve No. 30 (0.6 mm)
Soil With Greater Than 50 Percent Passing No. 200 Sieve	D 4751	AOS < Sieve No. 50 (0.3 mm)
Minimum Grab Strength in lb (kN) at 50% Elongation	D4632/D4632M	130 (0.6)
Minimum Puncture Strength in lb (kN)	D4833/D4833M	55 (0.25)

20-5.3.4 Trench Cap.

Cap edge drains placed outside of a paved area with a layer of low permeability material, such as an asphalt stabilized surface, to reduce the infiltration of surface water into the subsurface drainage system. If the area above the edge drain is to be sod surfaced, a filter layer will be required between the drain layer and sod.

20-5.4 Lateral Outlet Pipe.

20-5.4.1 Design.

The lateral outlet pipe provides both a means of getting water out of the edge drains, and for cleaning and inspecting the system as illustrated in Figure C20-10 and Figure C20-12 (Appendix C). Provide edge drains with lateral outlet pipes spaced at intervals 300 to 500 ft (90 to 150 m) along the edge drains and at the low point of all vertical curves. To facilitate drain cleanout, the outlet pipes should be placed at about a 45 degrees angle from the direction of flow in the collector drain. The lateral pipe should be a non-perforated solid-walled pipe and should be equipped with an outlet structure. A three percent slope from the edge drain to the outlet structure is recommended. To reduce outlet maintenance, outlet pipes should, where possible, be connected to existing storm drains or inlets. For lateral pipe flowing to a ditch, the invert of the outlet pipe should be a minimum of 6 in (150 mm) above the 2-year design flow in the ditch. To prevent piping, the trench for the outlet pipes must be backfilled with a material of low permeability, or provided with a cutoff wall or diaphragm. Dual outlets with large radius bend are recommended for maintenance considerations, as shown in Figure C20-11 (Appendix C). The dual outlet system allows sections of collector drains to be flushed out to clear any debris material blocking the free flow of water. Other recommended design details for drainage outlets are as follows:

- For pipe drains, use the same diameter pipe as the collector drains. For prefabricated geocomposite drains, 4 in (100 mm) to 6 in (150 mm) diameter pipe should provide adequate hydraulic capacity. The flow capacity of the outlets must be greater than that of the collector drains. In general, because of the greater slope provided for outlet pipes, the hydraulic capacity is not a problem.
- The discharge end of the outlet pipe should be placed at least 6 in (150 mm) above the 2 year design flow in the drainage ditch. The same requirement applies even if the outlet is discharging into storm drain inlets.
- In frost areas, give special attention to the placement of the outlet pipes such that they do not become clogged with ice or snow.

20-5.4.2 Outfall for Outlet Pipe.

The outfall for the outlet pipe should be provided with a headwall to protect the outlet pipe from damage, prevent slope erosion, and facilitate the location of outlet pipes. Place headwalls flush with the slope so that mowing operations are not impaired. Easily removed rodent screens should be installed at the pipe outlet. The headwall may be pre-cast or cast-in-place.

20-5.4.3 Reference Markers.

Although not a requirement, reference markers are recommended for the outlets to facilitate maintenance and observation. A simple flexible marker post or marking on the shoulder will suffice to mark the outlet.

20-5.5 Cross Drains.

Cross drains may be required at locations where flow in the drainage layer is blocked, on steep longitudinal grades where the water needs to be intercepted to prevent long drainage paths, or at the bottom of vertical curves. For example, cross drains may be required where pavements abut building foundations, at bridge approach slabs, or where drainage layers abut impermeable bases.

20-5.6 Manholes and Observation.

Manholes, observation basins, and risers are installed on subsurface drainage systems for access to the system to observe its operation and to flush or rod the pipe for cleaning. Manholes on subgrade pipe drains should be located at intervals of not over 1,000 ft (300 m) with one flushing riser located between manholes and at dead ends. Manholes should be provided at principal junction points of several drains.

CHAPTER 21 DESIGN OF AGGREGATE SURFACES

21-1 GENERAL.

The thickness design of aggregate surfaced roads and parking areas is similar to the design of flexible pavement as described in Chapter titled Flexible Pavement Design. This procedure involves selecting a vehicle mix or traffic, as explained in Chapter titled Vehicular Traffic, a subgrade CBR, and using unsurfaced design criteria contained within the PCASE software. The procedure determines total thickness of material to be placed above the subgrade, as well as its required strength in relation to the CBR value. A computer program is available for determining pavement thickness and compaction requirements and may be obtained as described in paragraph titled Pavement-Transportation Computer Assisted Structural Engineering.

21-2 ENTRANCES, EXITS, AND SEGMENTS.

Special consideration should be given to the design of approach roads, exit roads, and other heavily trafficked areas. Early failure or poor performance may be expected in these areas due to the channelized traffic. Since these areas will almost certainly be subjected to more frequent and heavier loads than the road, the design should be based on vehicular loads and passes usually used for primary road designs. In the case of large hardstands having multiple use and multiple entrances and exits, consideration should be given to partitioning and using different design sections. The immediate benefits that would accrue include economy through elimination of overdesign in some areas and better organization of vehicles and equipment.

21-3 THICKNESS CRITERIA (NON-FROST AREAS).

Refer to UFC 3-201-01 for minimum thickness requirements. Thickness requirements for aggregate surfaced roads and parking areas are determined using the PCASE software for a given soil strength and design vehicles and pass levels. Since roads and parking areas are usually designed for equivalent 18-kip (8,200-kg) axles, the design chart in Figure 21-1 is provided for convenience. The computed design thickness may be constructed of compacted granular fill for the total depth over the natural subgrade or in a layered system of granular fill (including subbases) and compacted subgrade for the same total depth. The layered section should be checked to ensure that an adequate thickness of material is used to protect the underlying layer and if it also meets the minimum surface CBR required. The granular fill may consist of base and subbase material provided the top 6 in (150 mm) meet the gradation requirements in Table 21-1.

21-4 FROST AREA CONSIDERATIONS.

In areas where frost effects have an impact on the design of pavements, additional considerations concerning thicknesses and required layers in the pavement structure must be addressed. The specific areas where frost has an impact on the design are discussed in the following paragraphs; however, a more detailed discussion of frost effects is presented in Chapter titled Seasonal Frost Conditions. For frost design purposes, soils have been divided into groups as shown in Table 19-2. Only the NFS group is suitable for base course. NFS, S1, or S2 soils may be used for subbase course and any of the eight groups may be encountered as subgrade soils. Soils are listed in approximate order of decreasing bearing capability during periods of thaw.

Figure 21-1 Aggregate Surfaced Design Chart; 18-kip Axle (8,200-kg)

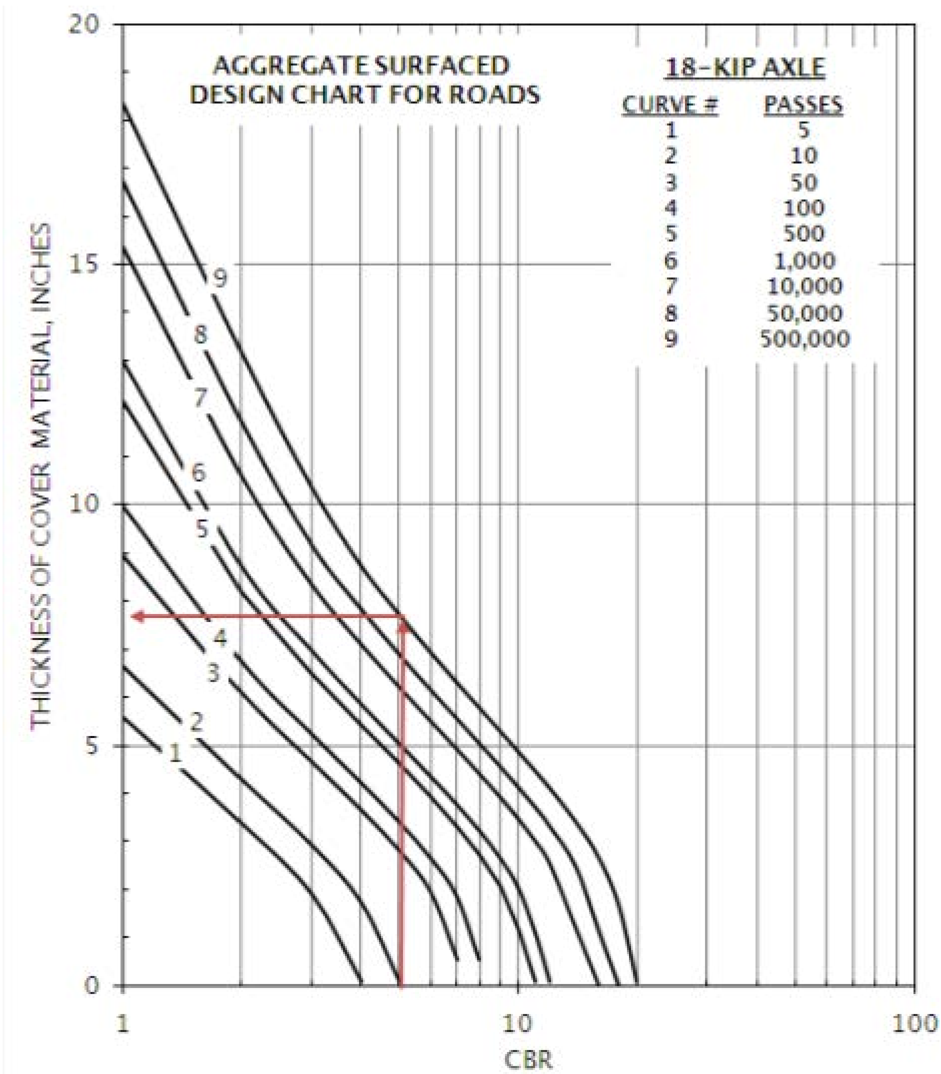


Table 21 1 Gradation for Aggregate Surface Courses

Sieve Designation	No. 1	No. 2	No. 3	No. 4
1 in (25 mm)	100	100	100	100
3/8 in (10 mm)	5-85	60-100	---	---
No. 4 (5 mm)	35-65	50-85	55-100	70-100
No. 10 (2 mm)	25-50	40-70	40-100	55-100
No. 40 (0.4 mm)	15-30	24-45	20-50	30-70
No. 200 (0.08 mm)	8-15	8-15	8-15	8-15
Note: The percent by weight finer than 0.02 mm must not exceed 3 percent.				

21-4.1 Required Thickness.

Where frost susceptible subgrades are encountered, determine the section thickness required according to the reduced subgrade strength method. The reduced subgrade strength method requires the use of frost area soil support indexes listed in Table 19-3. Frost-area soil support indexes are used as if they were CBR values; the term CBR is not applied to them, however, because, being weighted average values for an annual cycle, their values cannot be determined by CBR tests.

21-4.2 Required Layers in Pavement Section.

When frost is a consideration, it is recommended that the pavement section consist of a series of layers that will ensure the stability of the system, particularly during thaw periods. The layered system in the aggregate fill may consist of a wearing surface of fine crushed stone, a coarse-graded base course, a well-graded subbase of sand or gravelly sand. To ensure the stability of the wearing surface, the width of the base course and subbase should exceed the final desired surface width by a minimum of 12 in (300 mm) on each side.

21-4.3 Wearing Surface.

The wearing surface contains fines to provide stability in the aggregate surface. The presence of fines helps the layer's compaction characteristics and helps to provide a relatively smooth riding surface.

21-4.4 Base Course.

The coarse-graded base course is important in providing drainage of the granular fill. It is also important that this material be NFS so that it retains its strength during spring thaw periods.

21-4.5 Subbase.

The well-graded sand subbase is used for additional bearing capacity over the frost susceptible subgrade and as a filter layer between the coarse-graded base course and the subgrade to prevent the migration of the subgrade into the voids in the coarser material during periods of reduced subgrade strength. The material must therefore meet standard filter criteria. The sand subbase must be either NFS or of low frost susceptibility (S1 or S2). The filter layer may or may not be necessary depending upon the type of subgrade material. If the subgrade consists principally of gravel or sand, the filter layer may not be necessary and may be replaced by additional base course if the gradation of the base course is such that it meets filter criteria. However, for finer grained soils, the filter layer will be necessary. If a geotextile is used, the sand subbase or filter layer may be omitted as the fabric will be placed directly on the subgrade and will act as a filter.

21-4.6 Compaction.

Compact the subgrade to provide uniformity of conditions and a firm working platform for placement and compaction of subbase. Compaction of subgrade does not change its frost-area soil support index because frost action causes the subgrade to revert to a weaker state. Hence, in frost areas, the compacted subgrade is not considered part of the layered system of the road which is comprised of only the wearing, base, and subbase courses.

21-4.7 Thickness of Base Course and Filter Layer.

Relative thicknesses of the base course and filter layer are variable and should be based on the required cover and economic conditions.

21-4.8 Alternate Design.

The reduced subgrade strength design procedure provides the thickness of soil required above a frost-susceptible subgrade to minimize frost heave. To provide a more economical design, a frost susceptible select material or subbase may be used as a part of the total thickness above the frost susceptible subgrade. However, the thickness above the select material or subbase must be determined by using the Frost Area Soil Support Index (FASSI) of the select or subbase material. Where frost-susceptible soils are used as select materials or subbases, they must meet the requirements of current specifications except that the restriction on the allowable percent finer than 0.02 mm is waived.

21-5 SURFACE COURSE REQUIREMENTS.

The requirements for the various materials to be used in the construction of aggregate surfaced roads and parking areas are dependent upon whether or not frost is a consideration in the design.

21-5.1 Non-Frost Areas.

The material used for gravel surfaced roads and parking areas should be sufficiently cohesive to resist abrasive action. It should have a liquid limit no greater than 35 and a plasticity index between 4 and 9. It should also be graded for maximum density and minimum volume of voids to enhance optimum moisture retention while resisting excessive water intrusion. The gradation, therefore, should consist of the optimum combination of coarse and fine aggregates that will ensure minimum void ratios and maximum density. Such a material will then exhibit cohesive strength as well as inter-granular shear strength. Recommended gradations are as shown in Table 21-1. If the fine fraction of the material does not meet plasticity characteristics, modification by addition of chemicals might be required. Chloride products can, in some cases, enhance moisture retention, and lime can be used to reduce excessive plasticity.

21-5.2 Frost Areas.

As previously stated, where frost is a consideration in the design of roads and parking areas, a layered system should be used. The percentage of fines should be restricted in all the layers to facilitate drainage and reduce the loss of stability and strength during thaw periods. Gradation numbers 3 and 4 shown in Table 21-1 should be used with caution since they may be unstable in a freeze-thaw environment.

21-6 COMPACTION REQUIREMENTS.

Compaction requirements for the subgrade and granular layers are expressed as a percent of maximum density as determined by ASTM D1557. For the granular layers, the material must be compacted to 100 percent of the maximum ASTM D698 density. Select materials and subgrades in fills must have densities equal to or greater than the values shown in Table 21-2, except that fills will be placed at no less than 95 percent compaction for cohesionless soils (PI < 5; LL < 25) or 90 percent compaction for cohesive soils (PI > 5; LL > 25). Subgrades in cuts must have densities equal to or greater than the values shown in Table 21-2. Subgrades occurring in cut sections must be either compacted from the surface to meet the densities shown in Table 21-2, removed and replaced before applying the requirements for fills, or covered with sufficient material so that the un-compacted subgrade is at a depth where the in-place densities are satisfactory. The depths shown in Table 21-2 are measured from the surface of the aggregate road and not the surface of the subgrade.

Table 21-2 Compaction Depth Requirements for Aggregate Surfaces

Equivalent Passes of an 18,000-lb (8,200-kg) ESAL	Depth of Compaction or Percent Compaction Shown, in								
	Cohesive Soils PI > 5, LL > 25					Cohesionless Soils PI ≤ 5, LL ≤ 25			
	100	95	90	85	80	100	95	90	85
< 15,500	2	4	6	7	9	4	7	10	13
< 67,500	3	5	7	9	11	5	8	12	16
< 295,000	3	5	8	10	13	5	10	14	18
< 1.3 million	3	6	9	12	14	6	11	16	21
< 5.7 million	4	7	10	13	16	7	12	18	23
< 25 million	4	7	11	15	18	7	14	20	26
< 112 million	4	8	12	16	20	8	15	22	29
< 500 million	5	9	13	18	22	9	17	24	31
< 2,200 million	5	10	15	20	25	10	19	28	35
≥ 2,200 million	6	11	17	22	27	11	21	30	38
Symbols: < less than, > greater than; ≥ greater than or equal to. mm = inches x 25.4									

21-7 DRAINAGE REQUIREMENTS.

Adequate surface drainage should be provided to minimize moisture damage. Expeditious removal of surface water reduces the potential for absorption and ensures more consistent strength and reduced maintenance. Drainage, however, must be provided in a way to preclude damage to the aggregate surfaced road through erosion of fines or erosion of the entire surface layer. Also, care must be taken to ensure that the change in the overall drainage regime as a result of construction can be accommodated by the surrounding topography without damage to the environment or to the newly constructed road or airfield.

The surface geometry of a road should be designed so that drainage is provided at all points. Depending upon the surrounding terrain, surface drainage of the roadway can be achieved by a continual cross slope or by a series of two or more interconnecting cross slopes. The entire area should consist of one or more cross slopes having a gradient that meet the requirements of UFC 3-201-01. Judgment is required to arrange the cross slopes to remove water from the road at the nearest possible points while taking advantage of the natural surface geometry to the greatest extent possible.

Adequate drainage must be provided outside the road or airfield area to accommodate maximum possible drainage flow from the road. Ditches and culverts must be provided for this purpose. Culverts should be used sparingly and only in areas where adequate cover of granular fill is provided over the culvert. Additionally, adjacent areas and their drainage provisions should be evaluated to determine if rerouting is needed to prevent water from other areas flowing across the road or airfield.

Drainage is a critical factor in aggregate surface roads and parking area construction, and maintenance. Therefore, drainage should be considered before construction, and when necessary, serve as a basis for site selection.

21-7.1 Materials.

A wide selection of materials for dust control is available to the engineer. No one choice, however, can be singled out as being the most universally acceptable for all problem situations that may be encountered. However, several materials have been recommended for use and are discussed in UFC 3-260-17.

21-8 DESIGN EXAMPLES.

Appendix G contains two design examples of unsurfaced aggregate roads.

APPENDIX A REFERENCES

UNIFIED FACILITIES CRITERIA

http://www.wbdg.org/ccb/browse_cat.php?o=29&c=4

UFC 1-200-01 *DoD Building Code (General Building Requirements)*

UFC 3-201-01 - *Civil Engineering*

UFC 3-250-03 - *Bituminous Pavements Standard Practice*

UFC 3-250-04 - *Standard Practice for Concrete Pavements*

UFC 3-250-11 - *Soil Stabilization for Pavements*

UFC 3-260-02 - *Flexible Pavement Design for Airfields*

UFC 3-260-03 - *Flexible Airfield Pavement Evaluation*

UFC 3-260-17 - *Dust Control for Roads, Airfields, and Adjacent Areas*

AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS (AASHTO)

AASHTO M 288 - Standard Specification for Geotextile Specification for Highway Applications

AASHTO MEPDG - Mechanistic-Empirical Pavement Design Guide: A Manual of Practice

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM),
1916 Race St., Philadelphia, PA 19103

ASTM C78/C78M - Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)

ASTM D560/560M/560M - Standard Test Methods for Freezing and Thawing Compacted Soil-Cement Mixtures

ASTM D698 - Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft3 (600 kN-m/m3))

ASTM D1557 - Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft3 (2,700 kN-m/m3))

ASTM D1883 - Standard Test Method for California Bearing Ratio (CBR) of Laboratory-Compacted Soils

ASTM D2487 - Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)

ASTM D4429 - Standard Test Method for CBR (California Bearing Ratio) of Soils in Place

ASTM D4632/D4632M - Standard Test Method for Grab Breaking Load and Elongation of Geotextiles

ASTM D4751 - Standard Test Method for Determining Apparent Opening Size of a Geotextile

ASTM D4833/D4833M - Standard Test Method for Index Puncture Resistance of Geomembranes and Related Products

ASTM D6951/D6951M - Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications

APPENDIX B BEST PRACTICES

B-1 CONSTRUCTION OF THE DRAINAGE LAYER.

B-1.1 Experience.

Construction of drainage layers can present problems in handling, placement, and compaction. If the drainage material does not have adequate stability, major problems can develop in the placement of the surface layer above the drainage layer. Experience with highly permeable bases (drainage layers) both by the Corps of Engineers and various State Departments of Transportation indicates that pavements containing such layers can be constructed without undue difficulties provided due precautions are taken. The real key to successful construction of the drainage layers is the training and experience of the construction personnel. Before start of construction, instruct the construction personnel in the handling and placing of the drainage material. The placement of test strips is recommended for training of the construction personnel.

B-1.2 Placement of Drainage Layer.

Place the material for the drainage layer in a manner to prevent segregation and to obtain a layer of uniform thickness. The materials for the drainage layer require extra care in stockpiling and handling. Placement of the RDM and OGM is best accomplished using an asphalt concrete paver. To ensure good compaction, the maximum lift thickness should be no greater than 6 in (150 mm). If choke stone is used to stabilize the surface of OGM, place the choke stone after compaction of the final lift of OGM. Spread the choke stone in a thin layer no thicker than 1/2 in (10 mm) using a spreader box or asphalt paver. Work the choke stone into the surface of the OGM by the use of a vibratory roller and by wetting. The choke stone remaining on the surface should not migrate into the OGM by the action of water or traffic.

B-1.3 Compaction.

Compaction is a key element in the successful construction of the drainage layer. Compaction control normally used in pavement construction is not appropriate for materials such as the RDM and OGM. It is therefore, necessary to specify compaction techniques and level of effort instead of the properties of the end product. It is important to place the drainage material in relatively thin lifts of 6 in (150 mm) or less and to have a good firm foundation beneath the drainage material. The recommended method of determining the required compaction effort is to construct a test section and closely monitor the aggregate during compaction to determine when crushing of the aggregate appears excessive. Experience indicates that sufficient compaction can be obtained by six passes or less of a vibratory roller loaded at about 10 short tons (9 metric tons). Material not being stabilized with asphalt or cement should be kept moist during compaction. Asphalt stabilized material for drainage layers must be compacted at a somewhat lower temperature than a dense-graded asphalt material. In most cases, it will be necessary to allow an asphalt stabilized material to cool to less than 200 degrees F (93 degrees C) before beginning compaction.

B-1.4 Protection after Compaction.

After compaction, protect the drainage layer from contamination by fines from construction traffic and from flow of surface water. It is recommended to place the surface layer as soon as possible after placement of the drainage layer. Take precautions to protect the drainage layer from disturbance by construction equipment. Only tracked asphalt pavers should be allowed for paving over any RDM or OGM that has not been stabilized. Drivers should avoid rapid acceleration, hard braking, or sharp turning on the finished drainage layer. Although curing of cement stabilized drainage layers is not critical, efforts should be made to protect cement stabilized drainage layers at curing until the surface layer is placed.

B-1.5 Proof Rolling.

Proof rolling is not normally required, but for roads and parking areas that are to be subjected to traffic of heavy vehicles, it is good practice to require proof rolling. In particular, proof rolling the separation layer before placement of a drainage layer is recommended. For flexible pavements constructed for heavy material handling equipment, it is recommended that the proof rolling be accomplished using a rubber-tired roller load to provide a minimum tire force of 20,000 lb (90 kN) and inflated to at least 90 psi (620 kPa). A minimum of six coverages should be applied, where a coverage is the application of one tire print over each point in the surface of the designated area. For rigid pavements and other flexible pavements, proof rolling of the separation layer may be accomplished using the rubber-tired roller described above or by using a truck having tandem axles with either dual tires or super single tires. The truck should be loaded to provide 20,000 lb per axle. During proof rolling, action of the separation layer must be monitored for any sign of excessive movement or pumping that would indicate soft spots in the separation layer or the subgrade. Since the successful placement of the drainage layer depends on the stability of the separation layer, all weak spots must be removed and replaced with stable material. All replaced material must be proof rolled as specified above.

B-2 CONSTRUCTION: SEASONAL FROST CONDITIONS

B-2.1 CONTROL OF SUBGRADE AND BASE COURSE CONSTRUCTION.

Personnel responsible for field control of pavement construction in areas of seasonal freezing should give specific consideration to conditions and materials that could result in detrimental frost action. In frost areas, the contract plans and specifications should require the subgrade preparation work as indicated in paragraph titled Subgrade Requirements. They also should provide for special treatments such as removal of unsuitable materials encountered with sufficient information included to identify those materials and specify necessary corrective measures. However, construction operations quite often expose frost-susceptible conditions at isolated locations of a degree and character not revealed by even the most thorough subsurface exploration program. It is essential, therefore, that personnel assigned to field construction control be alert to recognize situations that require special treatment, whether or not anticipated by the designing agency. They must also be aware of their responsibility for such recognition.

B-2.2 BASE COURSE CONSTRUCTION.

Where the available base course materials are well within the limiting percentages of fine material set forth above, the base course construction control should be in accordance with normal practice. In instances where the material selected for use in the top 50 percent of the total thickness of granular unbound base is borderline with respect to percentage of fine material passing the No. 200 sieve, or is of borderline frost susceptibility (usually materials having 1.5 to 3 percent of grains finer than 0.02 mm by weight), frequent gradation checks should be made to ensure that the materials meet the design criteria. If it is necessary for the contractor to be selective in the pit to obtain suitable materials, his operations should be inspected at the pit. It is more possible to reject unsuitable materials at the source when large volumes of base course are being placed. It may be desirable to stipulate thorough mixing at the pit and, if necessary, stockpiling, mixing in windrows, and spreading the material in compacted thin lifts to ensure uniformity. Finish surface stripping of pits should be enforced to prevent mixing of detrimental fine soil particles or lumps in the base material.

B-2.3 Gradation of Base Course Materials.

The gradation of base course materials after compaction should be determined often, particularly at the start of the job, to learn whether or not fines are being manufactured in the base under the passage of the compaction equipment. For base course materials exhibiting serious degradation characteristics, a test embankment may be needed to study the formation of fines by the proposed compaction process. Mixing of base course materials with frost susceptible subgrade soils should be avoided by making certain that the subgrade is properly graded and compacted before placement of base course, by ensuring that the first layer of base course filters out subgrade fines under traffic, and by eliminating the kneading caused by over compaction or insufficient thickness of the first layer of base course. Excessive rutting tends to cause mixing of subgrade and base materials. This can be greatly minimized by frequent rerouting of material-hauling equipment.

B-2.4 Visual Inspection.

After completion of each layer of base course, a careful visual inspection should be made before permitting additional material placement to ensure that areas with high percentages of fines are not present. In many instances these areas may be recognized both by examination of the materials and by observation of their action under compaction equipment, particularly when the materials are wet. The materials in any areas that do not meet the requirements of the specifications, which will reflect the requirements of this UFC, should be removed and replaced with suitable material. Do not use a leveling course of fine-grained material as a construction expedient to choke open-graded base courses, to establish fine grade, or to prevent overrun of concrete. Since the base course receives high stresses from traffic, this prohibition is essential to minimize weakening during the frost-melting period. Action should be taken to vary the base course thickness so as to provide transition, when this is necessary, to avoid abrupt changes in pavement supporting conditions.

B-3 MAINTENANCE OF SUBSURFACE DRAINAGE SYSTEMS.

B-3.1 Monitoring Program.

Commitment to maintenance is as important as providing subsurface drainage systems. In fact, an improperly maintained drainage system can cause more damage to the pavement structure than if no drainage were provided at all. Poor maintenance leads to clogged or silted outlets and edge-drain pipes, missing rodent screens, excessive growth of vegetation blocking outlet pipes and openings on day-lighted bases, and growth of vegetation in side ditches. These problems can potentially cause backing up of water within the pavement system, thereby defeating the purpose of providing the drainage system. Therefore, inspections and maintenance of subsurface drainage systems should be made an integral part of the policy of any agency installing these systems. The inspection process comprises of two parts: (a) visual inspection and (b) video inspection.

B-3.1.1 Visual Inspection.

The visual inspection process includes the following items:

(i) Evaluation of external drainage-related features, including measurement of ditch depths and checking for crushed outlets, excessive vegetative growth, clogged and debris-filled day-lighted openings, condition of headwalls, presence of erosion, and missing rodent screens. This operation should be performed at least once a year.

(ii) Pavement condition evaluation to check for moisture-related pavement distresses such as pumping, faulting, and D-cracking in PCC pavements and fatigue cracking and AC stripping in AC pavements. This operation could be either a full-scale Pavement Condition Index (PCI) survey or a brief overview survey, depending on agency needs. The recommended frequency for this activity is once every 2 years.

B-3.1.2 Video Inspection.

Video inspections play a vital role in monitoring in-service drainage systems. The video inspection process can be used to check for clogged drains due to silting and intrusion of surrounding soil, as well as any problems with the drainage system, such as ruptured pipes and broken connections. Video inspections should be carried out on an as-needed basis whenever there is evidence of drainage-related problems. A video inspection system typically consists of a camera head, long flexible probe mounted on a frame for inserting the camera head into the pipe, and a data acquisition unit fitted with a video screen and a video recorder. This system can be used to detect and correct any construction problems before a project is accepted. The construction-related problems that are easily detected using the video equipment include crushed or ruptured drainage pipes and improper connections between drainage pipes, as well as the connection between the outlet pipe and headwall.

B-3.2 Maintenance Guidelines.

B-3.2.1 Collector Drains and Outlets.

Flush the collector drains and outlets periodically with high-pressure water jets to loosen and remove any sediment that has built up within the system. The key to this operation is having the appropriate outlet details that facilitate the process, such as the dual headwall system shown in Figure C20-11 (Appendix C). Keep the area around the outlet pipes should be kept mowed to prevent any buildup of water. Repair or replace missing rodent screens and outlet markers, damaged pipes and headwalls need to be either repaired or replaced.

B-3.2.2 Day-lighted Systems.

Routine removal of roadside debris and vegetation clogging the day-lighted openings of a permeable or dense-graded base is very important for maintaining the functionality of these systems.

B-3.2.3 Drainage Ditches.

Mow the drainage ditches should be kept mowed to prevent excessive vegetative growth. Clean the bottom of the ditch of debris and silt deposited at the bottom of the ditch should be cleaned periodically to maintain the ditch line and to prevent water from backing up into the pavement system.

B-4 AGGREGATE ROADS

B-4.1 MAINTENANCE REQUIREMENTS.

The two primary causes of deterioration of aggregate surfaced roads and parking areas requiring frequent maintenance are environmental conditions and traffic. Rain or water flow wash fines from the aggregate surface and reduce cohesion, while traffic action causes displacement of surface materials. Maintenance should be performed at least every 6 months and more often if required. The frequency of maintenance will be high for the first few years of use but will decrease over time to a constant value. The majority of the maintenance will consist of periodic grading to remove the ruts and potholes that will inevitably be created by the environment and traffic and to replace fines. Occasionally during the lifetime of the road, the surface layer may have to be scarified, additional aggregate added to increase the thickness back to that originally required, and the wearing surface re-compacted to the specified density.

B-4.2 DUST CONTROL.

The primary objective of a dust palliative is to prevent soil particles from becoming airborne as a result of wind or traffic. Where dust palliatives are considered for traffic areas, they must withstand the abrasion of the wheels or tracks. An important factor limiting the applicability of the dust palliative in traffic areas is the extent of surface rutting or abrasion that will occur under traffic. Some palliatives will tolerate deformations better than others, but normally ruts in excess of 1/2 in (13 mm) will result in the virtual destruction of any thin layer or shallow-depth penetration dust palliative treatment. The abrasive action of tank tracks may be too severe for use of some dust palliatives in a traffic area.

APPENDIX C GLOSSARY

C-1 ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt concrete
ADT	Average Daily Traffic
AOS	Apparent Opening Size
ASR	Alkali-Silica Reaction
ASTM	American Society for Testing and Materials
CBR	California Bearing Ratio
CD	Compact Disk
CPE	Corrugated Polyethylene
DoD	Department of Defense
DoT	Department of Transportation
ESAL	Equivalent Single Axle Load
FASSI	Frost Area Soil Support Index
HEMTT	Heavy Expanded Mobility Tactical Truck
HET	Heavy Equipment Transport System
HMMWV	High Mobility Multipurpose Wheeled Vehicle
LCF	Lime-Cement-Fly Ash
LL	Liquid Limit
NFS	Non-Frost Susceptible
OGM	Open Graded Material
PCASE	Pavement-Transportation Computer Assisted Structural Engineering
PCC	Portland Cement Concrete
PCI	Pavement Condition Index
PI	Plasticity Index

PVC	Polyvinyl Chloride
RCCP	Roller-Compacted Concrete Pavement
RDM	Rapid Draining Material
UFC	Unified Facilities Criteria
UFGS	Unified Facility Guide Specifications
U.S.	United States
USACE	United States Army Corp of Engineering
USCS	Unified Soil Classification System

C-2 DEFINITION OF TERMS

Apparent Opening Size (AOS): A measure of the opening size of a geotextile. AOS is the sieve number corresponding to the sieve size at which 95 percent of the single-size glass beads pass the geotextile (O95) when tested in accordance with ASTM D4751.

Average Daily Temperature: The average of the maximum and minimum temperatures for a day, or the average of several temperature readings taken at equal time intervals, generally hourly, during a day.

Base Course: Course containing all granular unbound, chemical- or bituminous-stabilized material between the pavement surfacing layer and the un-treated, chemical or bituminous stabilized subgrade.

Bound Base: Chemical-stabilized or bituminous-stabilized soil used in the base and subbase course, consisting of a mixture of mineral aggregates and soil with one or more commercial stabilizing additives. Bound base is characterized by a significant increase in compressive strength of the stabilized soil compared with the untreated soil. In frost areas bound base usually is placed directly beneath the pavement surfacing layer where its high strength and low deformability make possible a reduction in the required thickness of the pavement surfacing layer or the total thickness of pavement and base, or both. If the stabilizing additive is Portland cement, lime, or lime-cement-fly ash (LCF), the term bound base is applicable only if the mixture meets the requirements for cement-stabilized, lime-stabilized, or LCF-stabilized soil set forth within this UFC and in UFC 3-250-11.

Boulder Heave: The progressive upward migration of a large stone present within the frost zone in a frost-susceptible subgrade or base course. This is caused by adhesion of the stone to the frozen soil surrounding it while the frozen soil is undergoing frost heave. The stone will be kept from an equal, subsequent subsidence by soil that will have tumbled into the cavity formed beneath the stone. Boulders heaved toward the surface cause extreme pavement roughness and may eventually break through the surface, necessitating repair or reconstruction.

Coefficient of Permeability: A measure of the rate at which water passes through a unit area of material in a given amount of time under a unit hydraulic gradient.

Choke Stone: A small size stone used to stabilize the surface of an OGM. For a choke stone to be effective, the ratio of d15 of the coarse aggregate to the d15 of the choke stone must be less than 5, and the ratio of the d50 of the coarse aggregate to d50 of the choke stone must be greater than 2.

Composite Pavement: Existing pavement to be overlaid with rigid pavement is composed of an all-bituminous or flexible overlay on a rigid base pavement.

Cumulative Damage: The process by which each application of traffic load or each cycle of climatic change produces a certain irreversible damage to the pavement. The pavement deteriorates continuously under successive load applications or climatic cycles.

Degree-Days: The Fahrenheit degree-days for any given day equal to the difference between the average daily air temperature and 32 degrees Fahrenheit. The degree-days are minus when the average daily temperature is below 32 degrees Fahrenheit (freezing degree-days) and plus when above (thawing degree-days). Figure 19-1 shows sample curves obtained by plotting cumulative degree-days against time.

Design Freezing Index: The average air freezing index of the three coldest winters in the latest 30 year of record. If 30 years of record are not available, the air freezing index for the coldest winter in the latest 10 year period may be used. To avoid the necessity of adopting a new and only slightly different freezing index each year, the design freezing index at a site with continuing construction need not be changed more than once in 5 year unless the more recent temperature records indicate a significant change in thickness design requirements for frost. The design freezing index is illustrated in Figure 19-1.

Drainage Layer: A layer in the pavement structure that is specifically designed to allow rapid horizontal drainage of water from the pavement structure. The layer is also considered to be a structural component of the pavement and may serve as part of the base or subbase.

Effective Porosity: The effective porosity is defined as the ratio of the volume of voids that will drain under the influence of gravity to the total volume of a unit of aggregate. The difference between the porosity and the effective porosity is the amount of water that will be held by the aggregate. For materials such as the RDM and OGM, the water held by the aggregate will be small; thus, the difference between the porosity and effective porosity will be small (less than 10 percent). The effective porosity may be estimated by computing the porosity from the unit dry weight of the aggregate and the specific gravity of the solids which then should be reduced by 5 percent to allow for water retention on the aggregate.

Flexible Base Pavement: Existing pavement to be overlaid is composed of bituminous concrete, base, and subbase courses.

Flexible Overlay: A flexible pavement (either all-bituminous or bituminous with base course) used to strengthen an existing rigid or flexible pavement.

Freezing Index: The number of degree-days between the highest and lowest points on a curve of cumulative degree-days versus time for one freezing season. It is used as a measure of the combined duration and magnitude of below-freezing temperatures occurring during any given freezing season. The index determined for air temperature about 4.5 ft (1.4 m) above the ground is commonly designated as the air freezing index, while that determined for temperatures immediately below a surface is known as the surface freezing index.

Frost Action: The general term for freezing and thawing of moisture in materials and the resultant effects on these materials and on structures of which they are a part, or with which they are in contact.

Frost Boil: The breaking of a small section of a highway or airfield pavement under traffic with ejection of soft, semi-liquid subgrade soil. This is caused by the melting of the segregated ice formed by the frost action. This type of failure is limited to pavements with extreme deficiencies of total thickness of pavement and base over frost-susceptible subgrades, or pavements having a highly frost-susceptible base course.

Frost Heave: is the raising of a surface due to ice formation in the underlying soil.

Frost Melting Period: The interval of the year when the ice in the base, subbase, or subgrade materials is returning to a liquid state. It ends when all the ice in the ground has melted or when freezing is resumed. In some cases there may be only one frost-melting period, beginning during the general rise of air temperatures in the spring. However, one or more significant frost-melting intervals may occur during a winter season.

Frost Susceptible Soil: Soil in which significant detrimental ice segregation will occur when the requisite moisture and freezing conditions are present.

Geocomposite Edge Drain: A manufactured product using geotextiles, geogrids, geonets, or geomembranes in laminated or composite form, which can be used as an edge drain in place of trench-pipe construction.

Geotextile: A permeable textile used in geotechnical projects. For this UFC geotextile will refer to a nonwoven needle punch fabric that meets the requirements of the apparent opening size (AOS), grab strength and puncture strength specified for the particular application.

Granular Unbound Base Course: A base course containing no agents that impart higher cohesion by cementing action. Mixtures of granular soil with Portland cement, lime, or fly ash, in which the chemical agents have merely altered certain properties of the soil such as plasticity and gradation without imparting significant strength increase, also are classified as granular unbound base.

Ice Segmentation: The growth of ice as distinct lenses, layers, veins and masses in soils, commonly but not always oriented normal to the direction of heat loss.

Hardstand: An area for parking heavy vehicles, both wheeled and tracked, for significant periods of time. Hardstands are usually constructed of rigid concrete but may be constructed of compacted stone or compacted earth for short periods of time.

Hazen's Effective Particle Diameter: The Hazen's effective particle diameter is the particle size, in millimeters, which corresponds to 10 passing on the grain-size distribution curve. This parameter is one of the major parameters in determining the permeability of a soil.

Mean Daily Temperature: The mean of the average daily temperatures for a given day in each of several years.

Mean Freezing Index: The freezing index determined on the basis of mean temperatures. The period of record over which temperatures are averaged is usually a minimum of 10 year, preferably 30, and should be the latest available. The mean freezing index is illustrated in Figure 19-1.

Non-Frost Susceptible Materials: Cohesionless materials such as crushed rock, gravel, sand, slag, and cinders that do not experience significant detrimental ice segregation under normal freezing conditions. Non-Frost-susceptible materials also include cemented or otherwise stabilized materials that do not evidence detrimental ice segregation, loss of strength upon thawing, or freeze-thaw degradation.

Open Graded Material (OGM): A granular material having a very high permeability (greater than 5,000 ft/day (1,500 m/day)) which may be used for a drainage layer. Such a material will normally require stabilization for construction stability or for structural strength to serve as a base in a flexible pavement.

Open Storage Areas: Permanent exterior storage areas used by any type of wheeled vehicular traffic or having non-pneumatic loadings in excess of 200 psi (1.38 MPa), covered or uncovered, that are separate from the interior area of a building.

Overlay Pavement: A pavement constructed on an existing base pavement to increase load-carrying capacity or correct a surface defect.

Pavement Pumping: The ejection of water and soil through joints, cracks, and along edges of pavements caused by downward movements of sections of the pavement. This is actuated by the passage of heavy axle loads over the pavement after free water has accumulated beneath it.

Pavement Structure: Pavement structure is the combination of subbase, base, and surface layers constructed on a subgrade.

Period of Weakening: The interval of the year that starts at the beginning of a frost-melting period and ends when the subgrade strength has returned to normal summer values, or when the subgrade has again become frozen.

Permeable Base: An open-graded granular material with most of the fines removed (e.g., less than 10 percent passing the No. 16 sieve) to provide high permeability (1,000 ft/day or more) for use in a drainage layer.

Porosity: The amount of voids in a material, expressed as the ratio of the volume of voids to the total volume.

Rapid Draining Material (RDM): A granular material having a sufficiently high permeability 1,000 to 5,000 ft/day (300 to 1,500 m/day) to serve as a drainage layer and also having the stability to support construction equipment and the structural strength to serve as a base or a subbase.

Rigid Base Pavement: An existing rigid pavement is one on which an overlay is to be placed.

Rigid Overlay: A rigid pavement used to strengthen an existing flexible or rigid pavement.

Separation Layer: A layer provided directly beneath the drainage layer to prevent fines from infiltration or pumping into the drainage layer and to provide a working platform for construction and compaction of the drainage layer.

Stabilization: Stabilization refers to either mechanically or chemically stabilizing the drainage layer to increase the stability and strength to withstand construction traffic and design traffic. Mechanical stabilization is accomplished by the use of a choke stone and compaction. Chemical stabilization is accomplished by the use of either Portland cement or asphalt.

Subbase Course: The layer of supporting material between the base course and the subgrade.

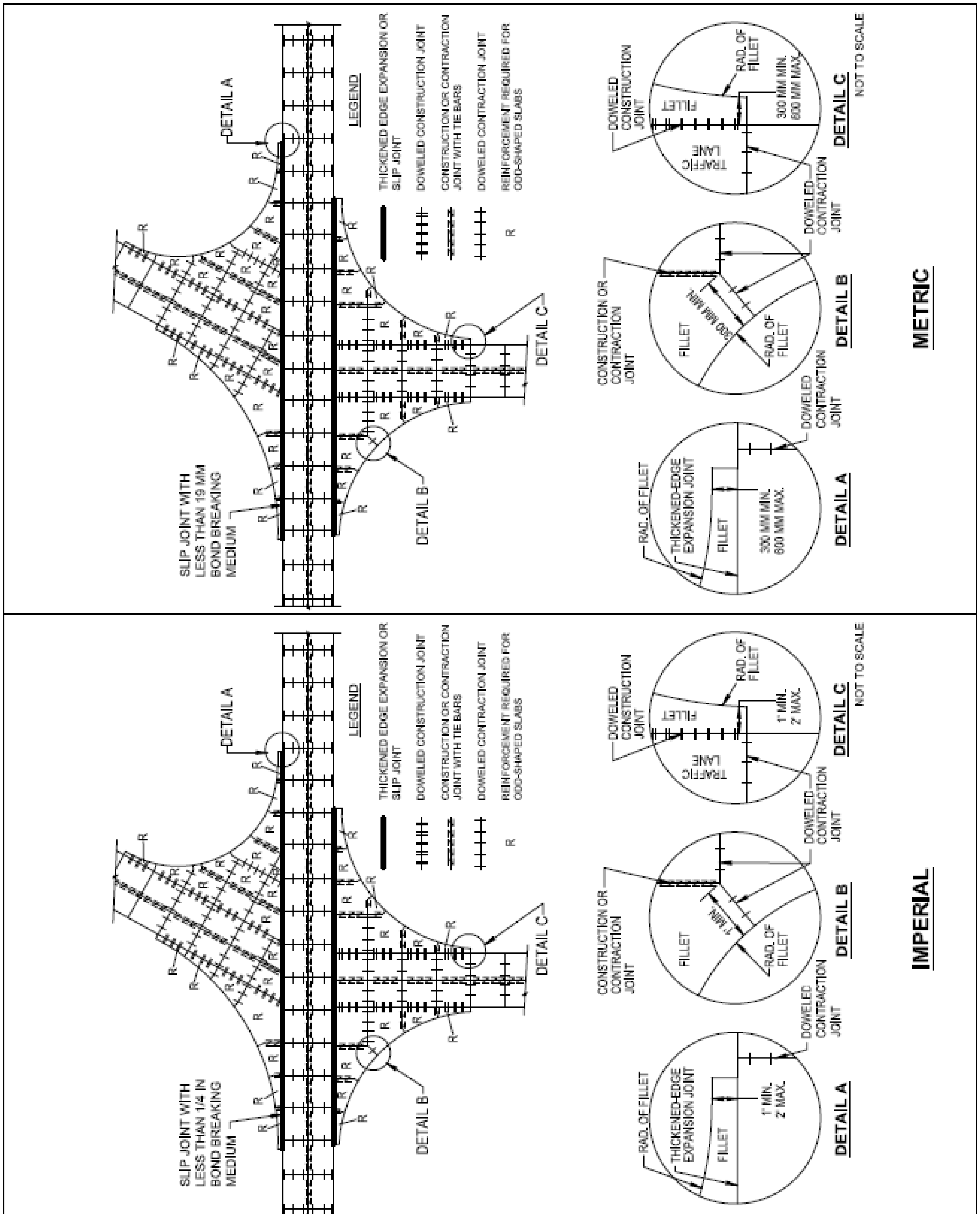
Subsurface Drainage: The process of collecting and removing water from the pavement structure. Subsurface drainage systems are categorized into two functional categories: one for draining surface infiltration water, and the other for controlling groundwater.

C-3 TRI-SERVICE PAVEMENT DETAILS

The Pavements and Airfields Tri-Service Working Group has developed typical details for use during design. These details can be download at http://www.wbdg.org/ccb/browse_cat.php?o=29&c=248. Some of these details contain information that was provided in earlier versions of the superseded criteria documents.

When these details are changed, an updated version will be posted to the Whole Building Design Guide webpage. Updated details will be included in the document during the next change or revision. Refer to http://www.wbdg.org/ccb/browse_cat.php?o=29&c=248 for the most recent version.

Figure C14-1 Typical Layout of Joints at Intersection



TYPICAL LAYOUT OF JOINTS AT INTERSECTION	DATE OCTOBER 2016	FIGURE 14-1

Figure C14-3A Reinforced Rigid Pavement with Two Traffic Lanes

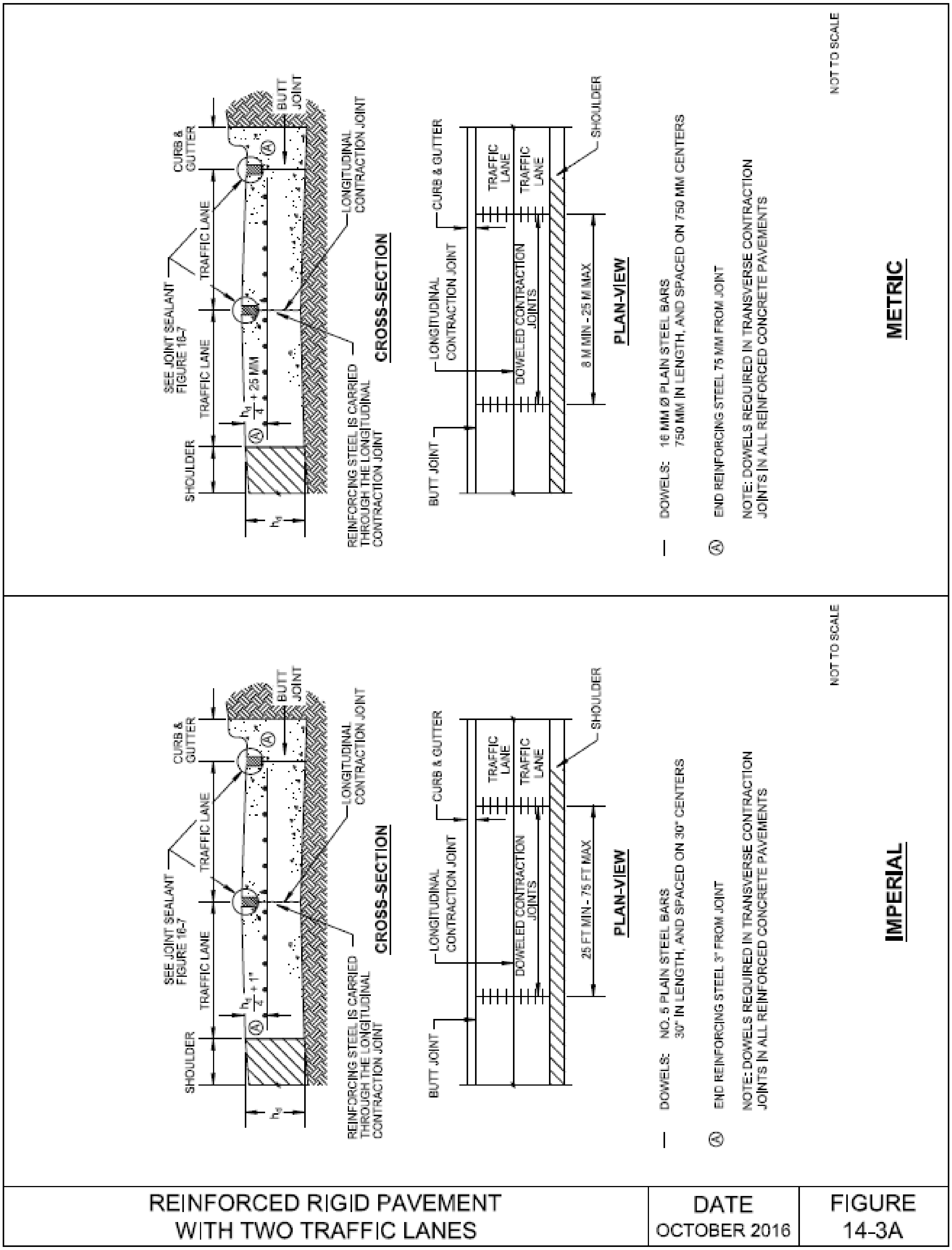
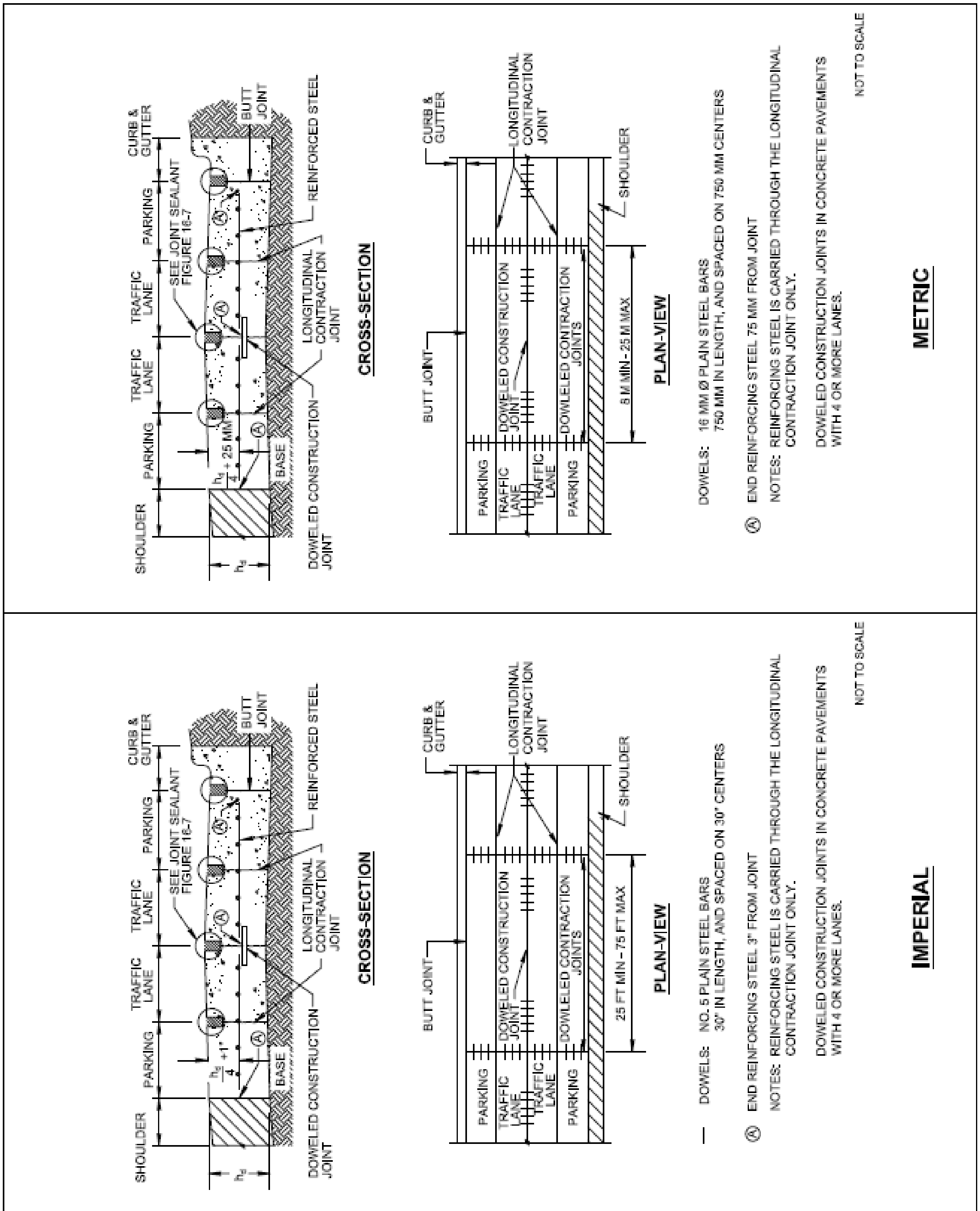
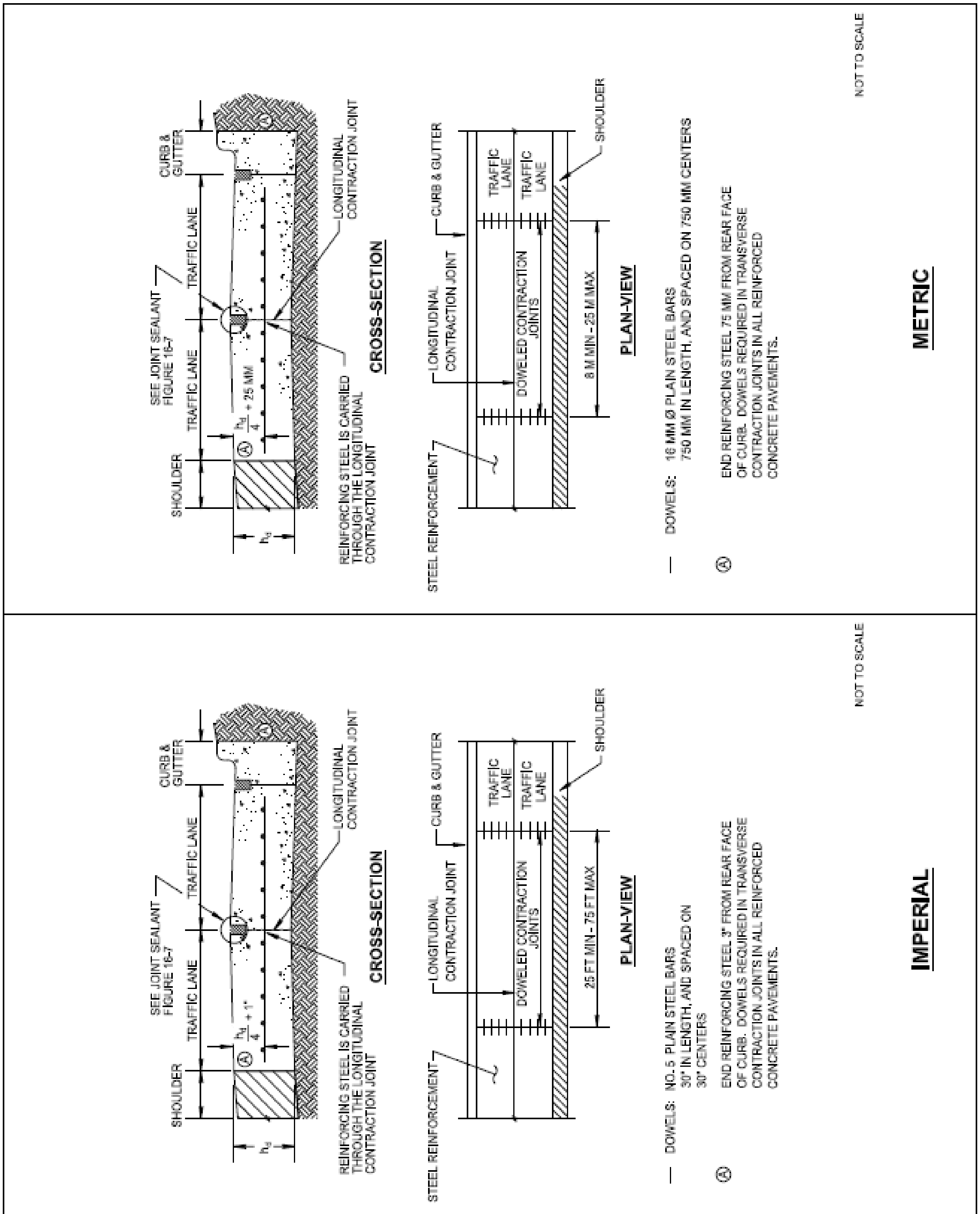


Figure C14-3B Reinforced Rigid Pavement with Two Traffic Lanes



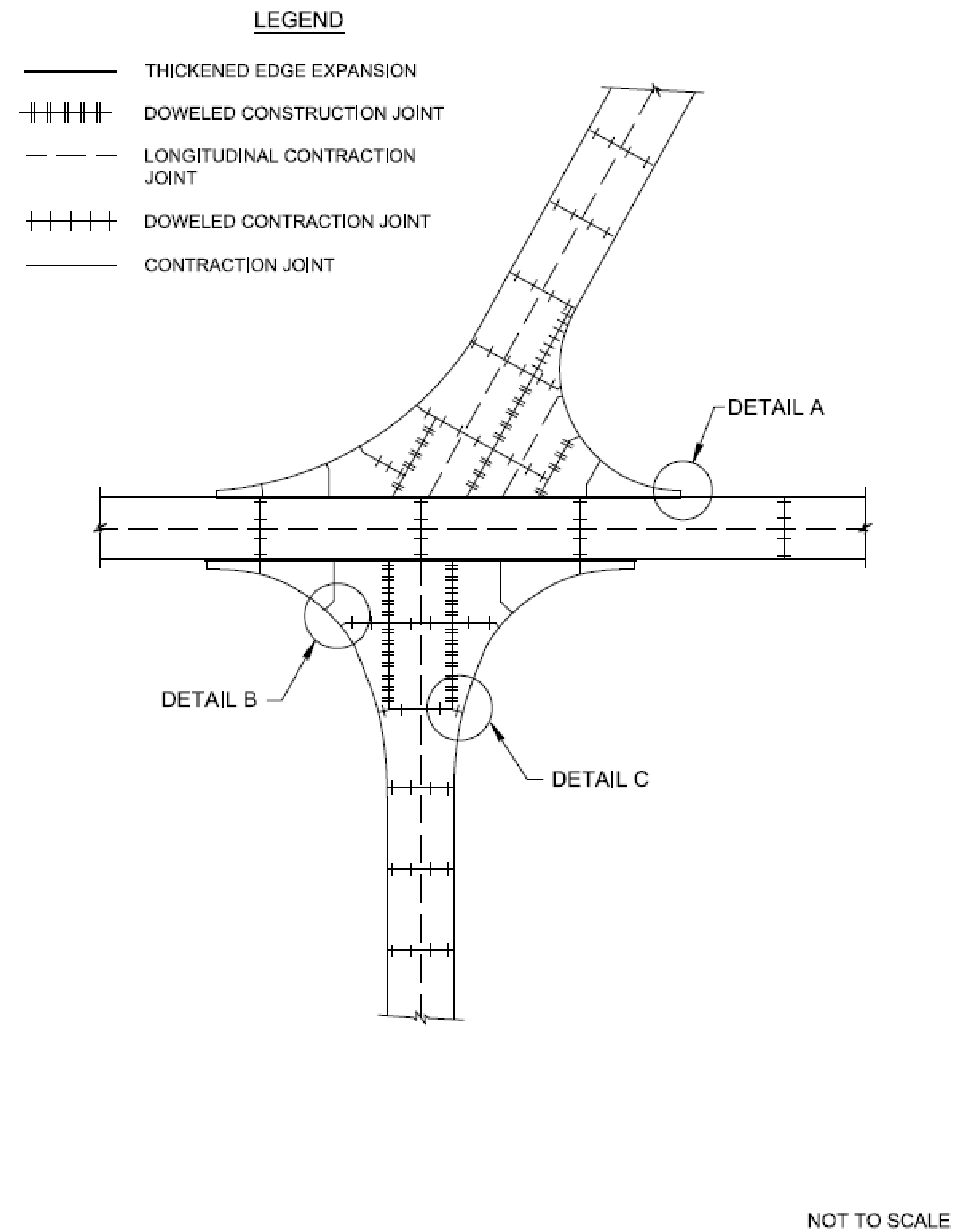
REINFORCED RIGID PAVEMENT WITH TWO TRAFFIC LANES	DATE OCTOBER 2016	FIGURE 14-3B

Figure C14-4 Reinforced Rigid Pavement with Traffic and Parking Lanes



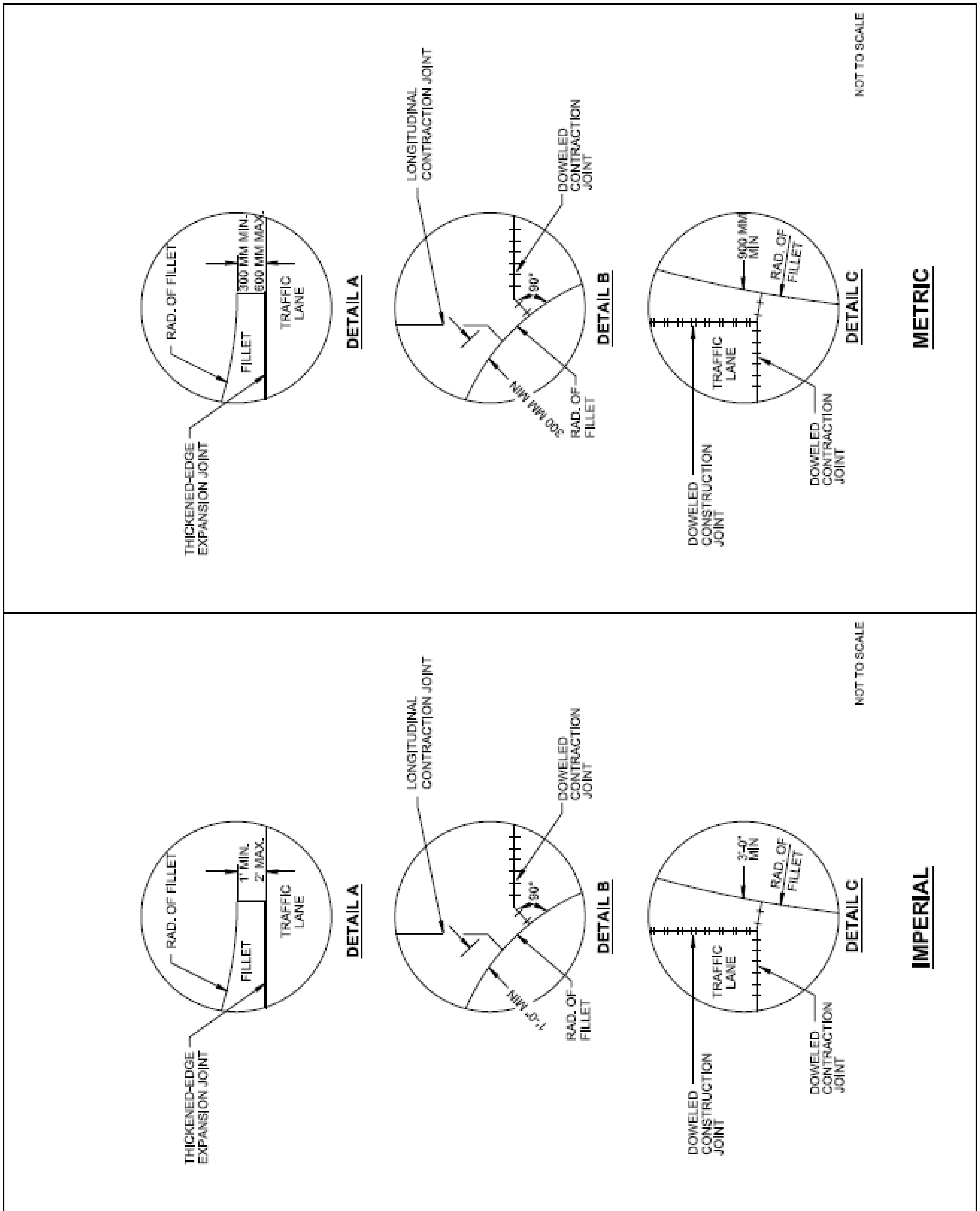
REINFORCED RIGID PAVEMENT WITH TRAFFIC AND PARKING LANES	DATE OCTOBER 2016	FIGURE 14-4

Figure C14-5A Layout of Joints at the Intersection of Reinforced Rigid Pavement



LAYOUT OF JOINTS AT THE INTERSECTION OF REINFORCED RIGID PAVEMENT	DATE OCTOBER 2016	FIGURE 14-5A

Figure C14-5B Layout of Joints at the Intersection of Reinforced Rigid Pavement



LAYOUT OF JOINTS AT THE INTERSECTION OF REINFORCED RIGID PAVEMENT	DATE OCTOBER 2016	FIGURE 14-5B

Figure C16-1A Plain Concrete Pavements

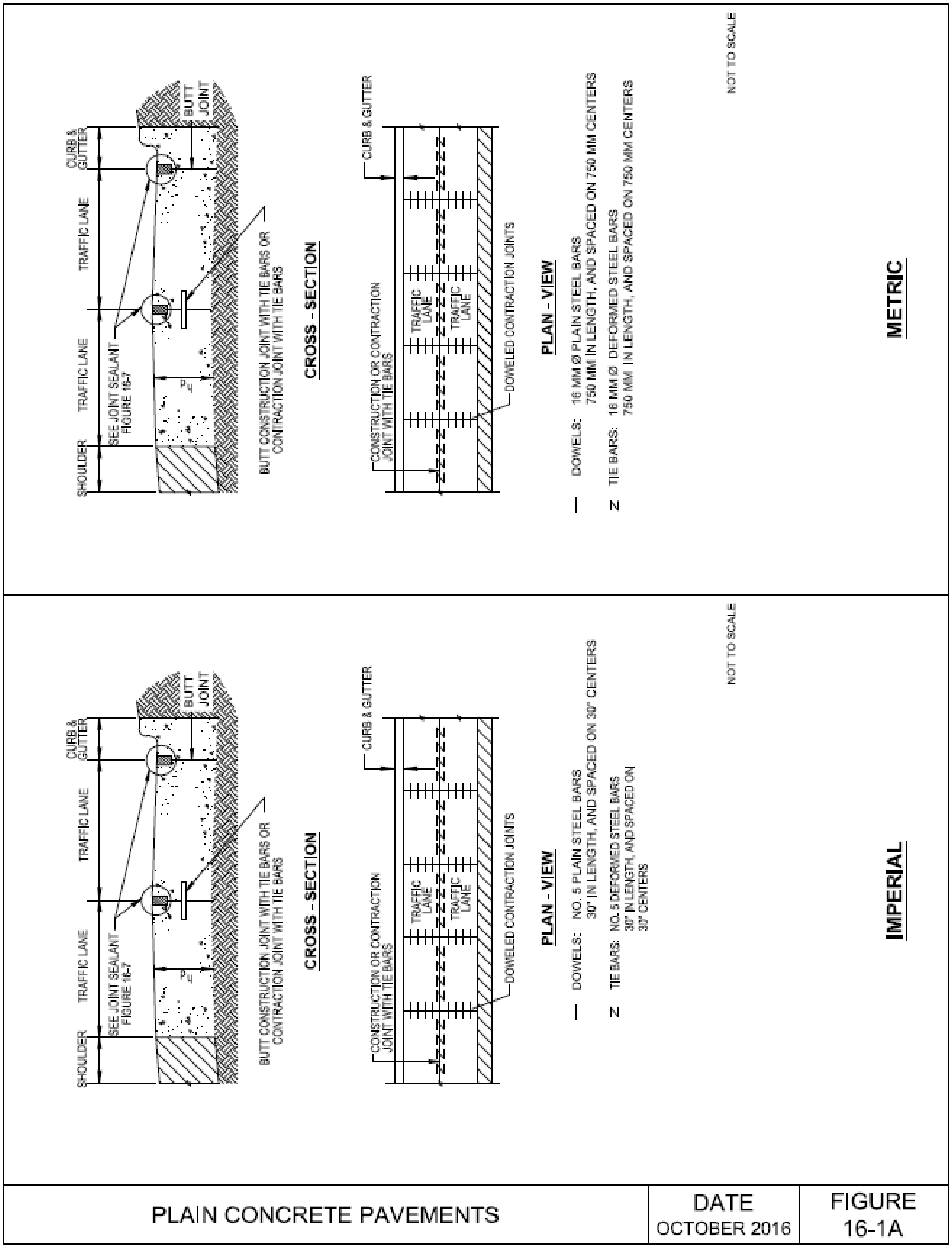
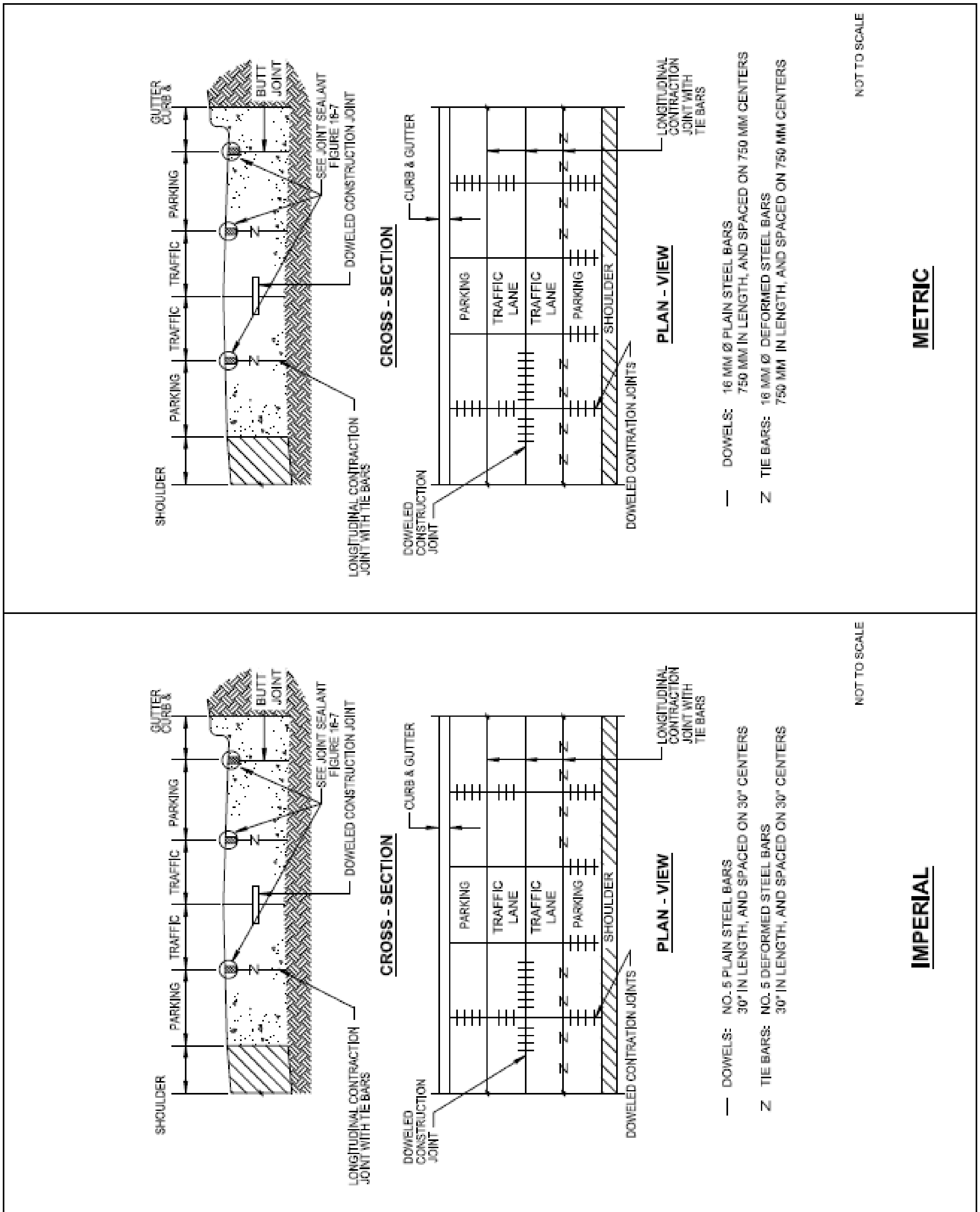
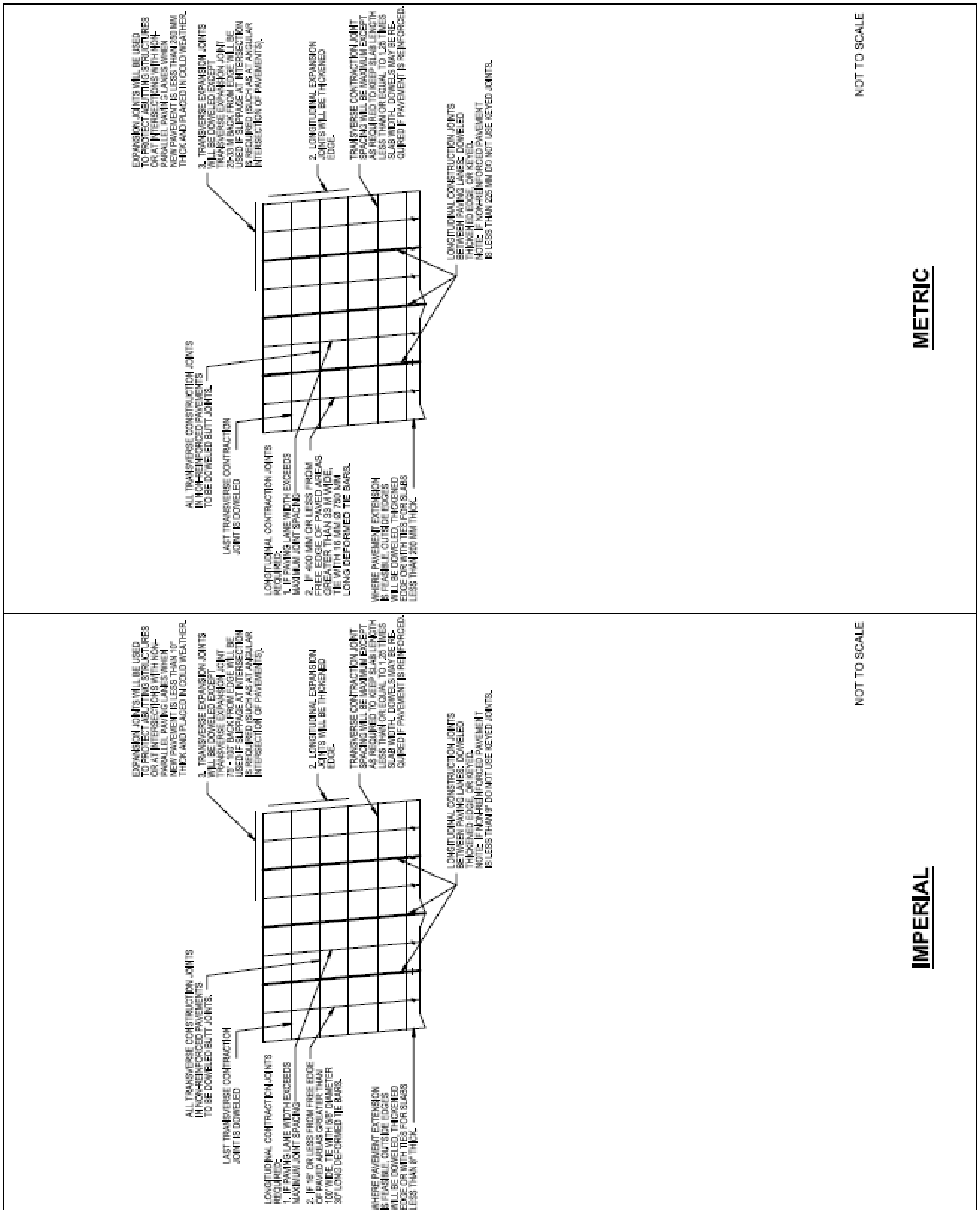


Figure C16-1B Design Details for Plain Concrete Pavements



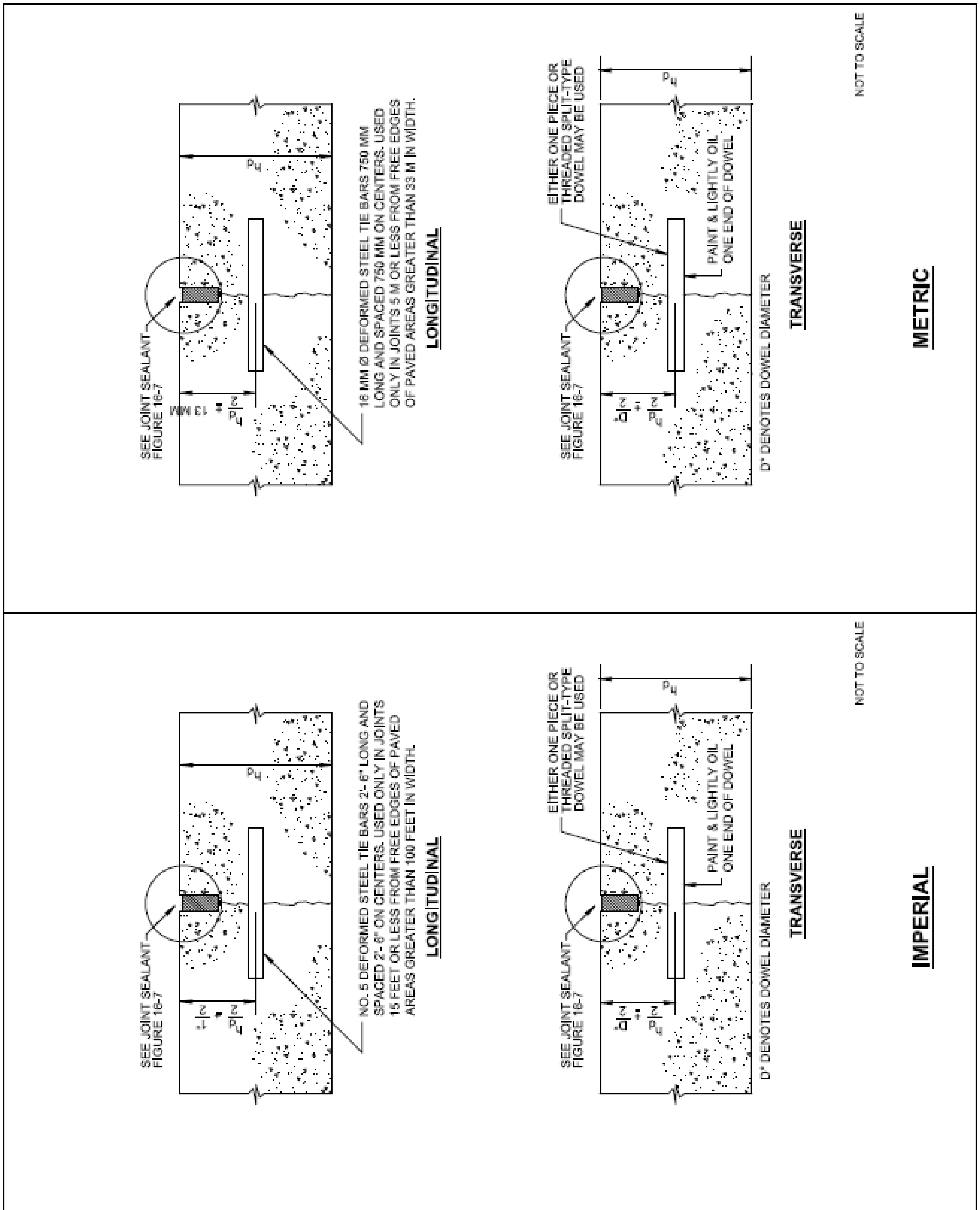
PLAIN CONCRETE PAVEMENTS WITH PARKING	DATE OCTOBER 2016	FIGURE 16-1B

Figure C16-2 Joint Layout for Vehicular Parking Areas



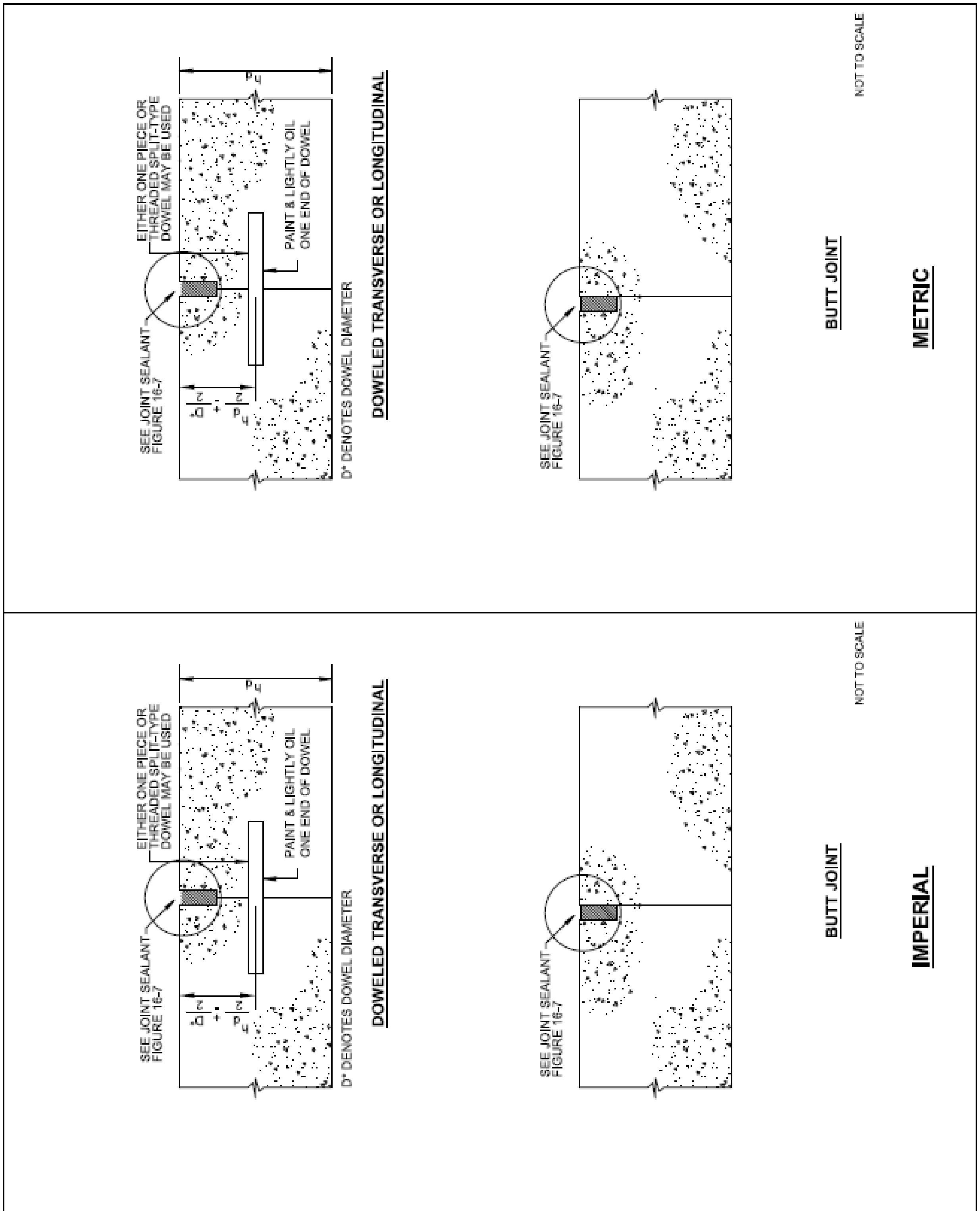
JOINT LAYOUT FOR VEHICULAR PARKING AREAS	DATE OCTOBER 2016	FIGURE 16-2

Figure C16-3 Contraction Joints for Plain Concrete Pavements



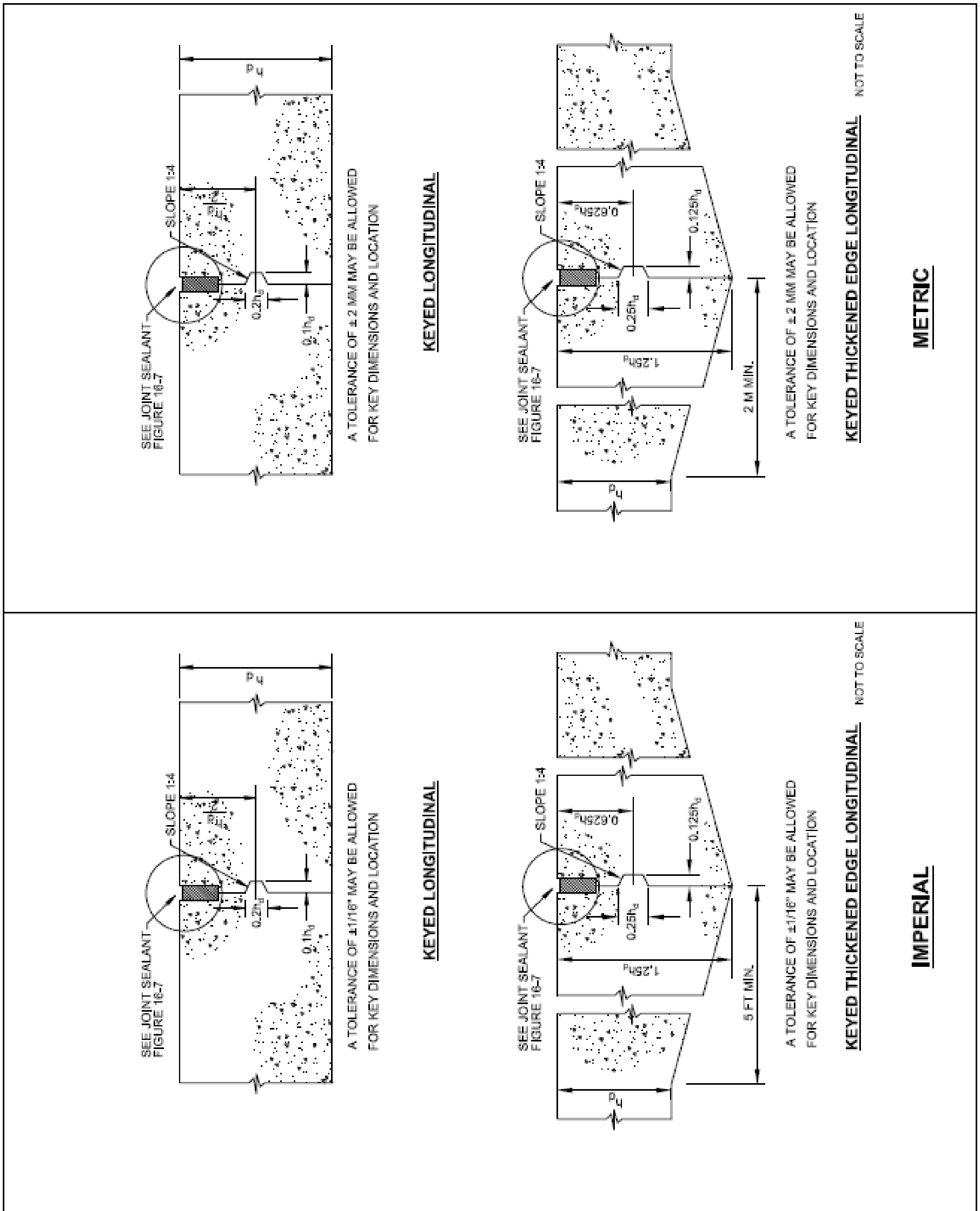
CONTRACTION JOINTS FOR PLAIN CONCRETE PAVEMENTS	DATE OCTOBER 2016	FIGURE 16-3

Figure C16-4A Construction Joints for Plain Concrete Pavements



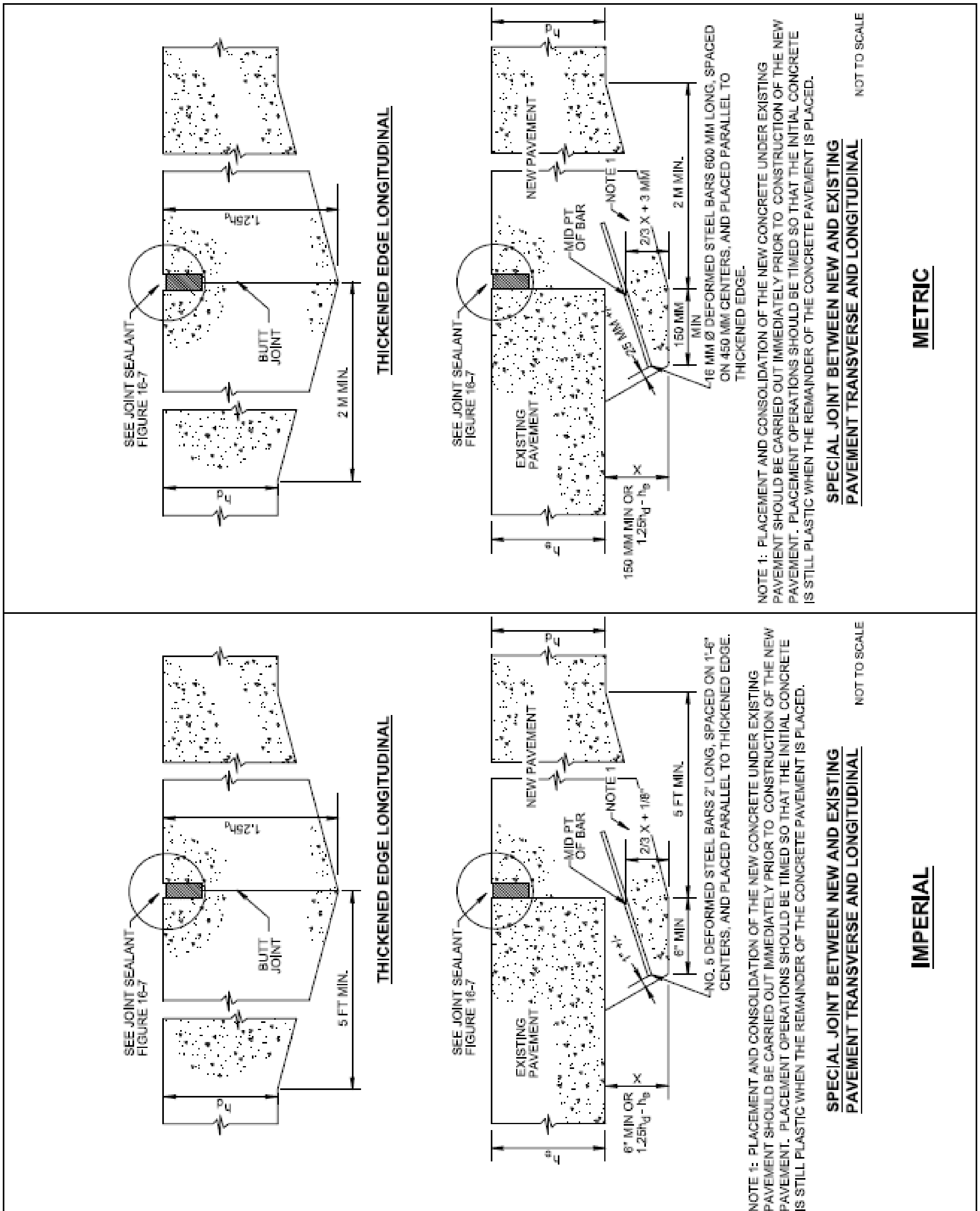
CONSTRUCTION JOINTS FOR PLAIN CONCRETE PAVEMENTS	DATE OCTOBER 2016	FIGURE 16-4A

Figure C16-4B Construction Joints for Plain Concrete Pavements



CONSTRUCTION JOINTS FOR PLAIN CONCRETE PAVEMENTS	DATE OCTOBER 2016	FIGURE 16-4B

Figure C16-4C Construction Joints for Plain Concrete Pavements



CONSTRUCTION JOINTS FOR PLAIN CONCRETE PAVEMENTS	DATE OCTOBER 2016	FIGURE 16-4C

Figure C16-4D Construction Joints for Plain Concrete Pavements

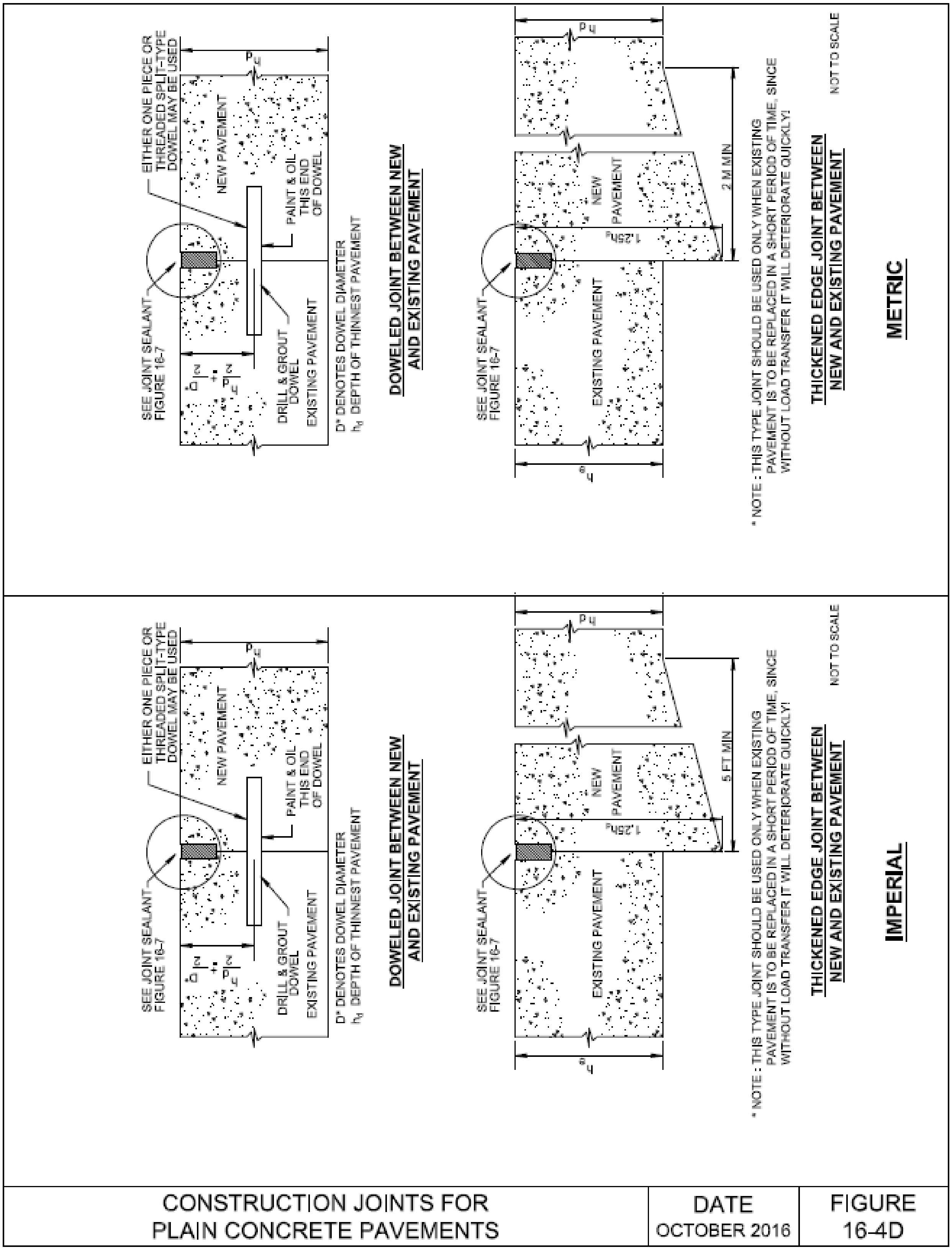
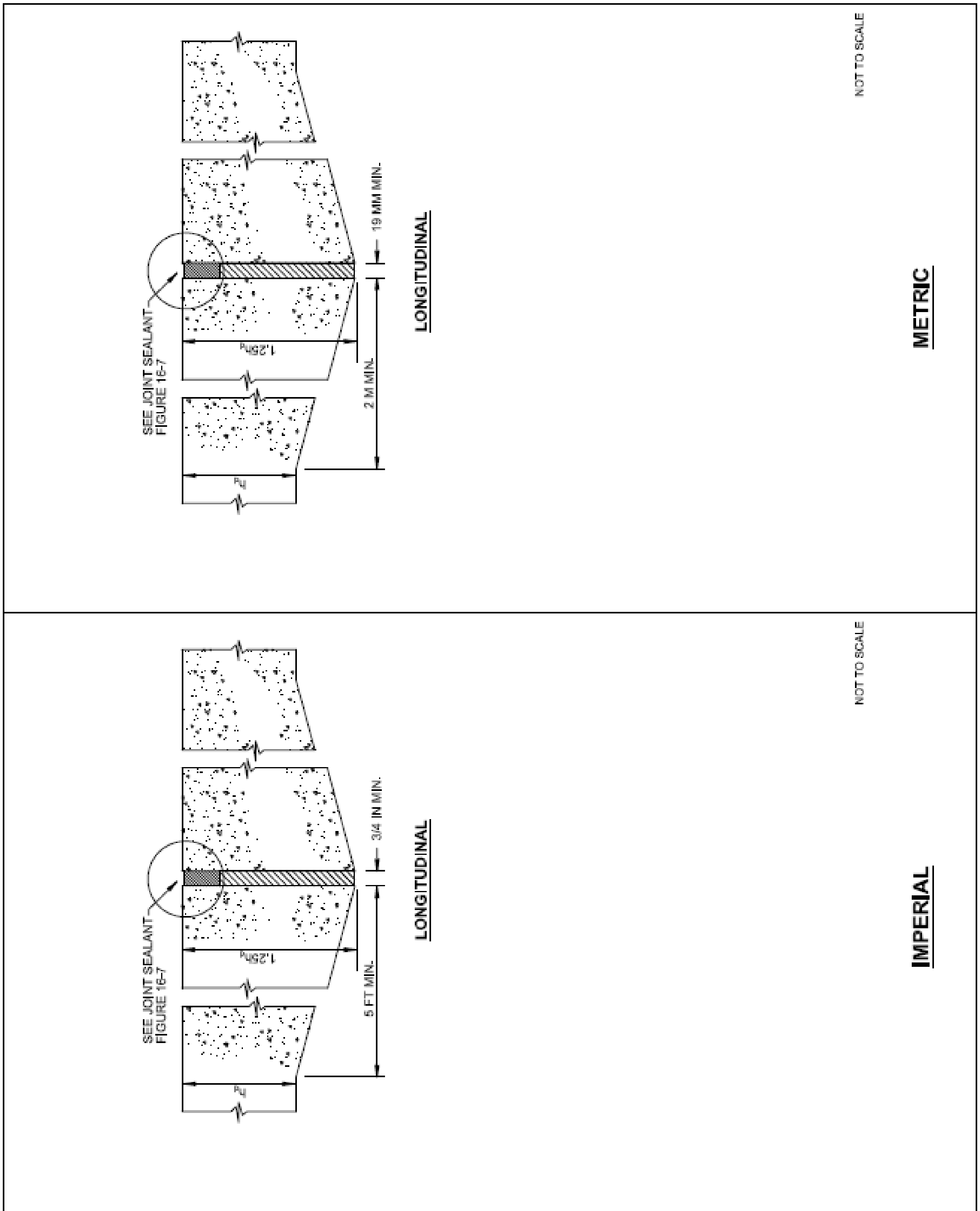


Figure C16-5 Expansion Joints for Plain Concrete Pavements



EXPANSION JOINTS FOR PLAIN CONCRETE PAVEMENTS	DATE OCTOBER 2016	FIGURE 16-5

Figure C16-6 Thickened-Edge Slip Joint

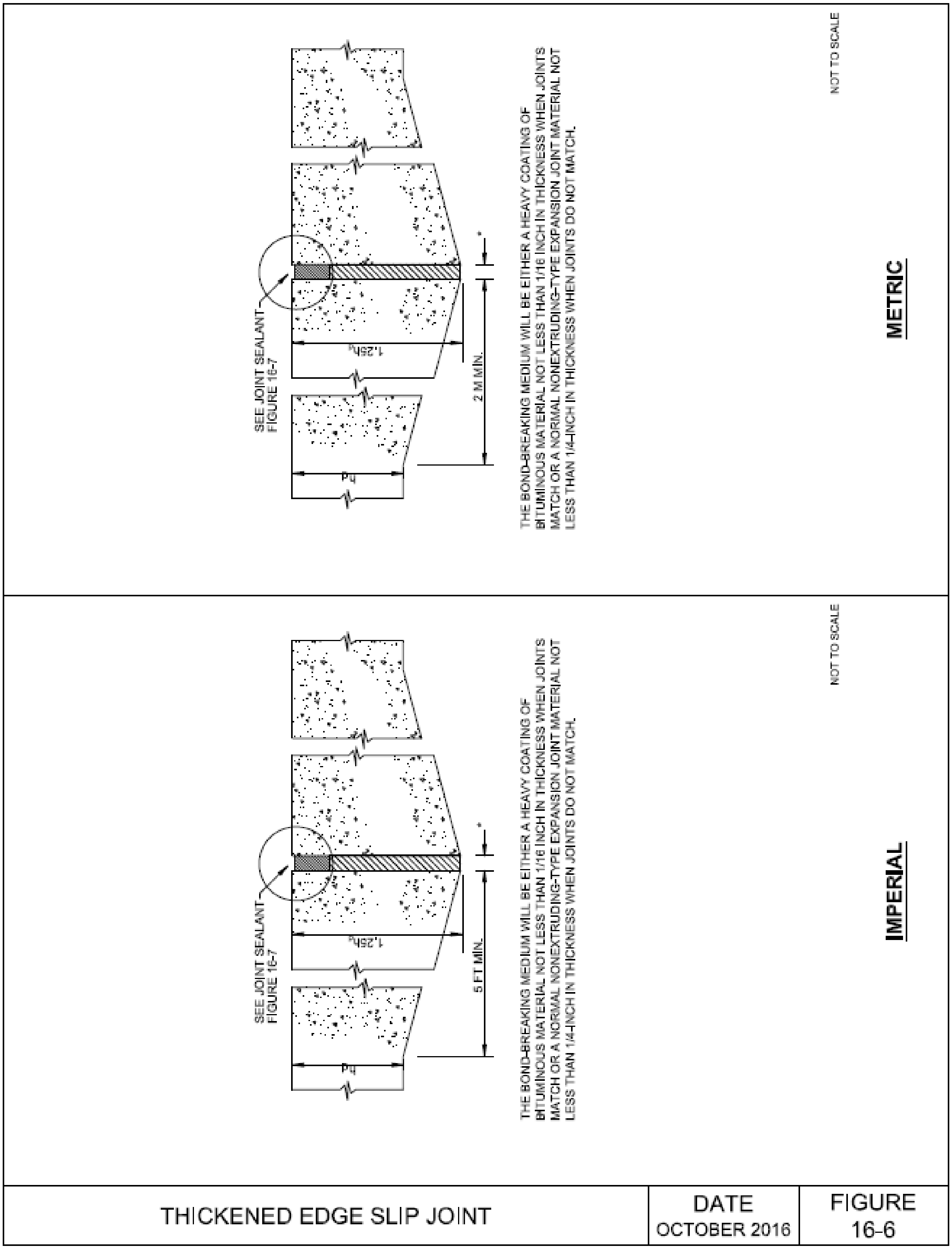
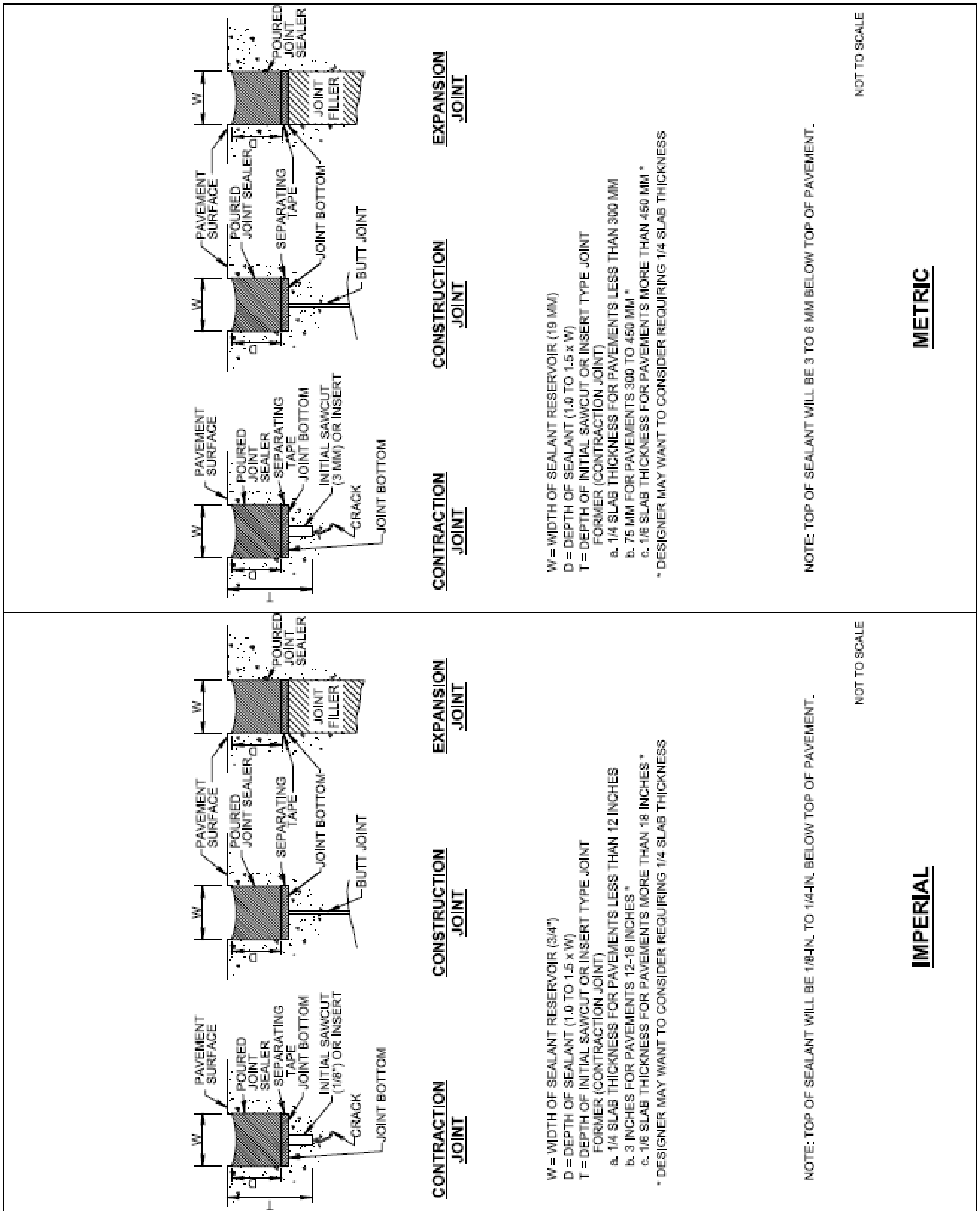


Figure C16-7A Joint Sealants



JOINT SEALANTS	DATE OCTOBER 2016	FIGURE 16-7A

Figure C16-7B Joint Sealants

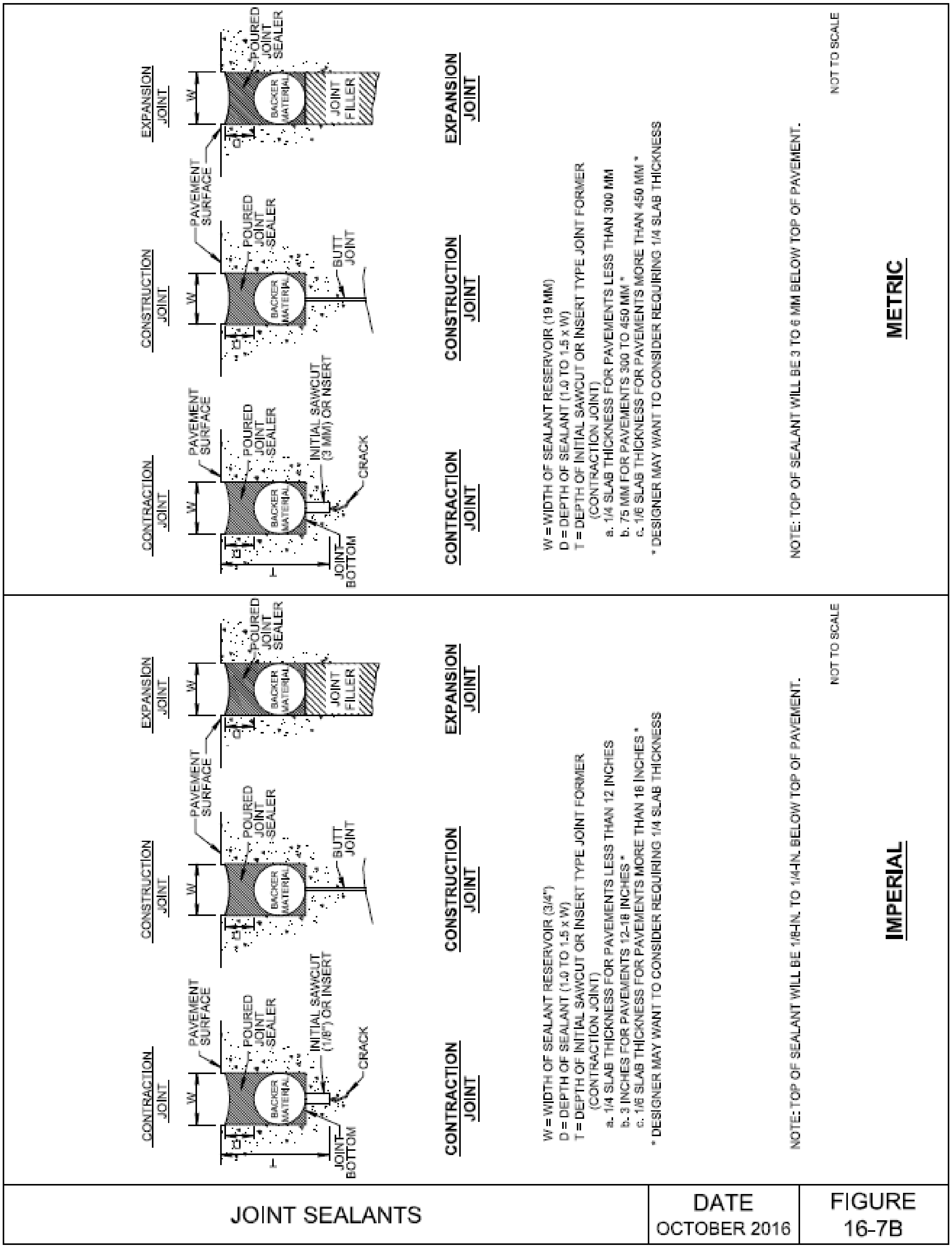


Figure C16-7C Joint Sealants

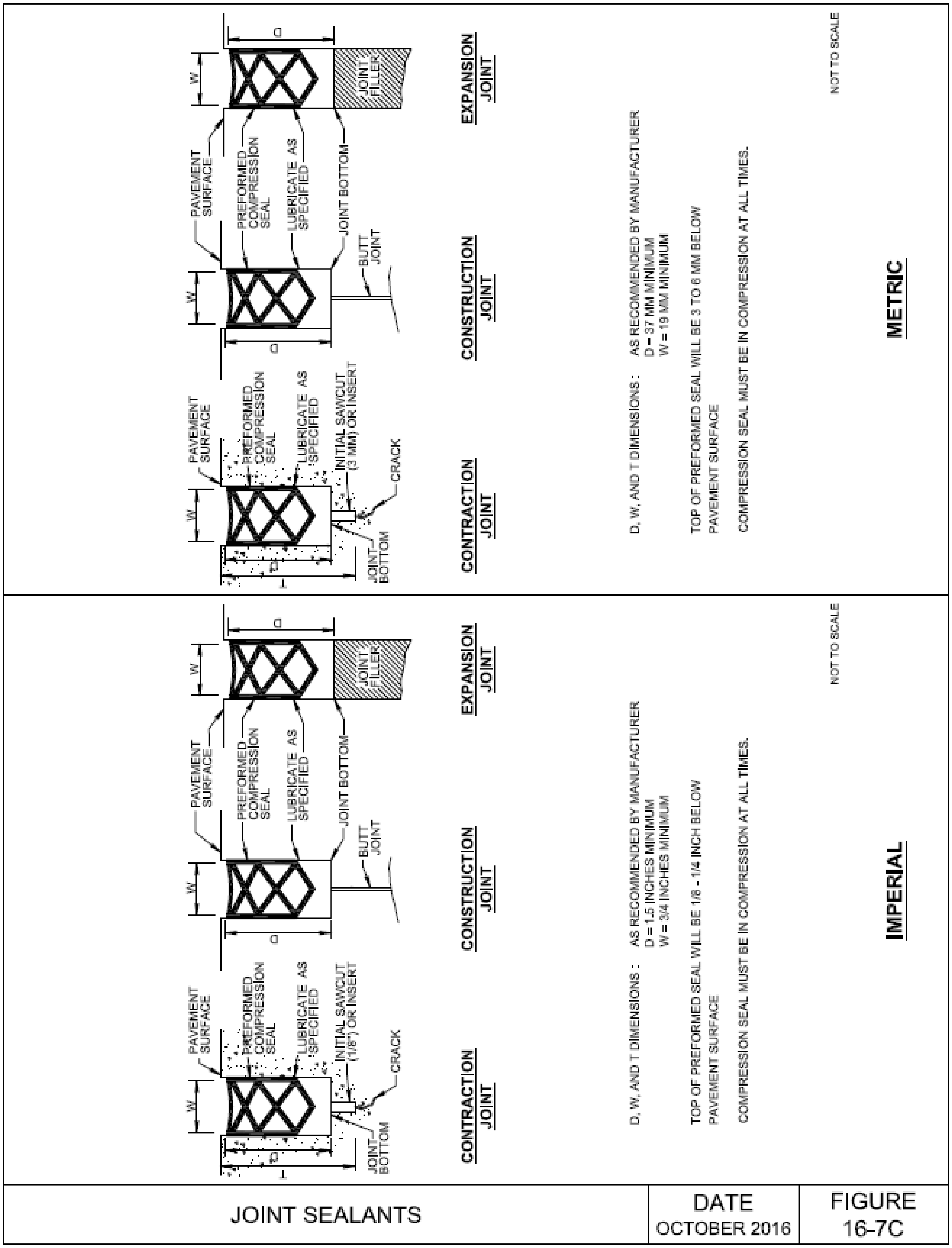
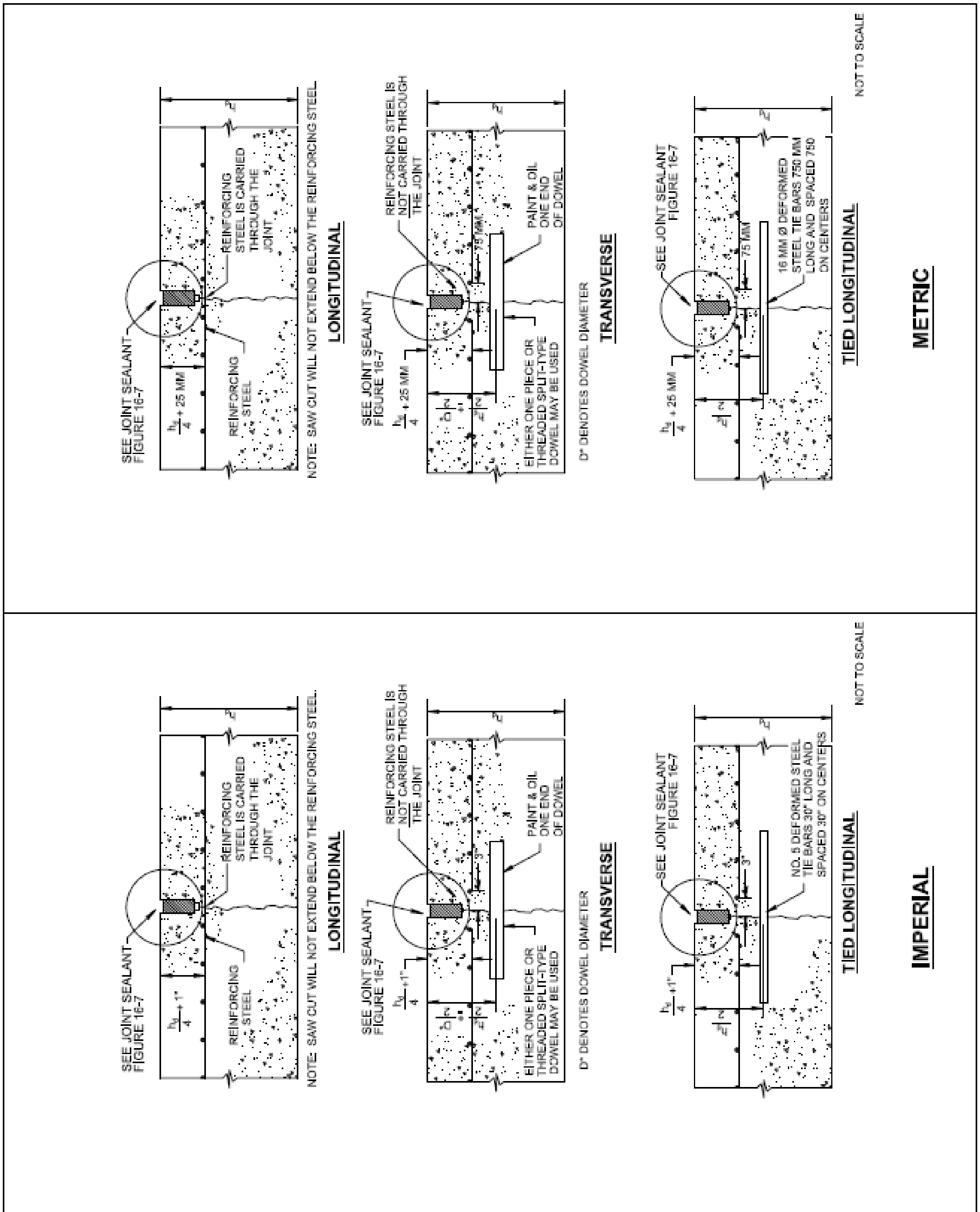
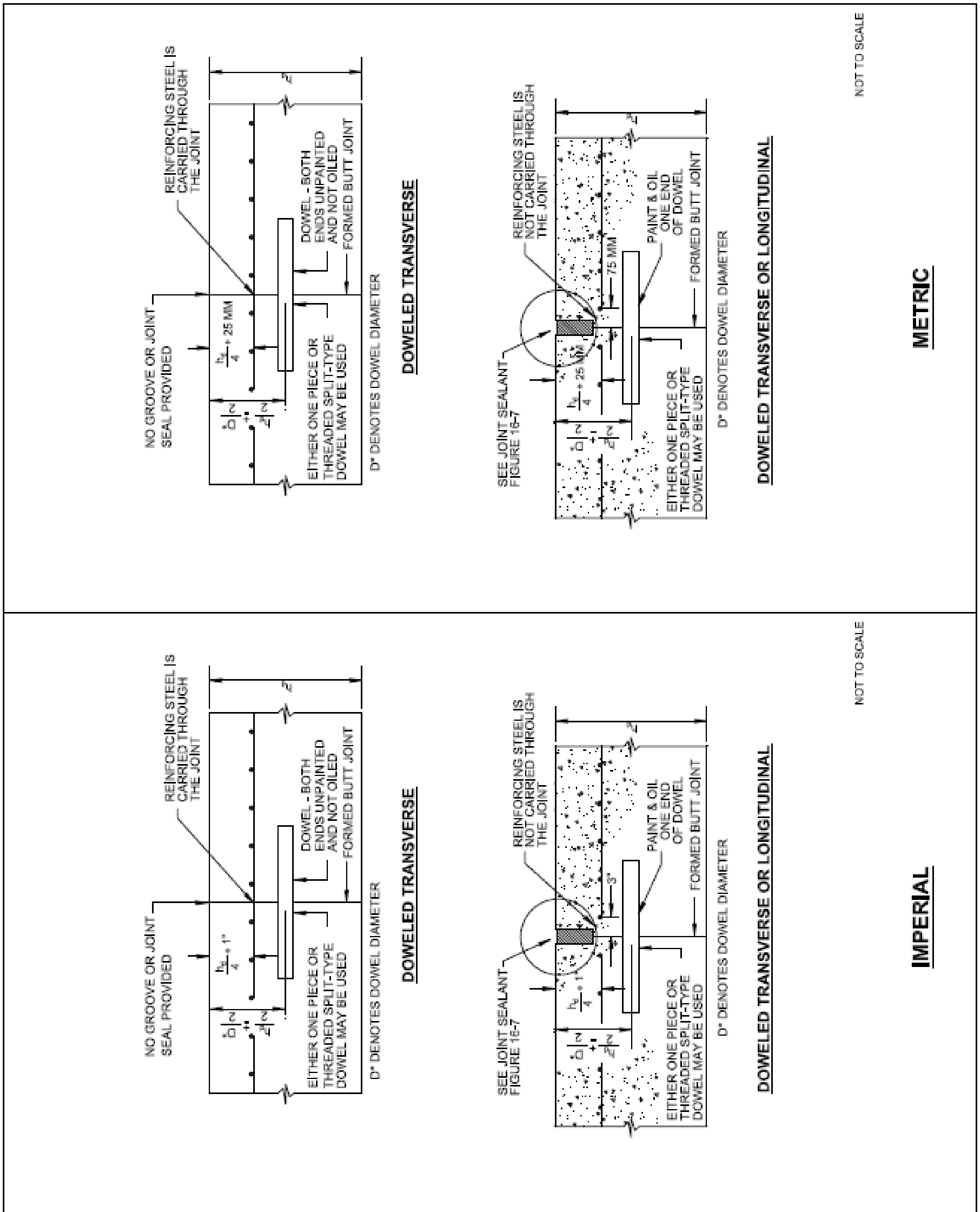


Figure C17-1 Contraction Joints for Reinforced Concrete Pavements



CONTRACTION JOINTS FOR REINFORCED CONCRETE PAVEMENTS	DATE OCTOBER 2016	FIGURE 17-1

Figure C17-2A Construction Joints for Reinforced Concrete Pavements



CONSTRUCTION JOINTS FOR REINFORCED CONCRETE PAVEMENTS	DATE OCTOBER 2016	FIGURE 17-2A

Figure C17-2B Construction Joints for Reinforced Concrete Pavements

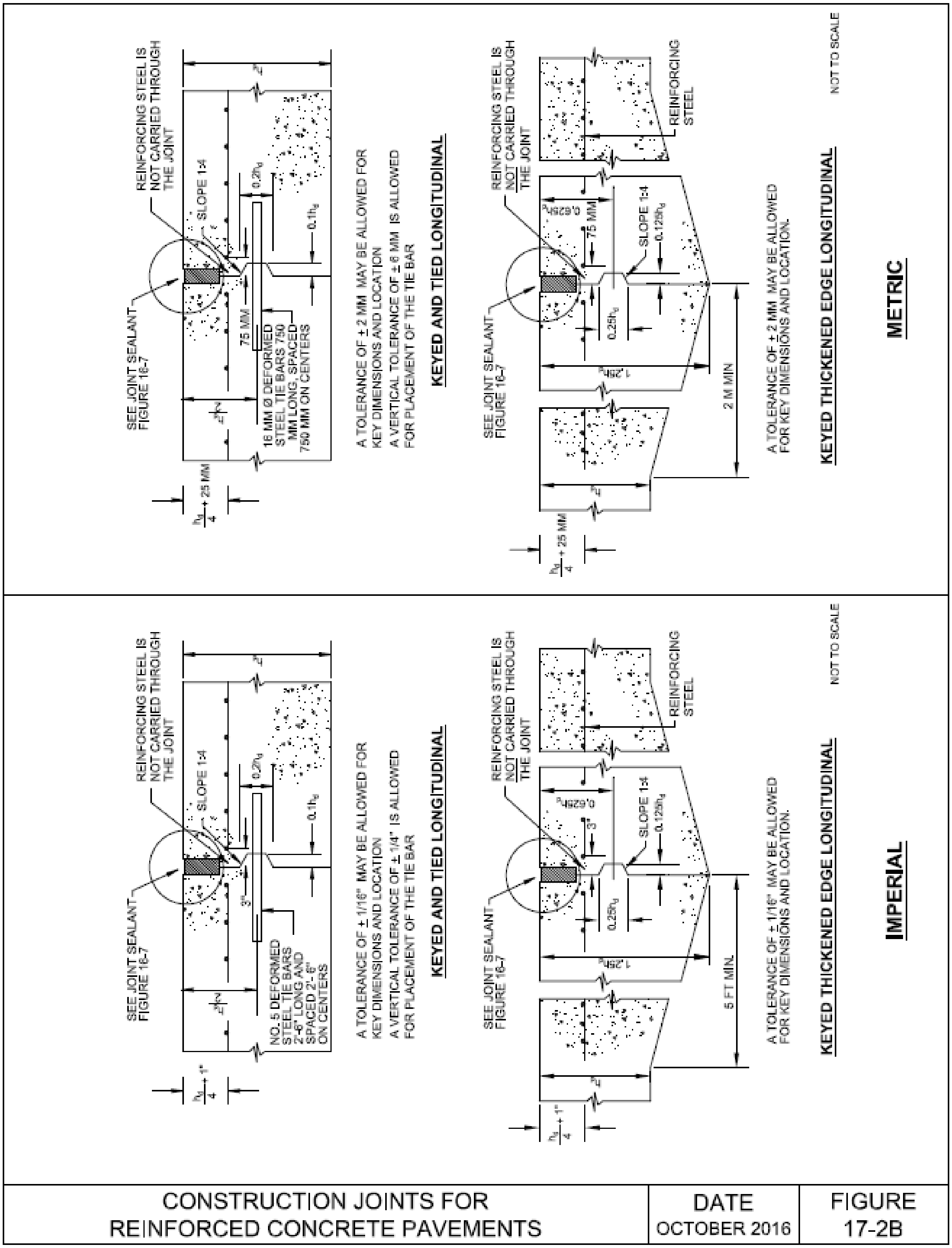
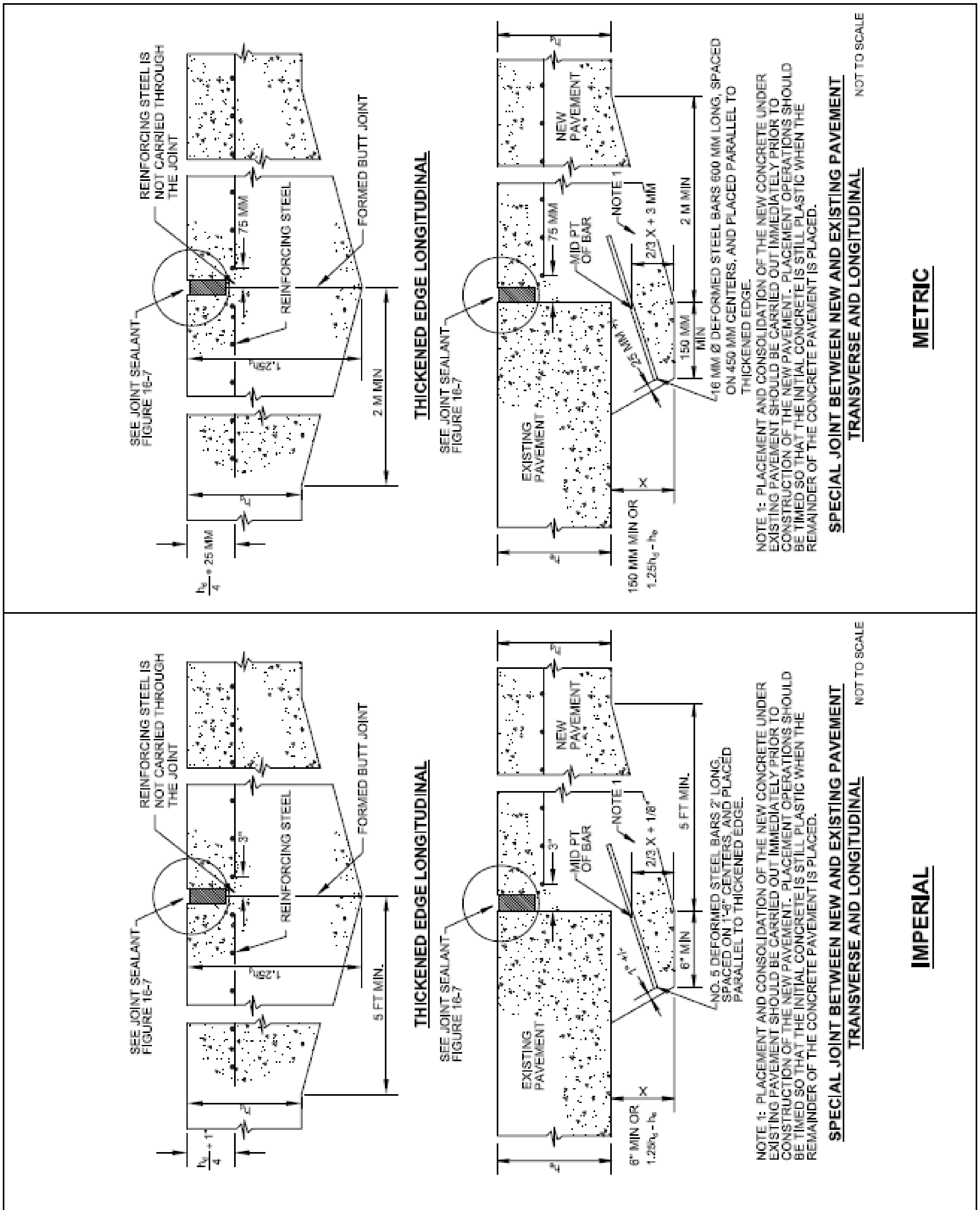
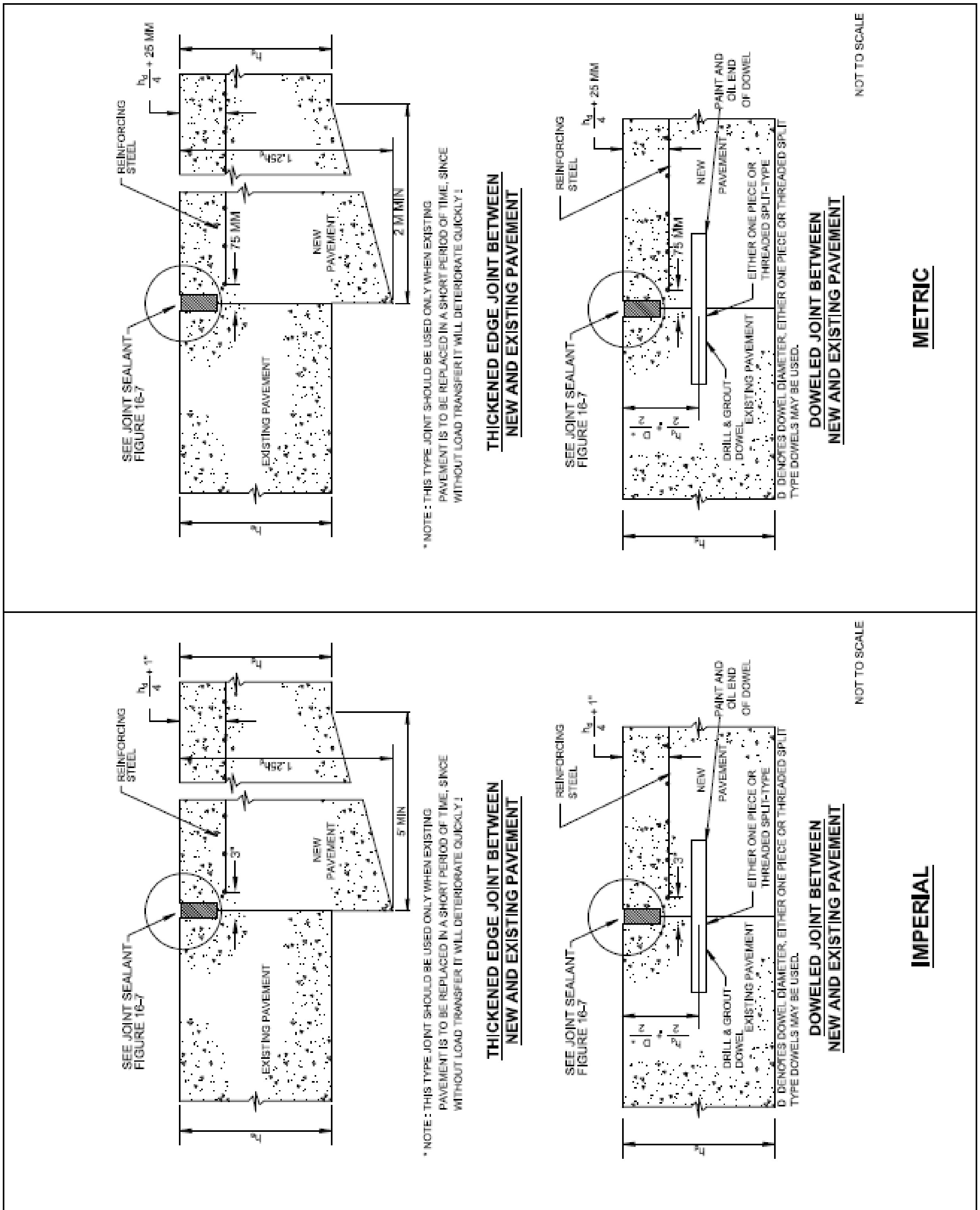


Figure C17-2C Construction Joints for Reinforced Concrete Pavements



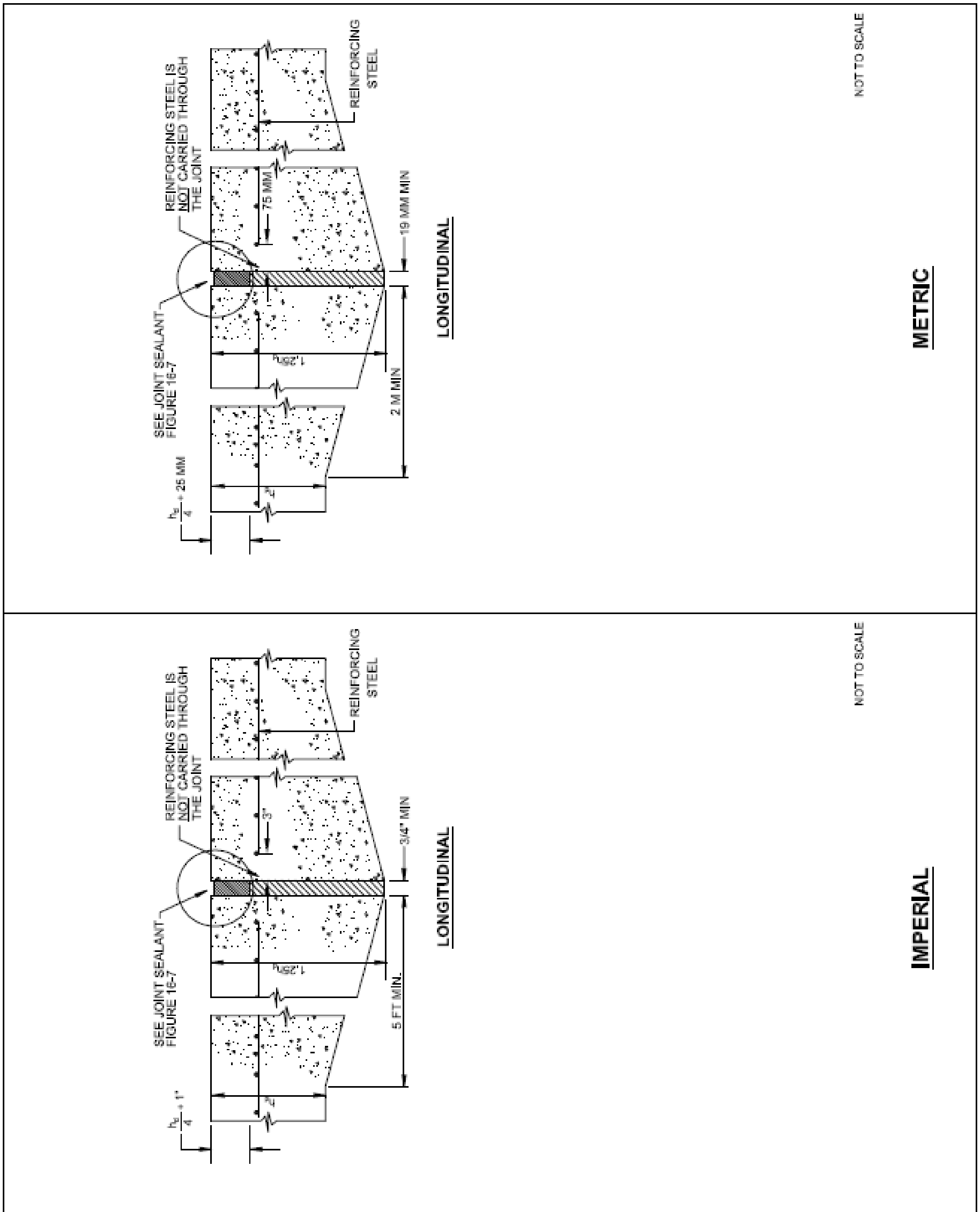
CONSTRUCTION JOINTS FOR REINFORCED CONCRETE PAVEMENTS	DATE OCTOBER 2016	FIGURE 17-2C

Figure C17-2D Construction Joints for Reinforced Concrete Pavements



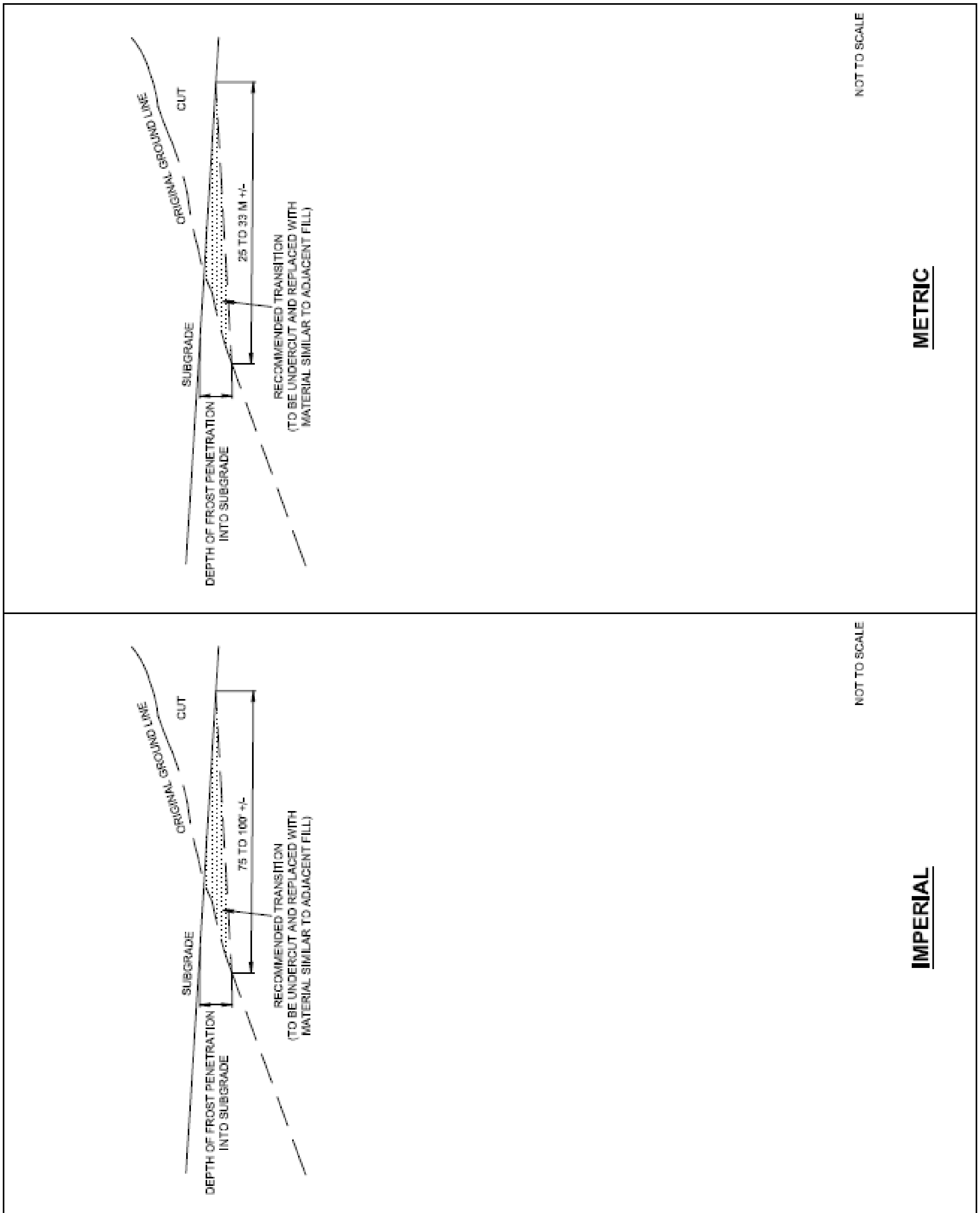
CONSTRUCTION JOINTS FOR REINFORCED CONCRETE PAVEMENTS	DATE	FIGURE
	OCTOBER 2016	17-2D

Figure C17-3 Expansions Joints for Reinforced Concrete Pavements



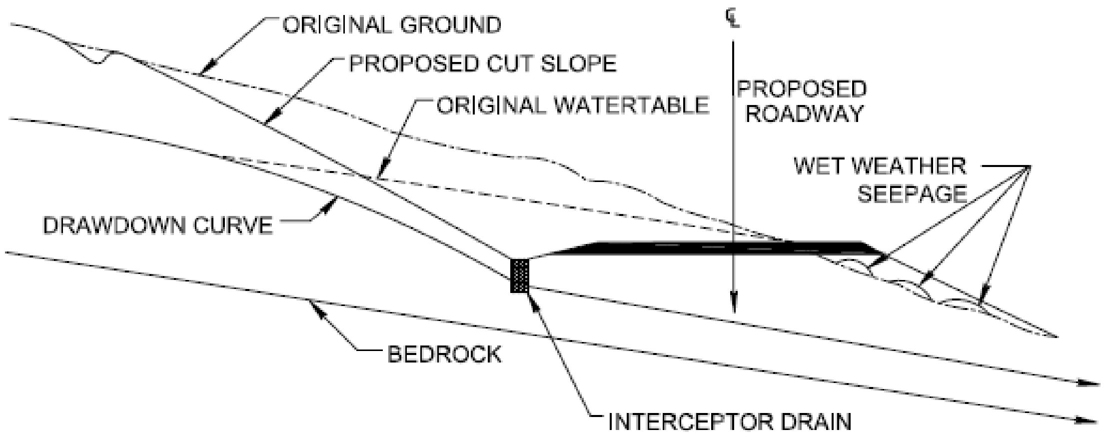
EXPANSION JOINTS FOR REINFORCED CONCRETE PAVEMENTS	DATE OCTOBER 2016	FIGURE 17-3

Figure C19-7 Tapered Transition



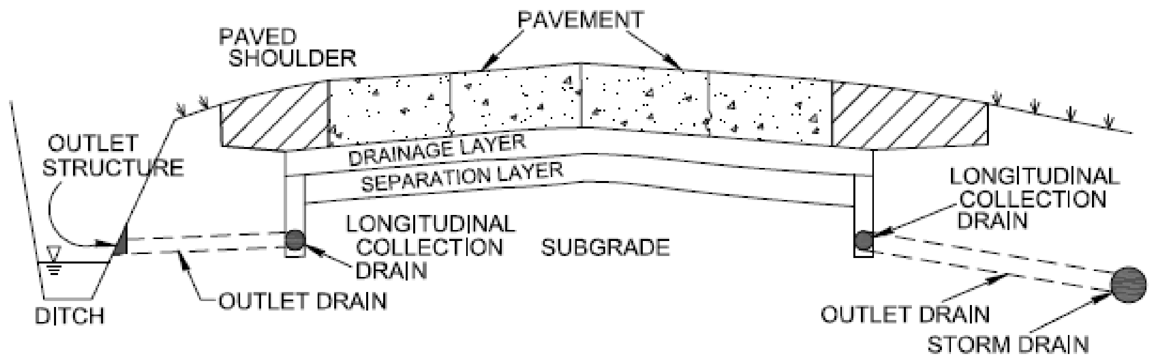
TAPERED TRANSITION	DATE OCTOBER 2016	FIGURE 19-7

Figure C20-1 Collector Drain



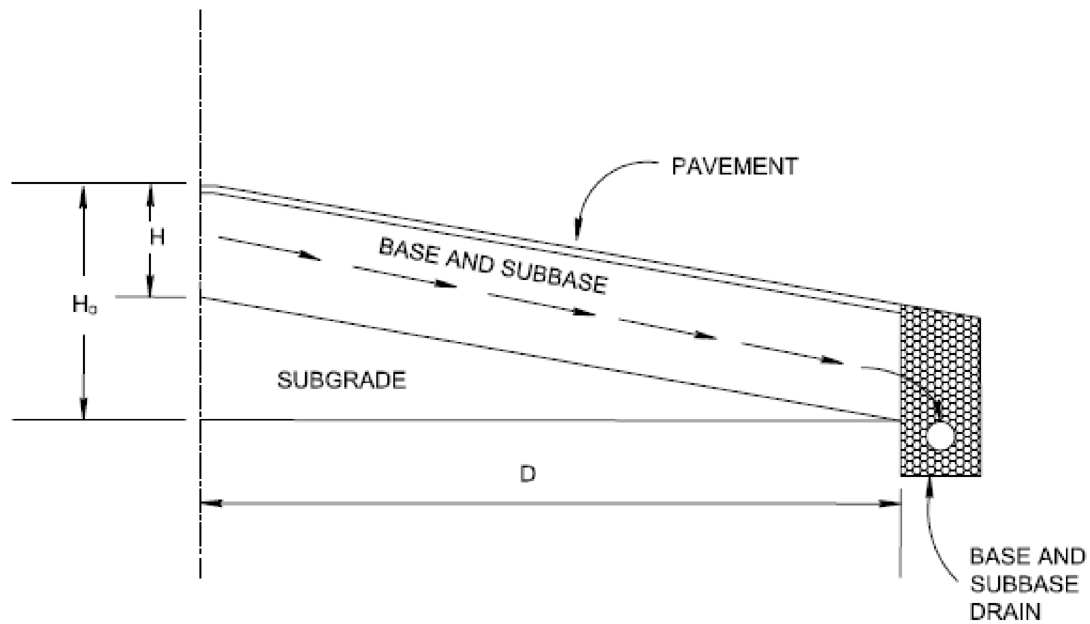
COLLECTOR DRAIN	DATE OCTOBER 2016	FIGURE 20-1

Figure C20-2 Collector Drain to Intercept Seepage and Lower the Groundwater Table



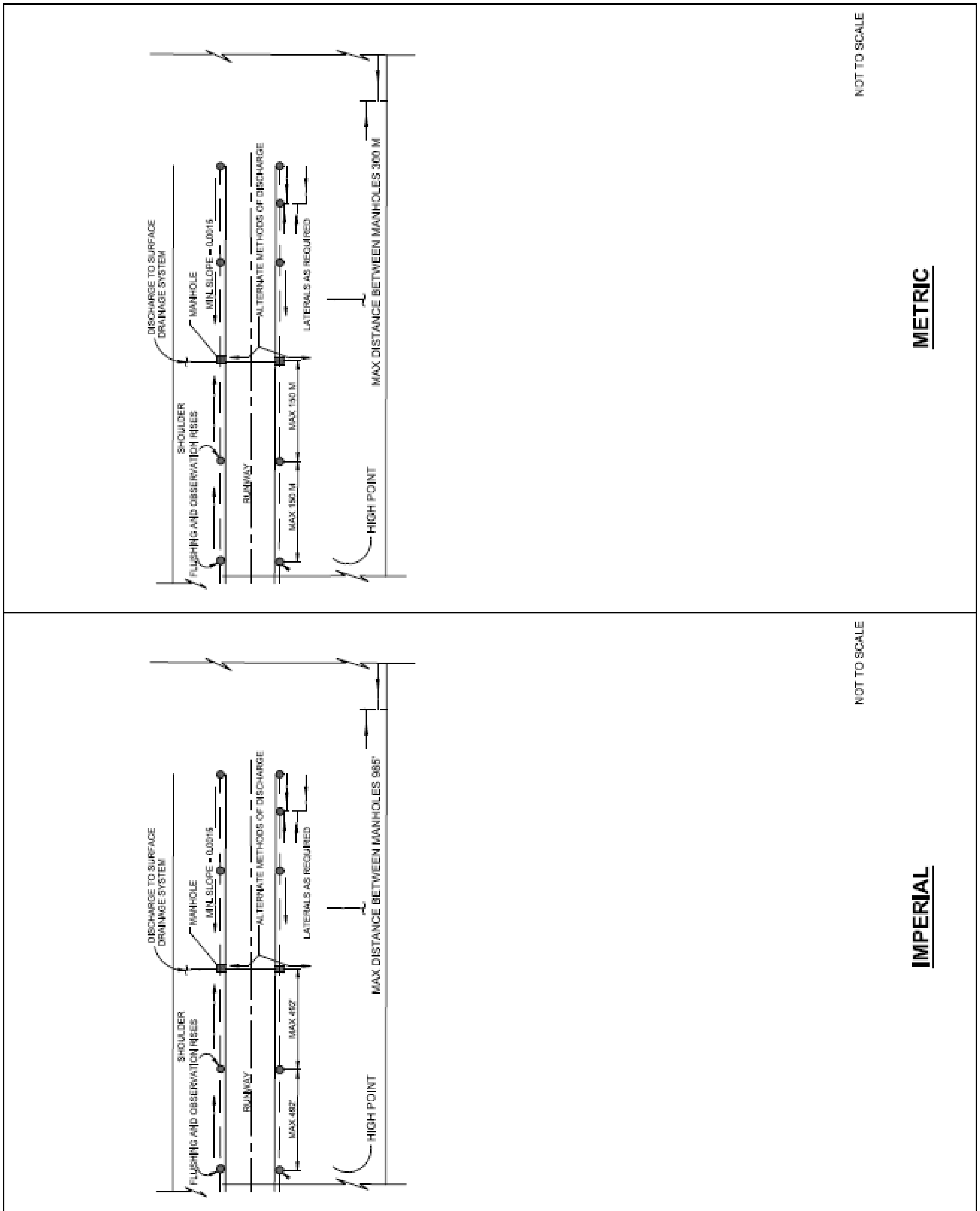
COLLECTOR DRAIN TO INTERCEPT SEEPAGE AND LOWER THE GROUNDWATER TABLE	DATE OCTOBER 2016	FIGURE 20-2

Figure C20-3 Pavement Geometry for Computation of Time for Drainage



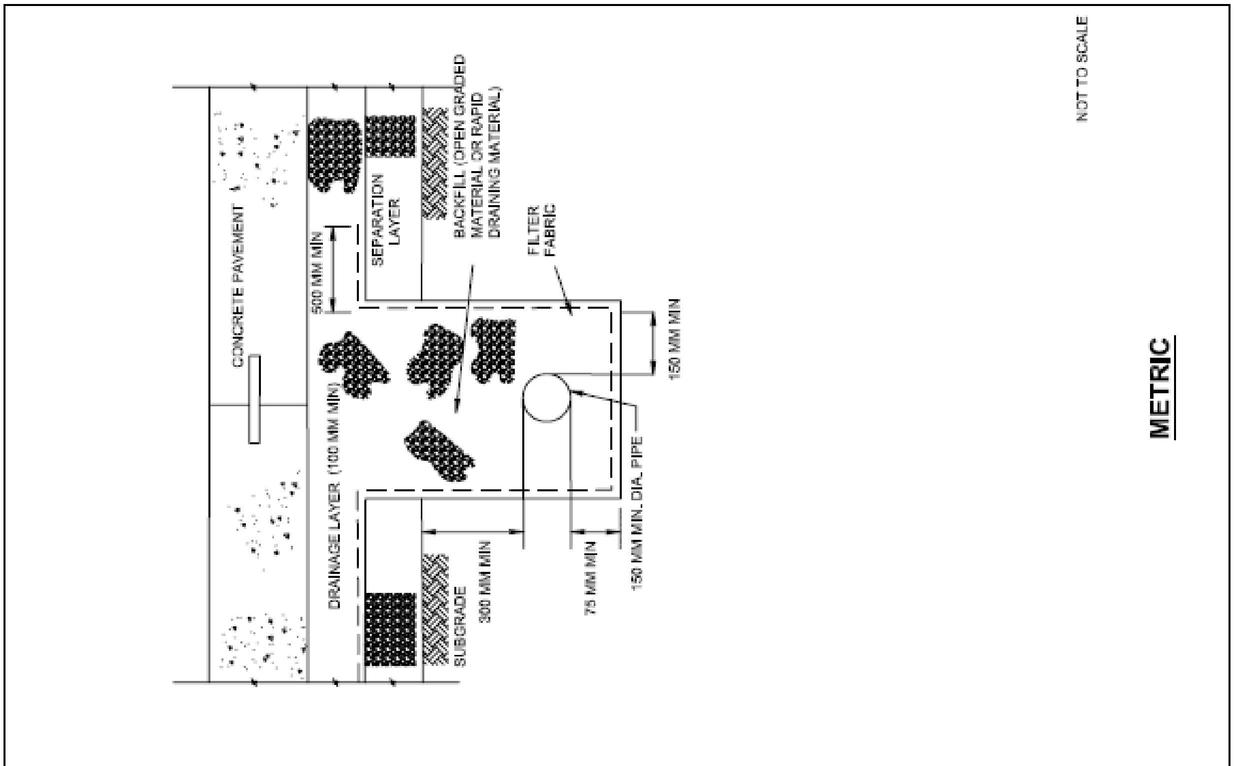
PAVEMENT GEOMETRY FOR COMPUTATION OF TIME FOR DRAINAGE	DATE OCTOBER 2016	FIGURE 20-3

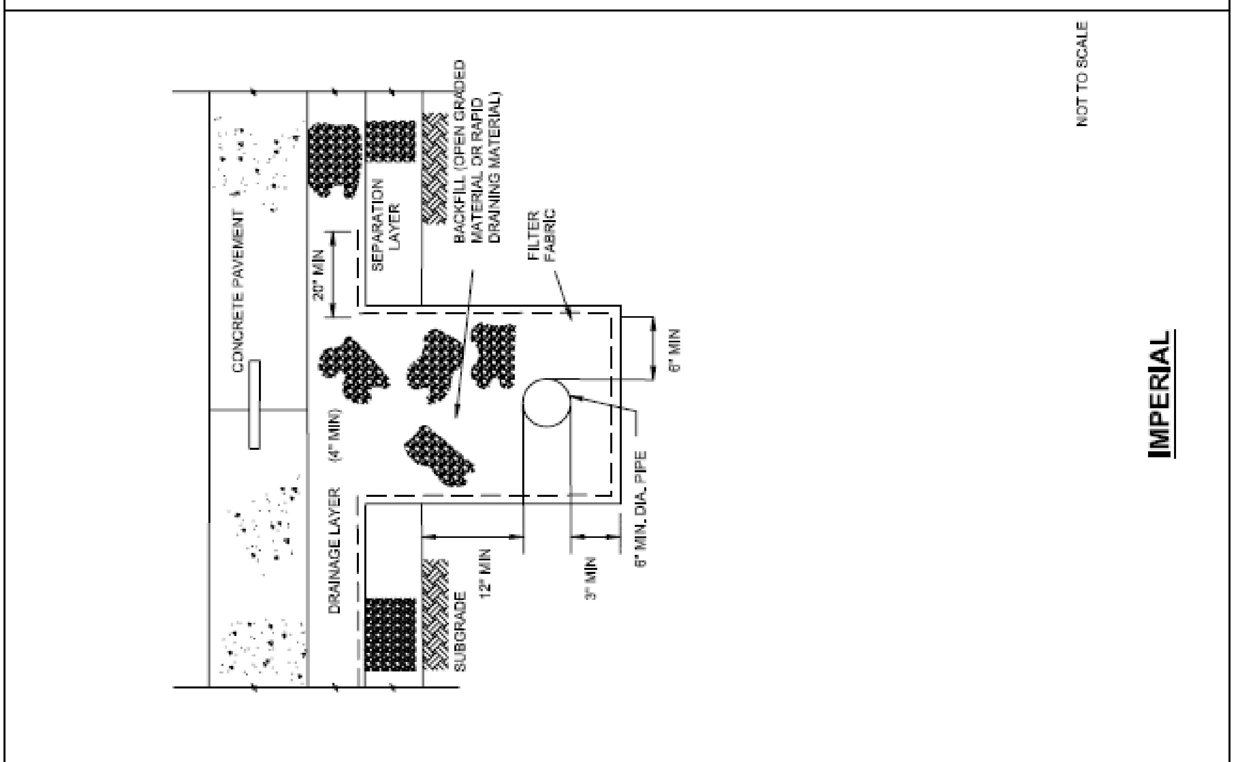
Figure C20-6 Plan View of Subsurface Drainage System



PLAN VIEW OF SUBSURFACE DRAINAGE SYSTEM	DATE OCTOBER 2016	FIGURE 20-6

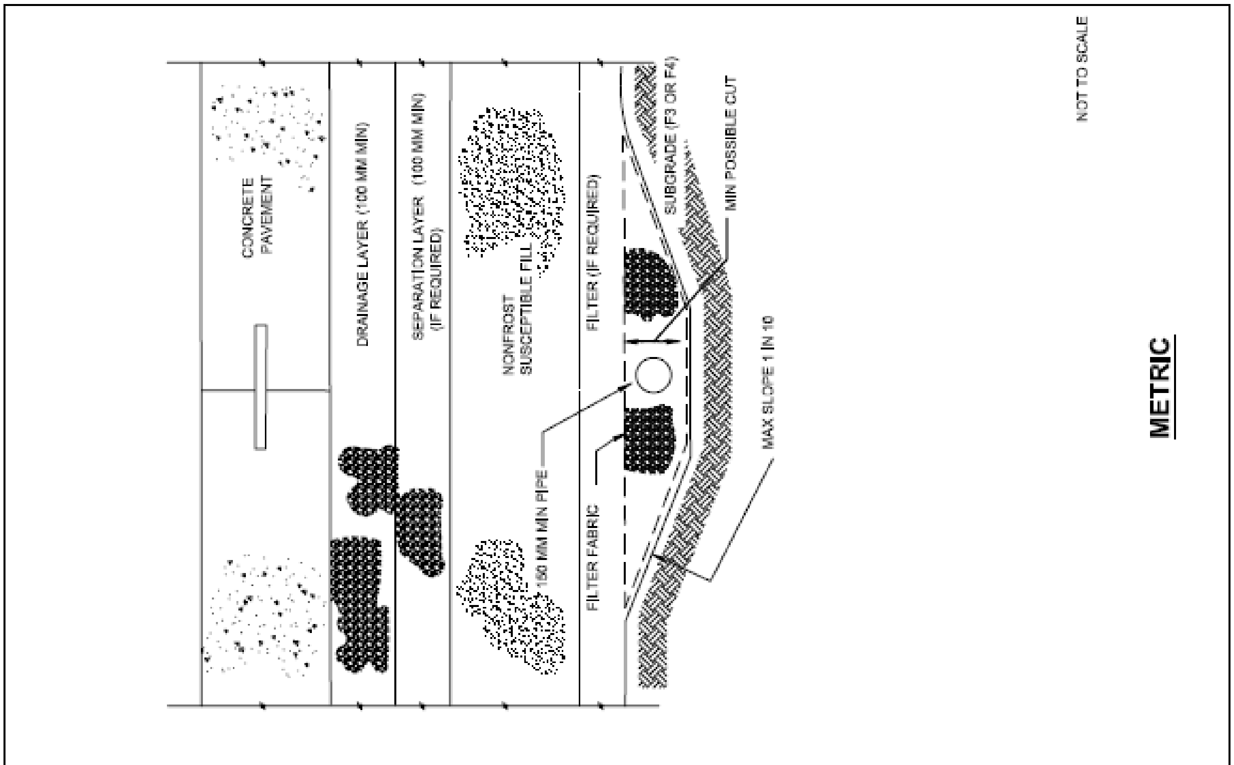
Figure C20-7A Typical Interior Subdrain for Rigid Pavement (Non-Frost Areas)

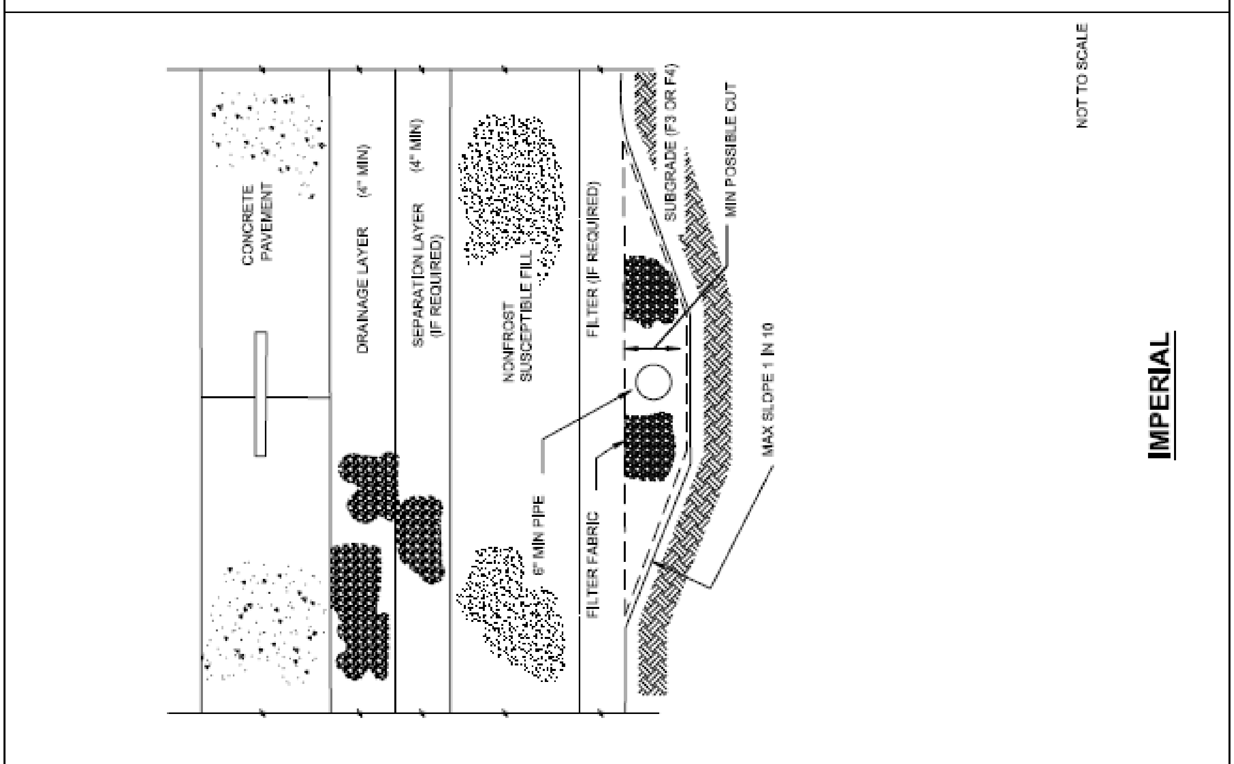




TYPICAL INTERIOR SUBDRAIN FOR RIGID PAVEMENT (NONFROST AREAS)	DATE OCTOBER 2016	FIGURE 20-7A

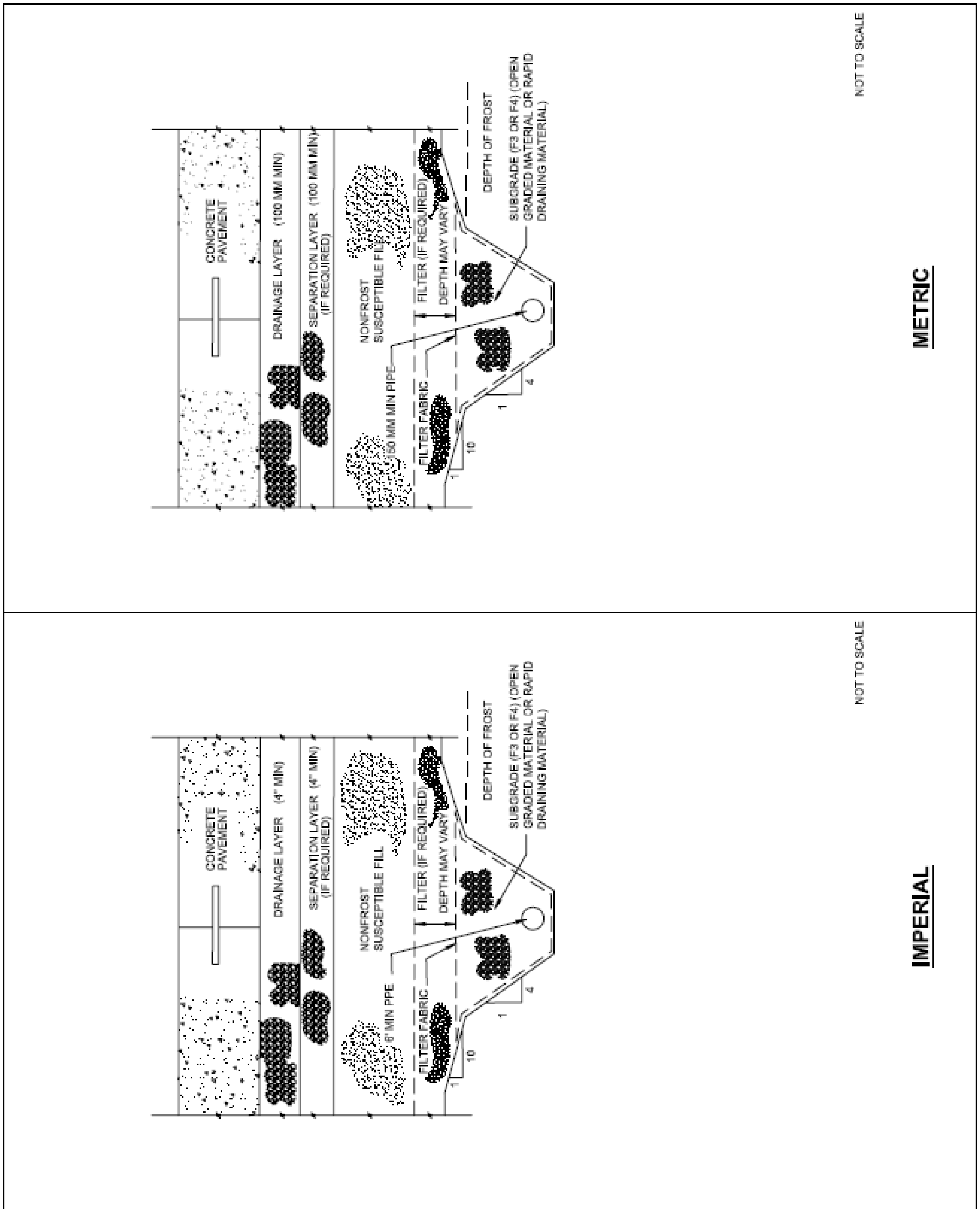
Figure C20-7B Typical Interior Subdrain for Rigid Pavement (Frost Areas, Depth of Frost > Depth to Pipe)





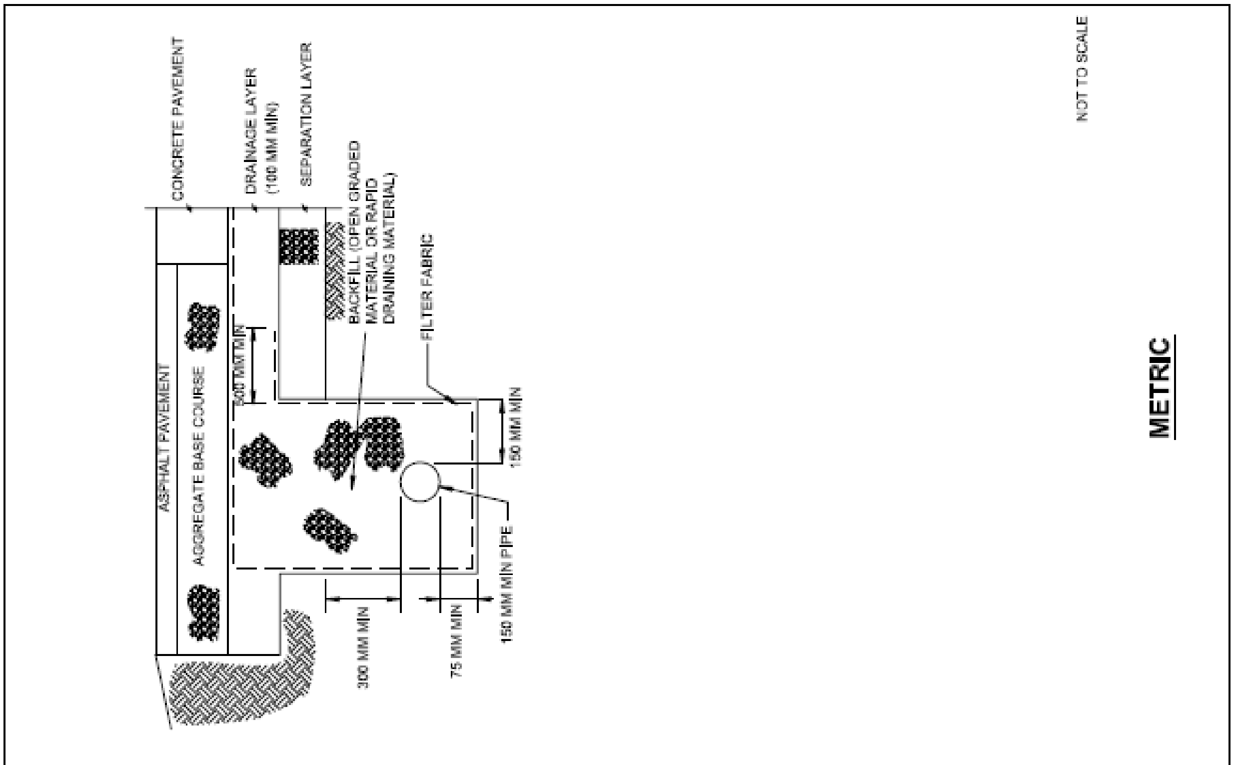
TYPICAL INTERIOR SUBDRAIN FOR RIGID PAVEMENT (FROST AREAS, DEPTH OF FROST > DEPTH TO PIPE)	DATE	FIGURE
	OCTOBER 2016	20-7B

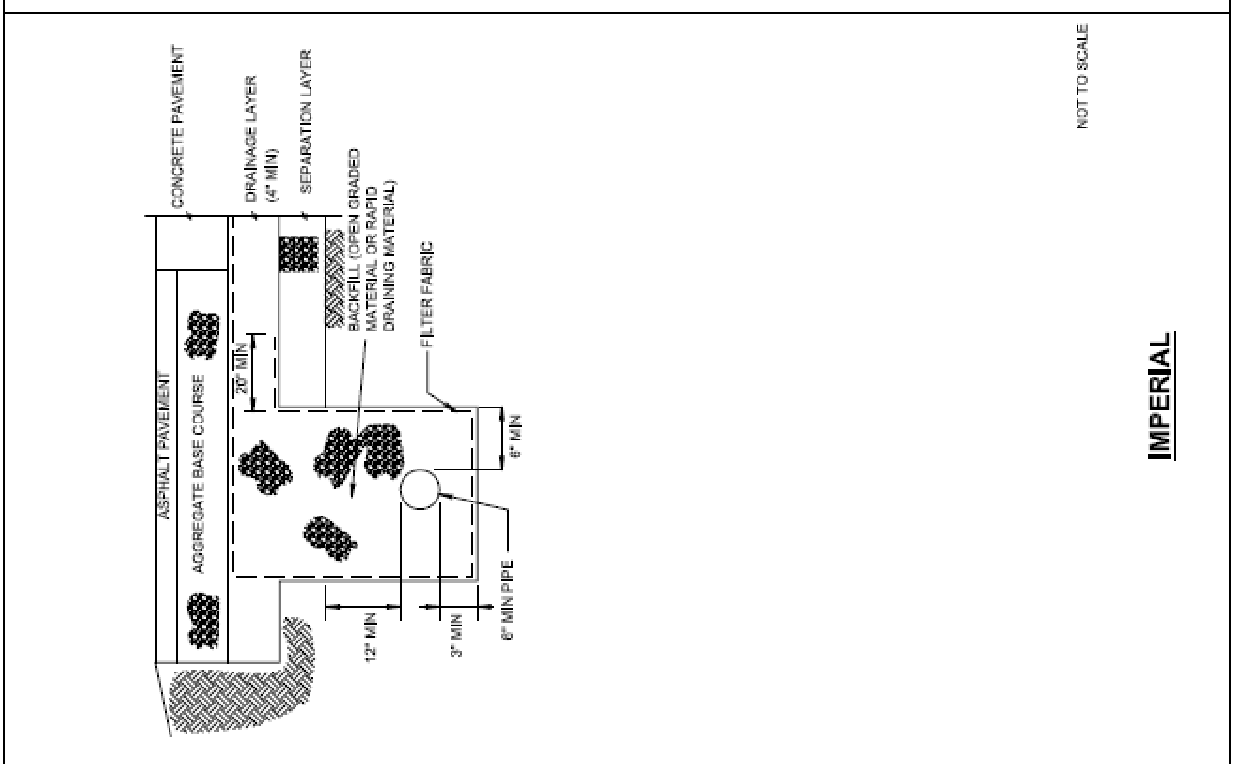
Figure C20-7C Typical Interior Subdrain for Rigid Pavement (Frost Areas, Depth of Frost < Depth to Pipe)



TYPICAL INTERIOR SUBDRAIN FOR RIGID PAVEMENT (FROST AREAS, DEPTH OF FROST < DEPTH TO PIPE)	DATE OCTOBER 2016	FIGURE 20-7C

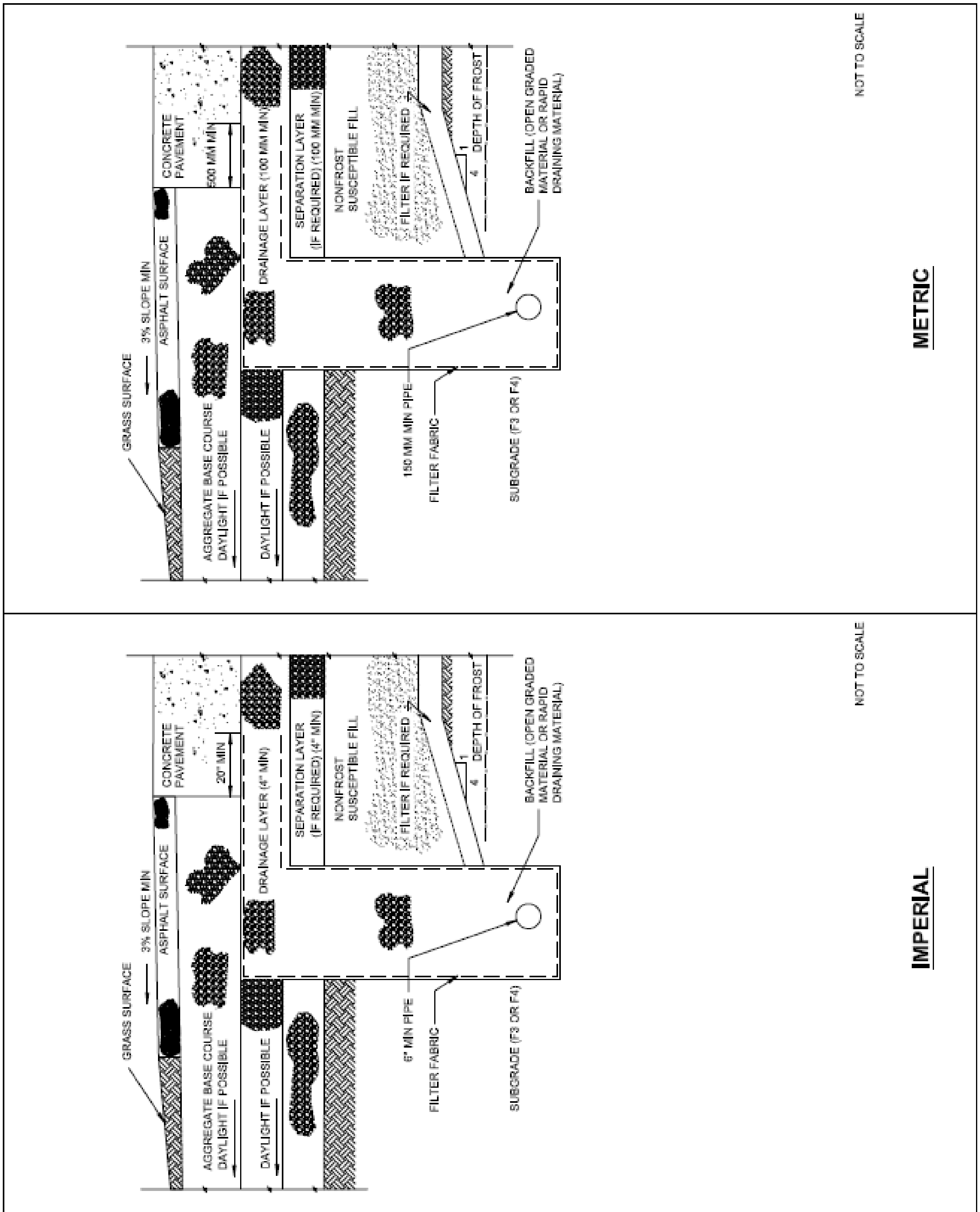
Figure C20-8A Typical Edge Subdrain for Rigid Pavement with Shoulder (Non-Frost Areas)





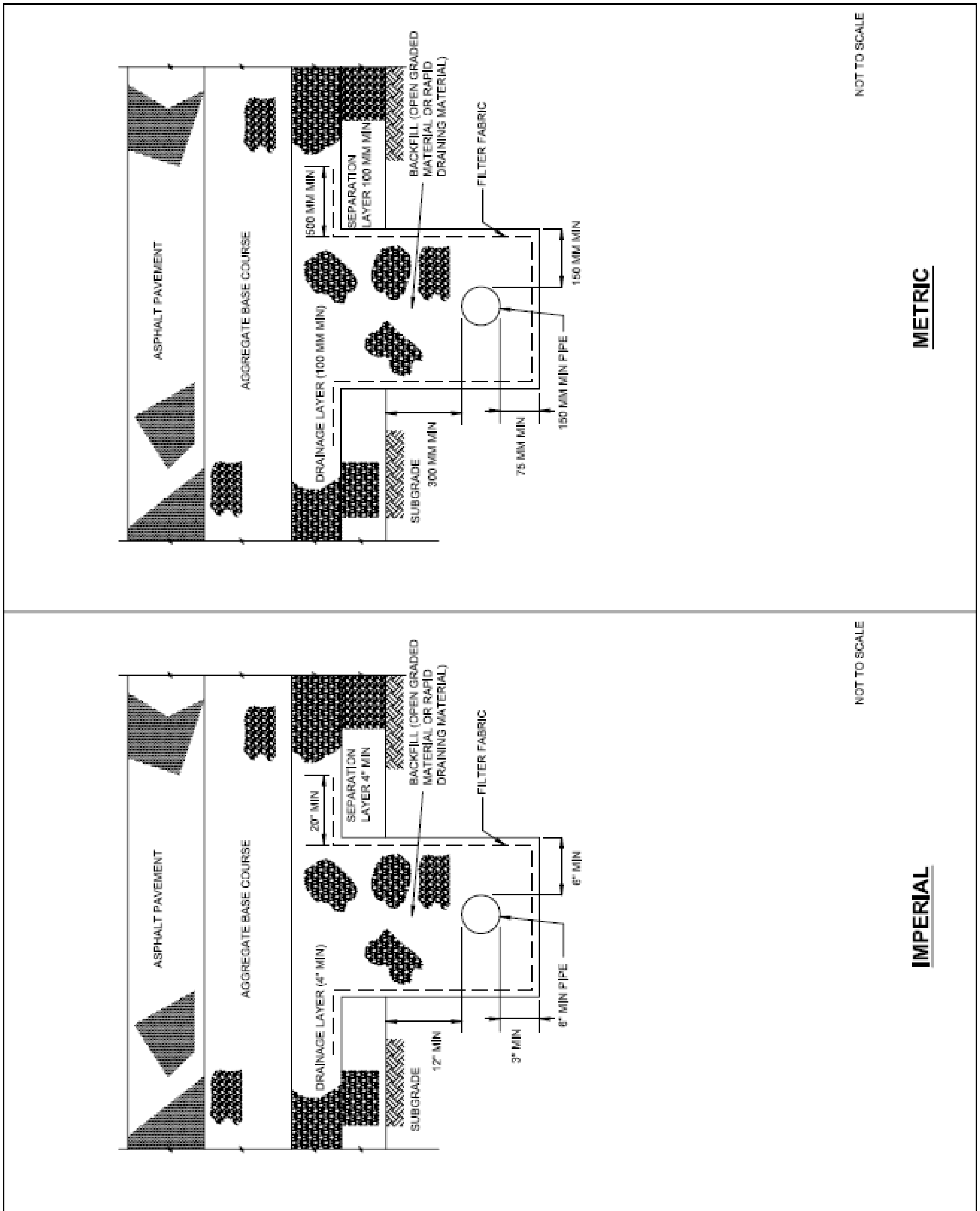
TYPICAL EDGE SUBDRAIN FOR RIGID PAVEMENT WITH SHOULDER (NONFROST AREAS)	DATE OCTOBER 2016	FIGURE 20-8A

Figure C20-8B Typical Edge Subdrain for Rigid Pavement (Frost Areas)



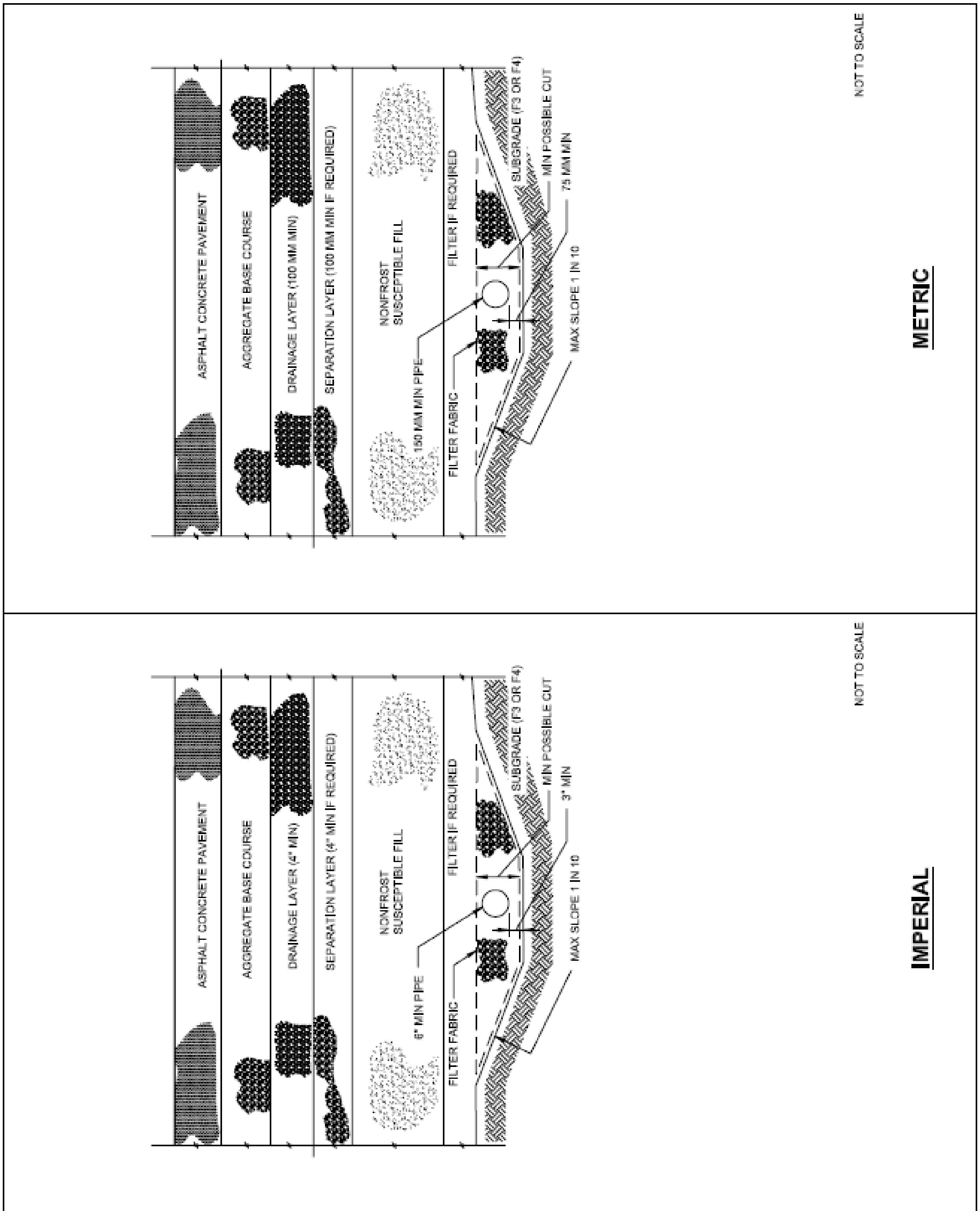
TYPICAL EDGE SUBDRAIN FOR RIGID PAVEMENT (FROST AREAS)	DATE OCTOBER 2016	FIGURE 20-8B

Figure C20-9A Typical Interior Subdrain for Flexible Pavement (Non-Frost Areas)



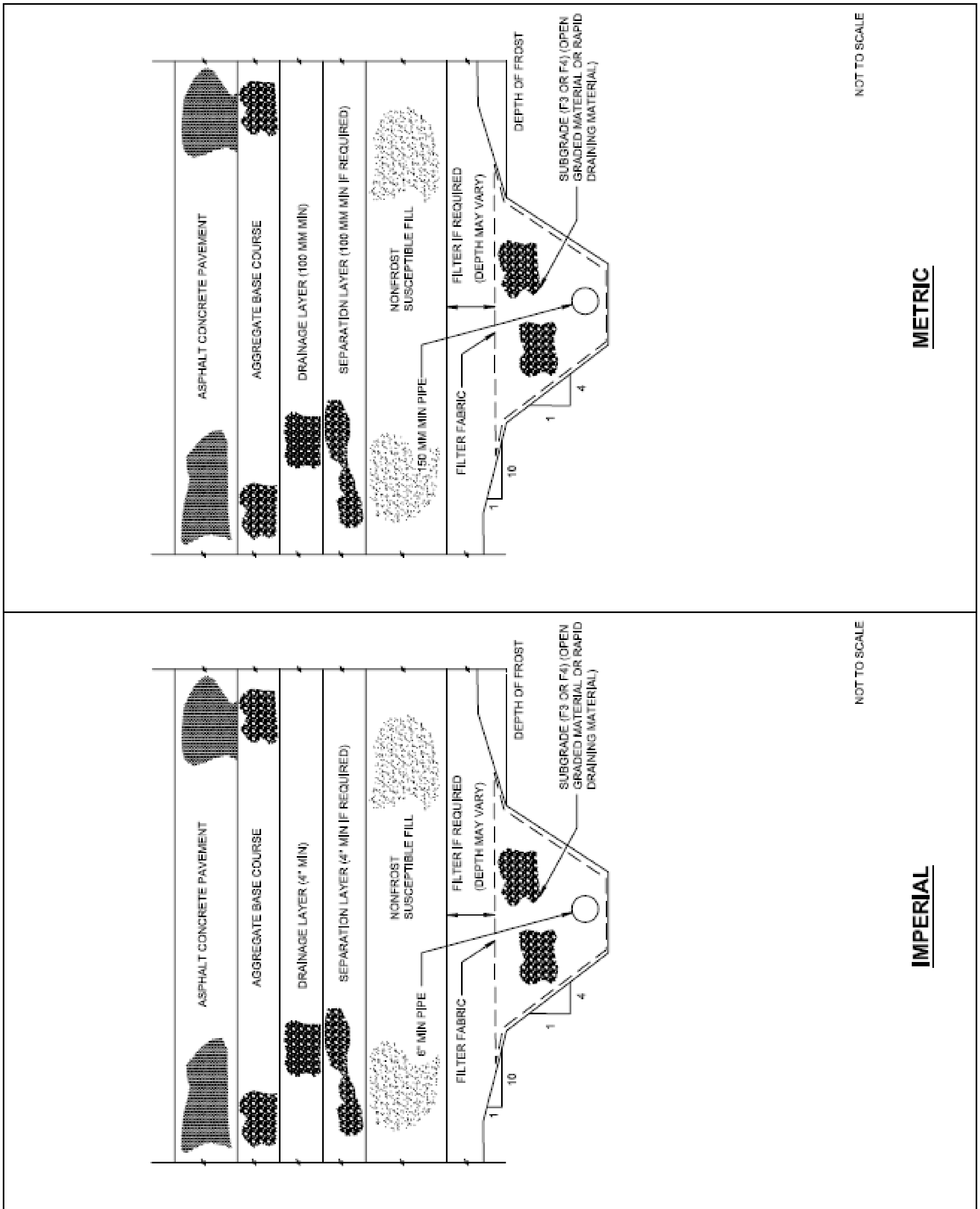
TYPICAL INTERIOR SUBDRAIN FOR FLEXIBLE PAVEMENT (NONFROST AREAS)	DATE OCTOBER 2016	FIGURE 20-9A

Figure C20-9B Typical Interior Subdrain for Flexible Pavement (Frost Areas, Depth of Frost > Depth of Pipe)



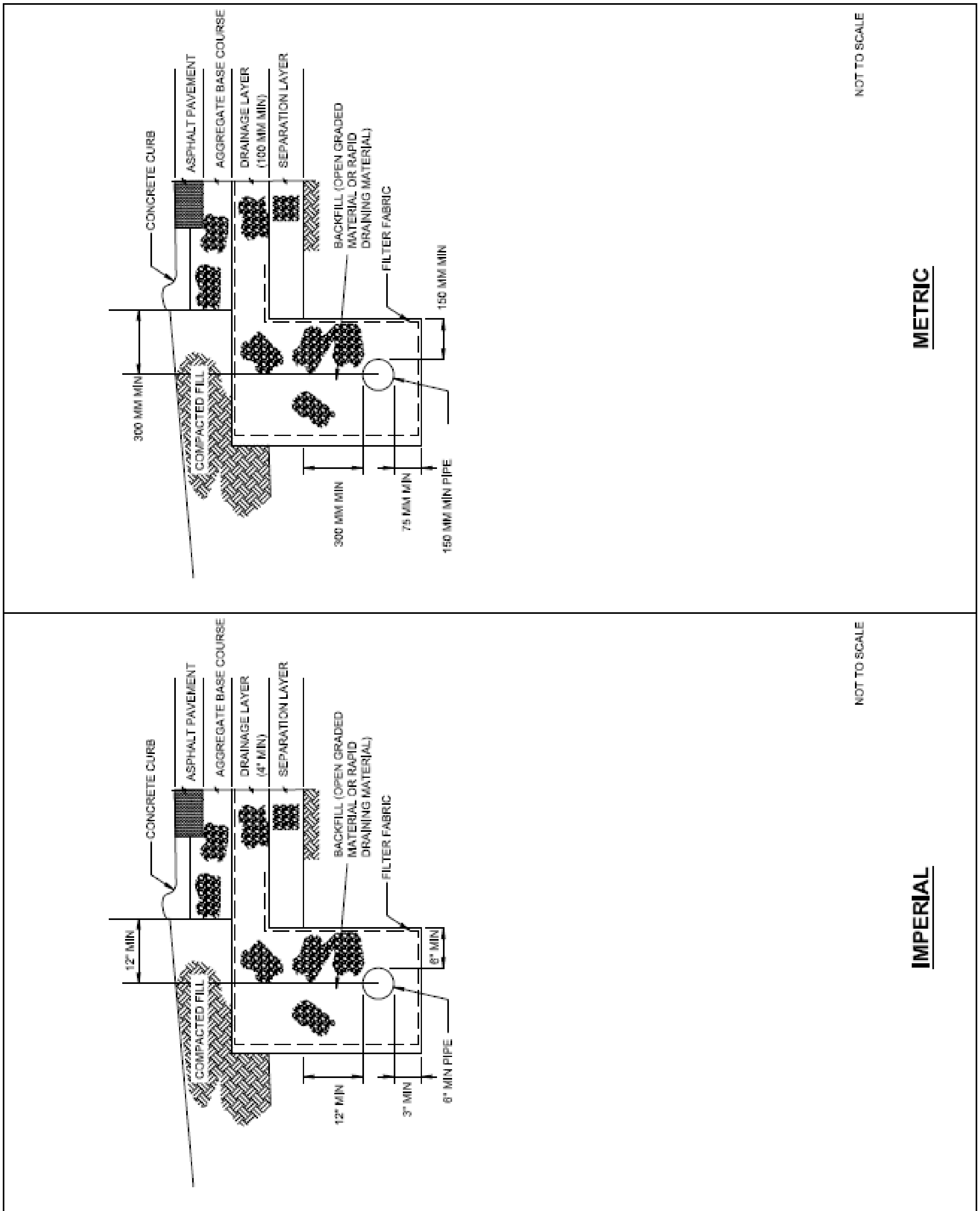
TYPICAL INTERIOR SUBDRAIN FOR FLEXIBLE PAVEMENT (FROST AREAS, DEPTH OF FROST > DEPTH OF PIPE)	DATE OCTOBER 2016	FIGURE 20-9B

Figure C20-9C Typical Interior Subdrain for Flexible Pavement (Frost Areas, Depth of Frost < Depth of Pipe)



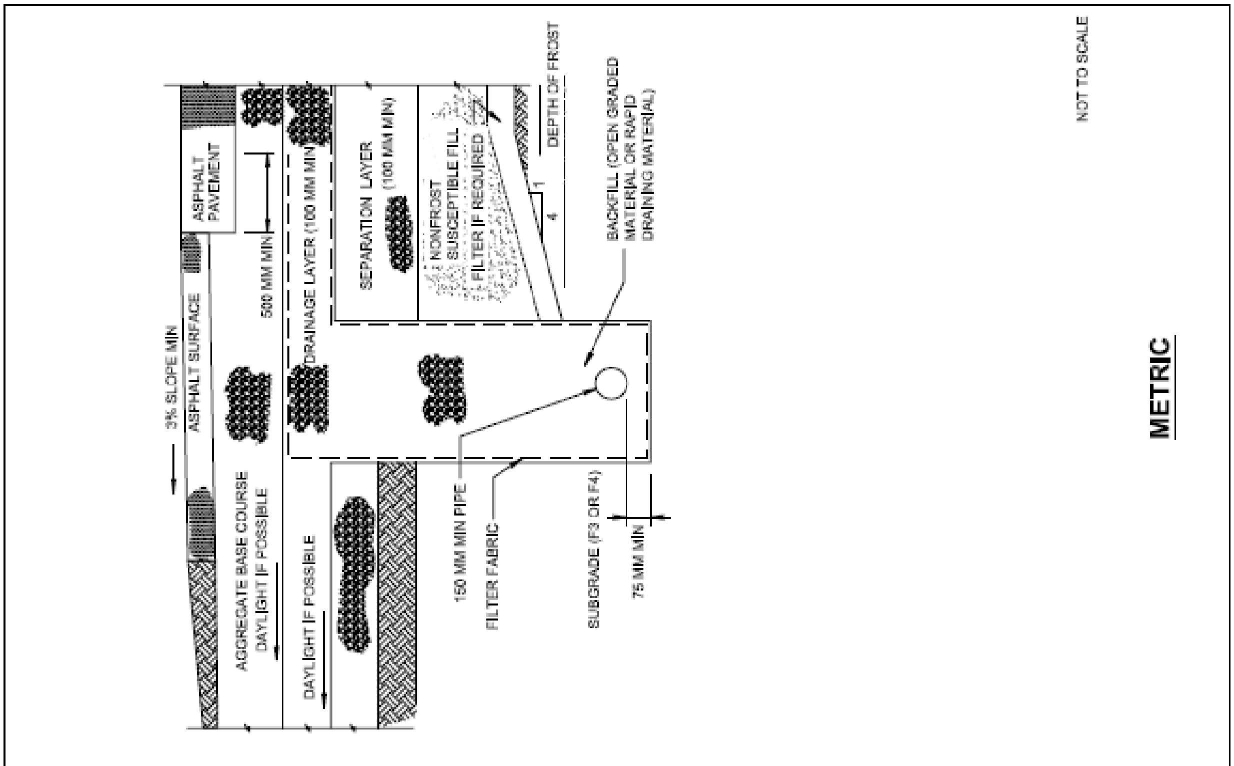
TYPICAL INTERIOR SUBDRAIN FOR FLEXIBLE PAVEMENT (FROST AREAS, DEPTH OF FROST < DEPTH OF PIPE)	DATE OCTOBER 2016	FIGURE 20-9C

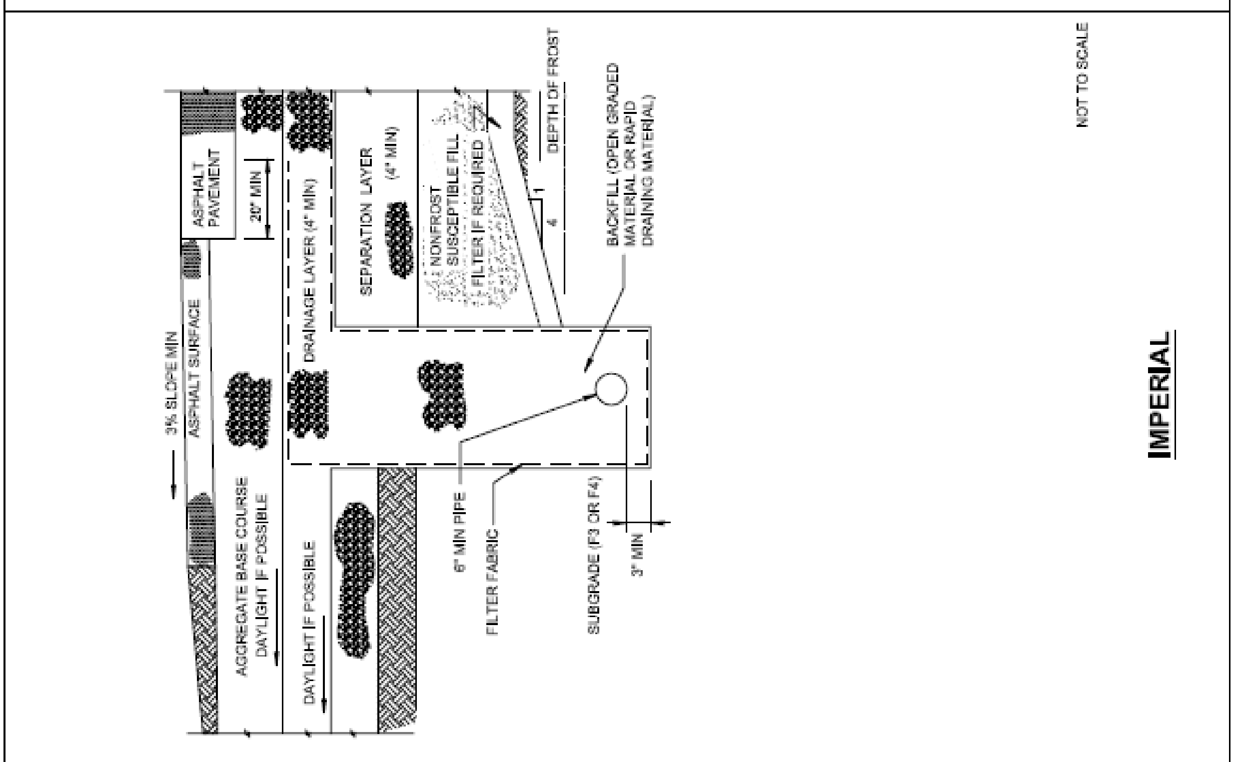
Figure C20-10A Typical Edge Subdrain for Flexible Pavement (Non-Frost Areas)



TYPICAL EDGE SUBDRAIN FOR FLEXIBLE PAVEMENT (NONFROST AREAS)	DATE OCTOBER 2016	FIGURE 20-10A

Figure C20-10B Typical Edge Subdrain for Flexible Pavement (Frost Areas)





TYPICAL EDGE SUBDRAIN FOR FLEXIBLE PAVEMENT (FROST AREAS)	DATE	FIGURE
	OCTOBER 2016	20–10B

Figure C20-11 Dual Outlet System Layout

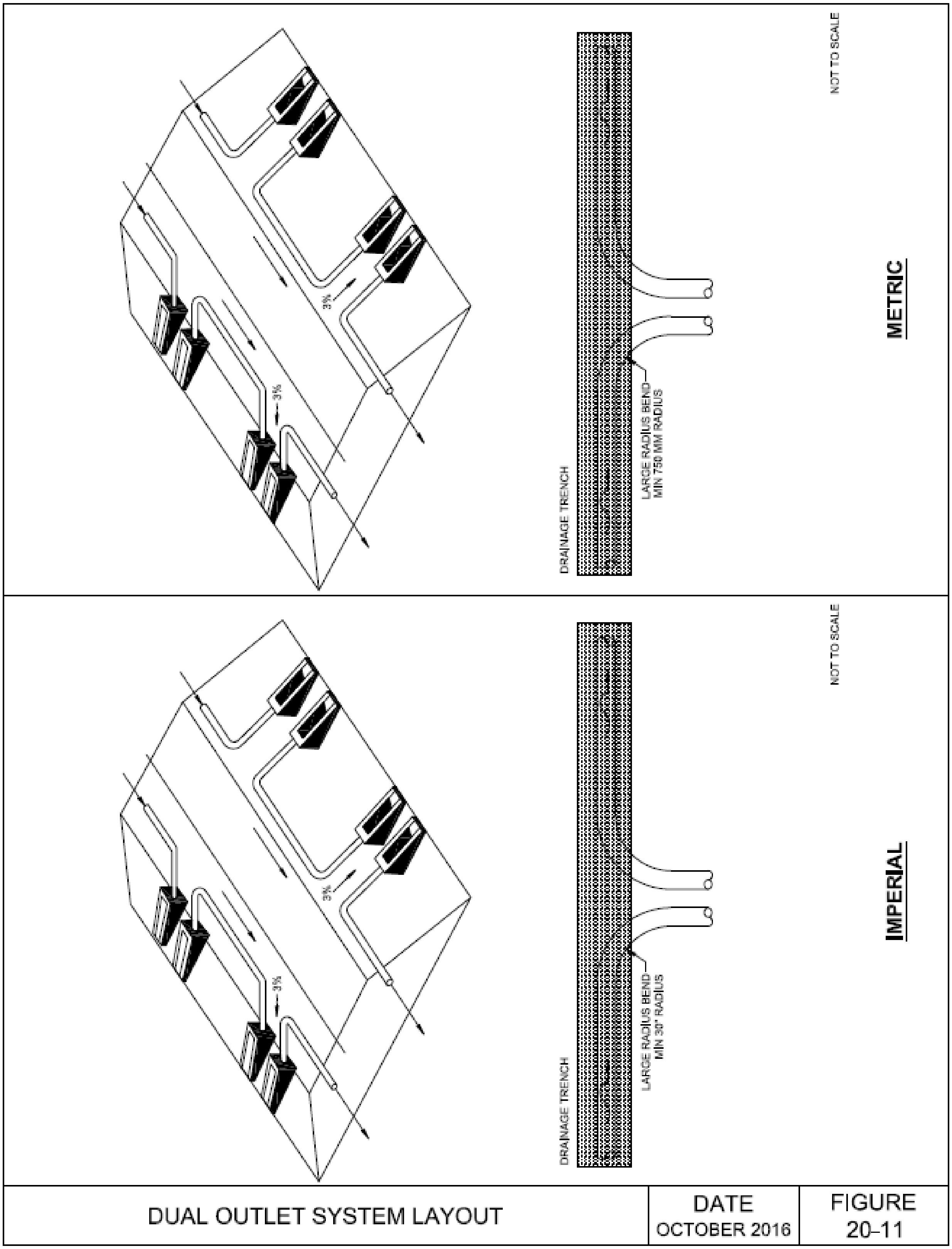
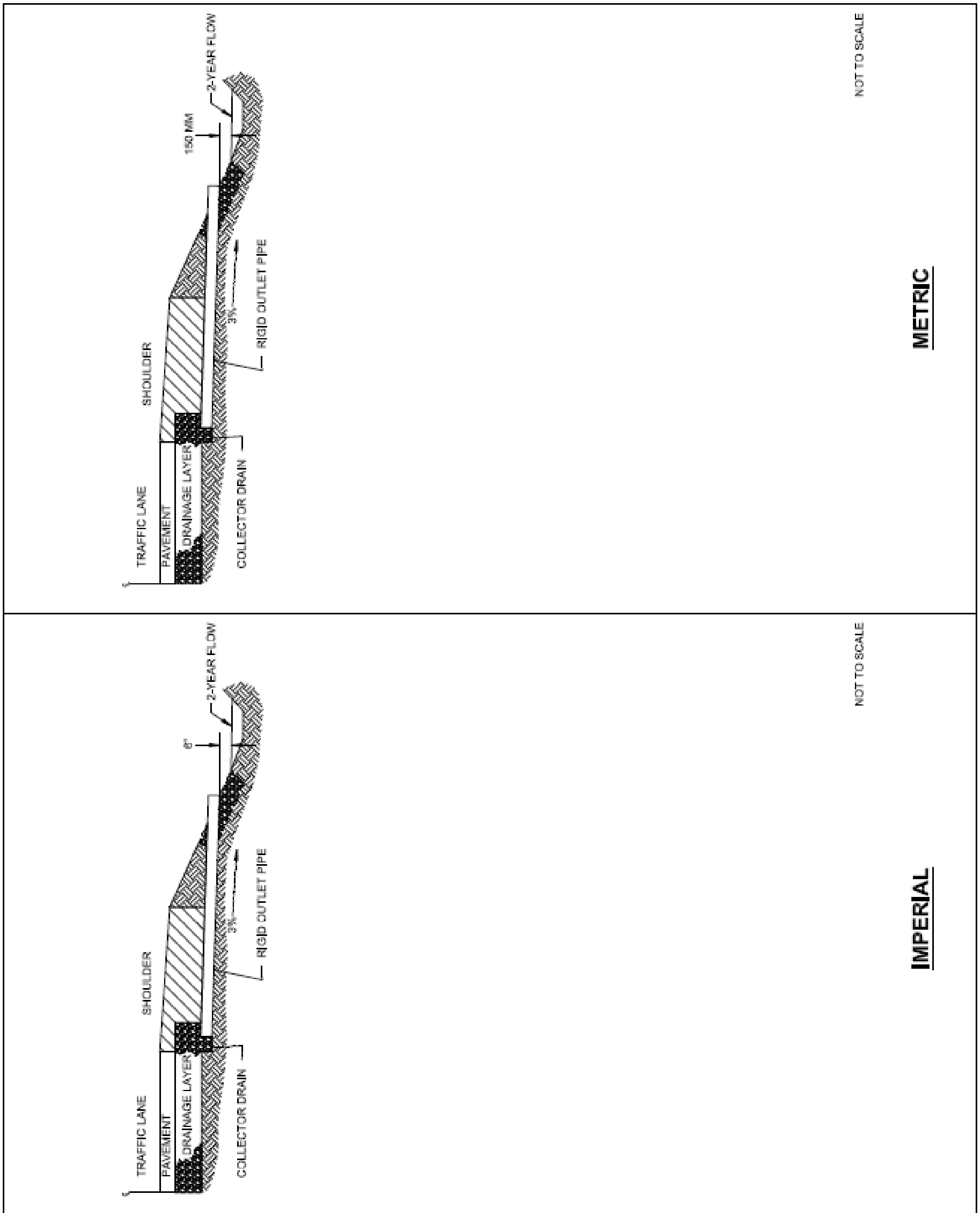


Figure C20-12 Illustration of Large-Radius Bends Recommended for Drainage Outlet



RECOMMENDED OUTLET DESIGN	DATE OCTOBER 2016	FIGURE 20-12

C-4 UNIFIED SOIL CLASSIFICATION SYSTEM SOIL TYPES

GW	Well-graded gravel, fine to coarse gravel
GP	Poorly graded gravel
GM	Silty gravel
GC	Clayey gravel
SW	Well-graded sand, fine to coarse sand
SP	Poorly graded sand
SM	Silty sand
SC	Clayey sand
ML	Silt
CL	Low plasticity clay, lean clay
OL	Organic silt, organic clay
MH	High plasticity silt, elastic silt
CH	High plasticity clay, fat clay
OH	Organic clay, organic silt
Pt	Peat

C-5 UNITS OF MEASUREMENT AND UNIT CONVERSIONS

FROM ENGLISH		CONVERSION FACTOR	TO METRIC	
Unit	**Definition**		**Unit**	**Definition**
ft	Foot	x 0.305	m	Meter
in	Inch	x 25.4	mm	Millimeters
kip	Kilopound	x 454	kg	Kilogram
lb	Pound	x 0.454	kg	Kilogram
lb	Pound	x 0.00445	kN	KiloNewton
psi	Pound per Square Inch	x 0.00690	MPa	MegaPascal
F	Fahrenheit	$(T_{°F}-32)/1.8$	C	Celsius

FROM METRIC		CONVERSION FACTOR	TO ENGLISH	
Unit	**Definition**		**Unit**	**Definition**
m	Meter	x 3.28	ft	Foot
mm	Millimeters	x 0.0394	in	Inch
kg	Kilogram	x 0.0022	kip	Kilopound
kg	Kilogram	x 2.20	lb	Pound
kN	KiloNewton	x 224.7	lb	Pound
MPa	MegaPascal	x 145	psi	Pound per Square Inch
C	Celsius	$(1.8*T_{°C})+32$	F	Fahrenheit

APPENDIX D USE OF INSULATION MATERIALS IN PAVEMENTS

D-1 INSULATING MATERIALS AND INSULATED PAVEMENT SYSTEMS.

The only acceptable insulating material for use in roads is extruded polystyrene board stock. Results from laboratory and field tests have shown that extruded polystyrene does not absorb a significant volume of moisture and that it retains its thermal and mechanical properties for several years. The material is manufactured in board stock ranging from 1 in (25 mm) to 4 in (100 mm) thick. Approval from the Government Civil Engineer is required for use of insulating materials other than extruded polystyrene.

D-1.1 Synthetic Insulating Material.

The use of a synthetic insulating material within a pavement cross section is permissible with the written approval of the Government Civil Engineer. Experience has shown that surface icing may occur on insulated pavements at times when uninsulated pavements nearby are ice-free and vice versa. Surface icing creates possible hazards to fast-moving motor vehicles. Accordingly, in evaluating alternative pavement sections, the designer should select an insulated pavement only in special cases not sensitive to differential surface icing. Special attention should be given to the need for adequate transitions to pavements having greater or lesser protection against sub grade freezing.

D-1.2 Insulated Pavement System.

An insulated pavement system comprises conventional surfacing and base above an insulating material of suitable thickness to restrict or prevent the advance of subfreezing temperatures into a frost-susceptible subgrade. Unless the thickness of insulation and overlying layers is sufficient to stop subgrade freezing, additional layers of granular materials are placed between the insulation and the subgrade to contain a portion of the frost zone that extends below the insulation. In consideration of only the thermal efficiency of the insulated pavement system, 1 in (25 mm) of granular material placed below the insulating layer is much more effective than 1 in (25 mm) of the same material placed above the insulation. Hence, under the design procedure outlined below, the thickness of the pavement and base above the insulation is determined as the minimum that will meet structural requirements for adequate cover over the relatively weak insulating material. The determination of the thickness of insulation and of additional granular material is predicated on the placement of the latter beneath the insulation.

D-2 DETERMINATION OF THICKNESS OF COVER ABOVE INSULATION.

On a number of insulated pavements in the civilian sector, the thickness of material above the insulation has been established to limit the vertical stress on the insulation caused by dead loads and wheel loads to not more than one-third of the compressive strength of the insulating material. The Boussinesq equation should be used for this determination. If a major project incorporating insulation is planned, advice and assistance in regard to the structural analysis should be sought from the Government Civil Engineer.

D-3 DESIGN OF INSULATED PAVEMENT TO PREVENT SUBGRADE FREEZING.

Once the thickness of pavement and base above the insulation has been determined, it should be ascertained whether a reasonable thickness of insulation will keep subfreezing temperatures from penetrating through the insulation. Calculations for this purpose make use of the design air and surface freezing indexes and the mean annual soil temperature at the site. If the latter is unknown, it may be approximated by adding 7 degrees Fahrenheit to the mean annual air temperature. For paved surfaces kept free from snow and ice, an n-factor of 0.75 should be used. For calculating the required thickness of insulation, the design surface freezing index and the mean annual soil temperature are used with Figure D-1 to determine the surface temperature amplitude A. The initial temperature differential V_o is obtained by subtracting 32 degrees Fahrenheit from the mean annual soil temperature, or it also may be read directly from Figure D-1. The ratio V_o/A is then determined. Figure D-2 is then entered with the adopted thickness of pavement and base to obtain the thickness of extruded polystyrene insulation needed to prevent subgrade freezing beneath the insulation. If the required thickness is less than about 2 (50 mm) to 3 in (75 mm), it will usually be economical to adopt for design the thickness given by Figure D-2, and to place the insulation directly on the subgrade. If more than about 2 (50 mm) to 3 in (75 mm) of insulation is required to prevent subgrade freezing, it usually will be economical to use a lesser thickness of insulation, underlain by subbase material (S1 or S2). Alternative combinations of thicknesses of extruded polystyrene insulation and granular material base and subbase to contain completely the zone of freezing can be determined from Figure D-3, which shows the total depth of frost for various freezing indexes, thicknesses of extruded polystyrene insulation, and base courses. The thickness of subbase needed to contain the zone of freezing is the total depth of frost penetration less the total thickness of pavement, base, and insulation.

D-4 DESIGN OF INSULATED PAVEMENT FOR LIMITED SUB GRADE FREEZING.

It may be economically advantageous to permit some penetration of frost into the subgrade. Accordingly, the total depth of frost penetration given by Figure D-3 may be taken as the value in Figure 19-4, and a new combined thickness **b** of base, insulation, and subbase is determined that permits limited frost penetration, into the subgrade. The thickness of subbase needed beneath the insulation is obtained by subtracting the previously established thicknesses of base, determined from structural requirements, and of insulation, determined from Figure D-3. Not less than 4 in (100 mm) of subbase material meeting the requirements of Chapter titled Seasonal Frost Conditions should be placed between the insulation and the subgrade. If less than 4 in (100 mm) of subbase material is necessary, consideration should be given to decreasing the insulation thickness and repeating the process outlined above.

D-5 CONSTRUCTION PRACTICE.

While general practice has been to place insulation in two layers with staggered joints, this practice should be avoided at locations where subsurface moisture flow or a high groundwater table may be experienced. In the latter cases it is essential to provide means for passage of water through the insulation to avoid possible excess hydrostatic pressure in the soil on which the insulating material is placed. Free drainage may be provided by leaving the joints between insulating boards slightly open, or by drilling holes in the boards, or both. The Government Civil Engineer may be contacted for more detailed construction procedures.

Figure D-1 Equivalent Sinusoidal Surface Temperature Amplitude A and Initial Temperature Difference V_o (°C = 5/9 (°F-32)

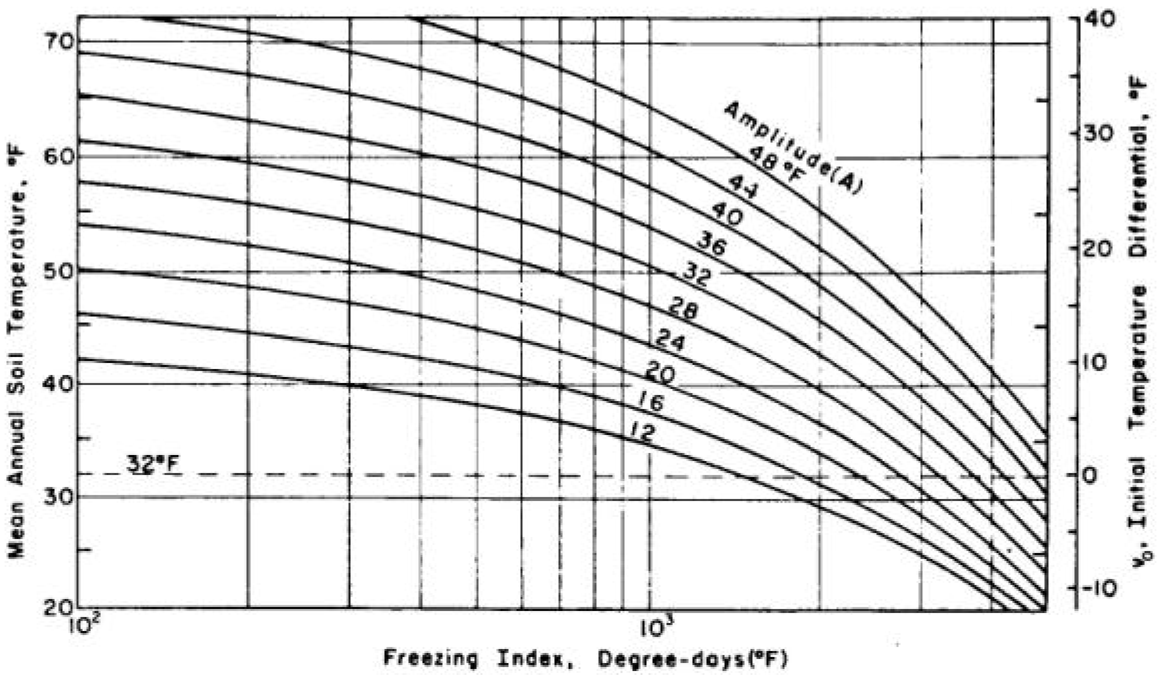
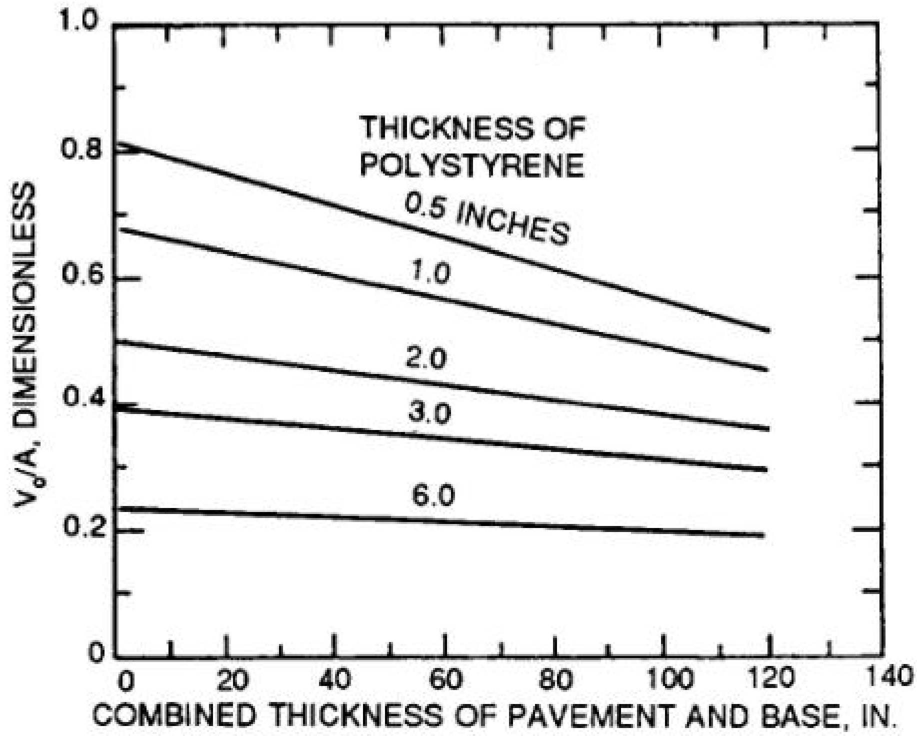


Figure D-2 Thickness of Extruded Polystyrene Insulation to Prevent Subgrade Freezing (millimeter = 25.4 × inches, meter = 3.28 ft)



NOTES

DESIGN CURVES BASED ON THE FOLLOWING MATERIAL PRO
PAVEMENT:SAME THERMAL PROPERTIES AS UPPER BASE
BASE: Y_d = 135 PCF, w = 7 PERCENT
EXTRUDED POLYSTYTRENE INSULATION

$$Y_d = 2.0 \text{ PCF}, \underline{K} = 0.21 \frac{\text{BTU IN.}}{\text{FT}^2 \text{ HR °F}}$$

Figure D-3 Effect of Thickness of Insulation and Base on Frost Penetration (Sheet 1 of 4) (millimeters = 25.4 × inches)

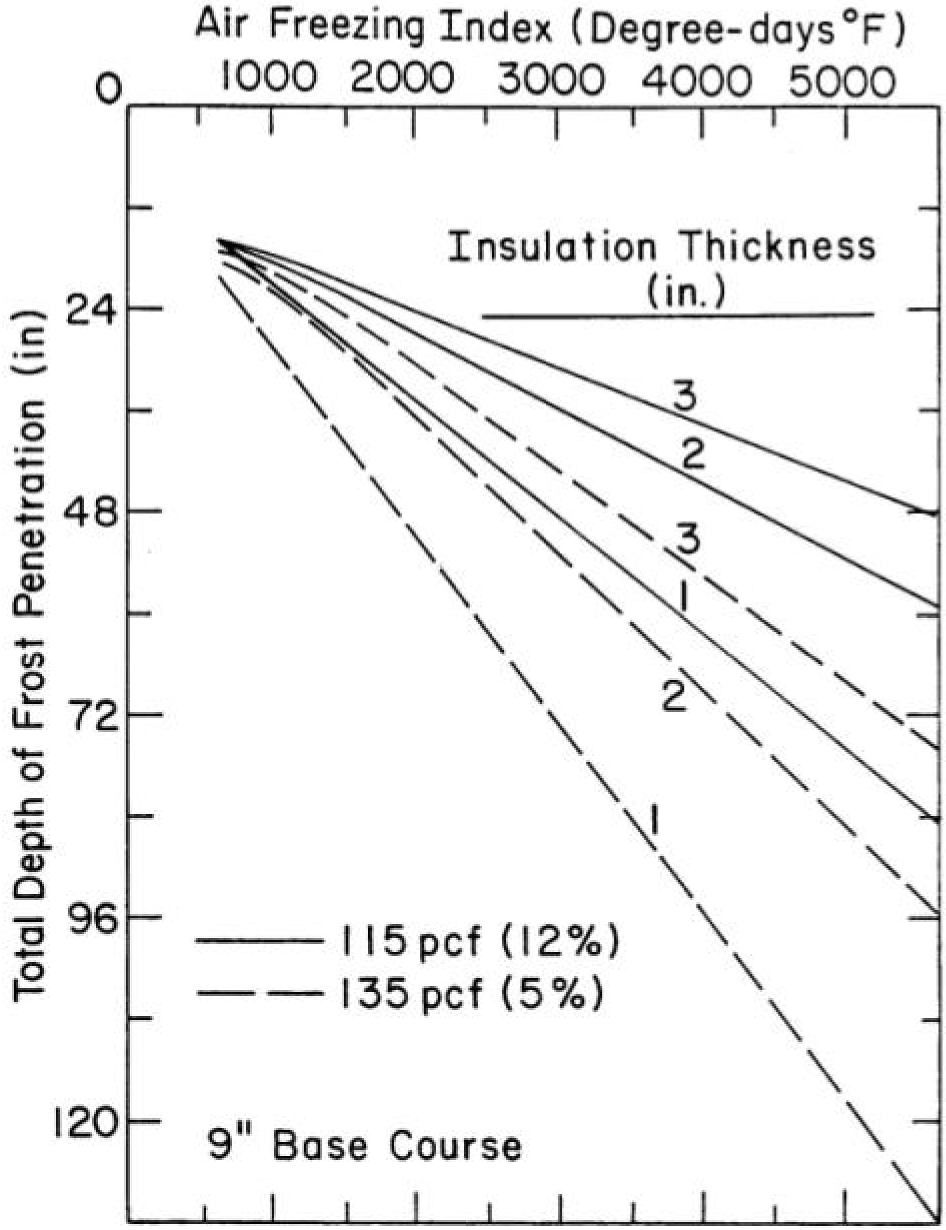


Figure D-3 Effect of Thickness of Insulation and Base on Frost Penetration (Sheet 2 of 4) (millimeters = 25.4 × inches) (kg/m^3 = 16 × pcf)

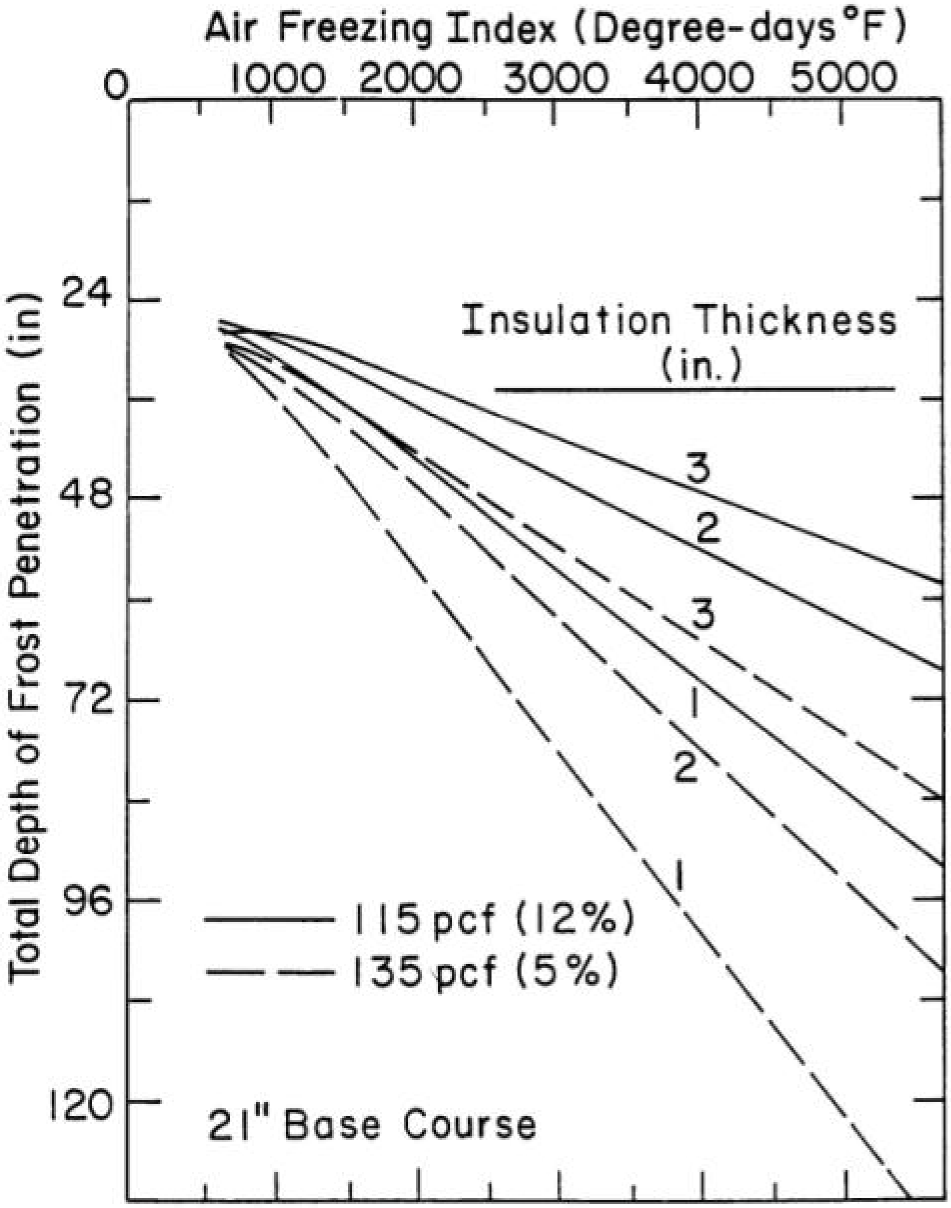


Figure D-3 Effect of Thickness of Insulation and Base on Frost Penetration (Sheet 3 of 4) (millimeters = 25.4 × inches) (kg/m³ = 16 × pcf)

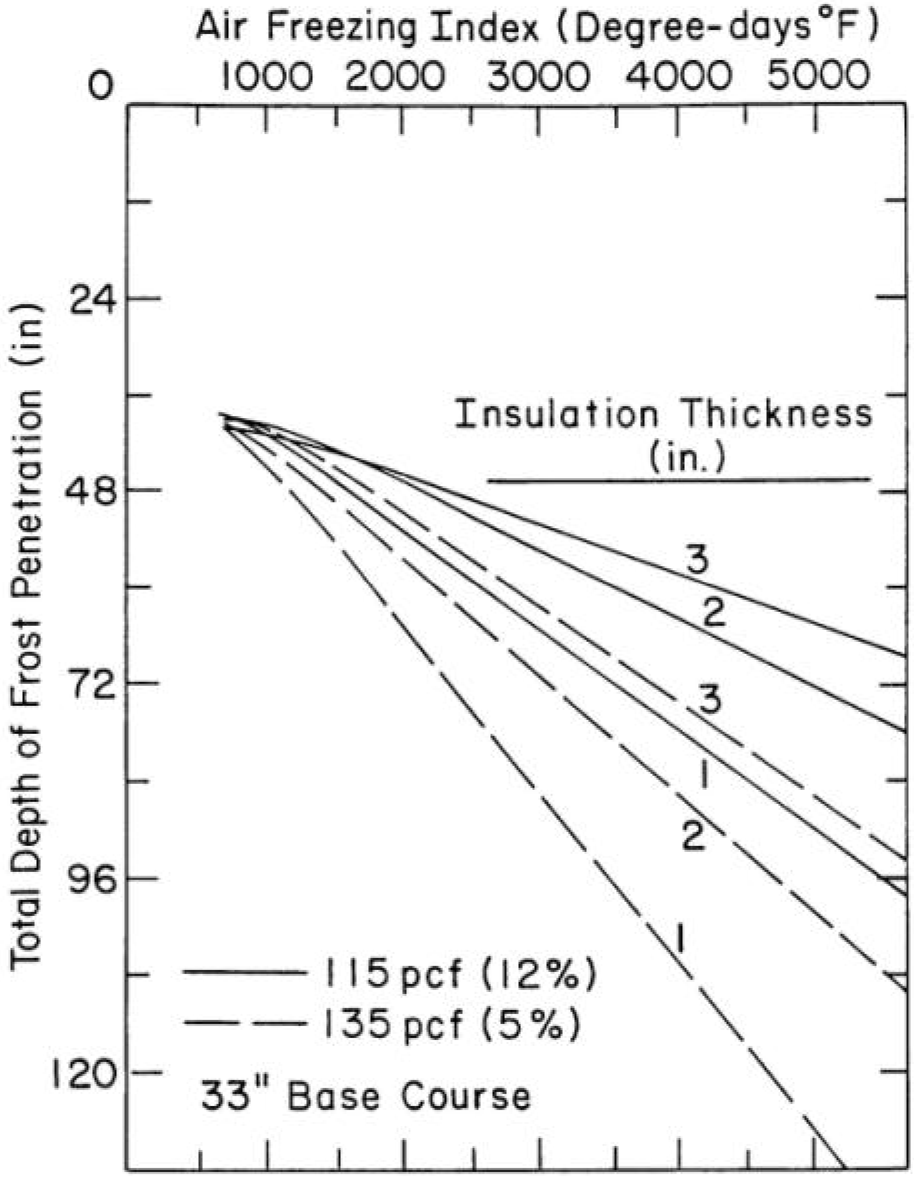
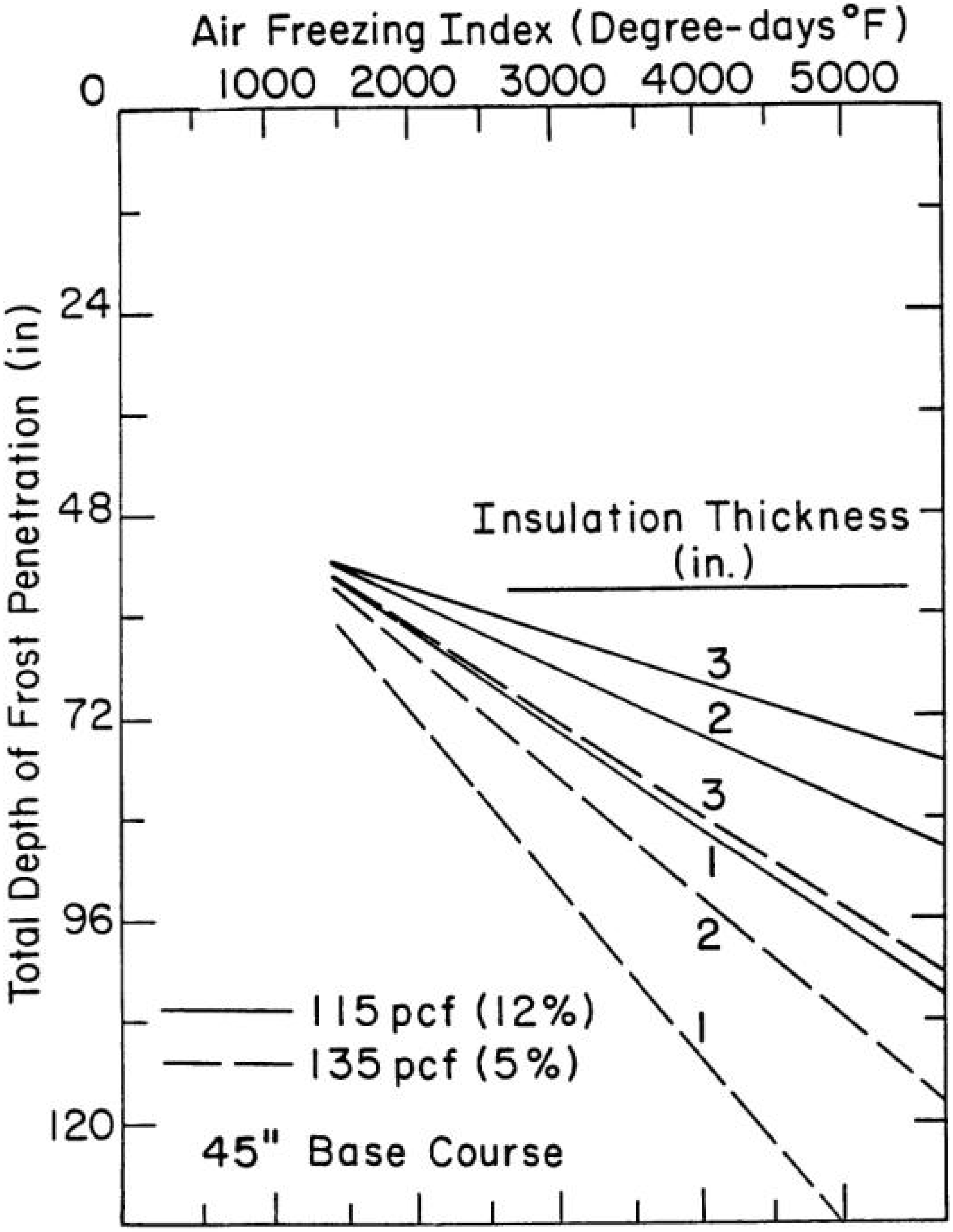


Figure D-3 Effect of Thickness of Insulation and Base on Frost Penetration (Sheet 4 of 4) (millimeters = 25.4 × inches) (kg/m^3 = 16 × pcf)



APPENDIX E FLEXIBLE PAVEMENT DESIGN CURVES

Figure E-1 Single Axle, Dual-Tire Load Flexible Pavement Design Curve

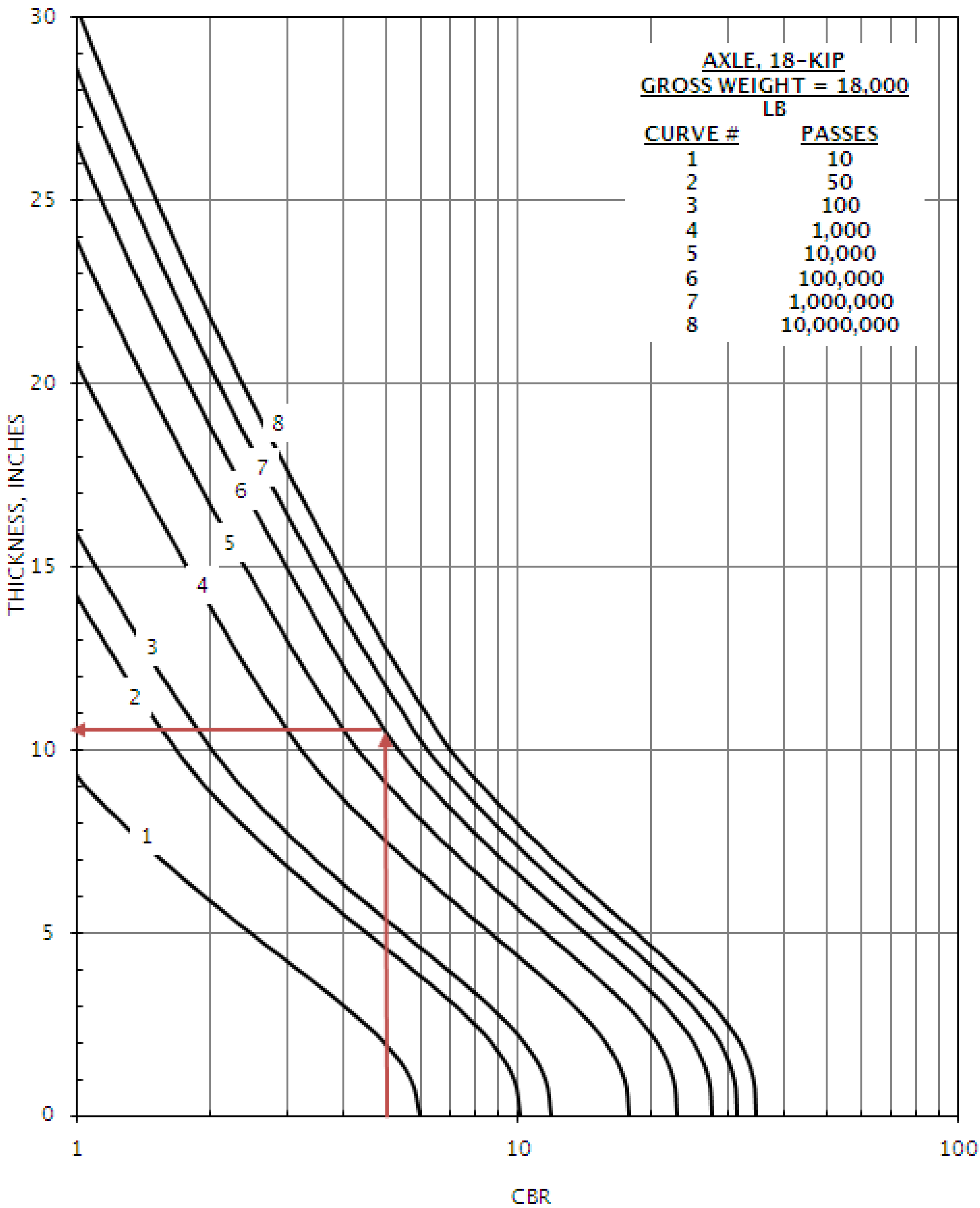


Figure E-2 Passenger Car
Flexible Pavement Design Curve

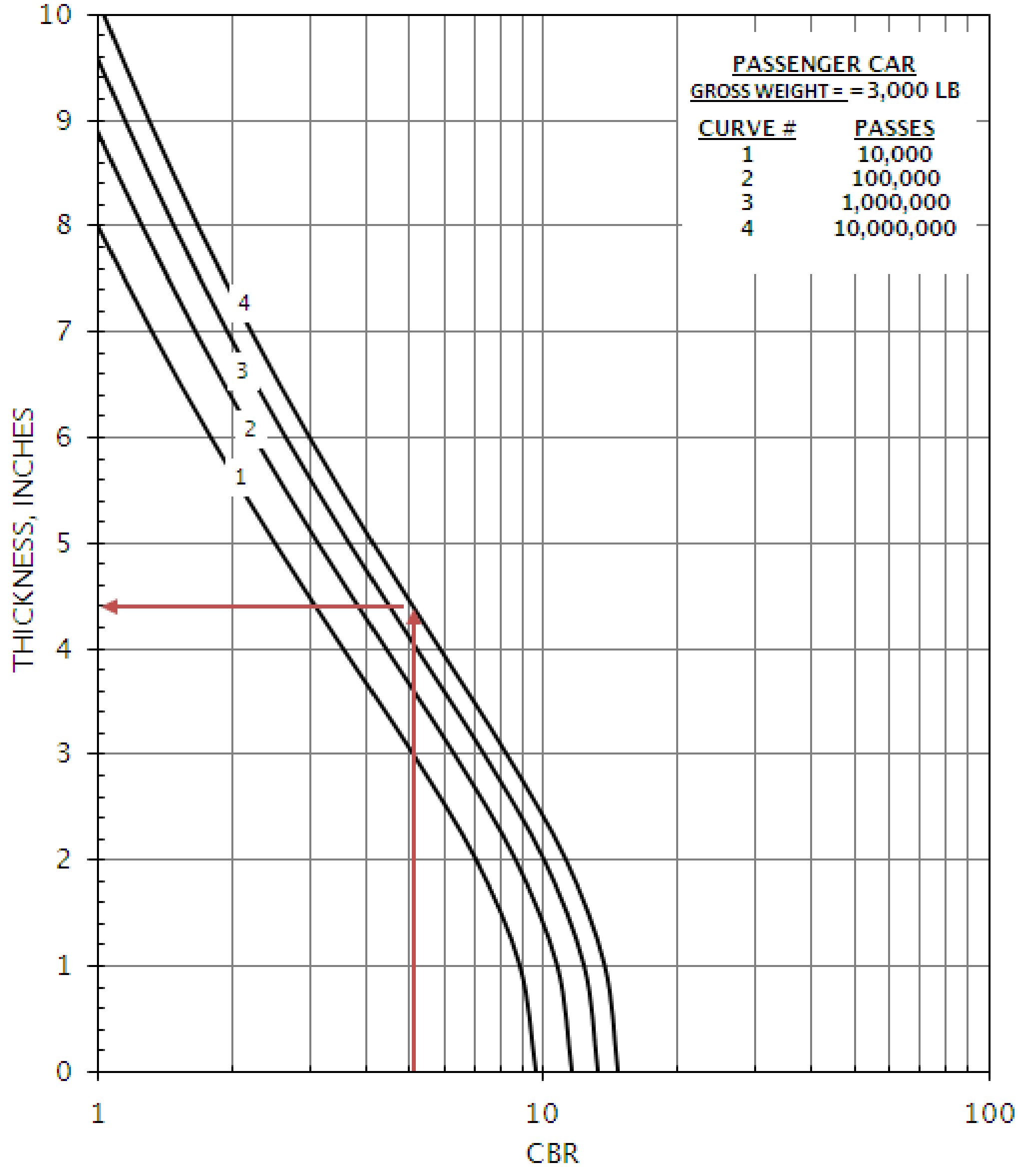


**Figure E-3 Light Strike Vehicle
Flexible Pavement Design Curve**

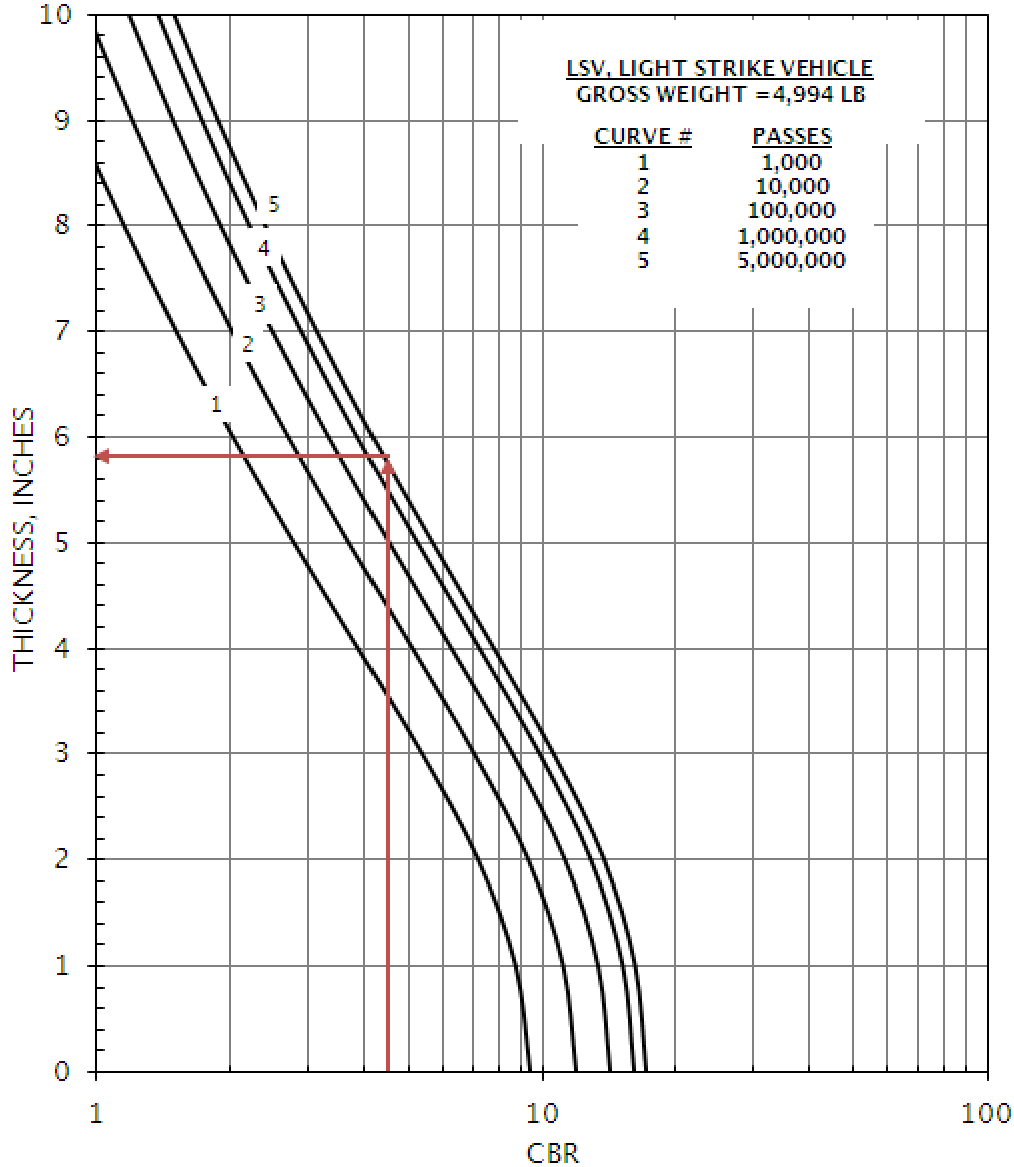


**Figure E-4 M1A1 Main Tank
Flexible Pavement Design Curve**

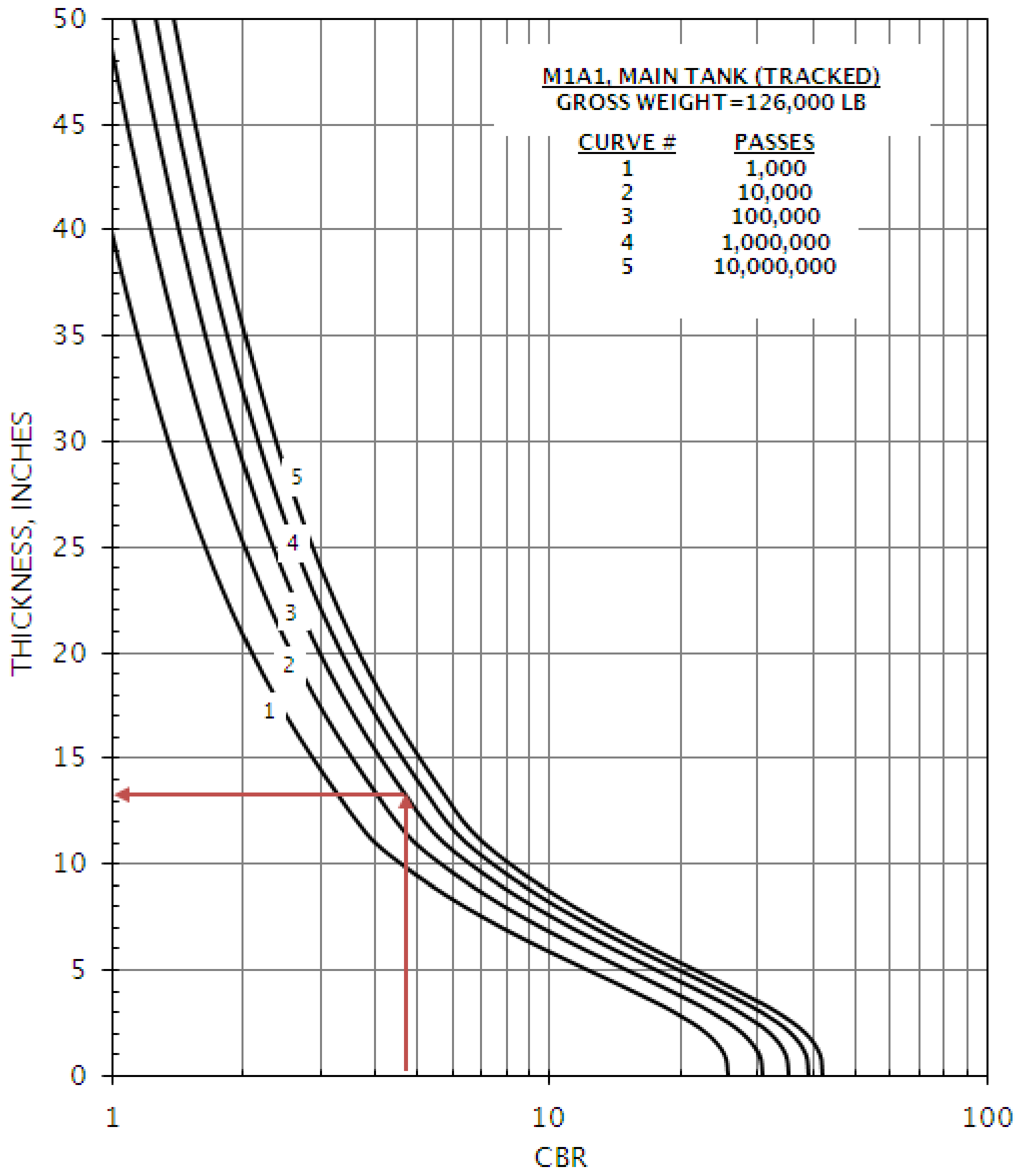


Figure E-5 M1A2 Main Tank
Flexible Pavement Design Curve

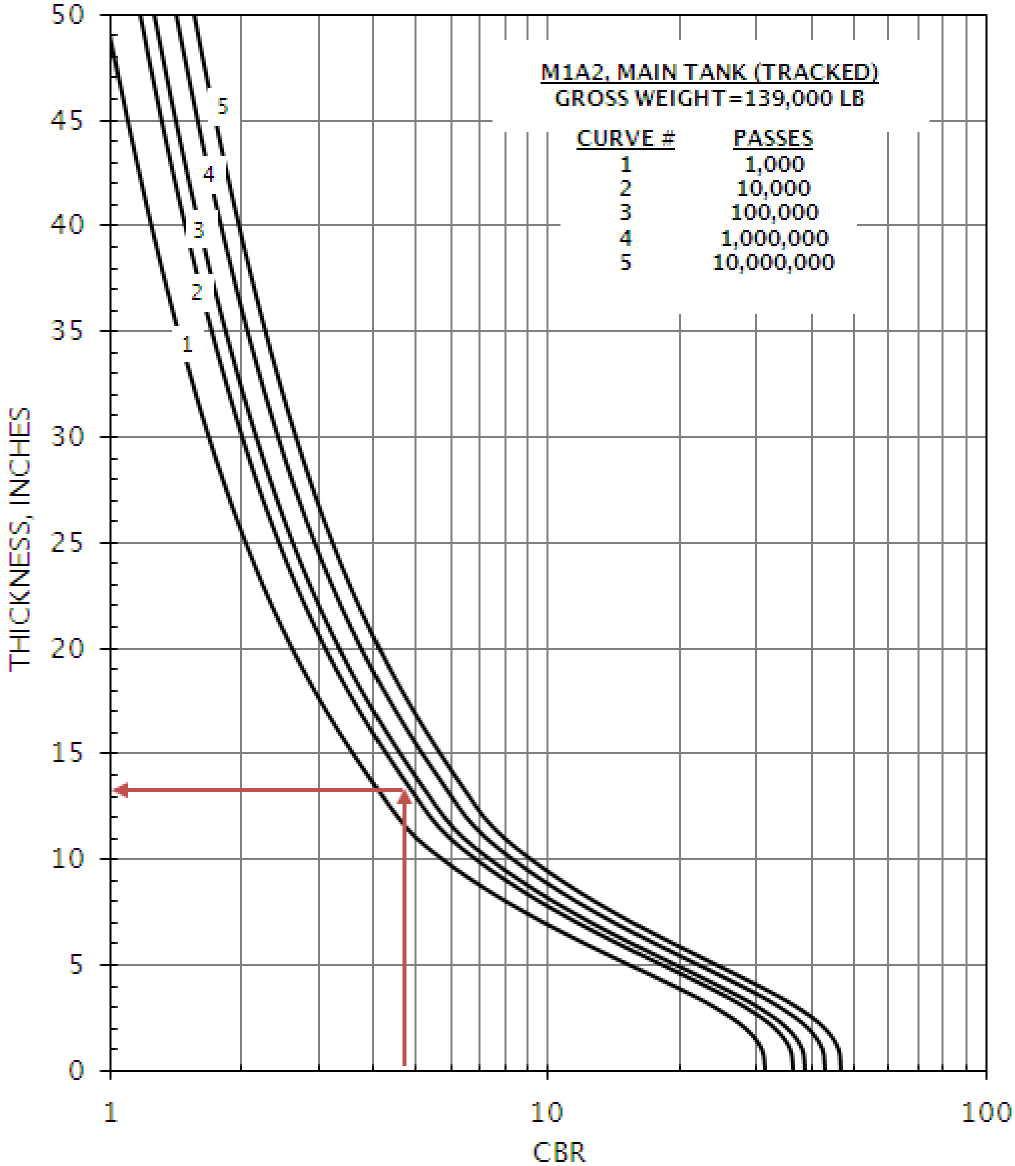


Figure E-6 M2A3 Bradley Vehicle Tracked Flexible Pavement Design Curve

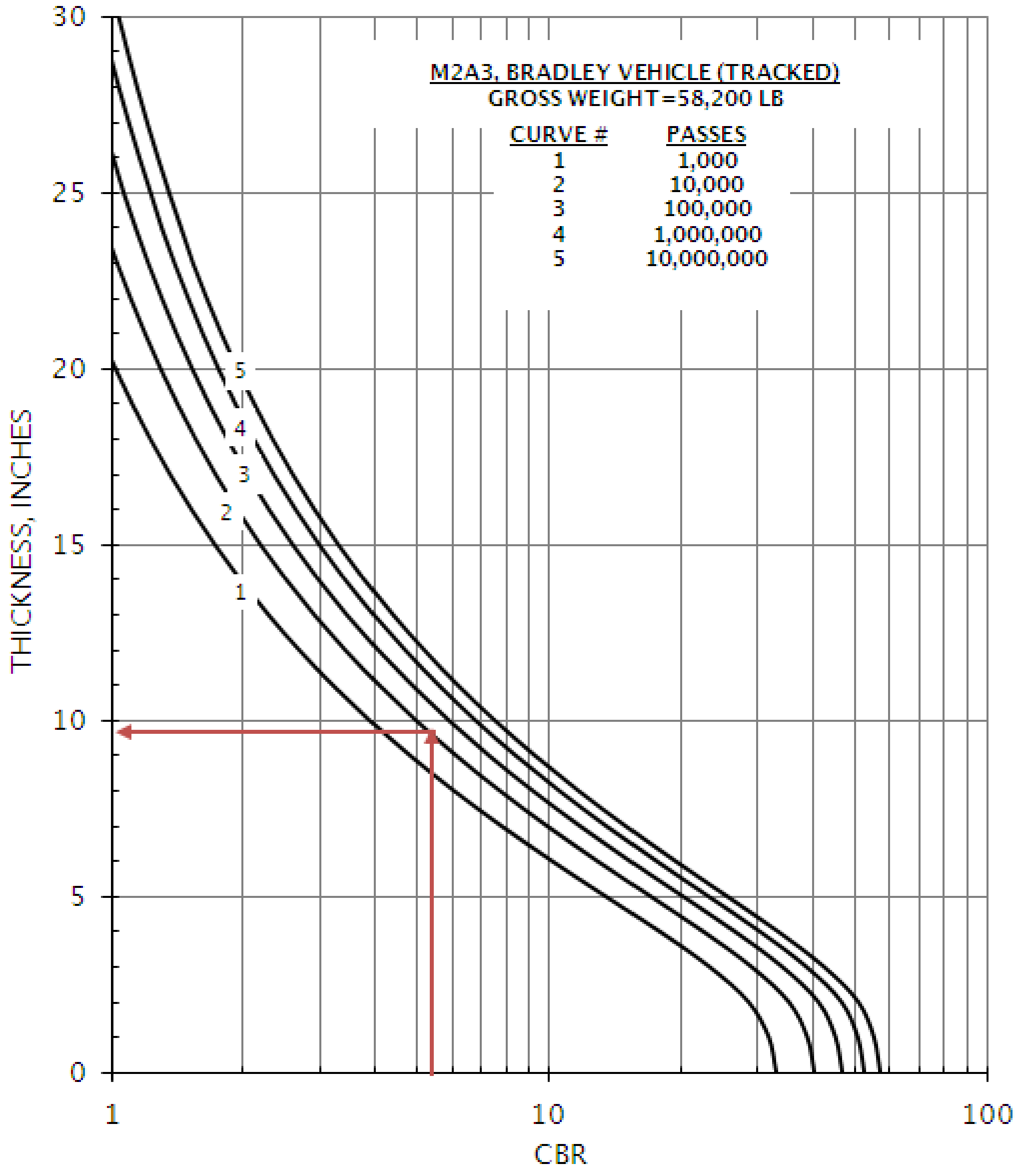


**Figure E-7 M35A2 2.5-Ton Cargo Truck 6x6
Flexible Pavement Design Curve**

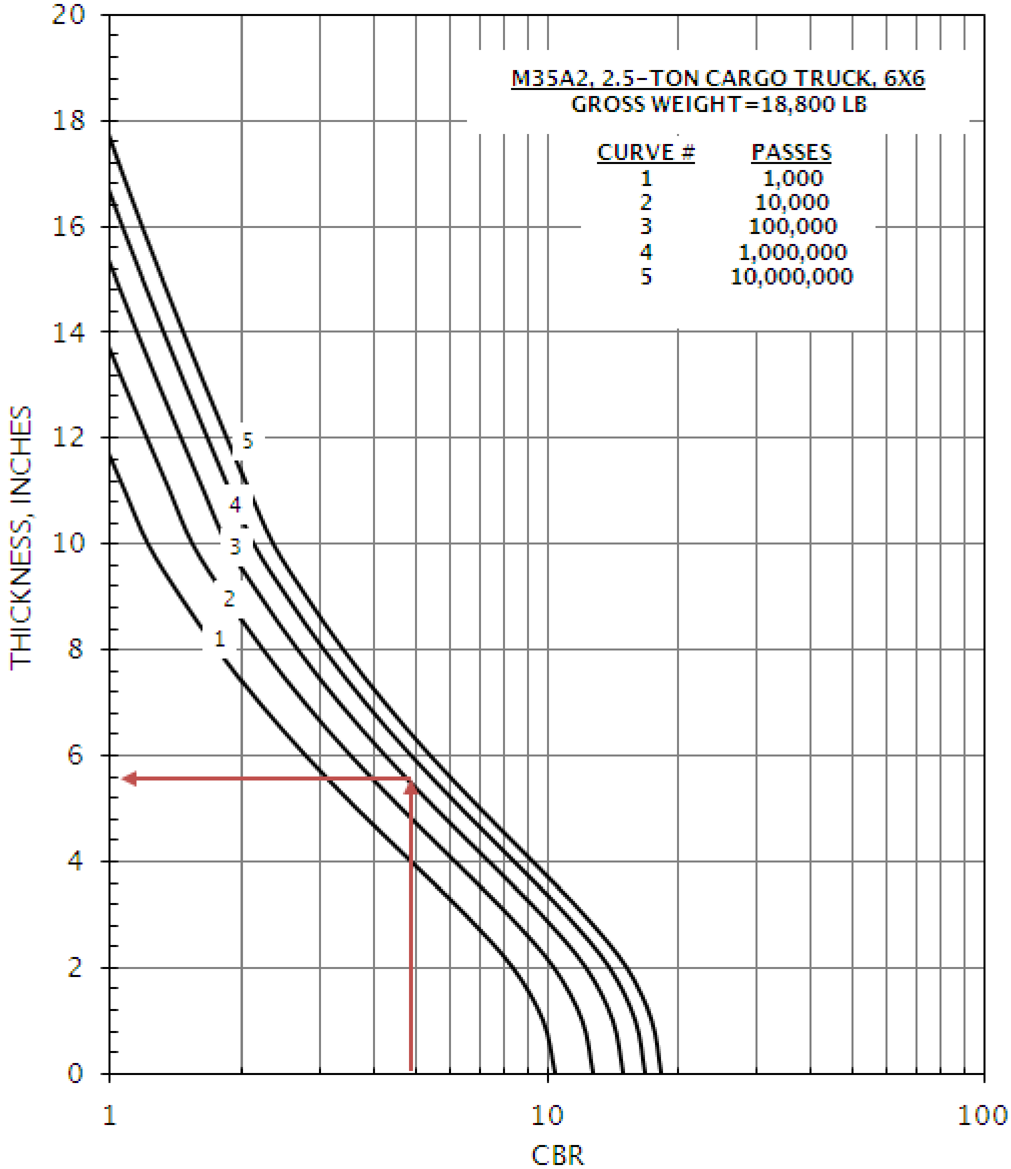


**Figure E-8 M60A3 Main Tank
Flexible Pavement Design Curve**

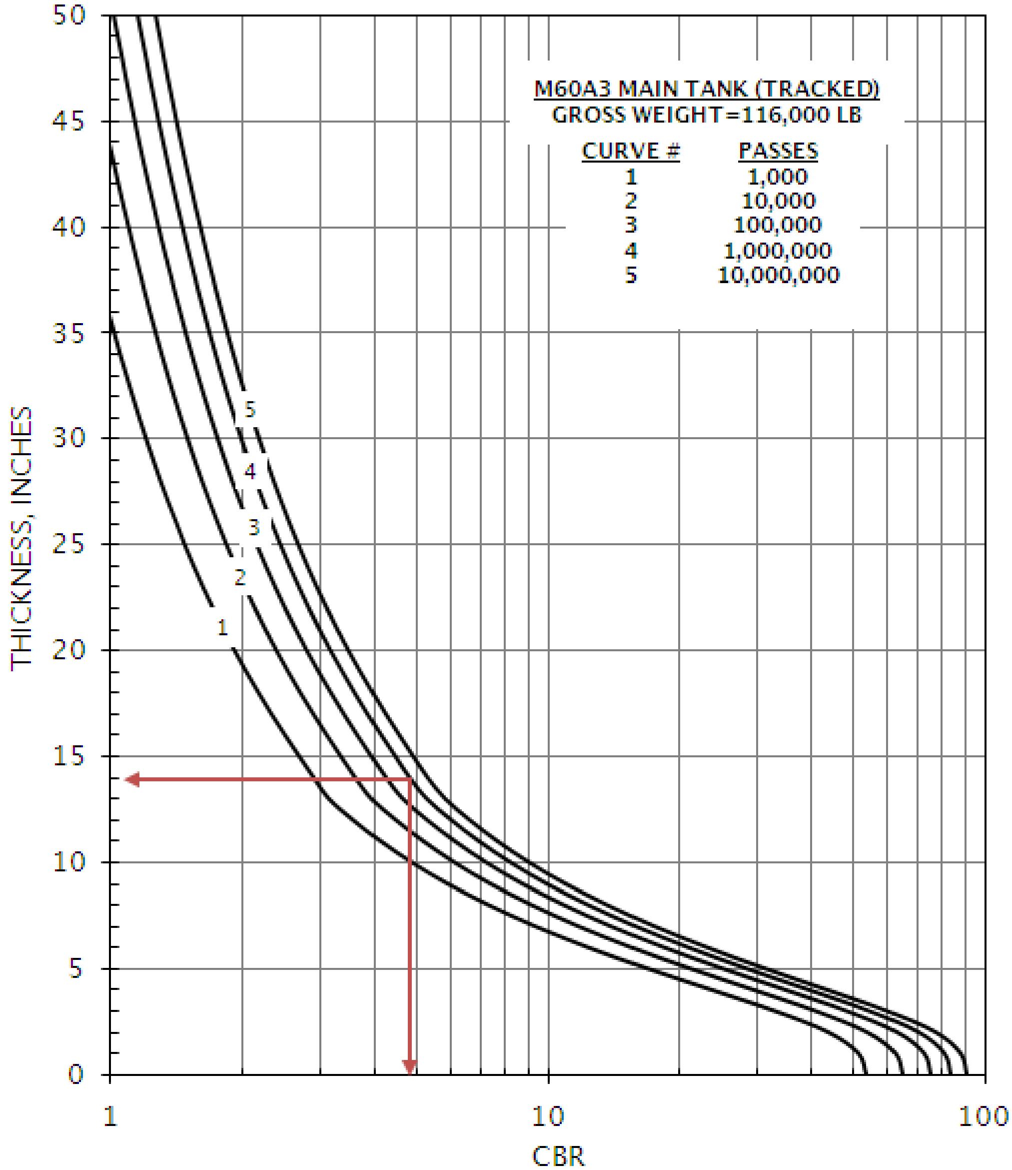


Figure E-9 M109A6, 155 Howitzer Tracked Flexible Pavement Design Curve

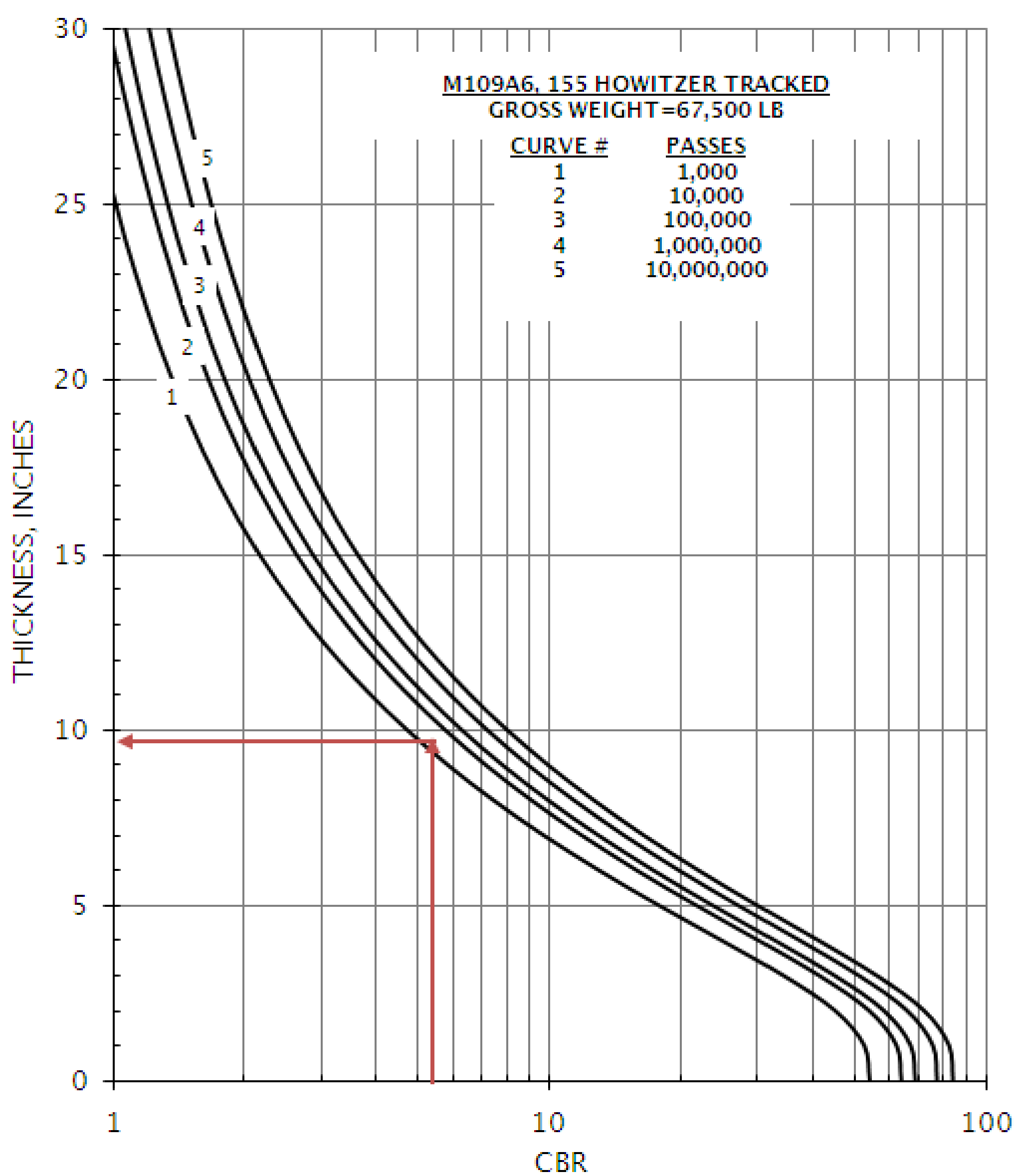


Figure E-10 M113A1 Armored Carrier Tracked Flexible Pavement Design Curve

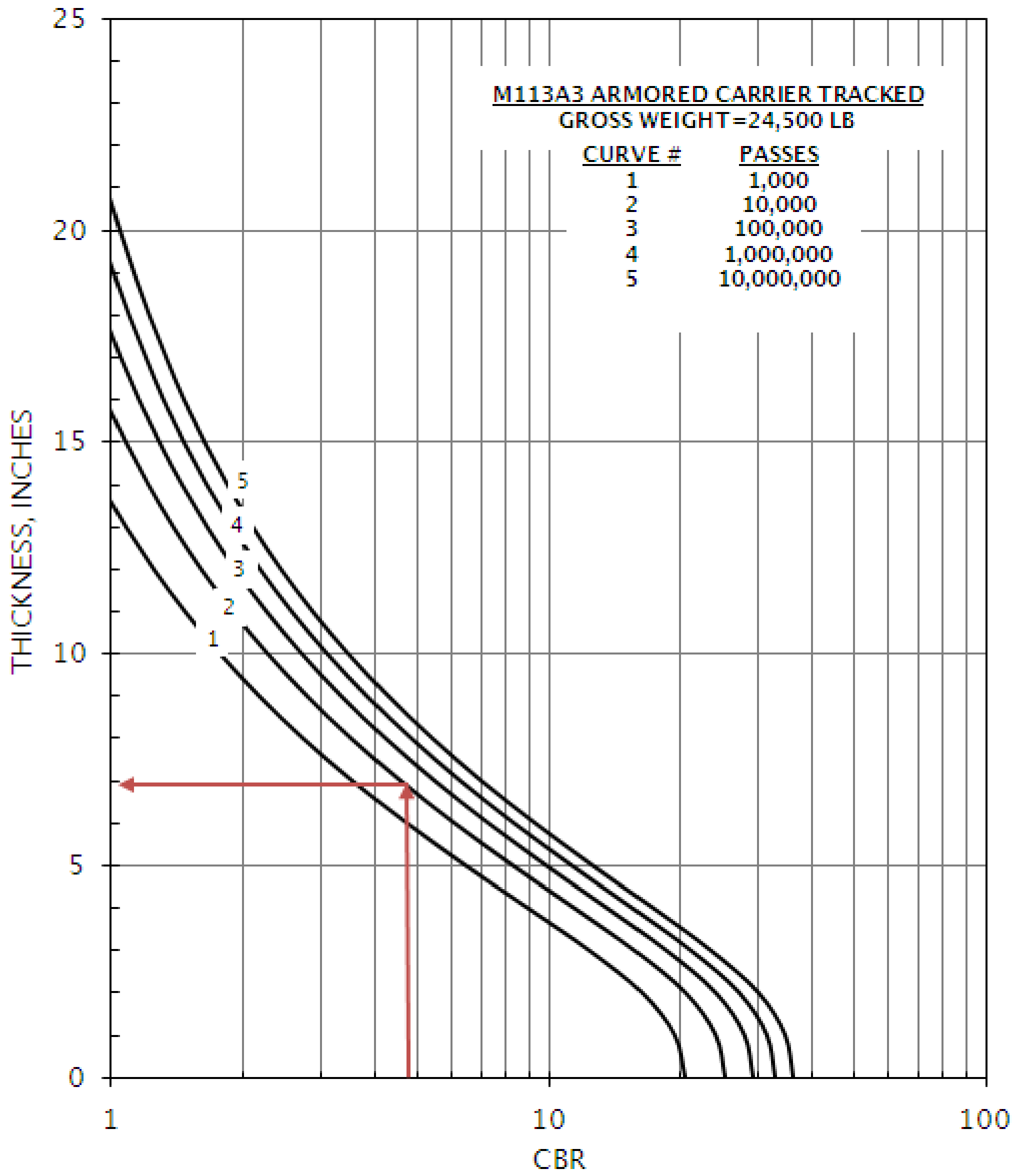


**Figure E-11 M923 5-Ton Cargo Truck 6x6
Flexible Pavement Design Curve**

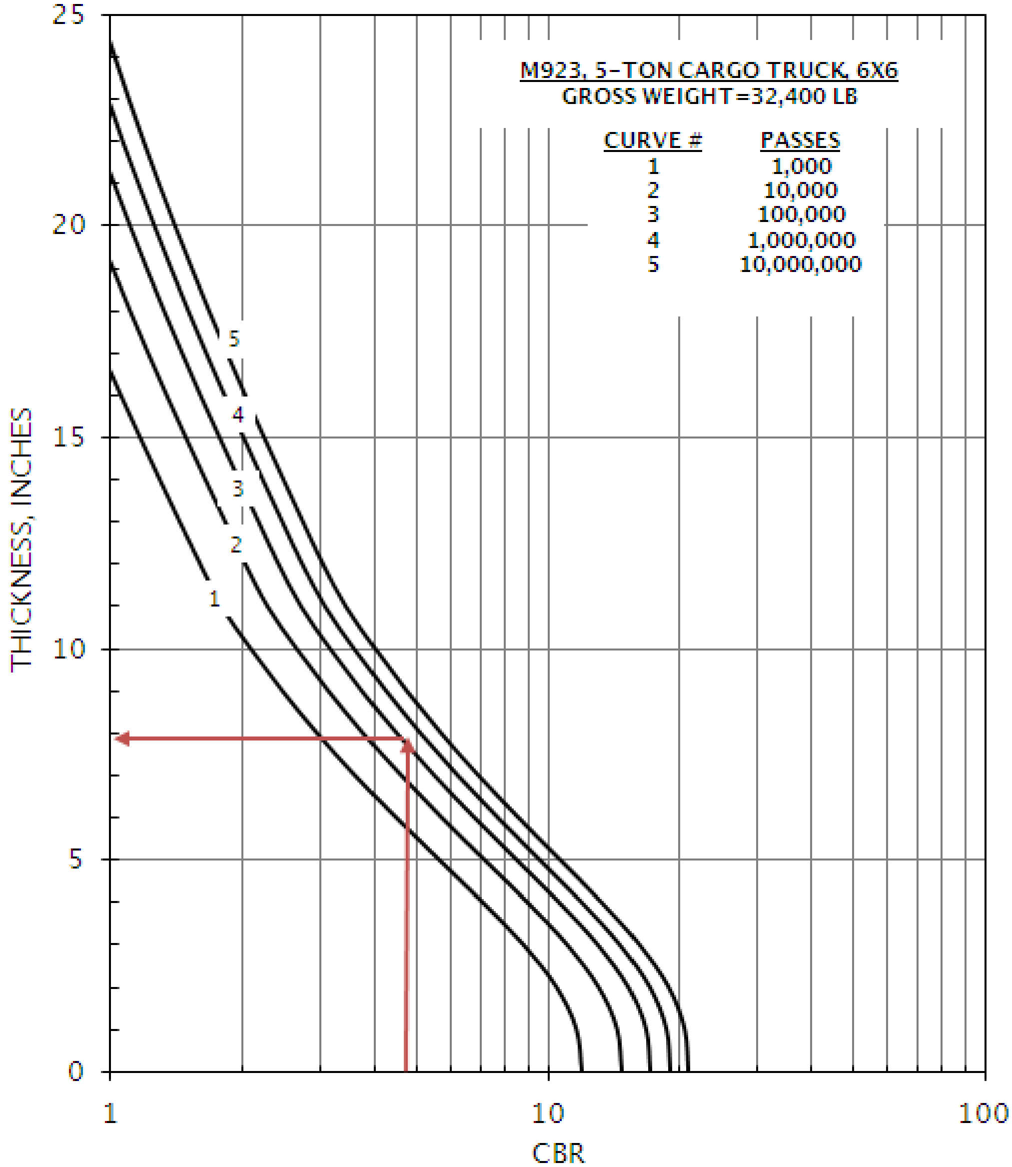


**Figure E-12 M977 Hemtt 10-Ton Cargo Truck 8x8
Flexible Pavement Design Curve**

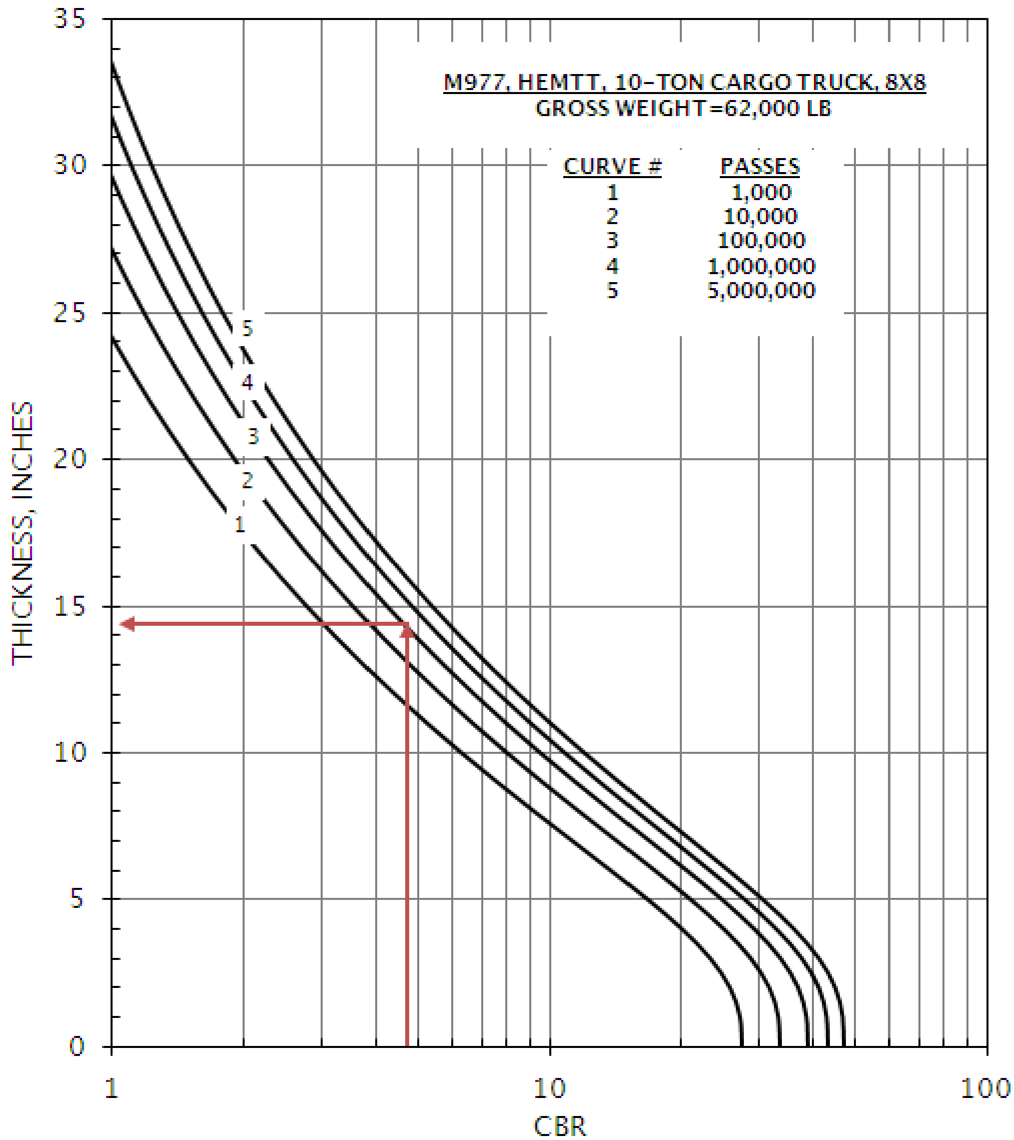


**Figure E-13 M978 Hemtt 10-Ton Fuel Truck 8x8
Flexible Pavement Design Curve**

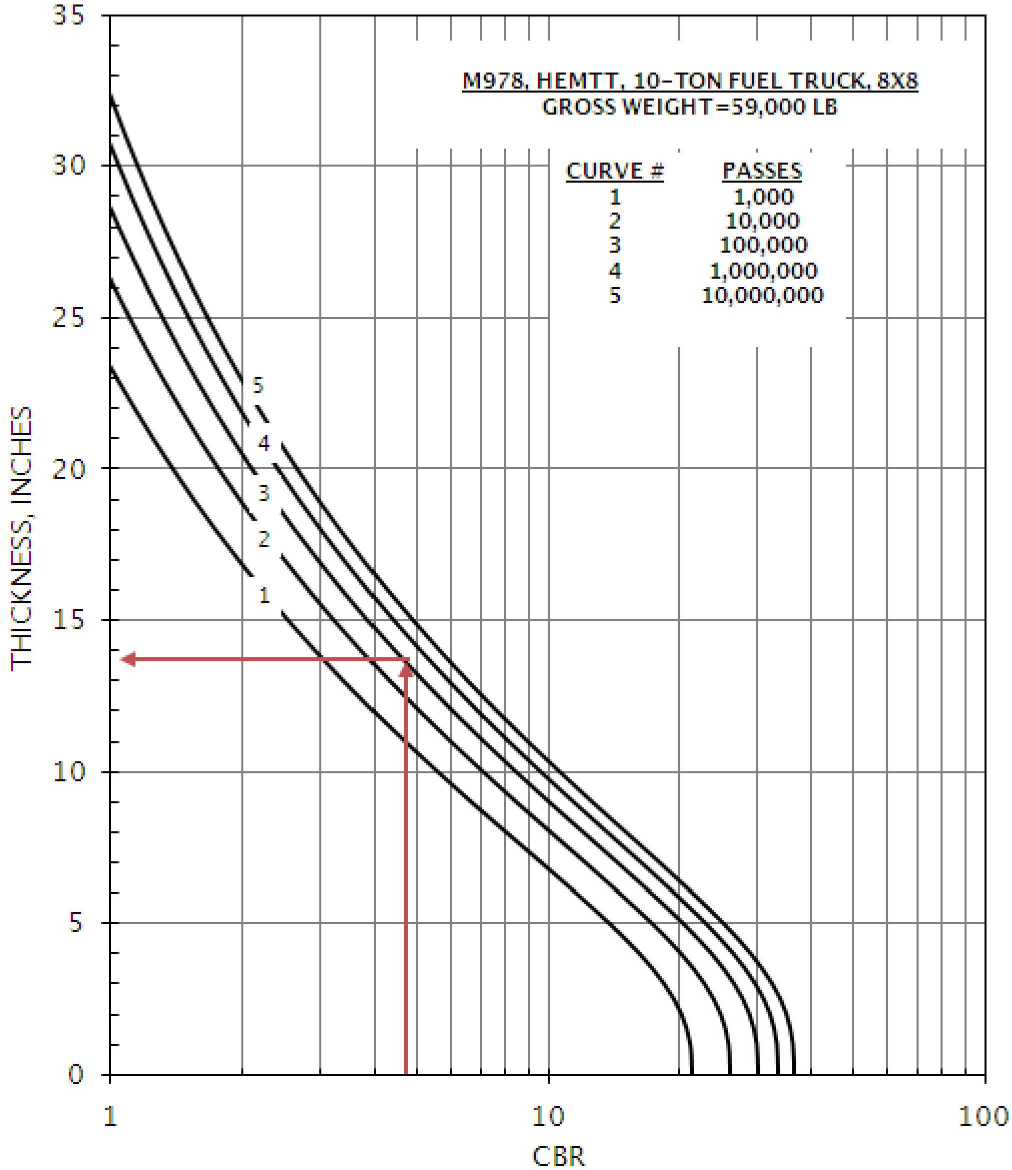


**Figure E-14 M983 Hemtt With XM860A1 Trailer
Flexible Pavement Design Curve**

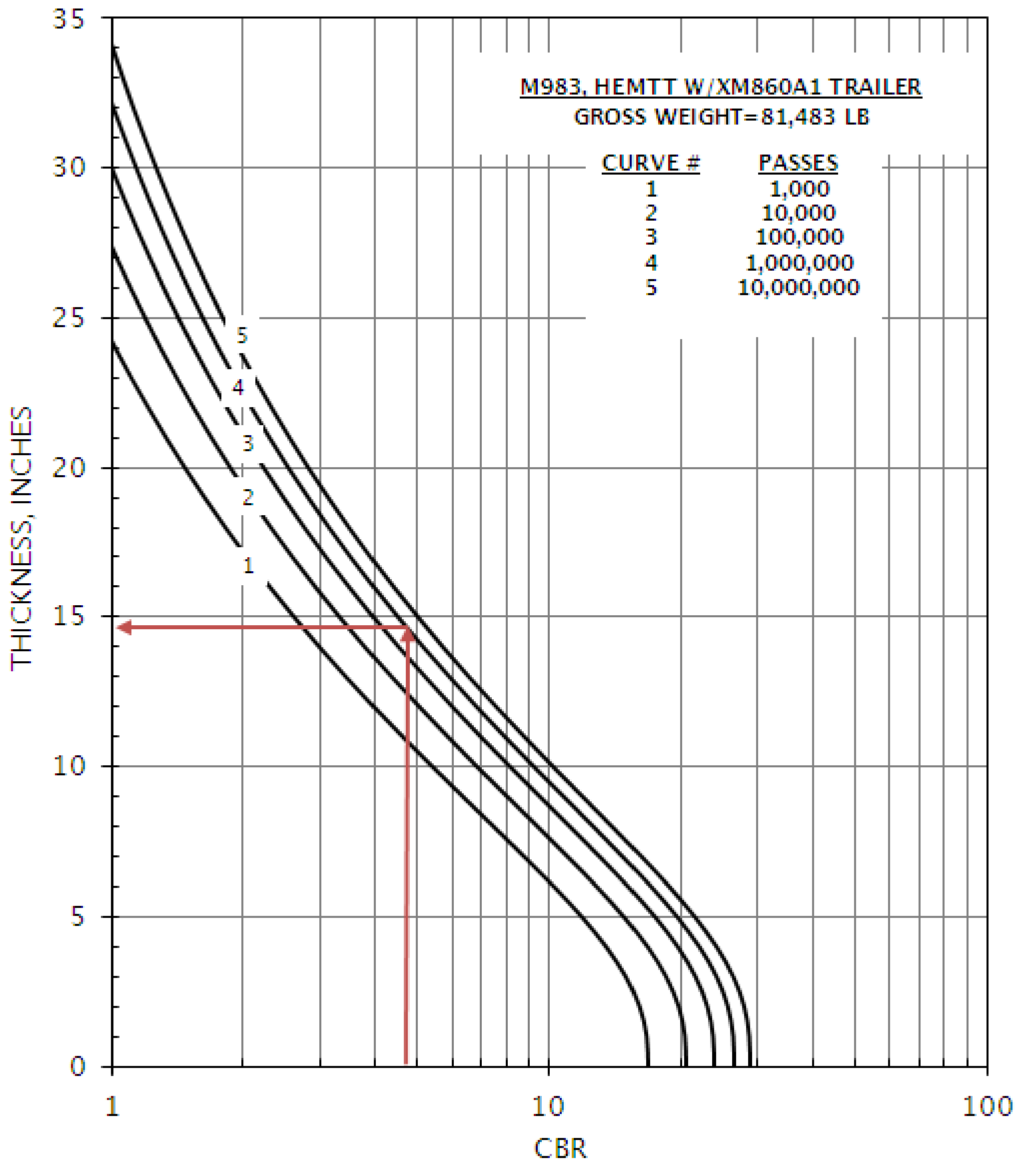


**Figure E-15 M998 HMMWV 1.25-Ton Carrier
Flexible Pavement Design Curve**

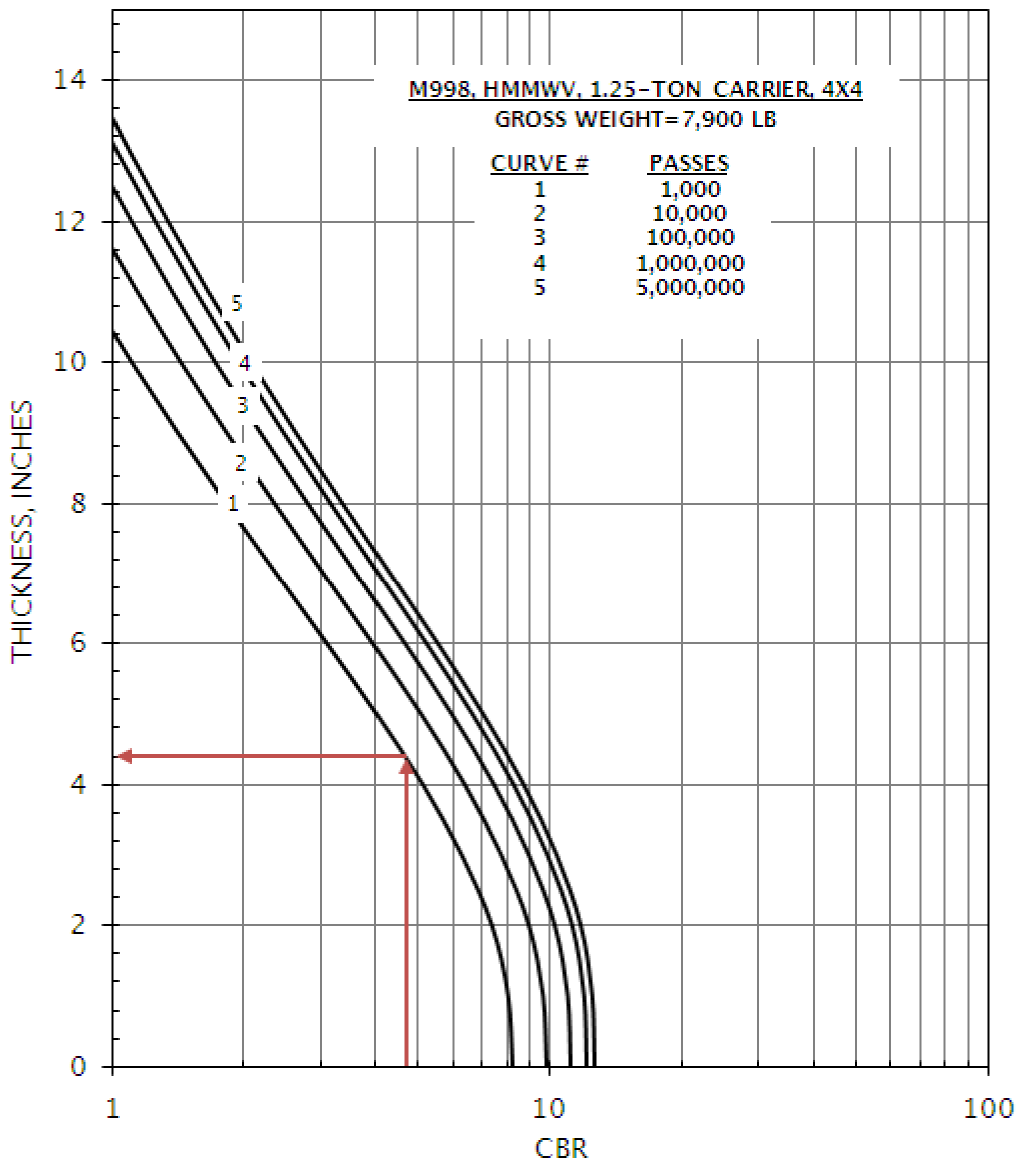


**Figure E-16 M988B RTCH FORKLIFT
Flexible Pavement Design Curve**

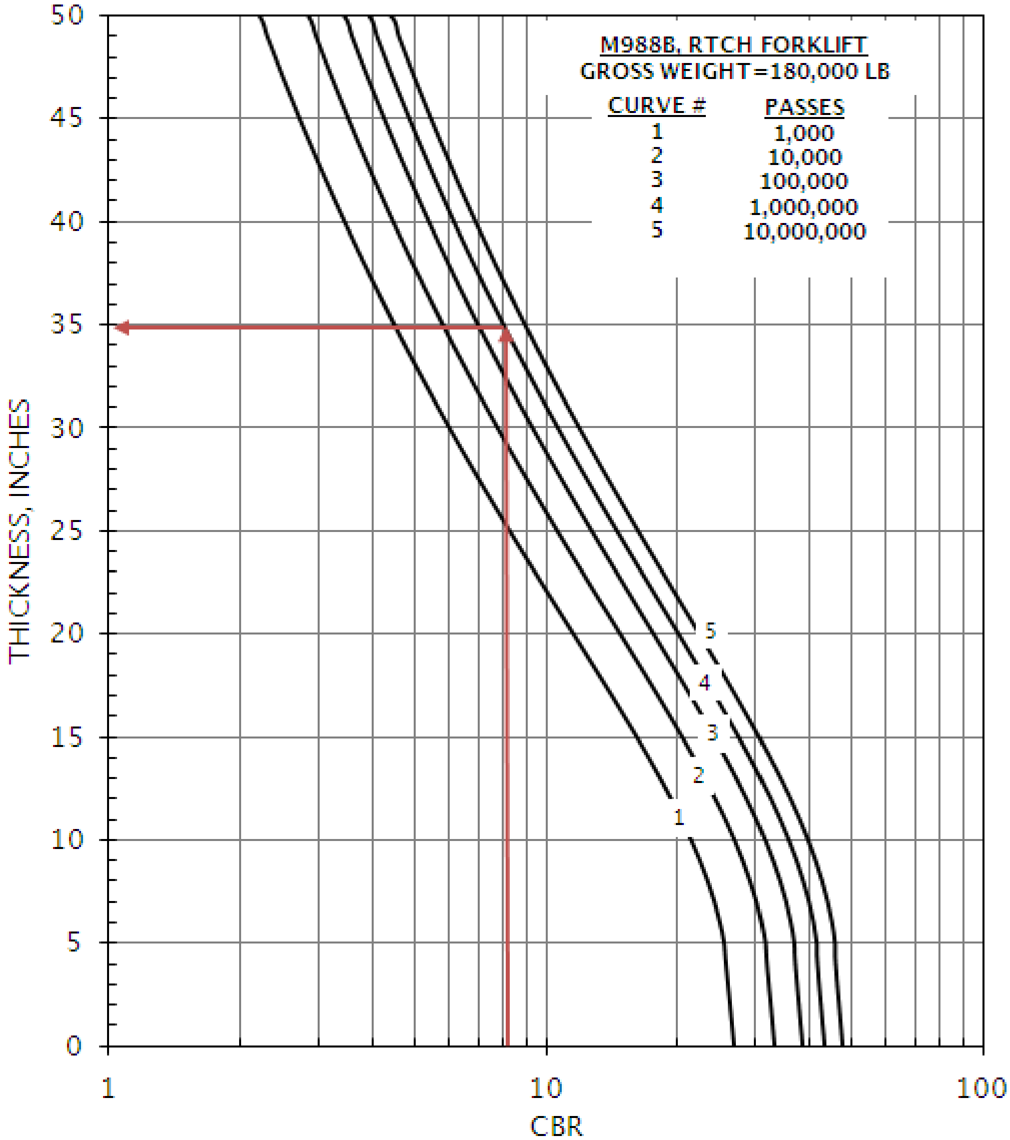


Figure E-17 M1070 HET Tractor W/M1000 TRL W/M1A1 Tank Flexible Pavement Design Curve

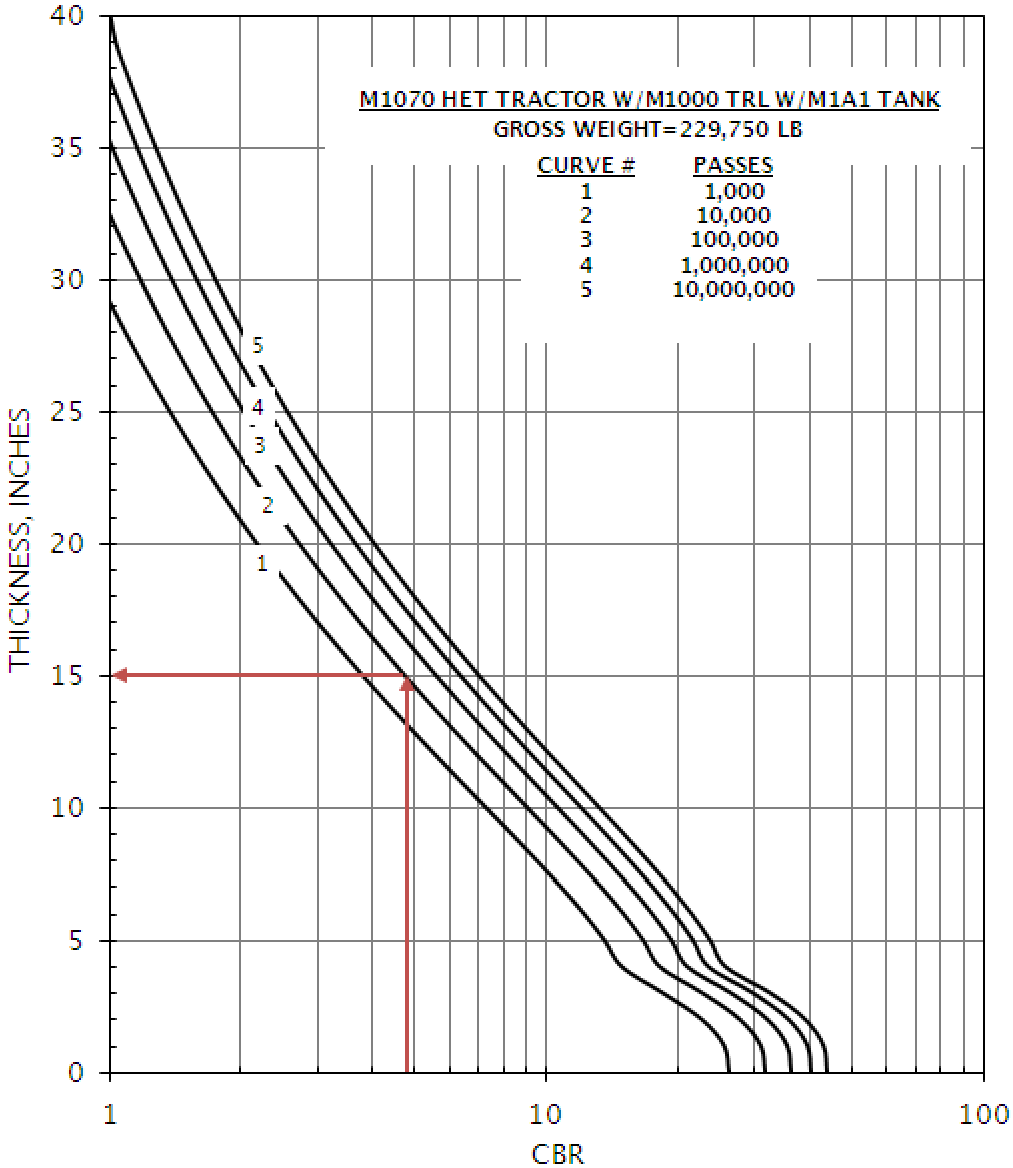


Figure E-18 M1074 Load System w/Crane w/M1076 Trailer Flexible Pavement Design Curve

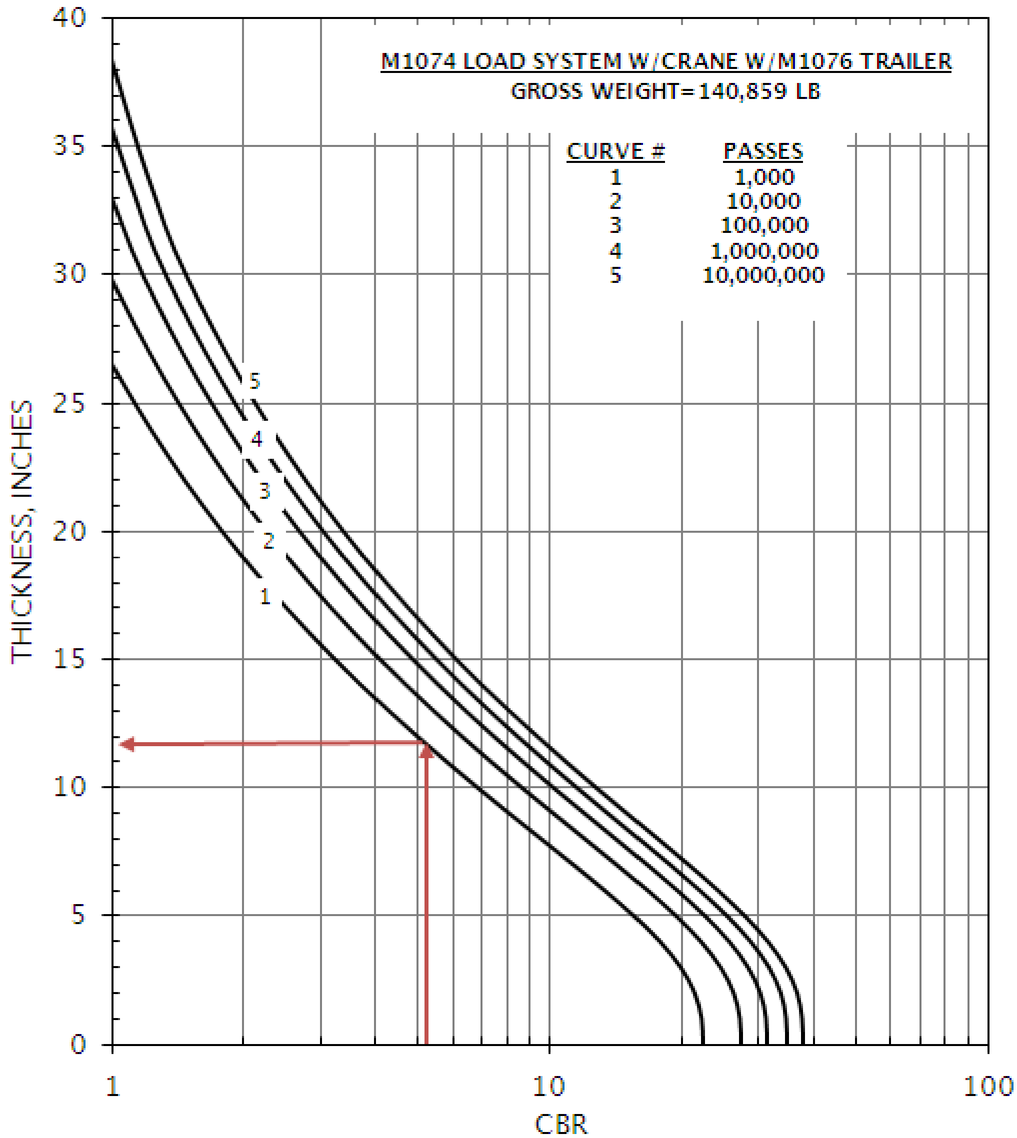


**Figure E-19 M1075 Load System
Flexible Pavement Design Curve**

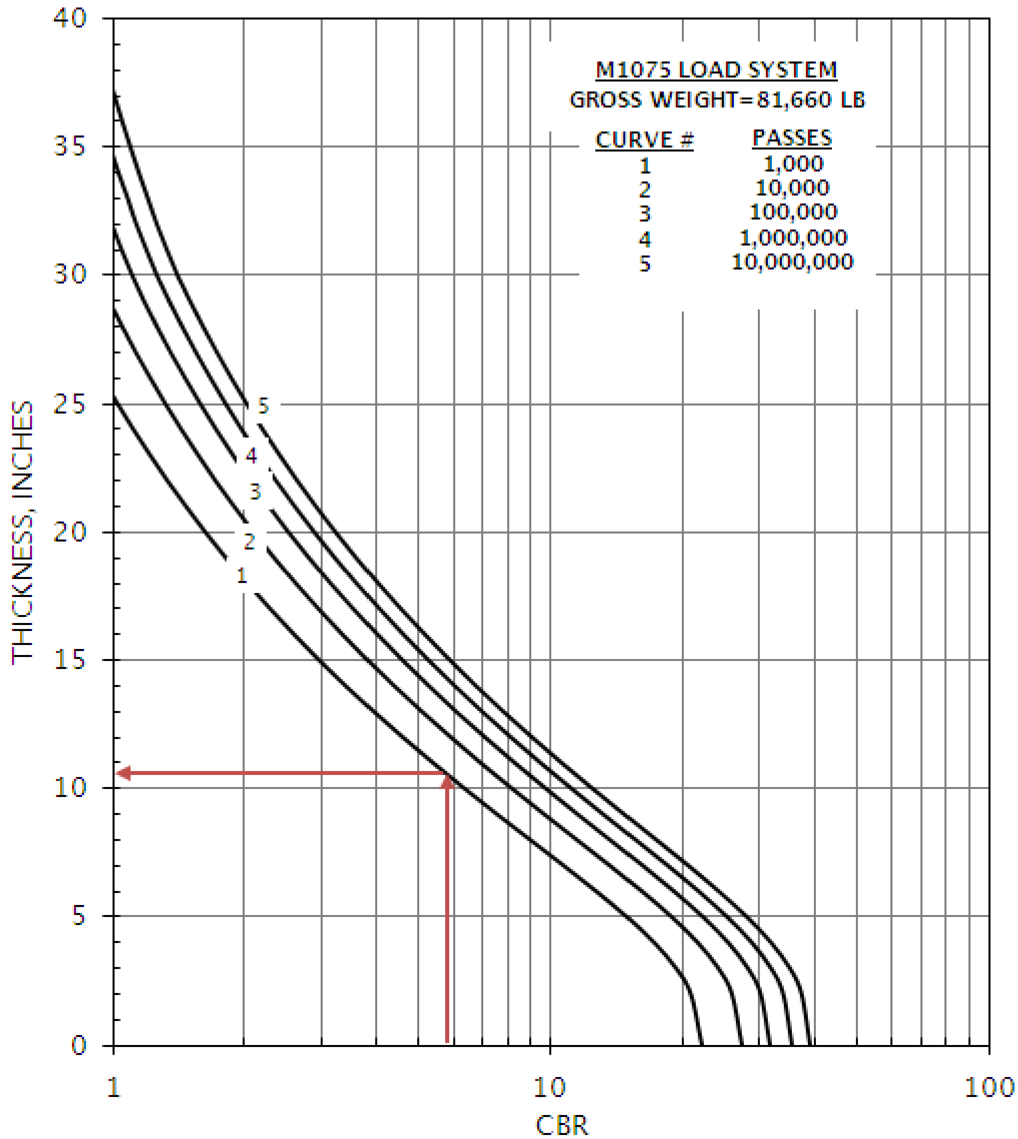


Figure E-20 M1075 Load System w/M1076 Trailer Flexible Pavement Design Curve

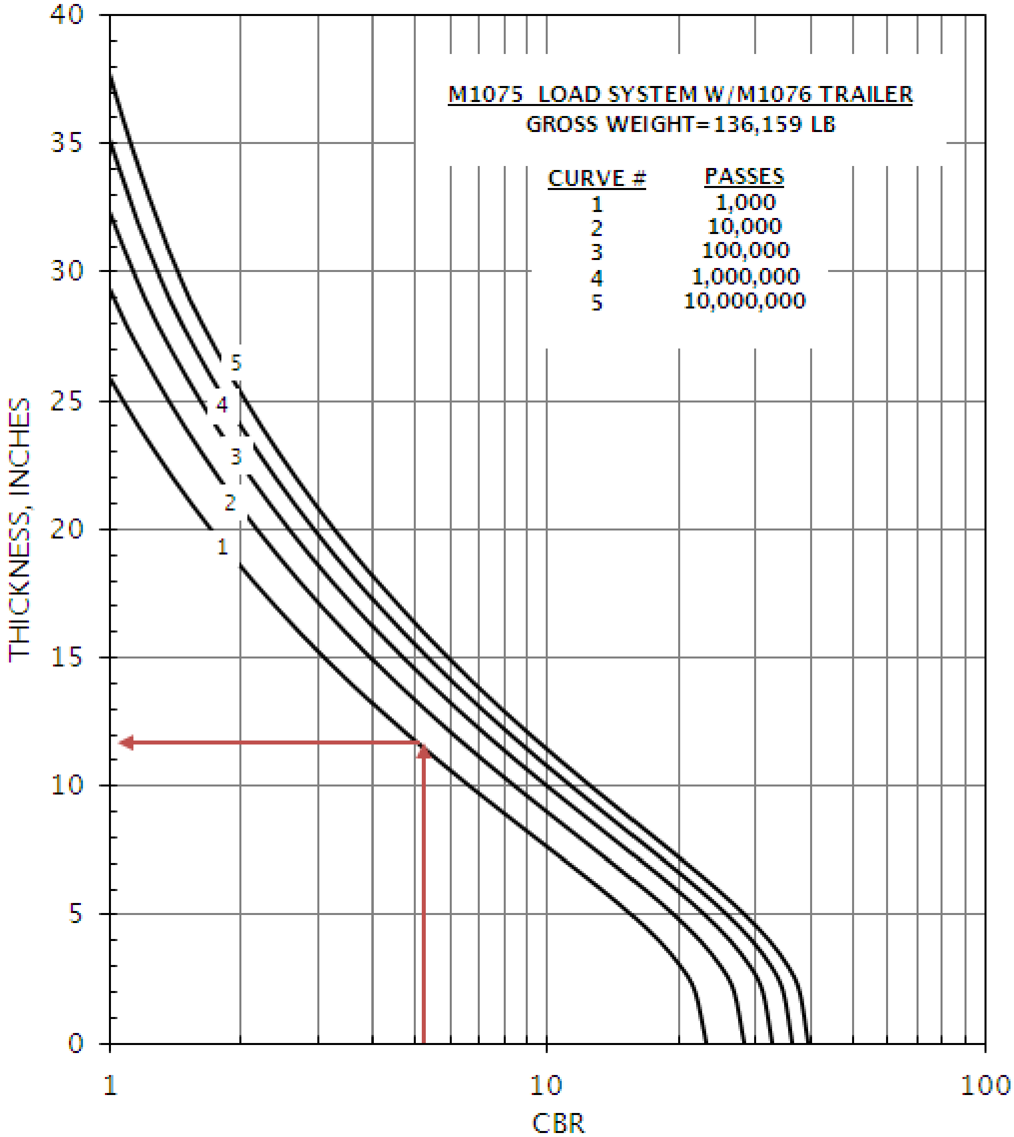


**Figure E-21 M1078 2.5-Ton Cargo Truck 4x4
Flexible Pavement Design Curve**

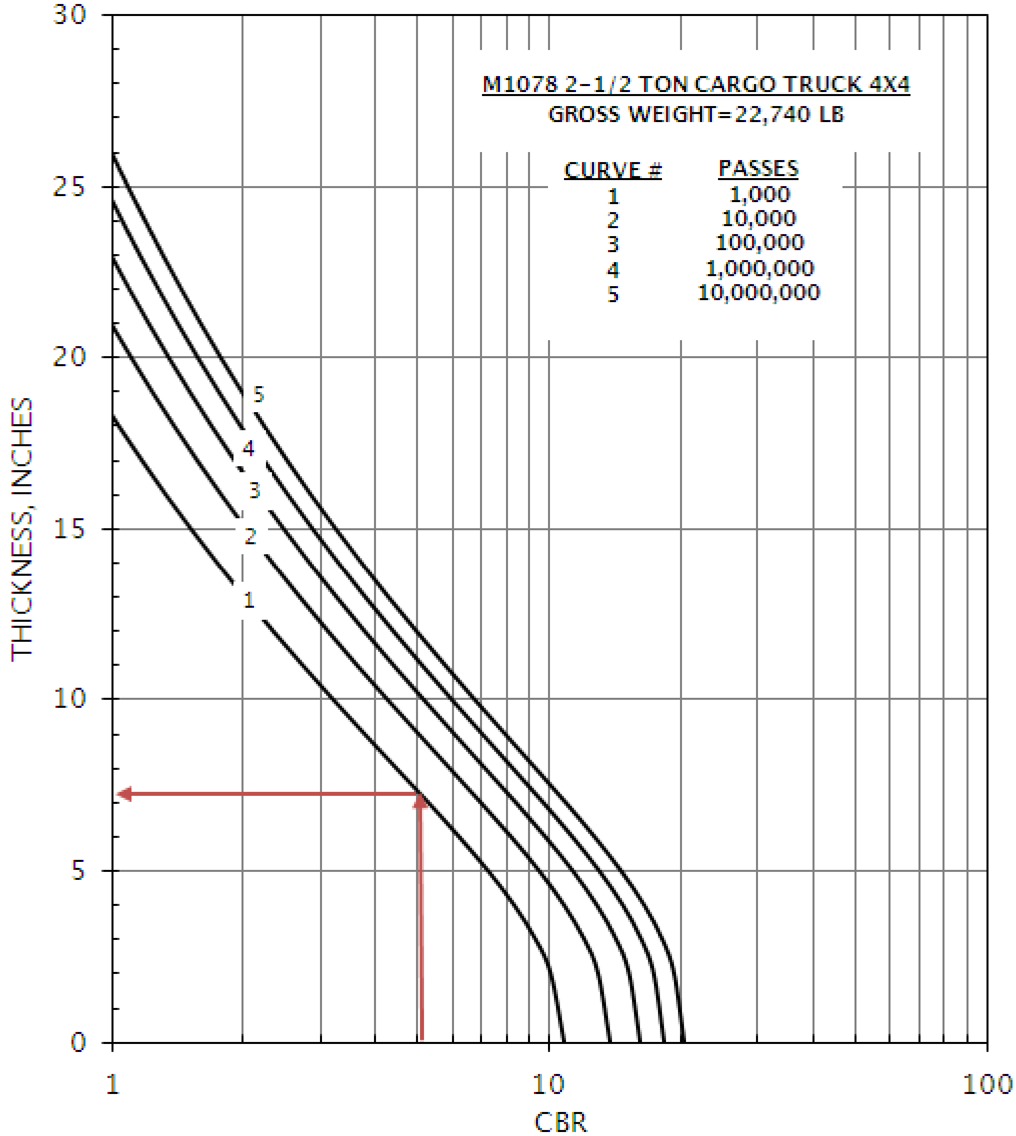


**Figure E-22 P-23 Crash Truck (Fire Truck)
Flexible Pavement Design Curve**

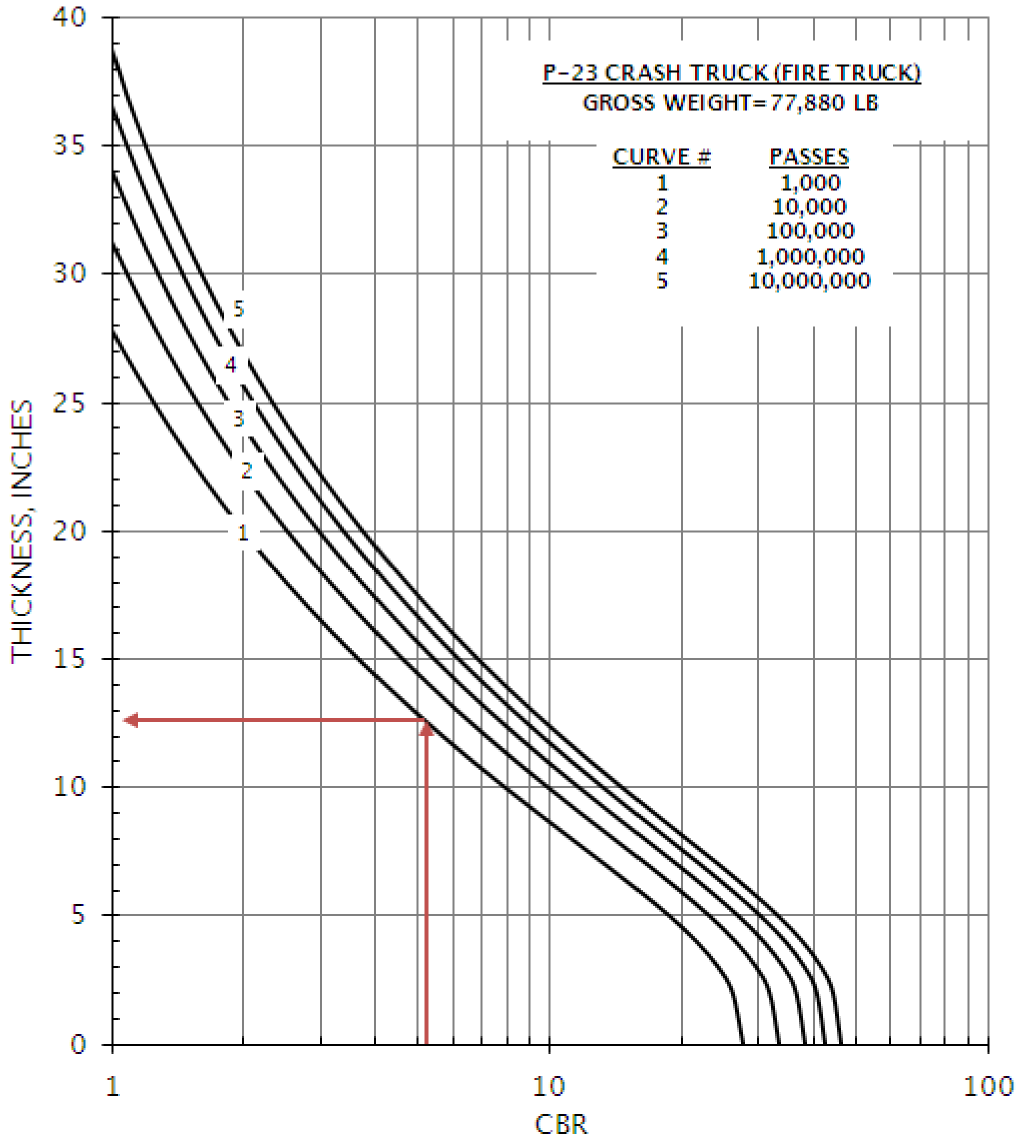


**Figure E-23 R-11 Refueler
Flexible Pavement Design Curve**

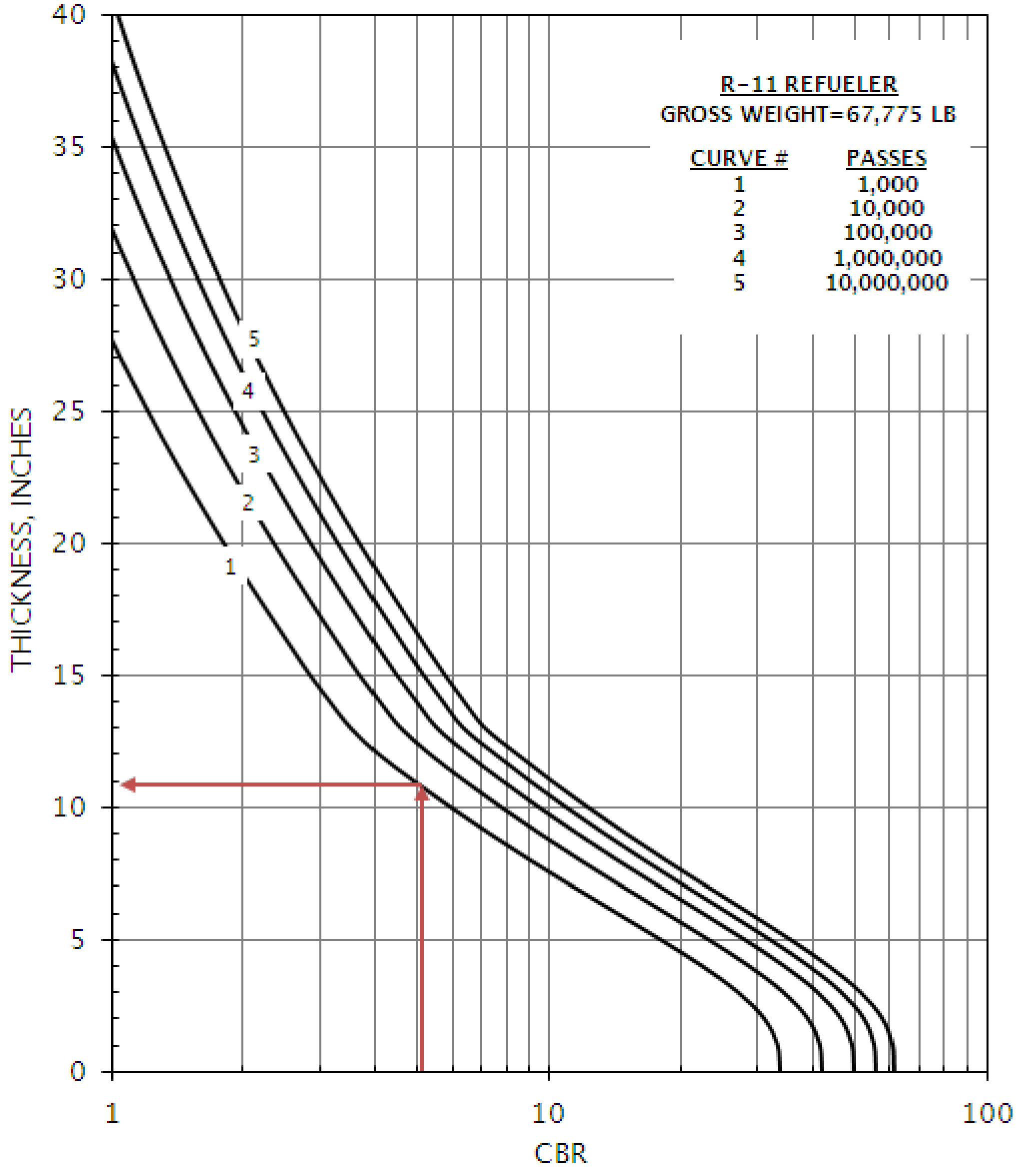


**Figure E-24 Truck, Small Pickup, or SUV
Flexible Pavement Design Curve**

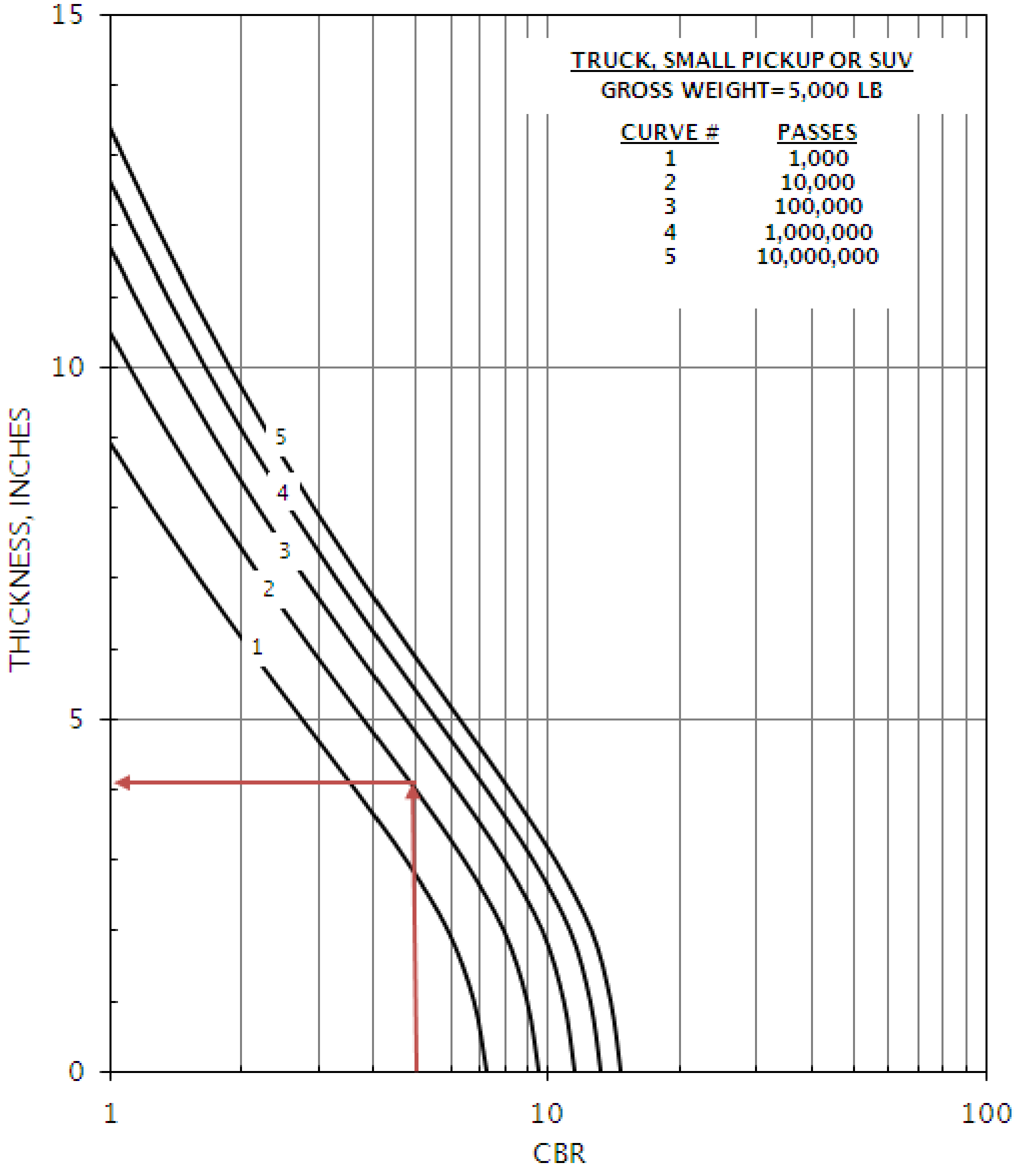


**Figure E-25 Truck, Large Pickup, or SUV
Flexible Pavement Design Curve**

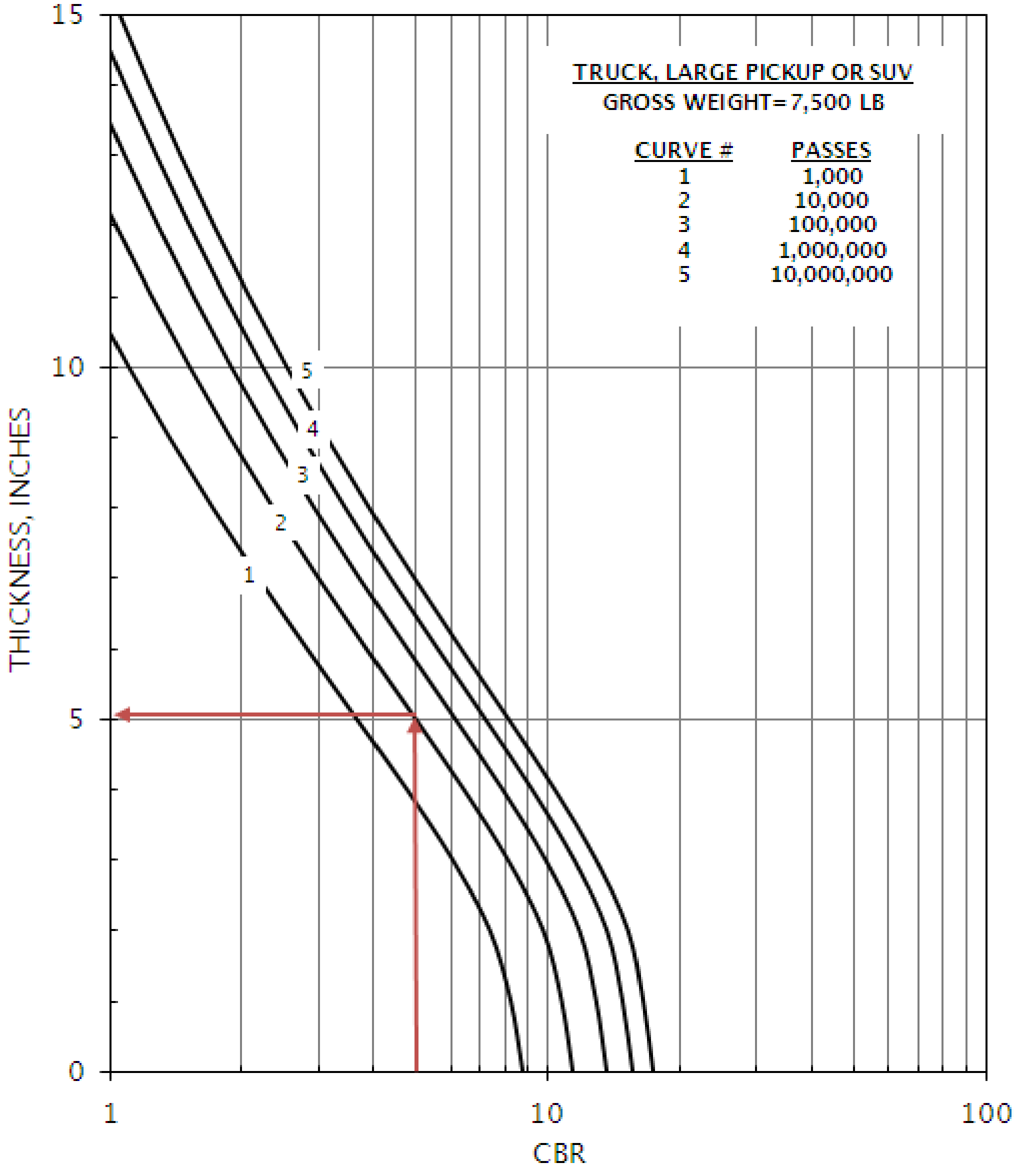


**Figure E-26 Truck 3-Axle
Flexible Pavement Design Curve**

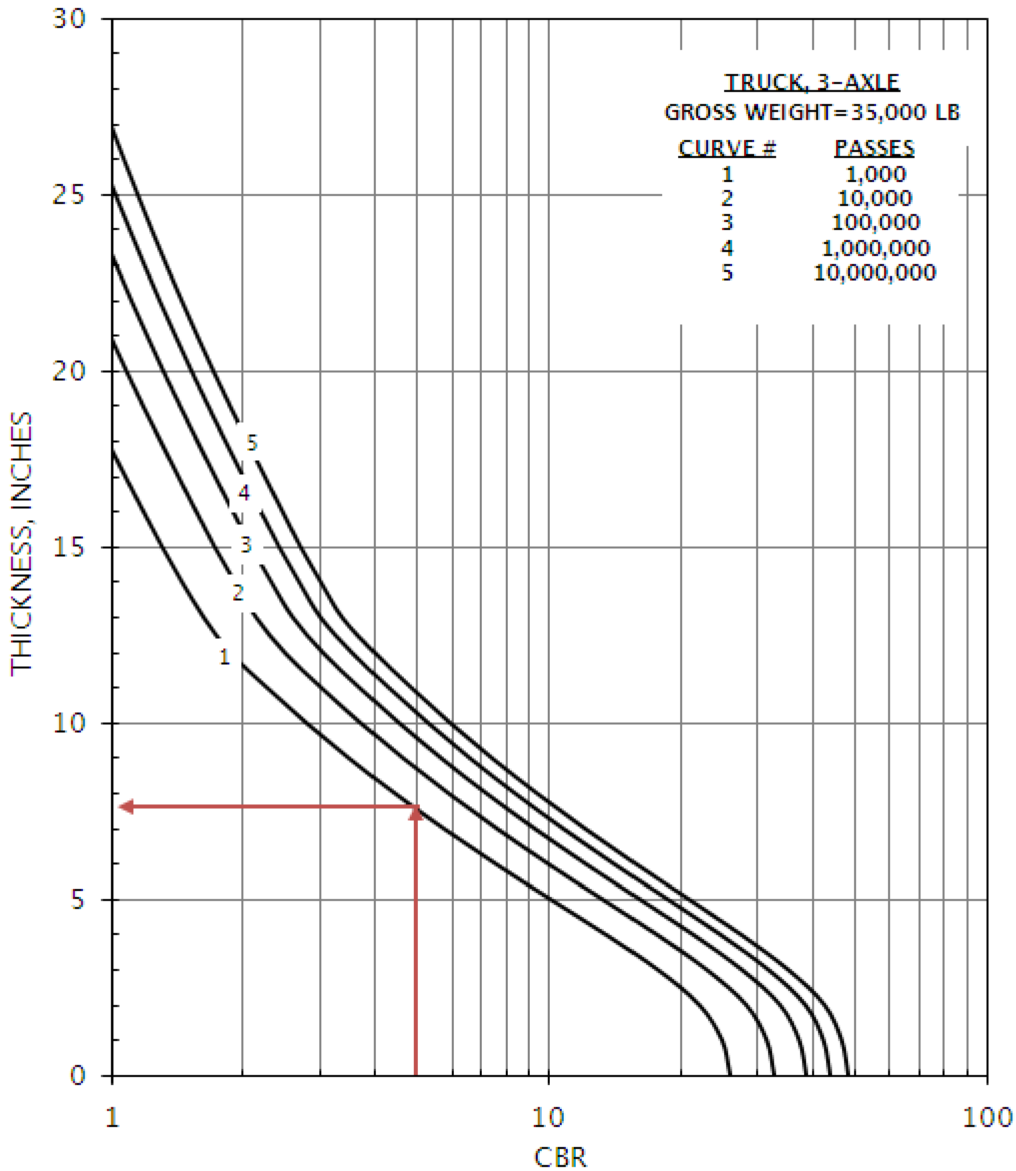


**Figure E-27 Truck 4-Axle
Flexible Pavement Design Curve**

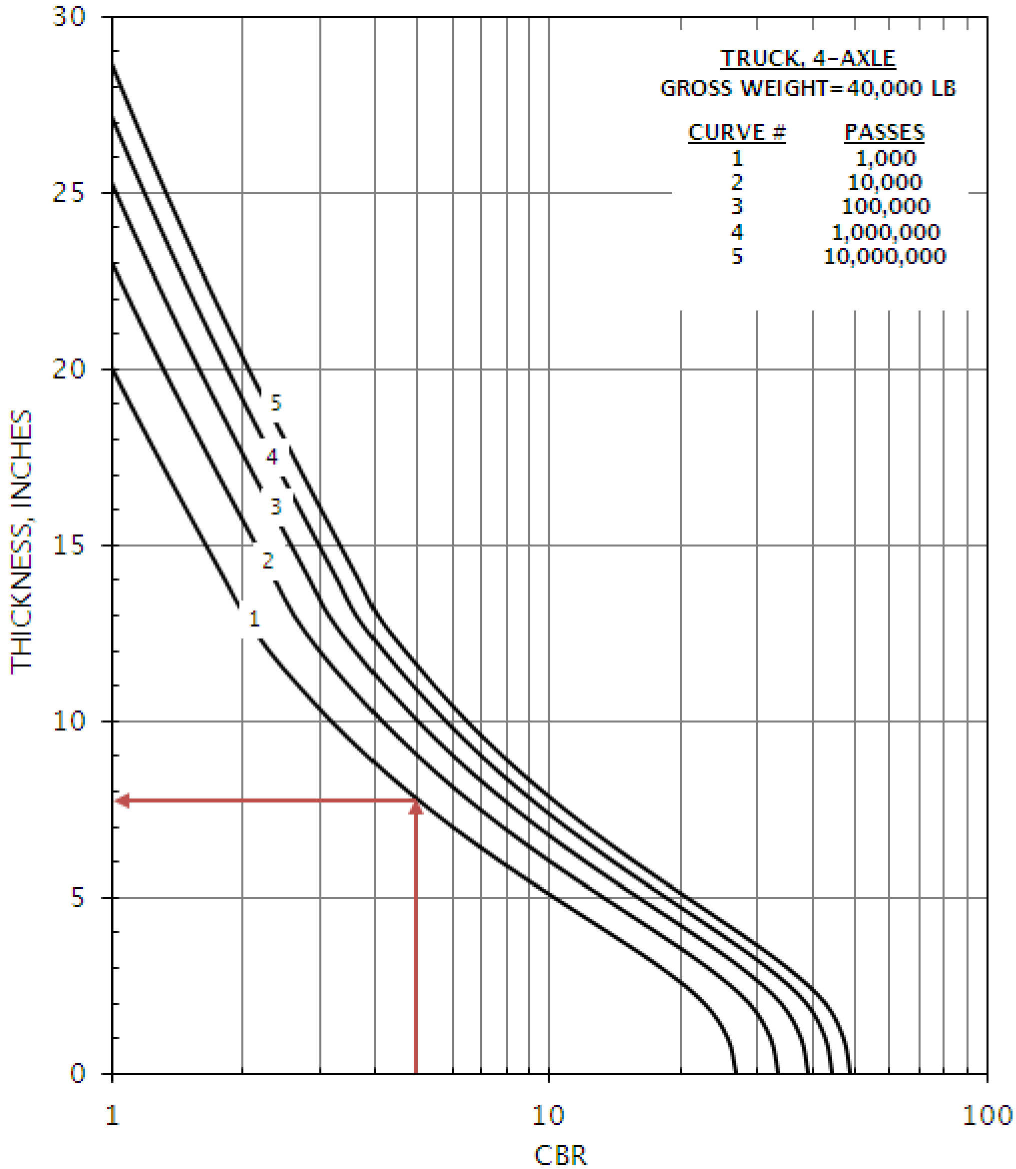


**Figure E-28 Truck 5-Axle
Flexible Pavement Design Curve**

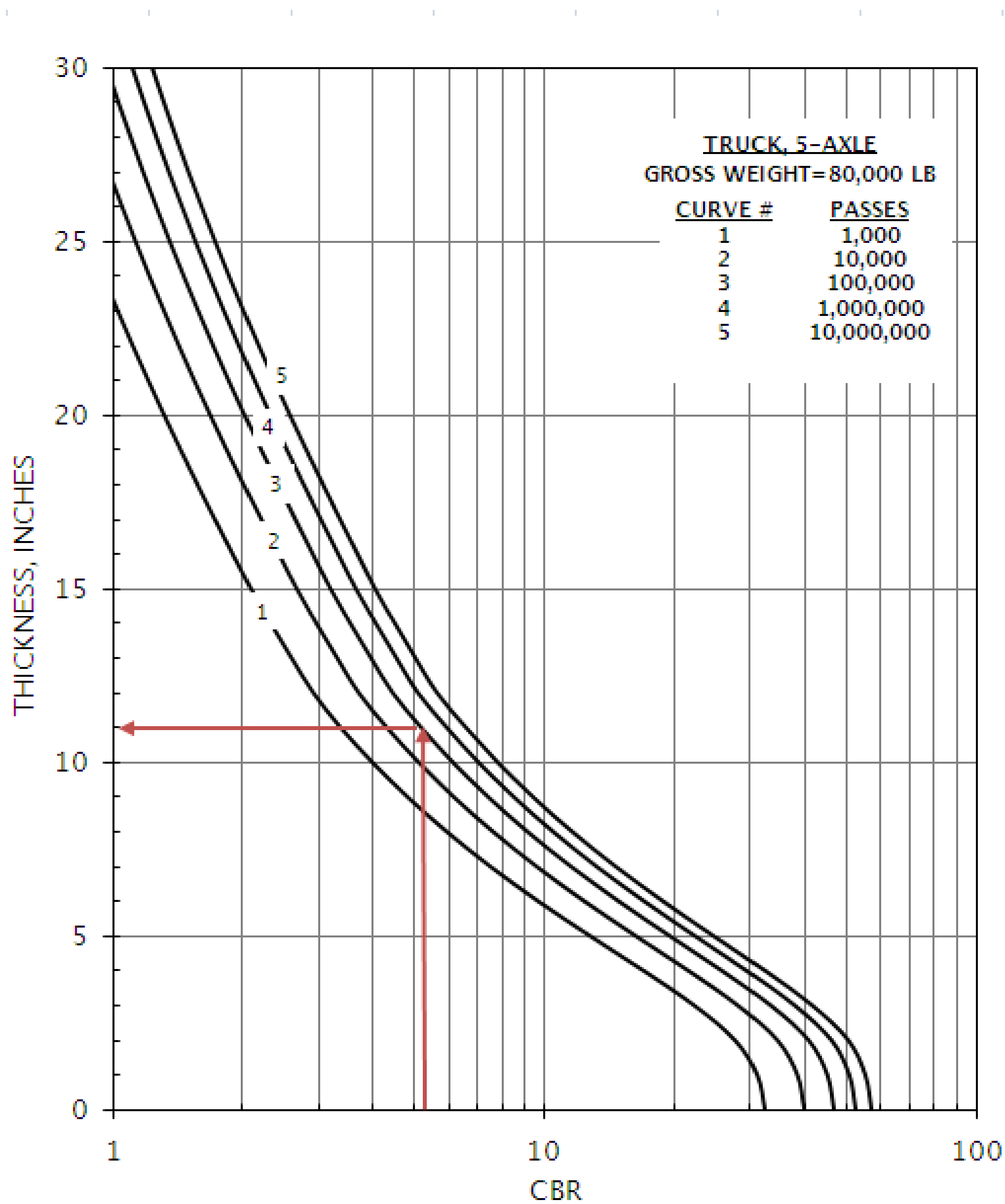


**Figure E-29 Truck 2-Axle, 6-Tire
Flexible Pavement Design Curve**

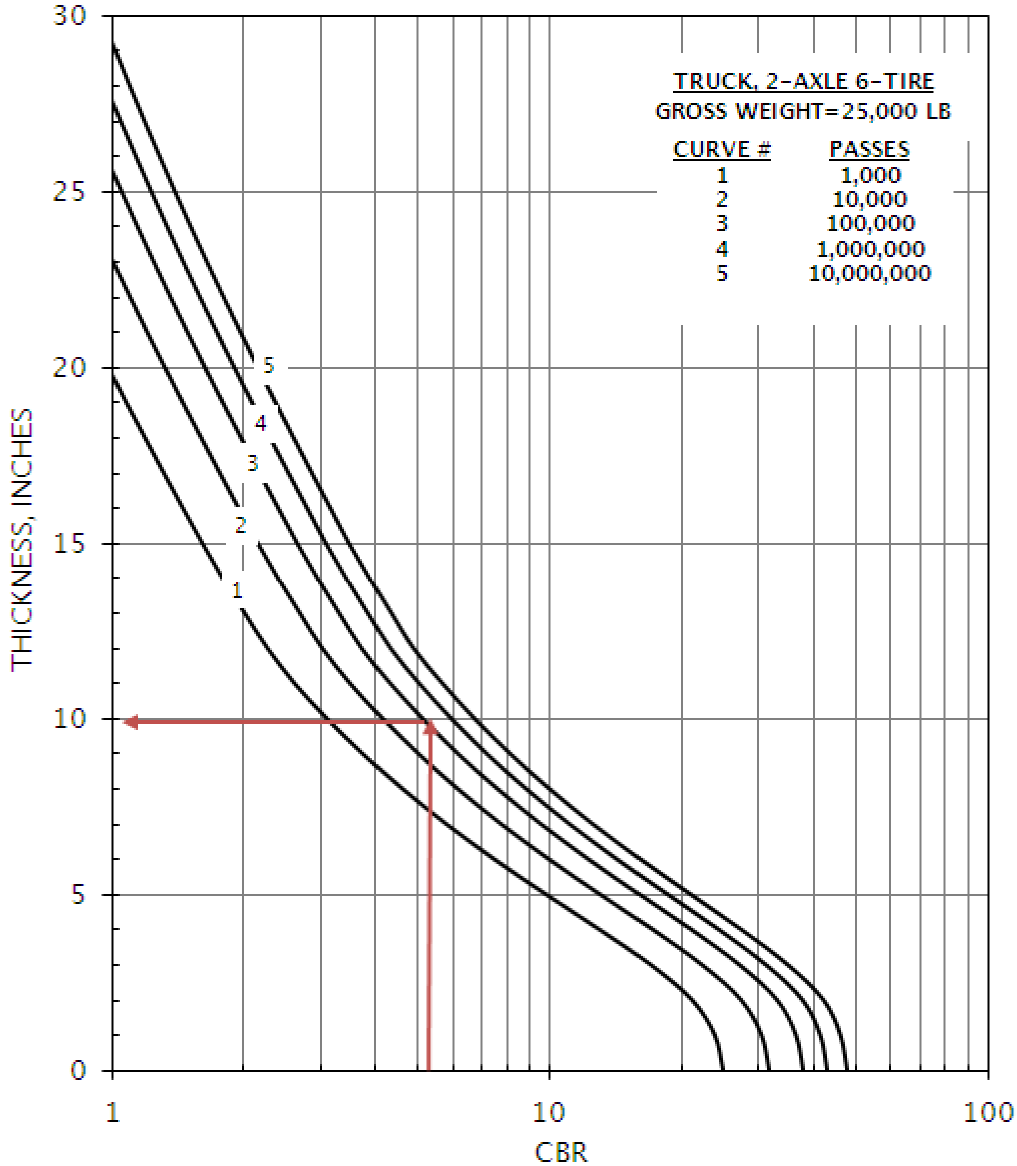


Figure E-30 TYC-850L Container Truck Flexible Pavement Design Curve

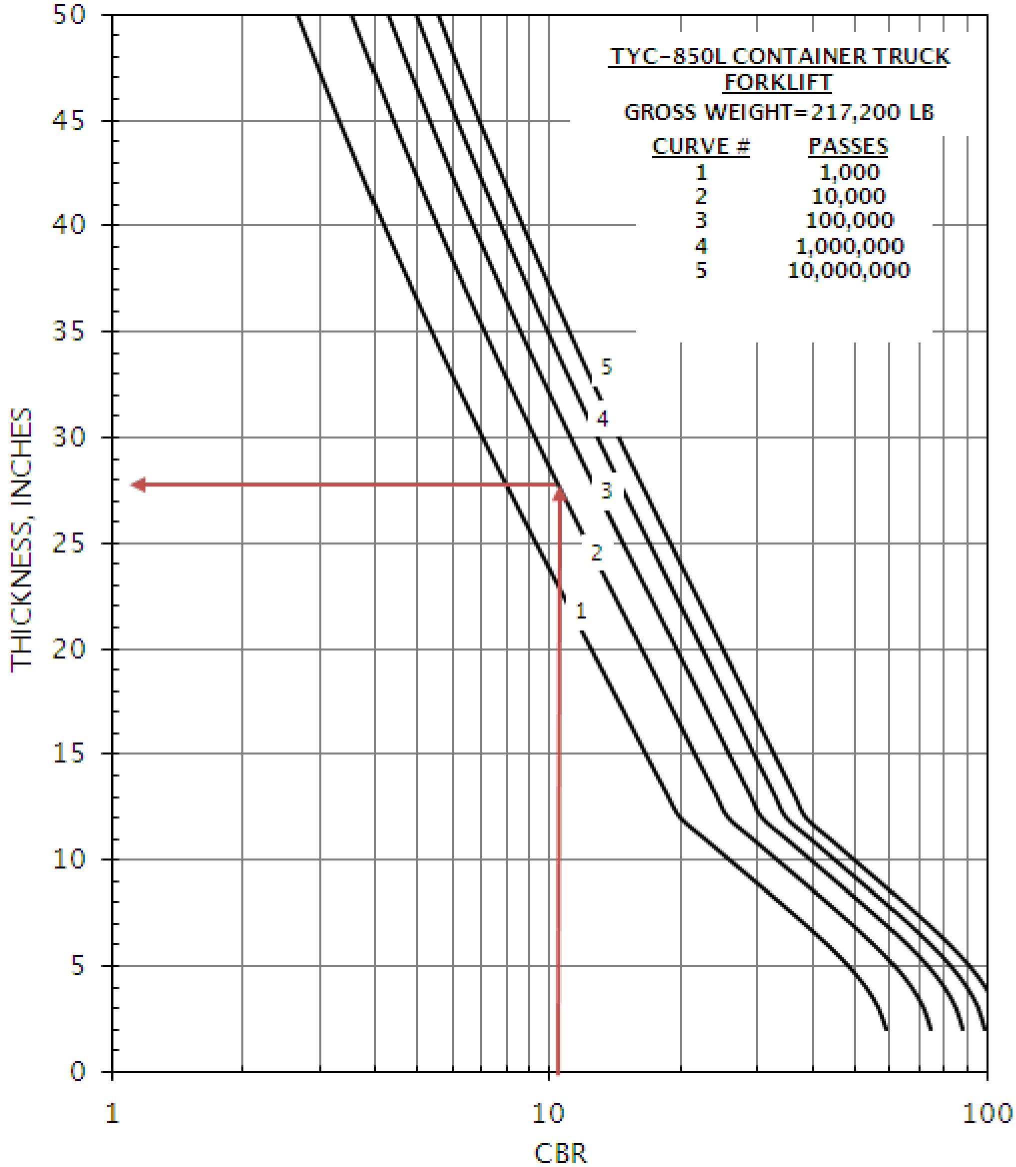
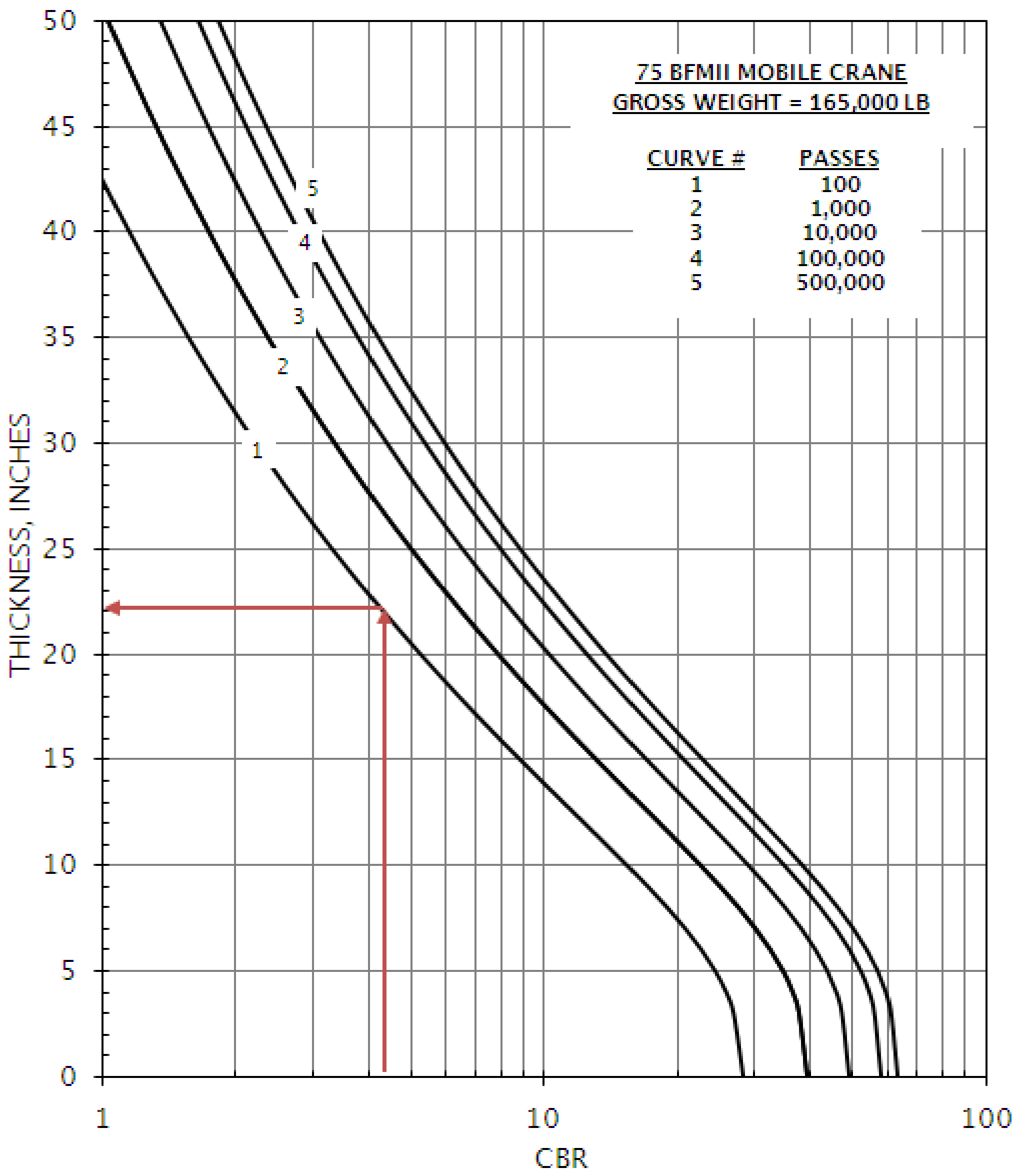


Figure E-31 75BFMII Mobile Crane Flexible Pavement Design Curve



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APPENDIX F RIGID PAVEMENT DESIGN CURVES

Figure F-1 Single Axle, Dual Tire Load Plain Concrete and RCCP

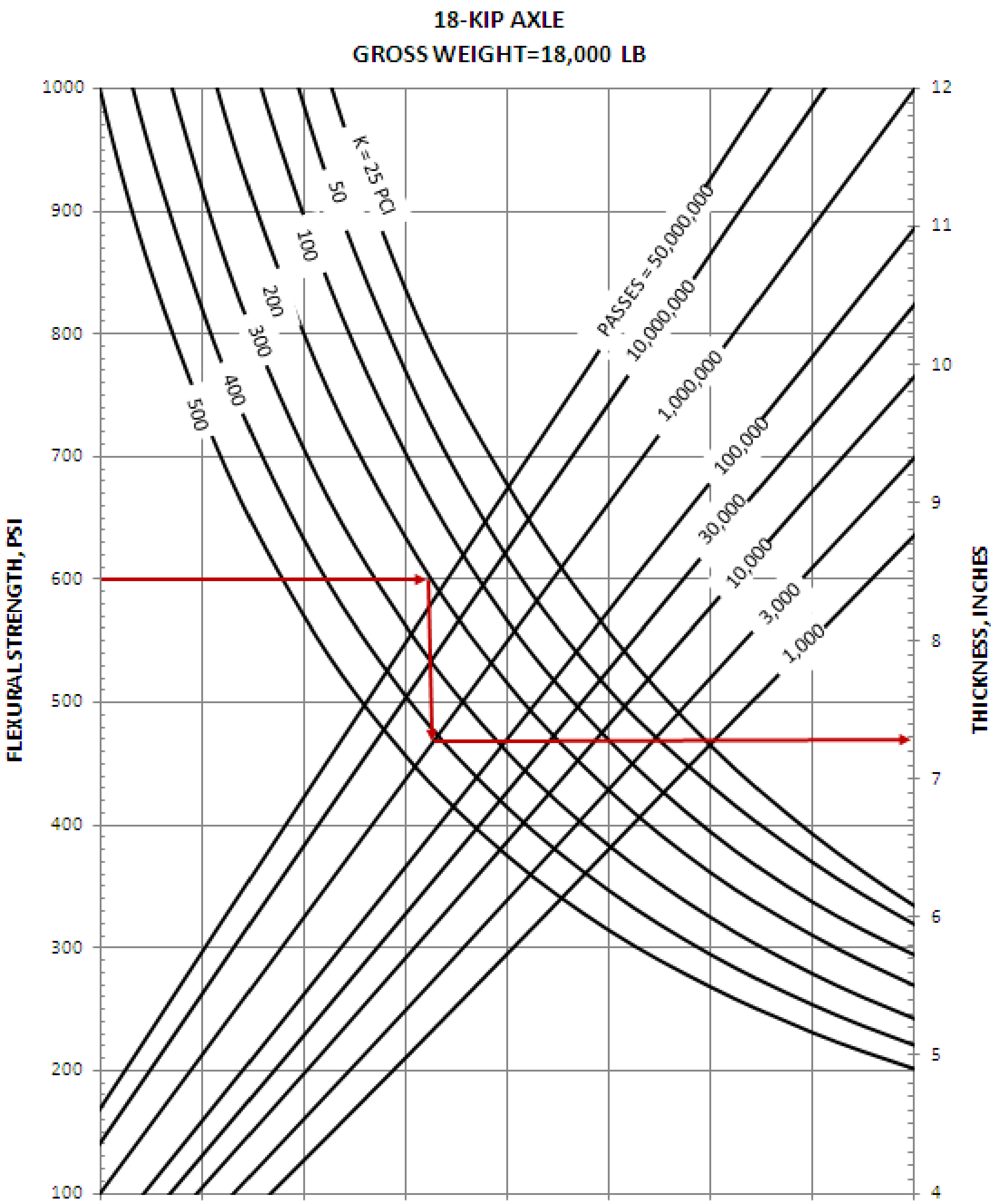


**Figure F-2 Passenger Car
Plain Concrete and RCCP**

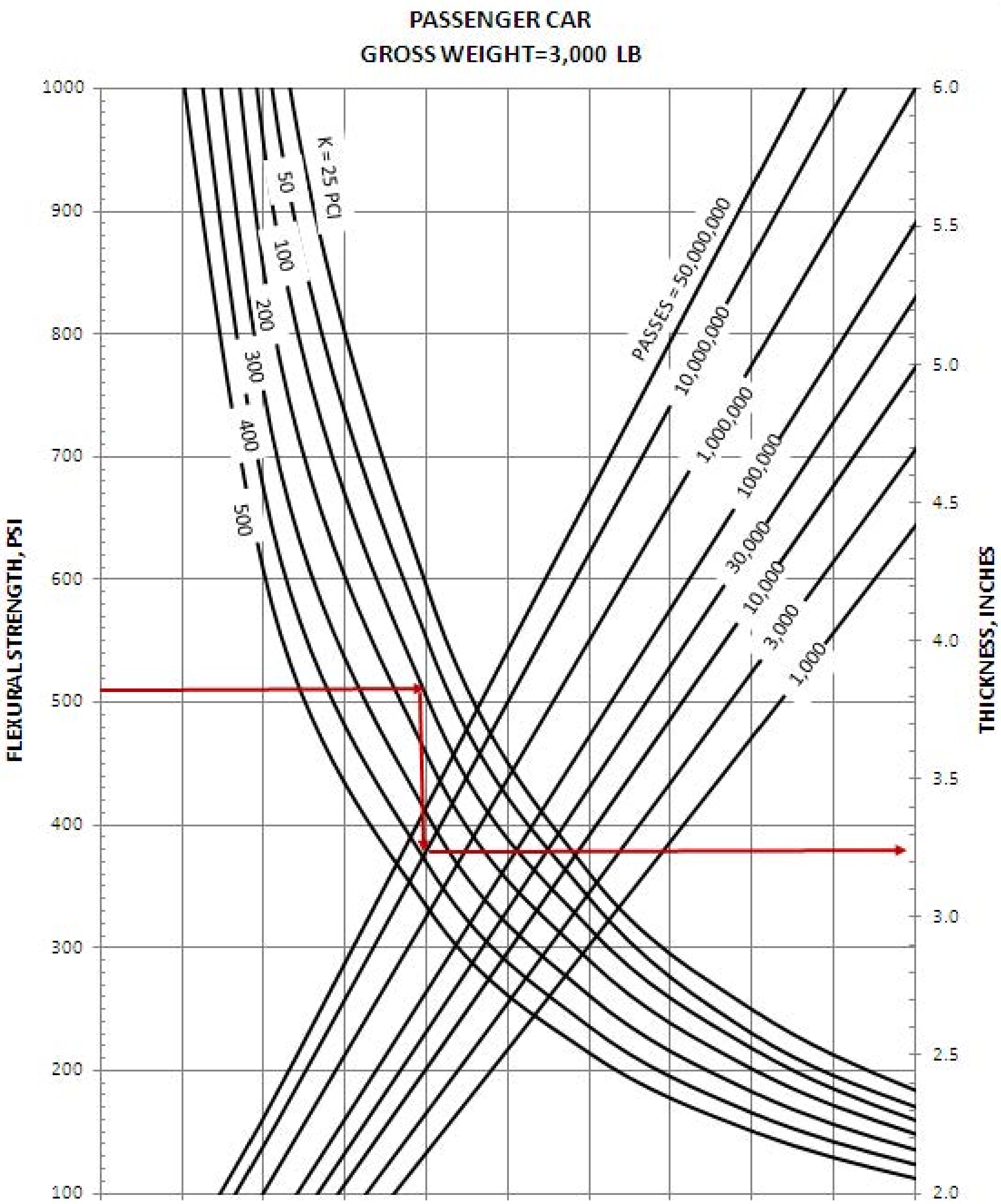


Figure F-3 Light Strike Vehicle
Plain Concrete and RCCP

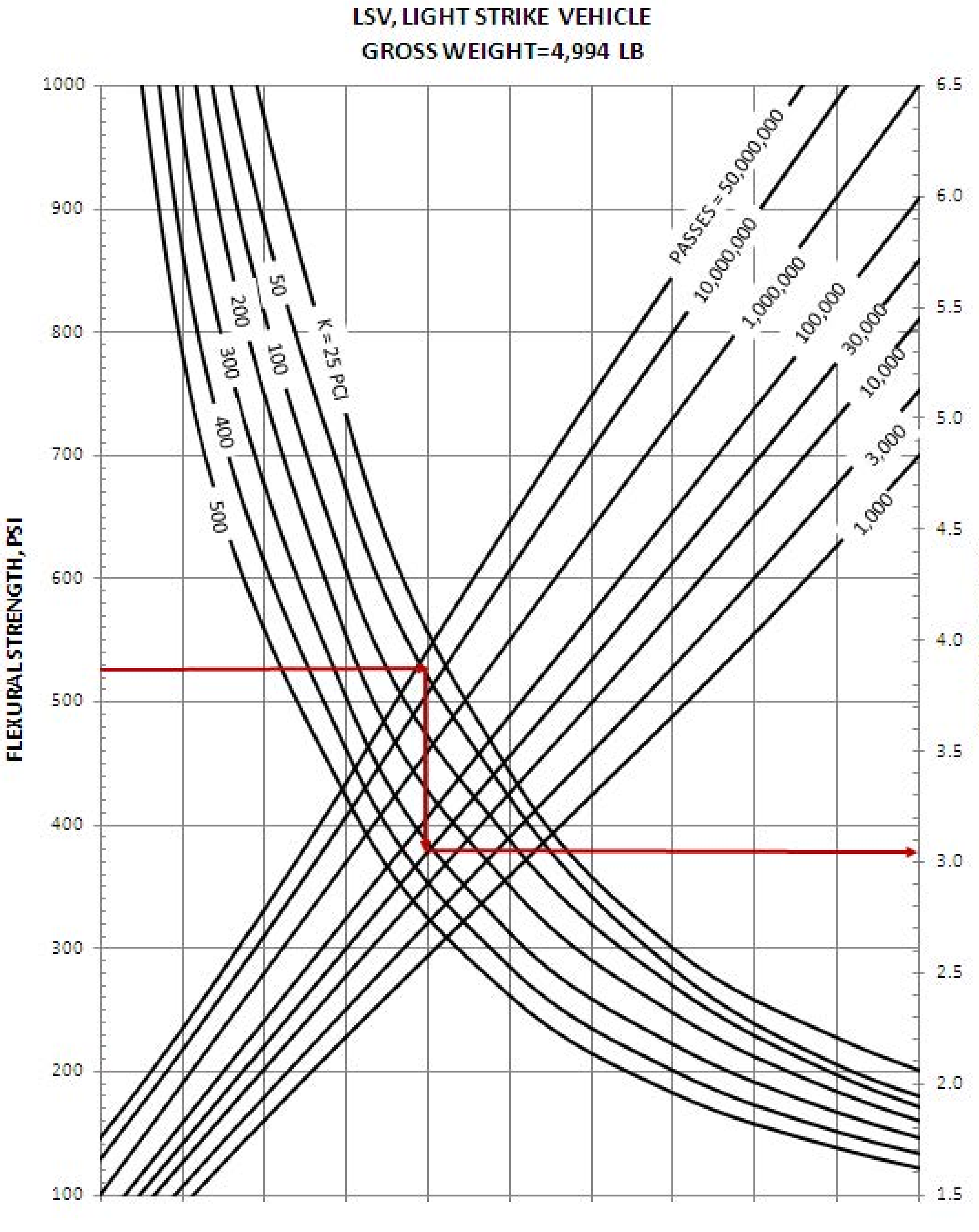


**Figure F-4 M1A1 Main Tank Tracked
Plain Concrete and RCCP**

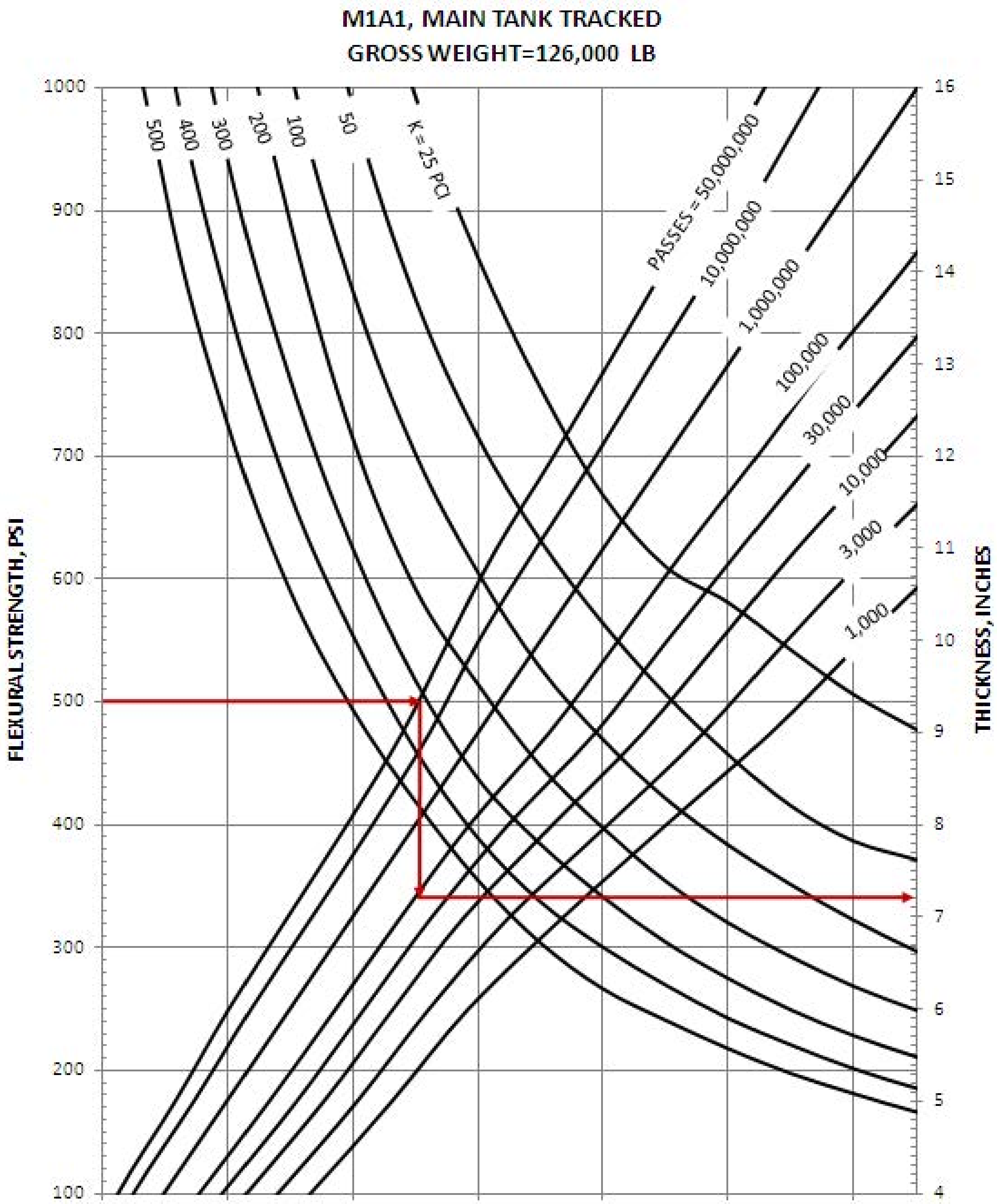


**Figure F-5 M1A2 Main Tank Tracked
Plain Concrete and RCCP**

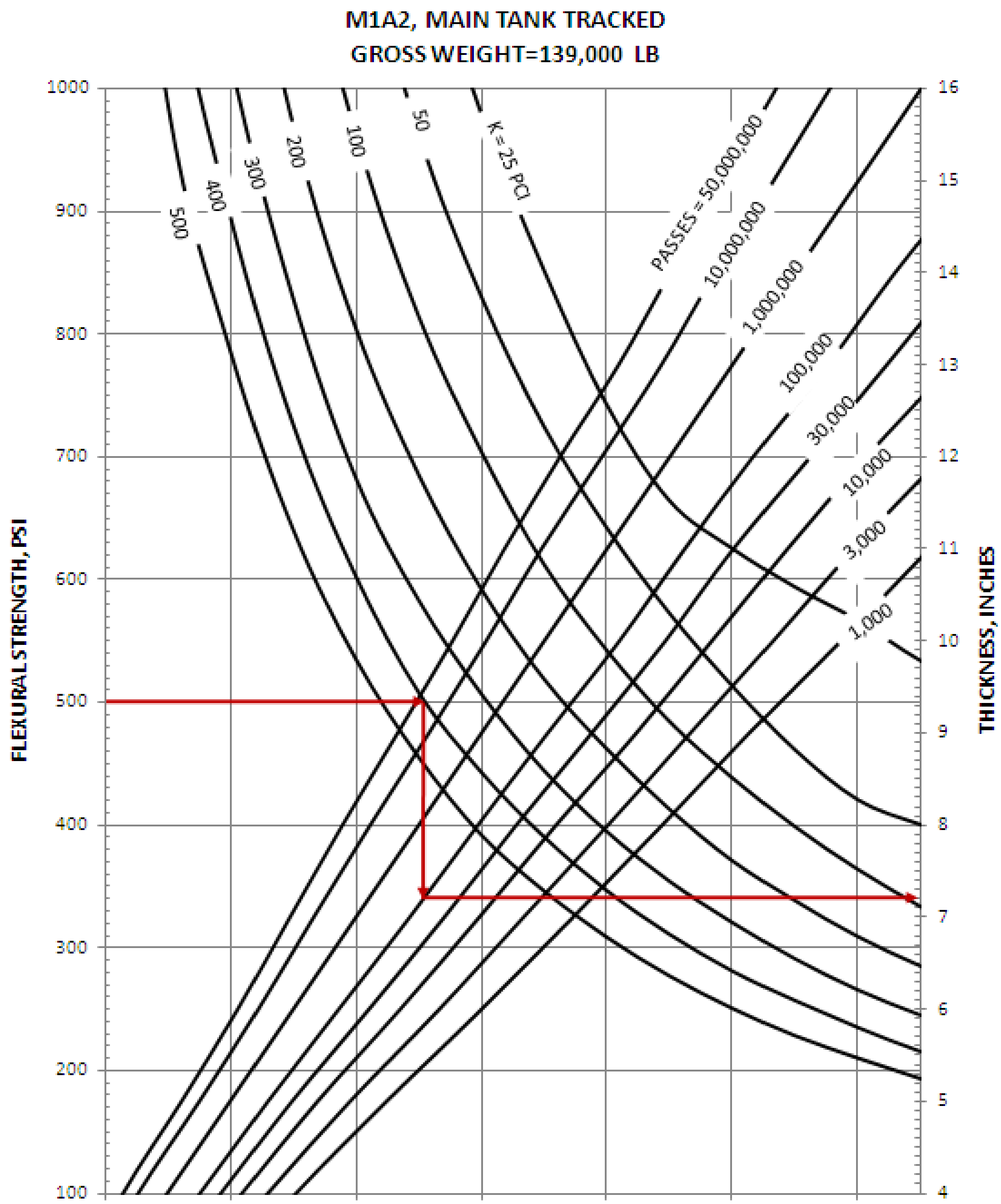


**Figure F-6 M2A3, Bradley Vehicle Tracked
Plain Concrete and RCCP**

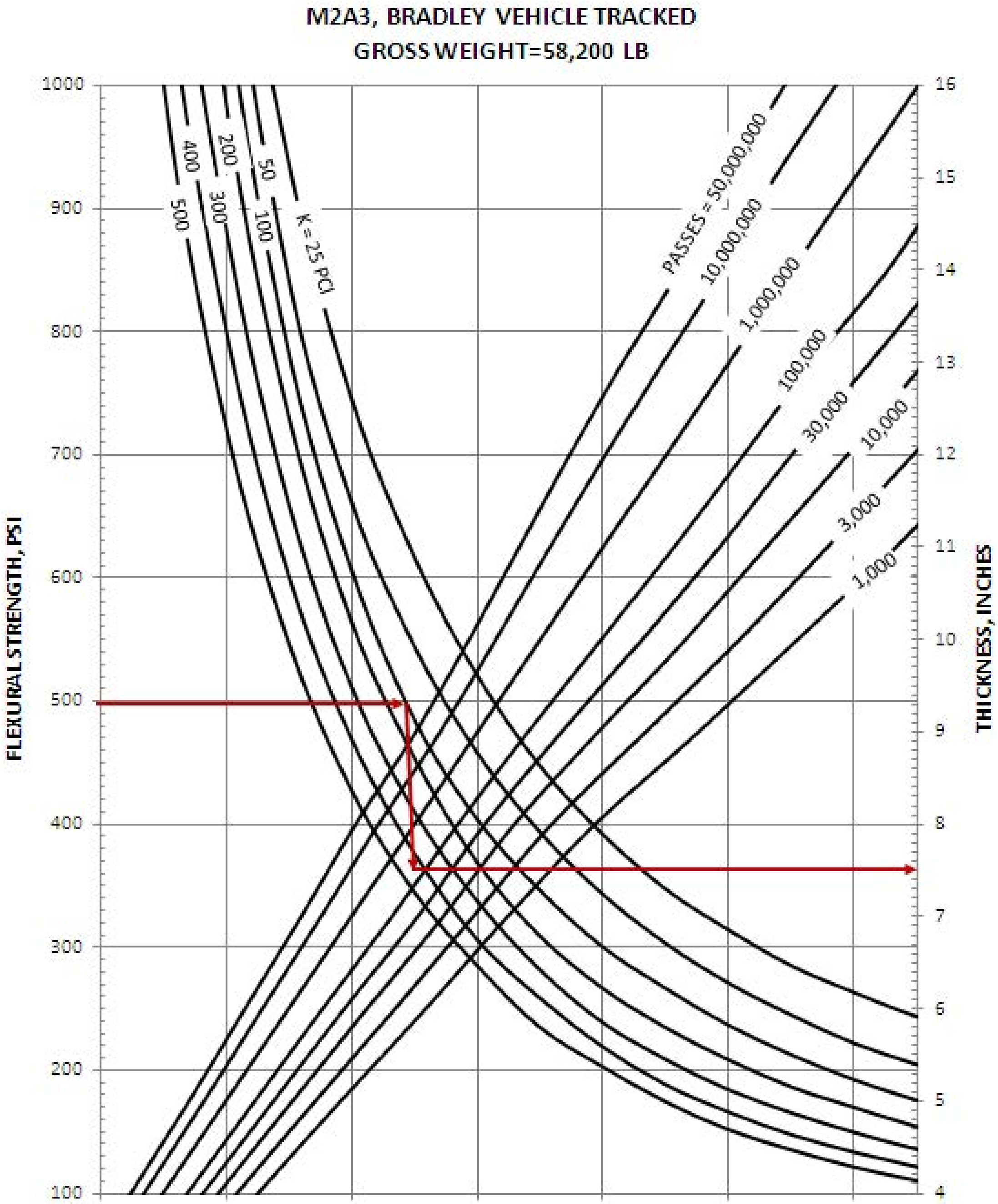


**Figure F-7 M35A2 2.5 Ton Cargo Truck 6x6
Plain Concrete and RCCP**

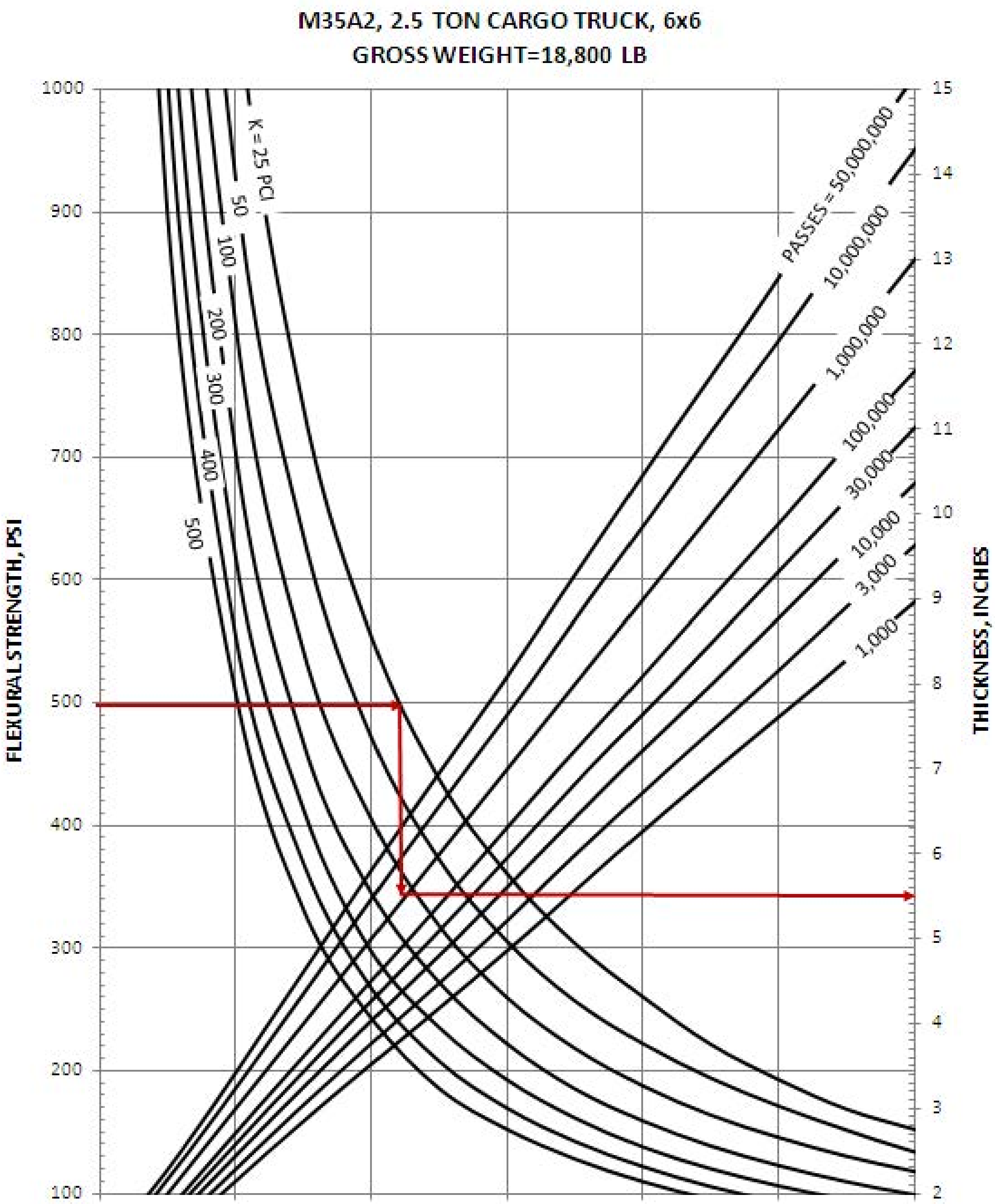


**Figure F-8 M60A3 Main Tank Tracked
Plain Concrete and RCCP**

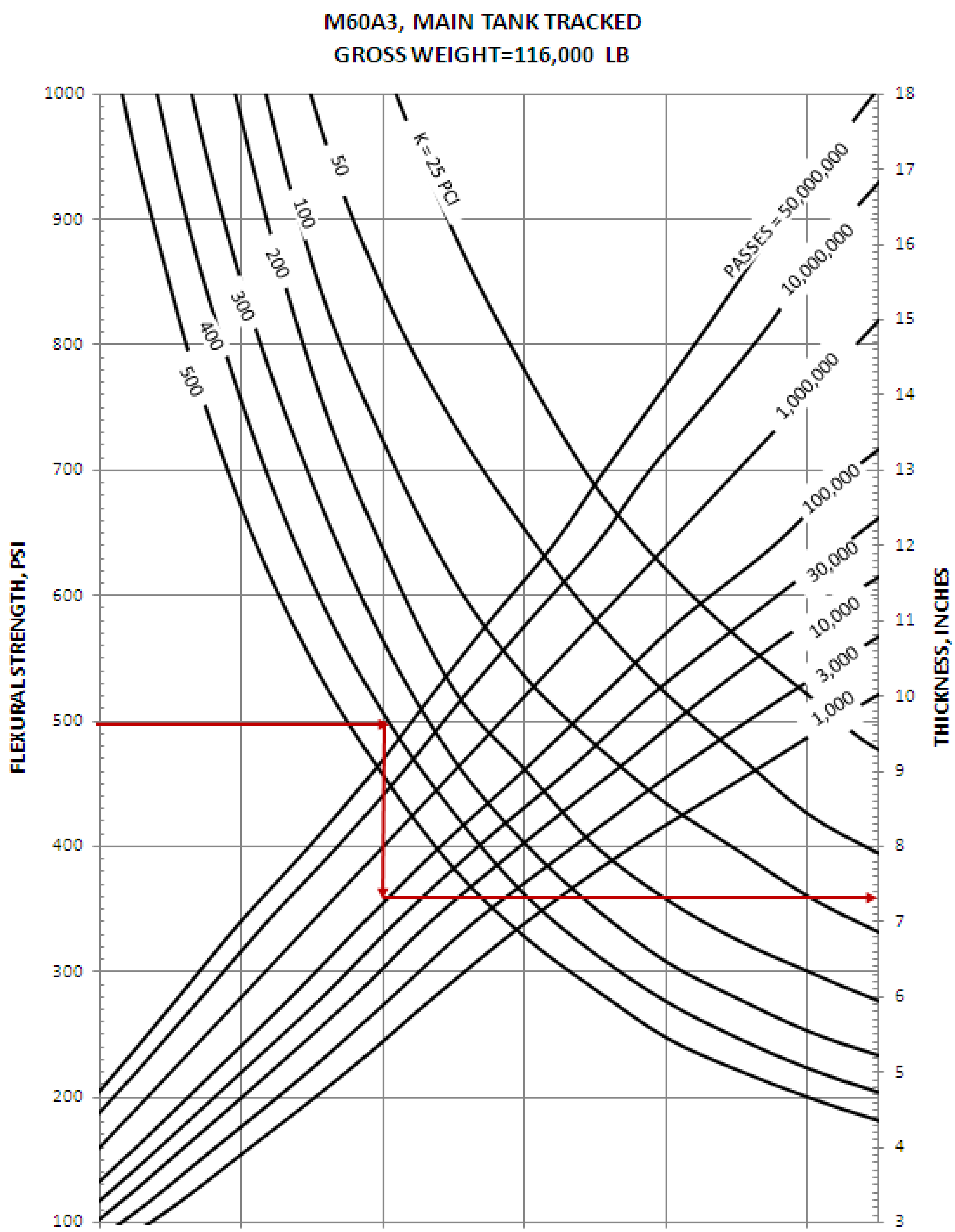


Figure F-9 M109A6, 155 Howitzer Tracked Plain Concrete and RCCP

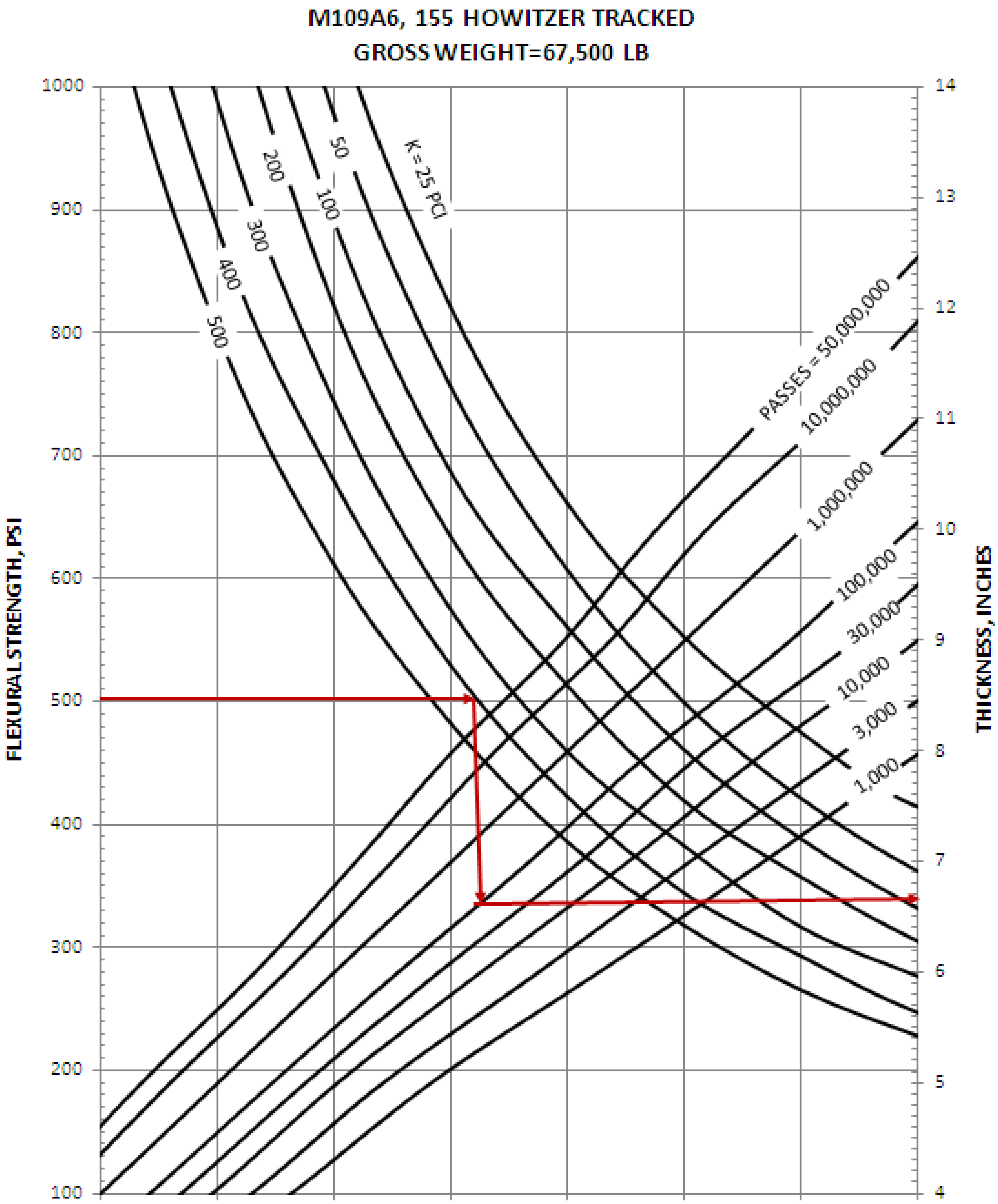


**Figure F-10 M113A1, Armored Carrier Tracked
Plain Concrete and RCCP**

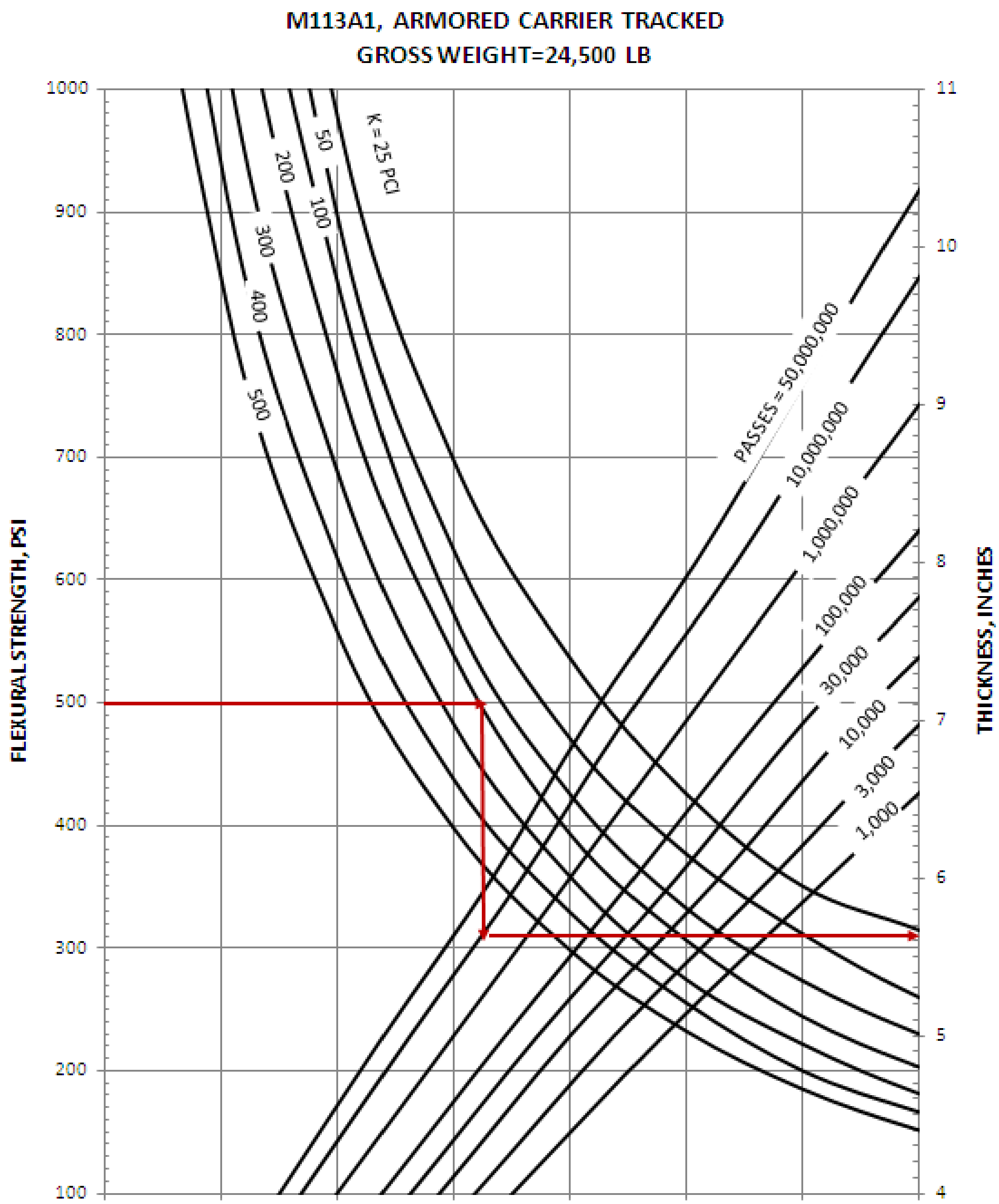


**Figure F-11 M923 5-Ton Cargo Truck
Plain Concrete and RCCP**

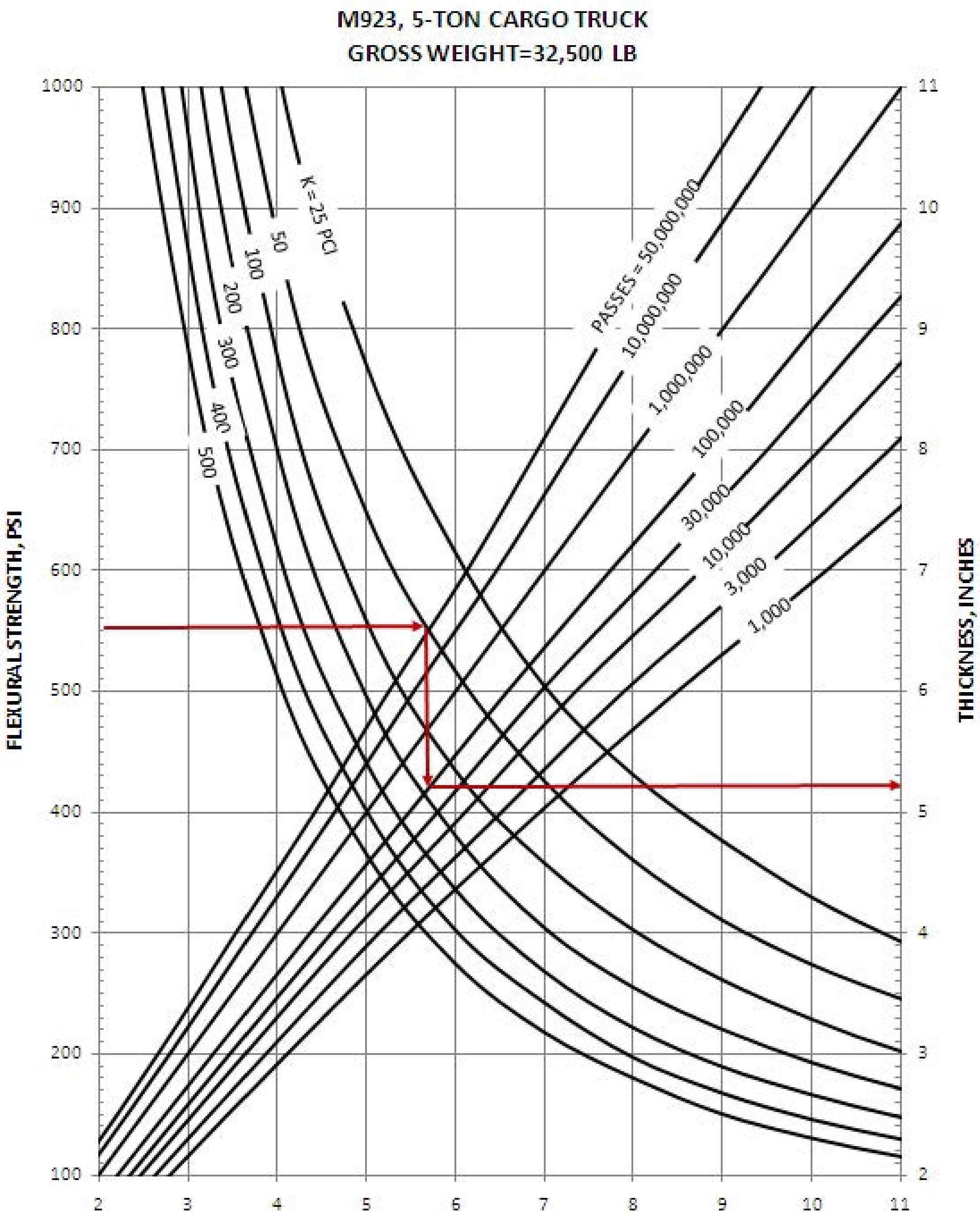


**Figure F-12 M977 HEMTT, 10-Ton Cargo Truck 8x8
Plain Concrete and RCCP**

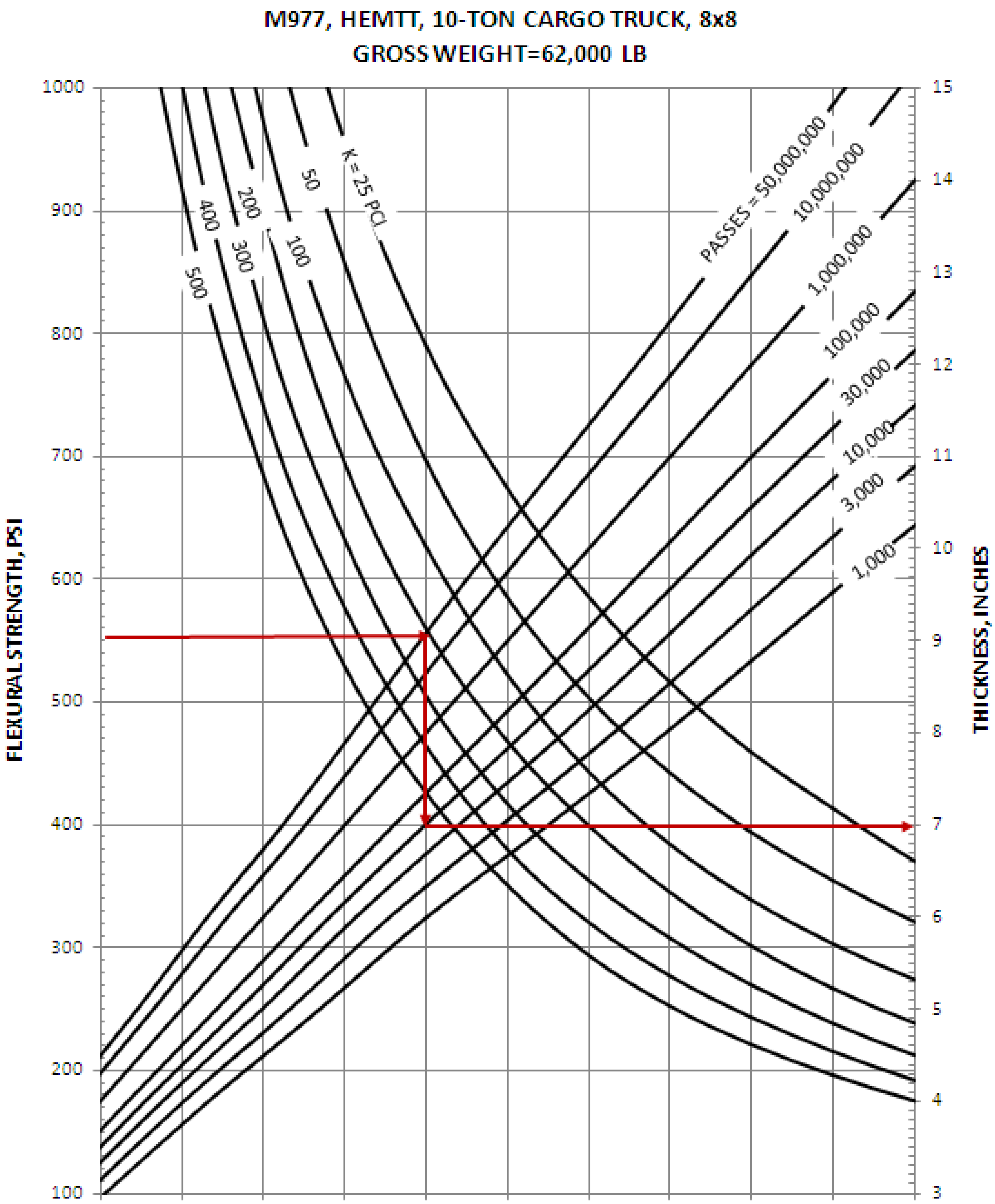


**Figure F-13 M978 HEMTT, 10-Ton Fuel Truck 8x8
Plain Concrete and RCCP**

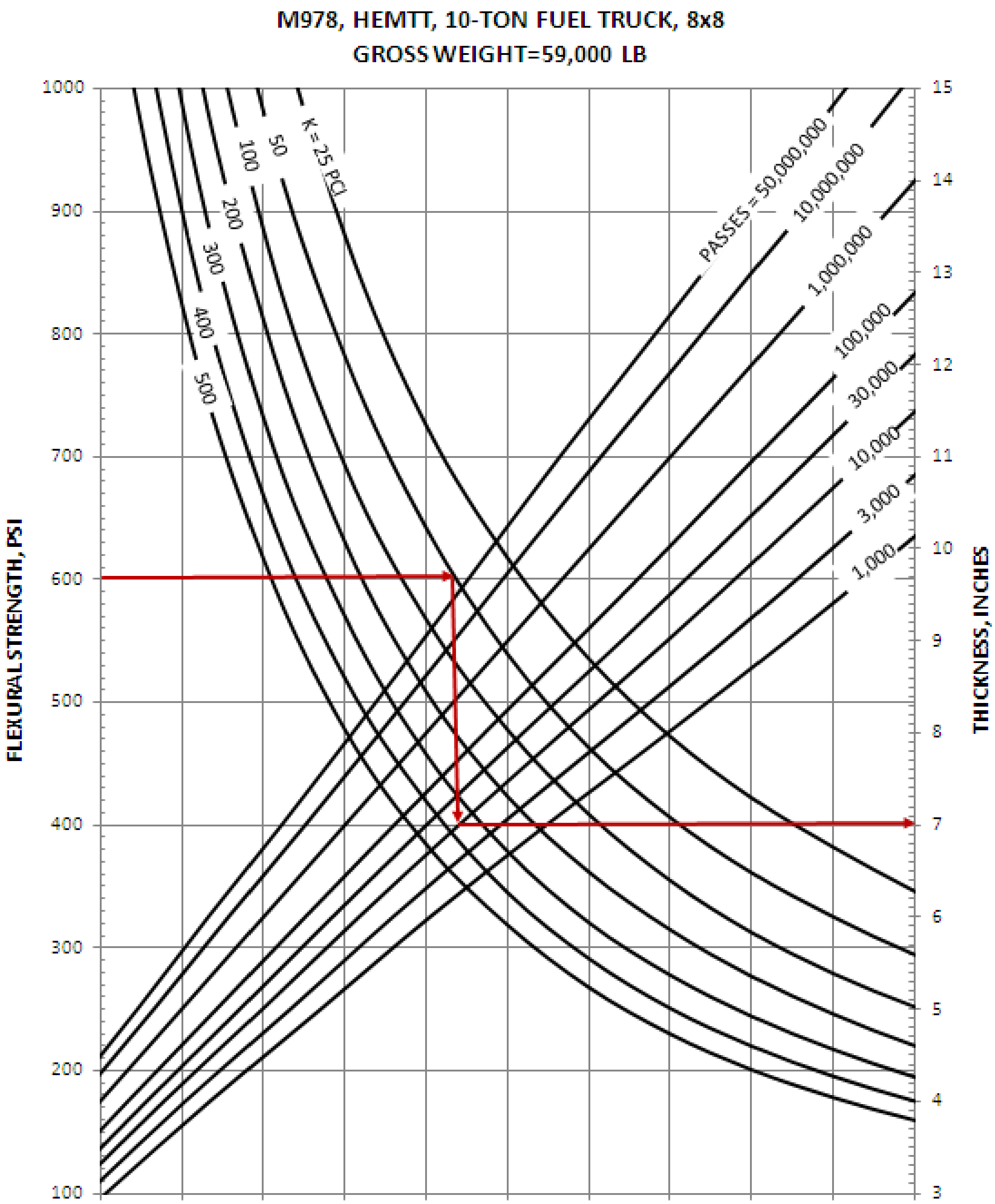


**Figure F-14 M983 HEMTT, w/XM860A1 Trailer
Plain Concrete and RCCP**

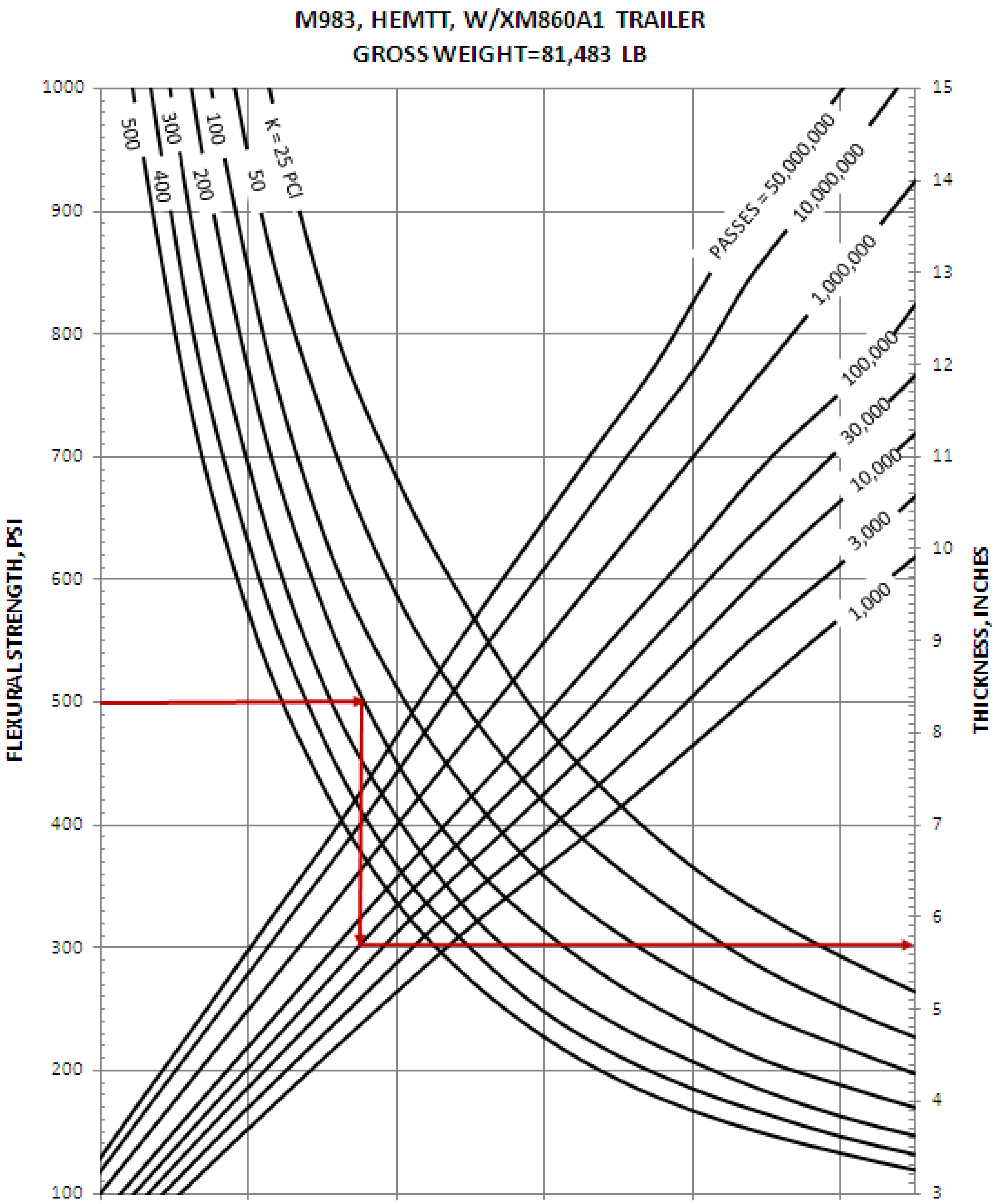


**Figure F-15 M998 HMMWV, 1.25-Ton Carrier 4x4
Plain Concrete and RCCP**

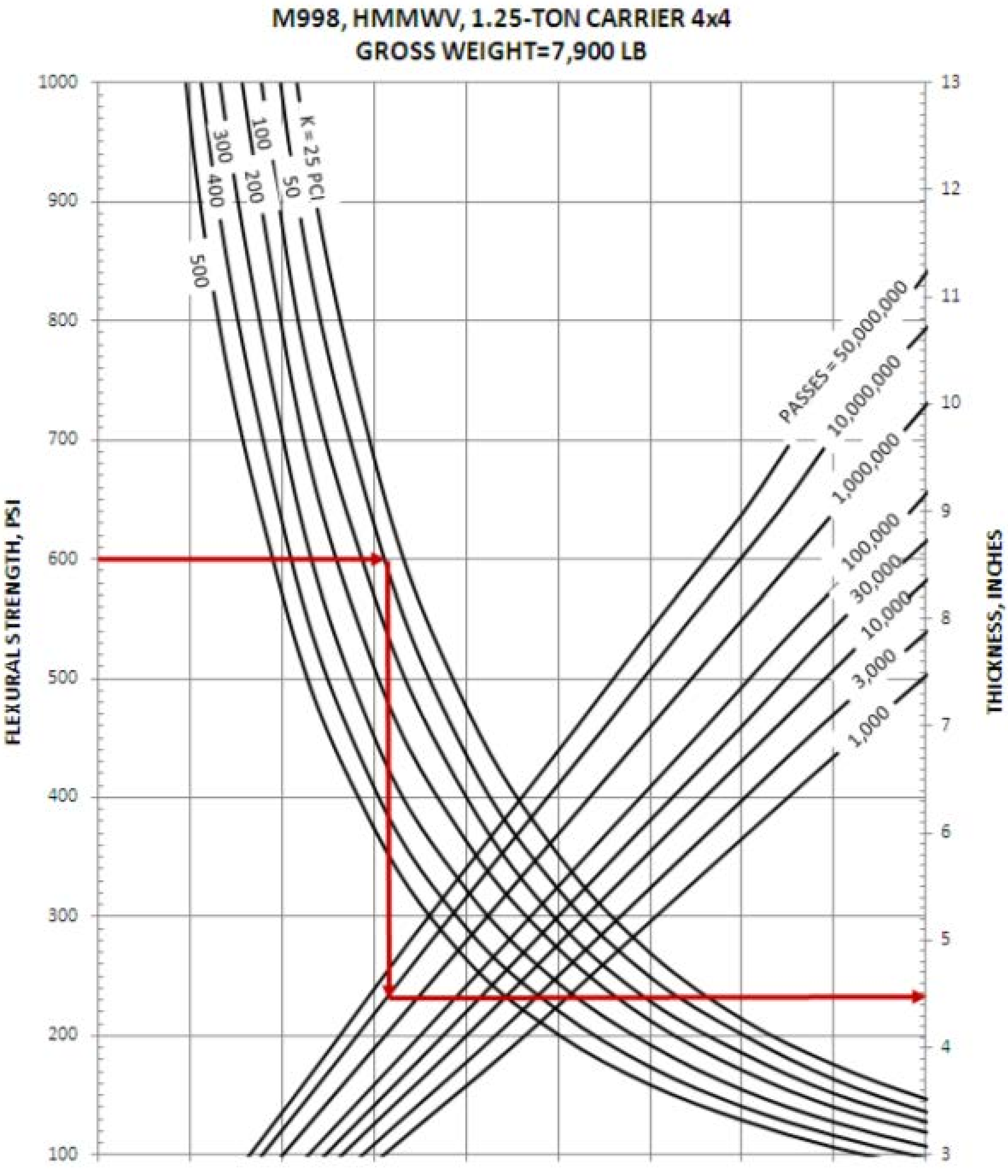


**Figure F-16 M988B RTCH Forklift
Plain Concrete and RCCP**

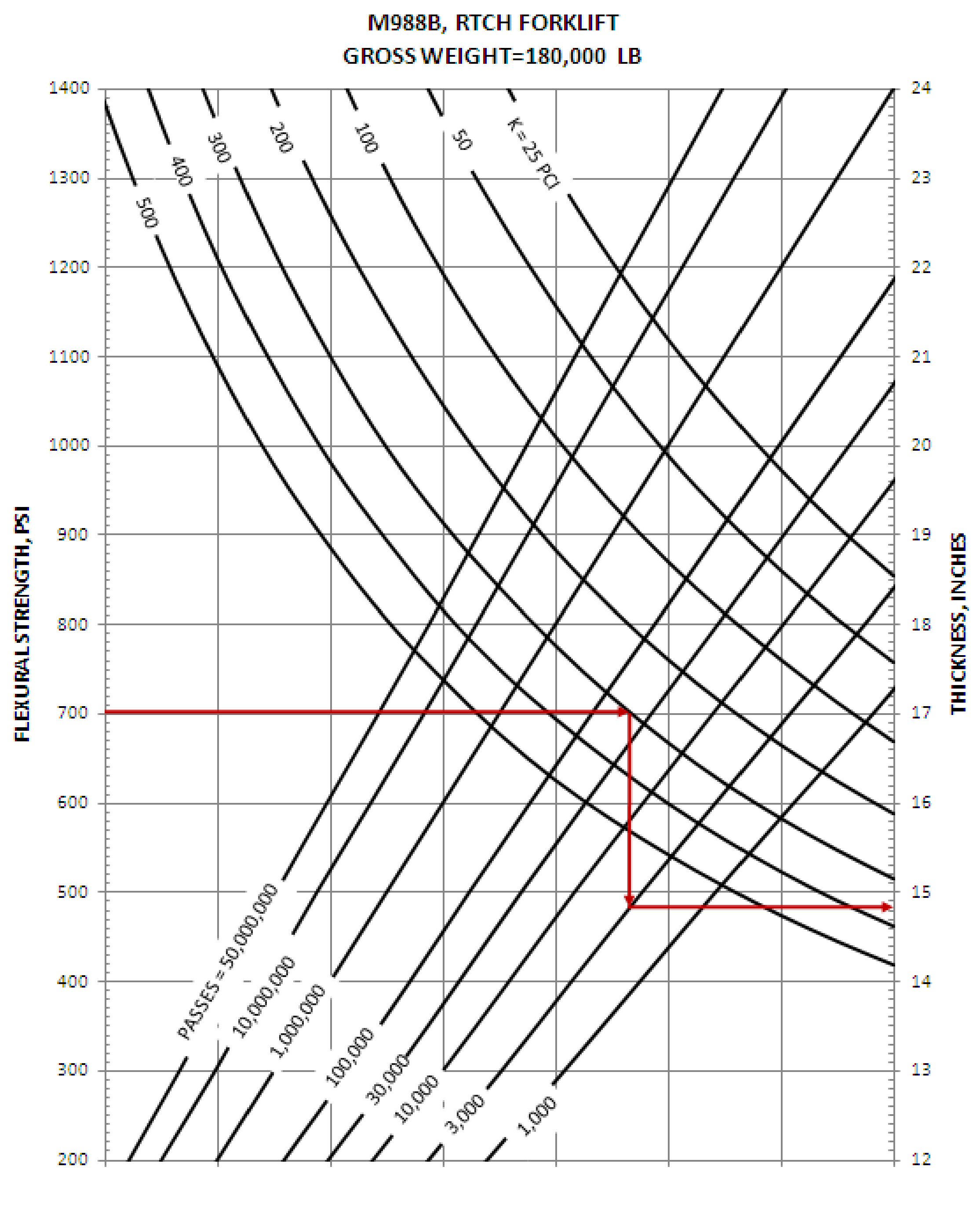


**Figure F-17 M1070 HET Tractor w/ M1000 TRL W/M1A1 Tank
Plain Concrete and RCCP**

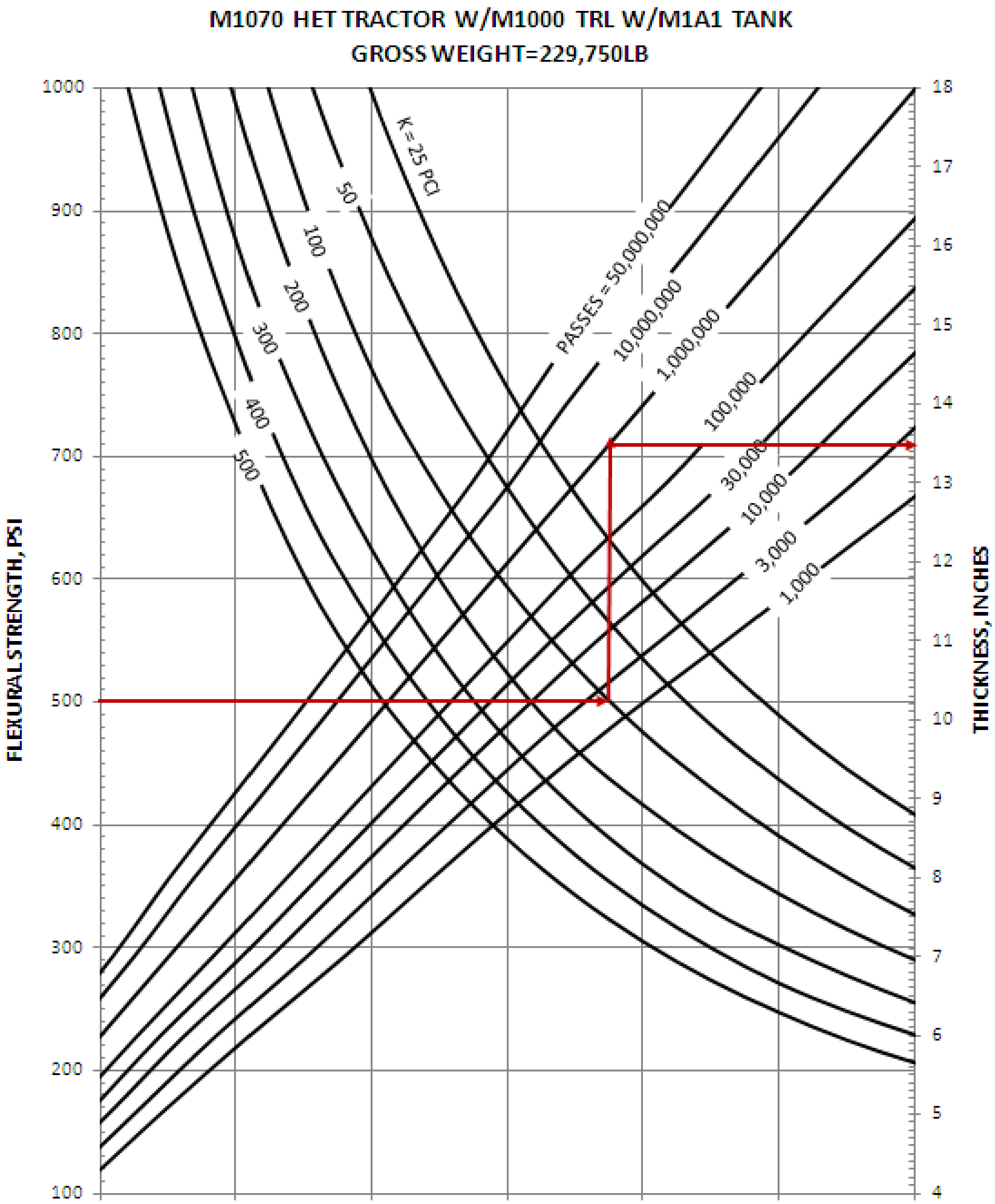


**Figure F-18 M1074 Load System with Crane
Plain Concrete and RCCP**

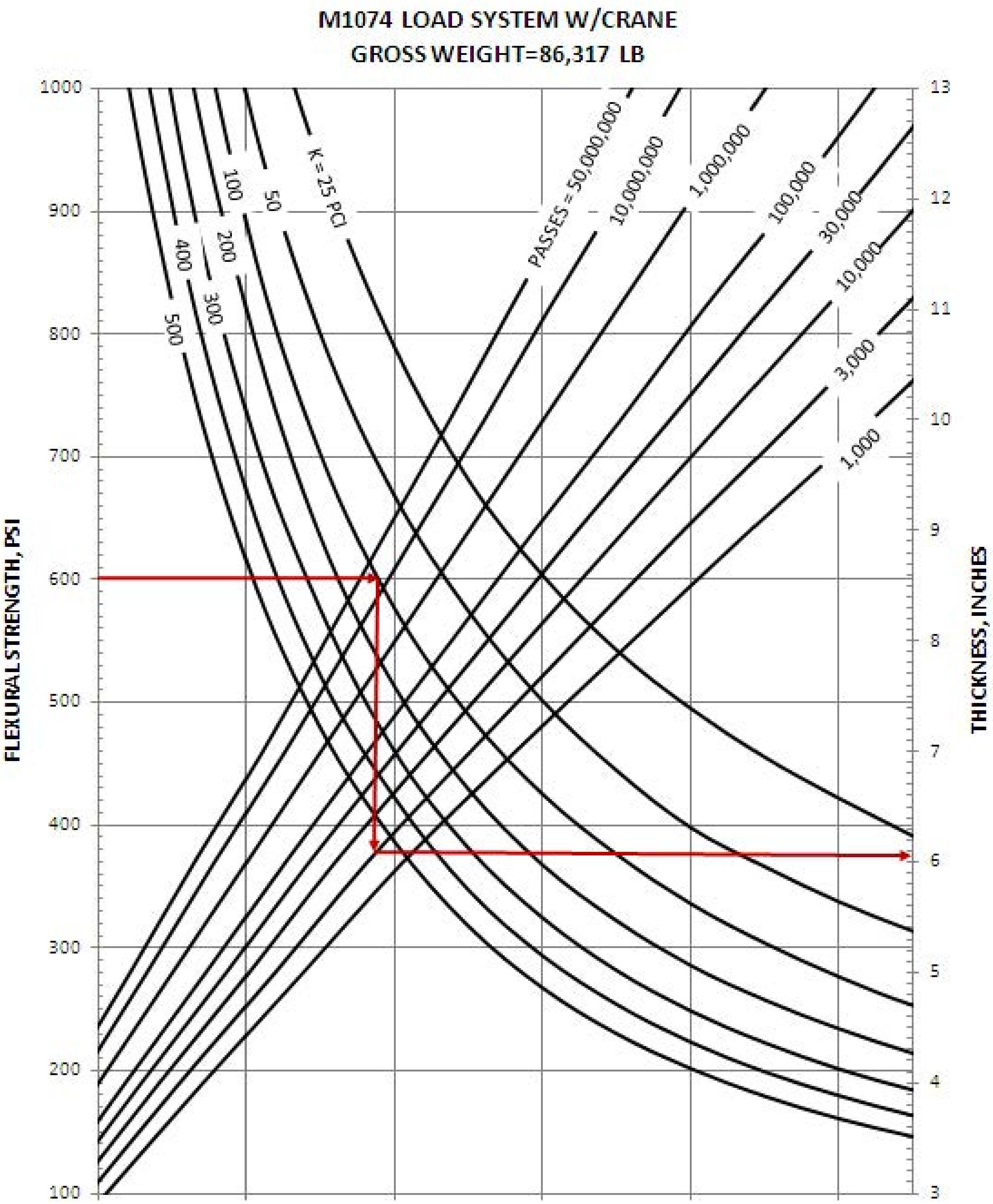


**Figure F-19 M1075 Load System
Plain Concrete and RCCP**

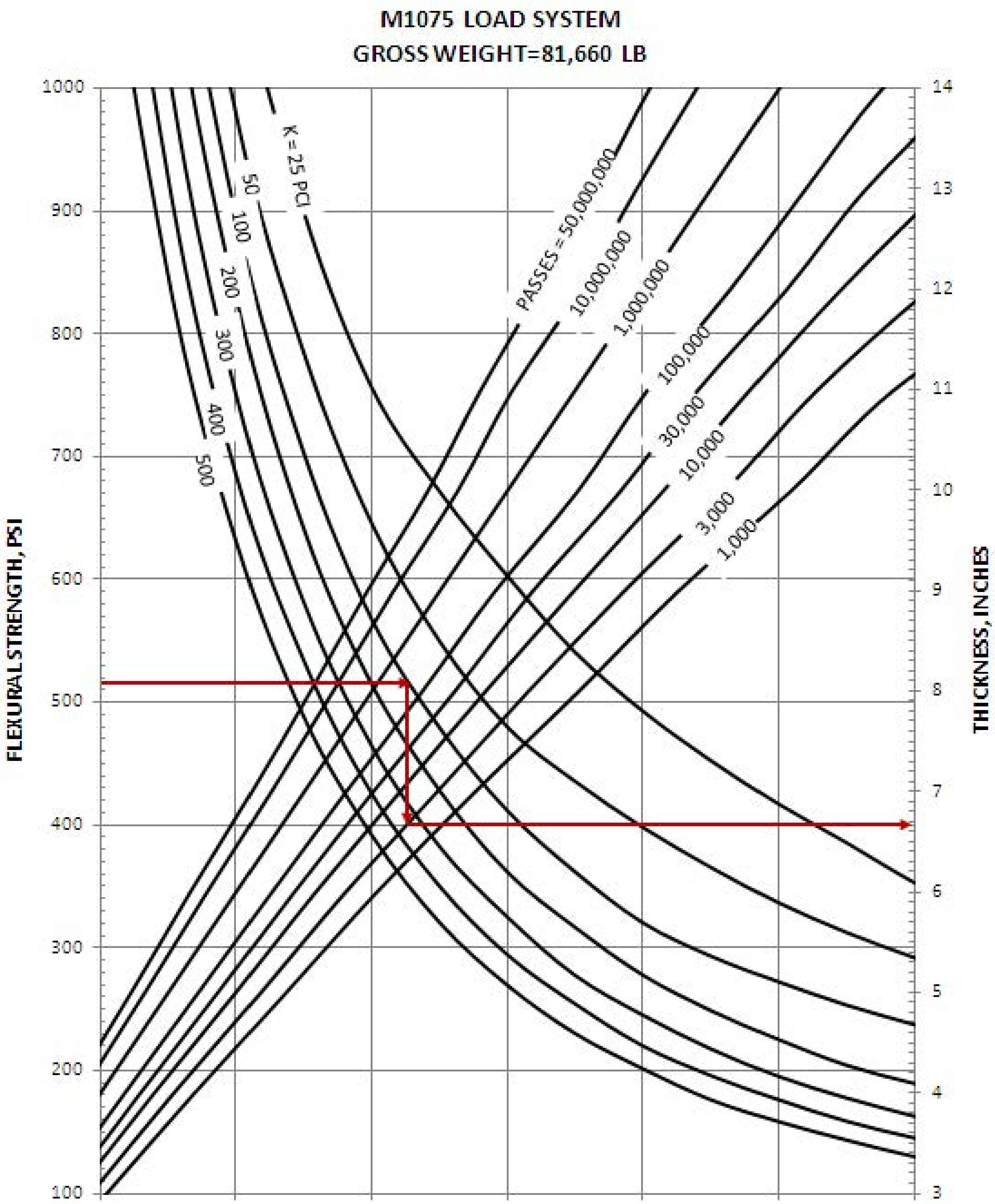


**Figure F-20 M1075 Load System w/M1076 Trailer
Plain Concrete and RCCP**

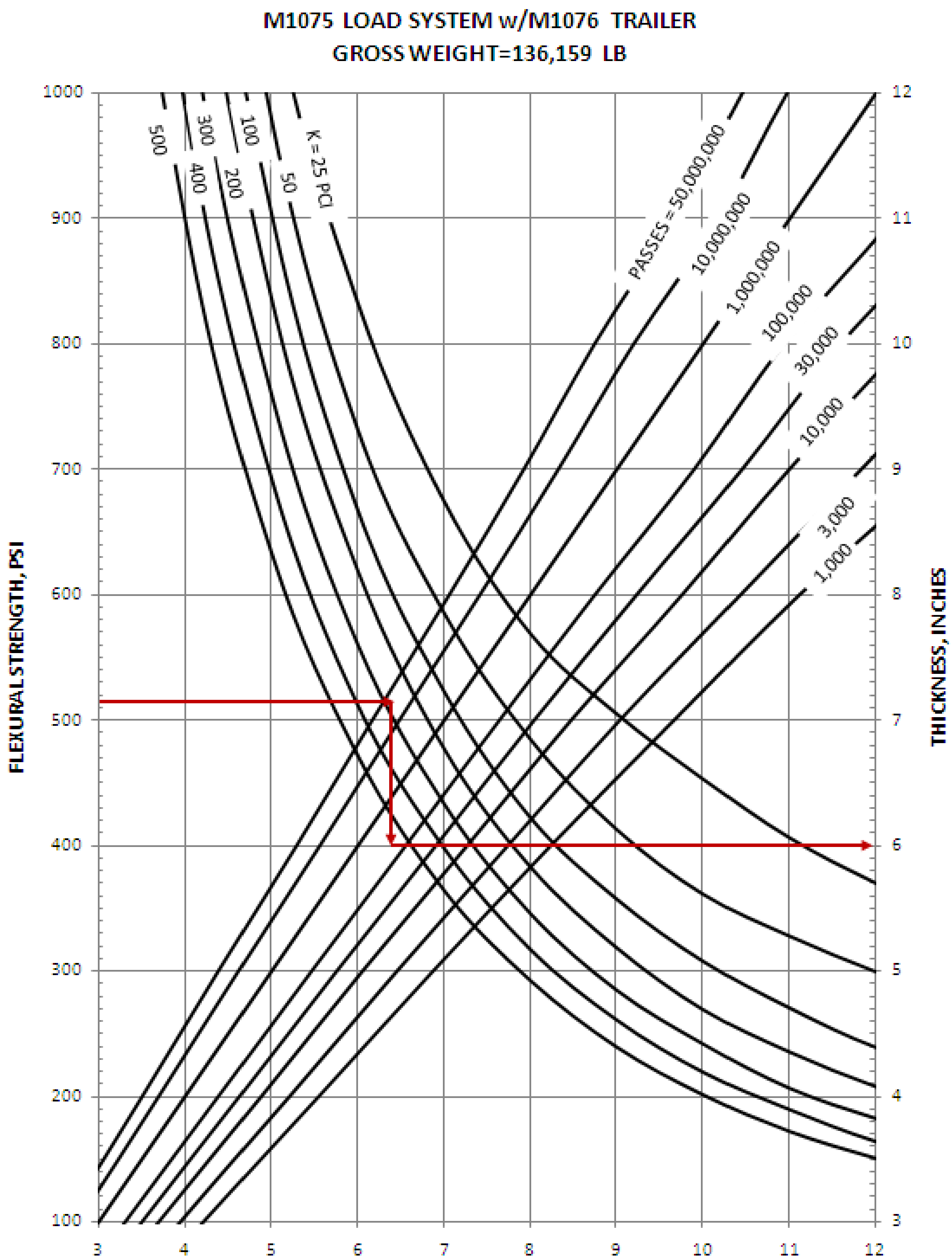


**Figure F-21 M1078 2-1/2 Ton Cargo Truck 4x4
Plain Concrete and RCCP**

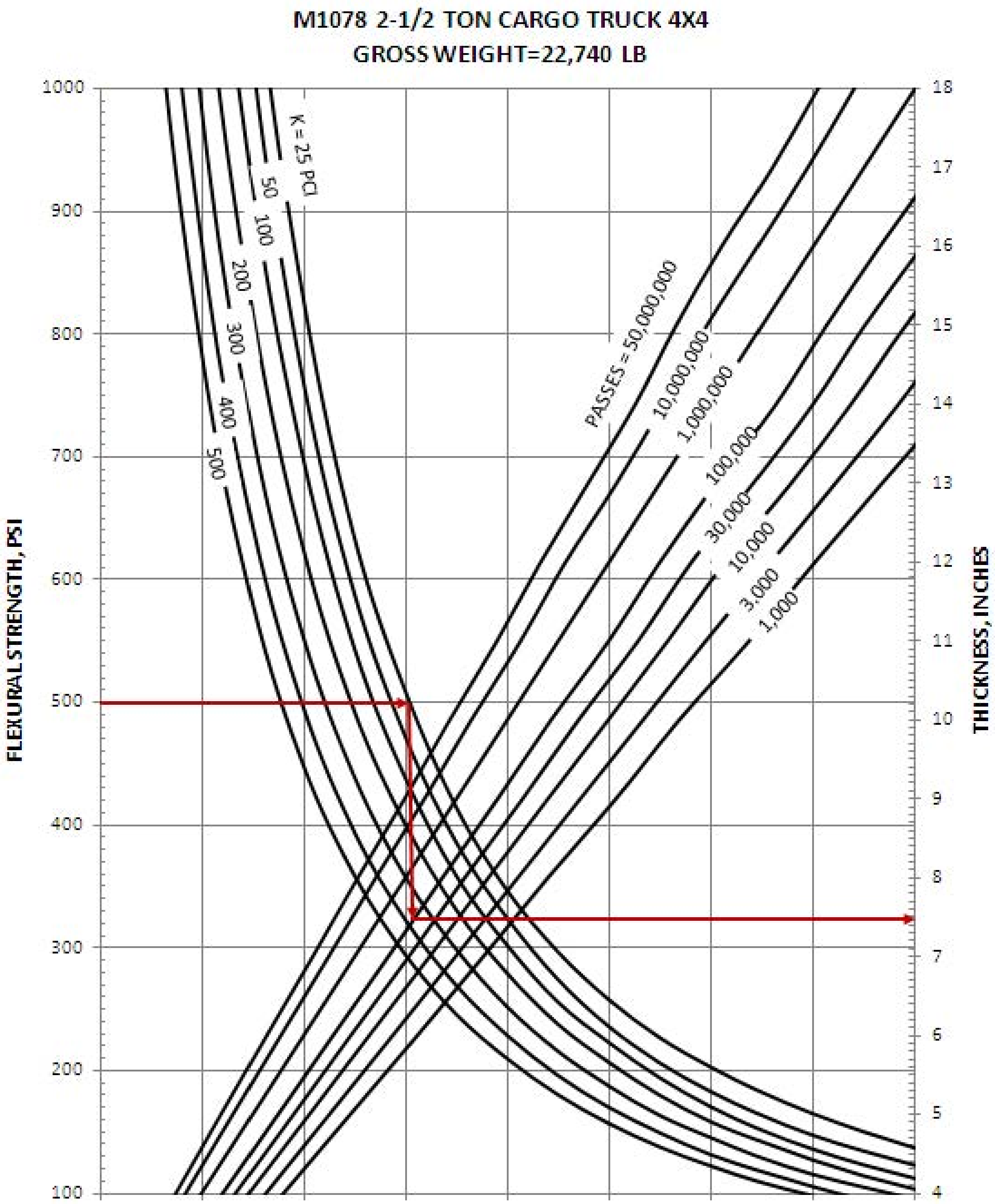


Figure F-21 P-22 Crash Truck (Fire Truck)
Plain Concrete and RCCP

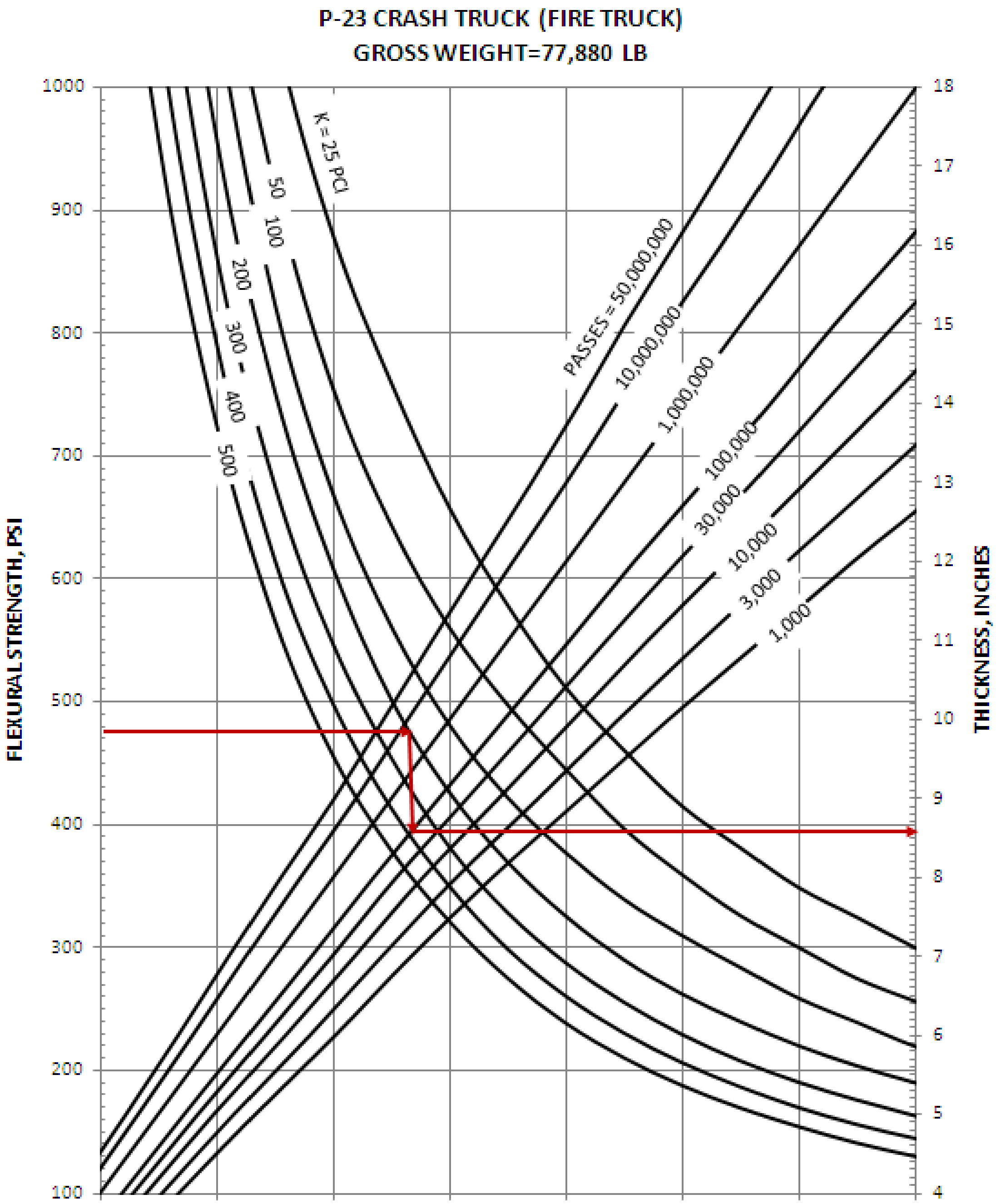


**Figure F-23 R-11 Refueler
Plain Concrete and RCCP**

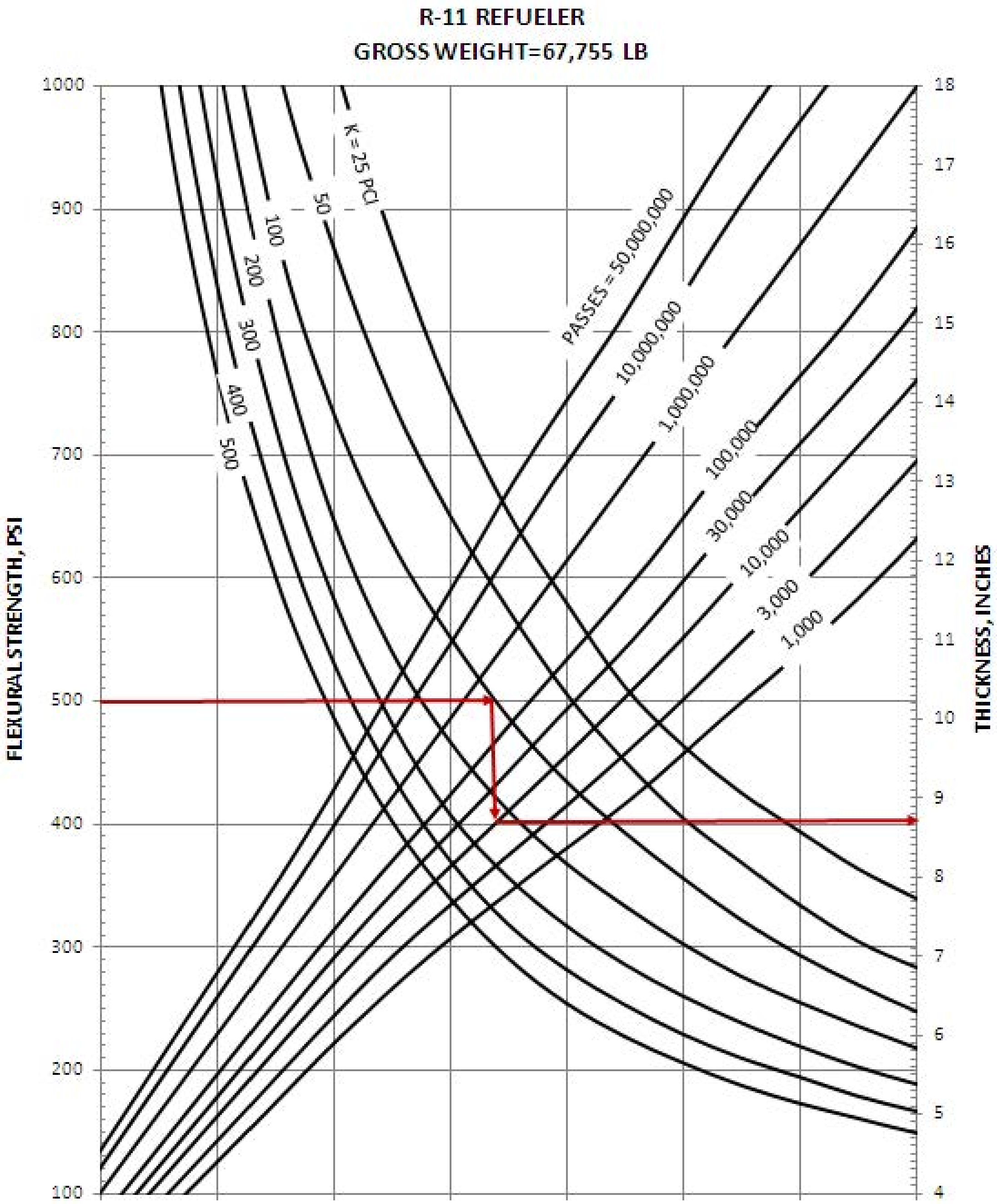


**Figure F-24 Small Pickup
Plain Concrete and RCCP**

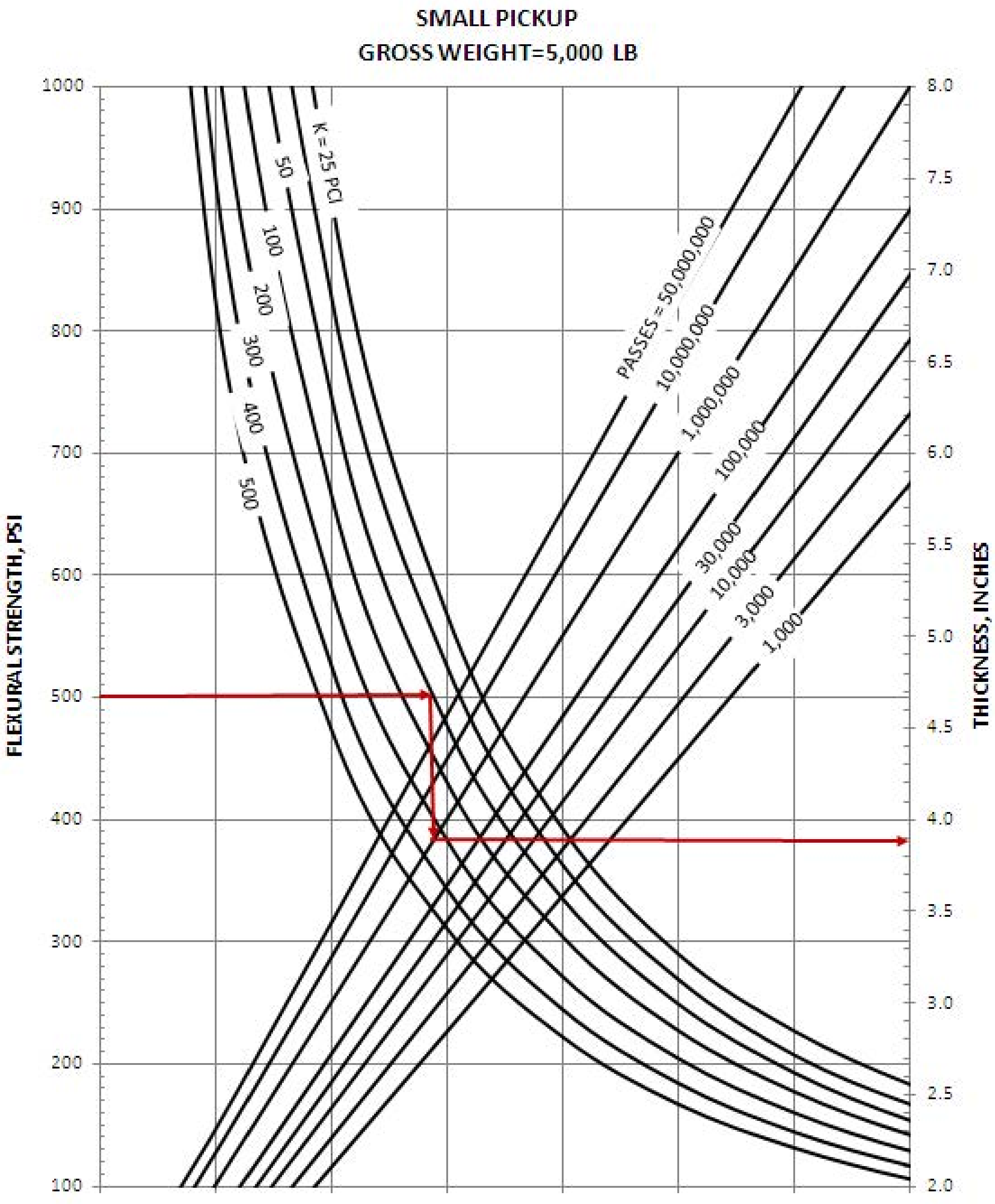


Figure F-25 Larger Pickup
Plain Concrete and RCCP

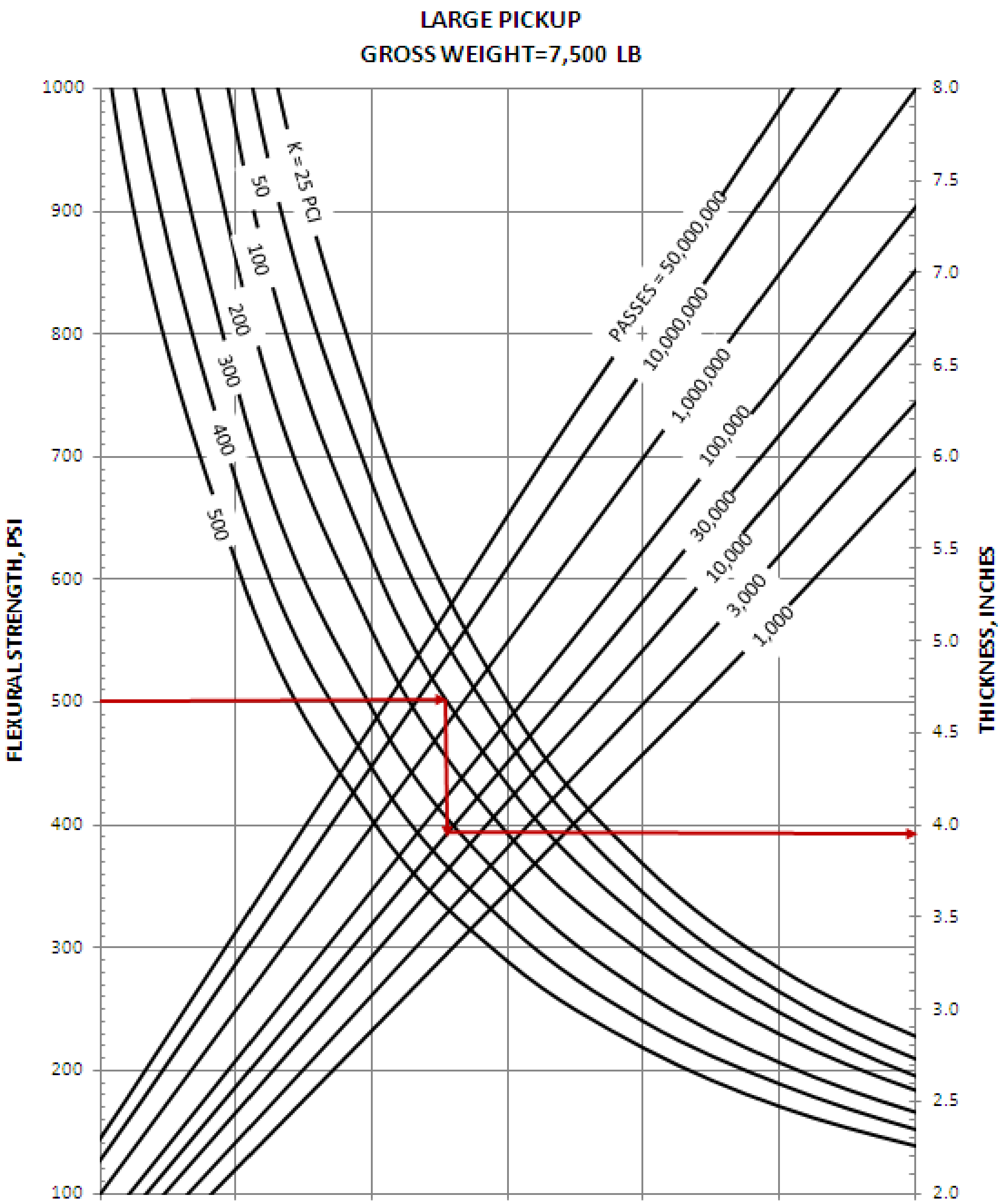


**Figure F-26 Truck 3-Axle
Plain Concrete and RCCP**

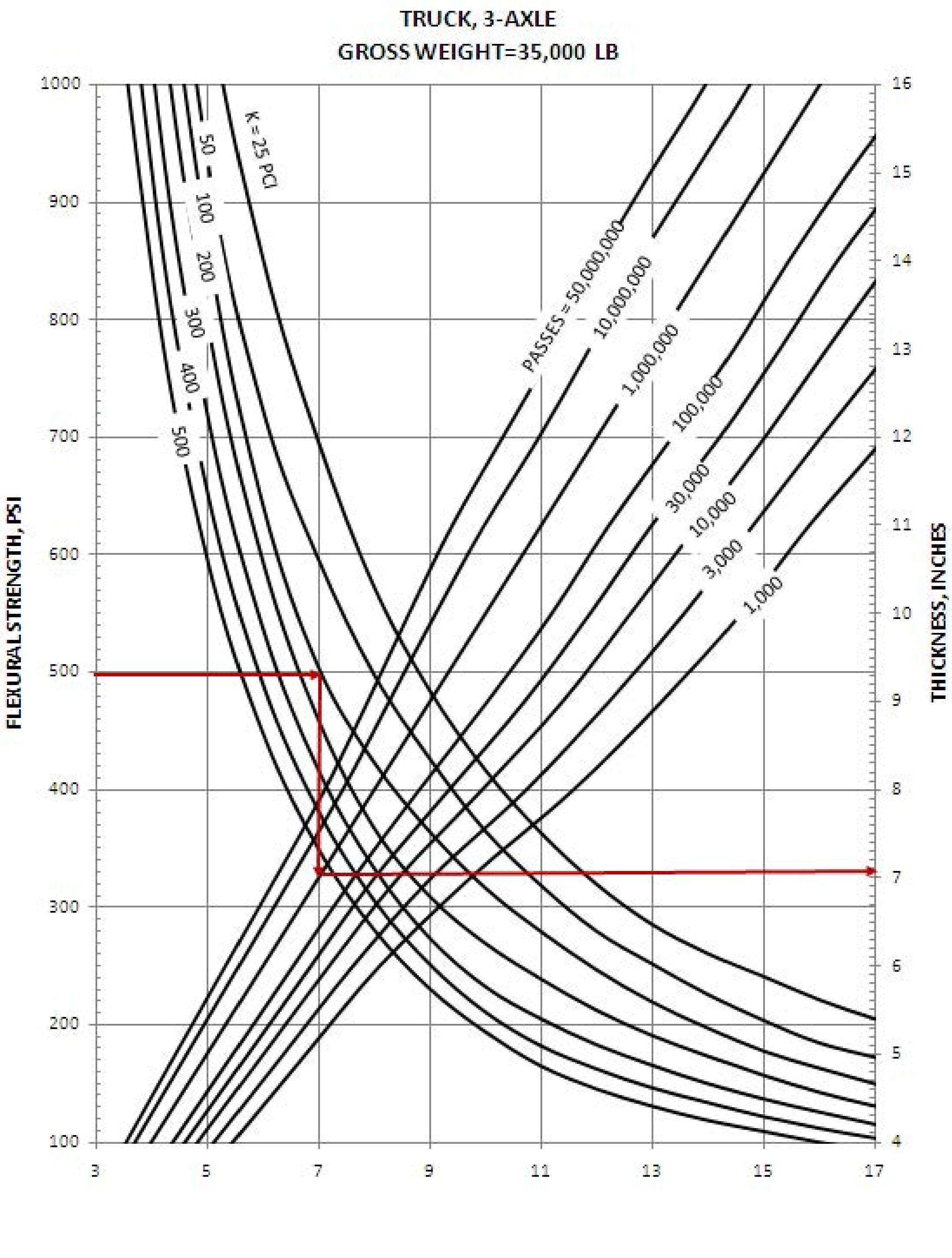


**Figure F-27 Truck 4-Axle
Plain Concrete and RCCP**

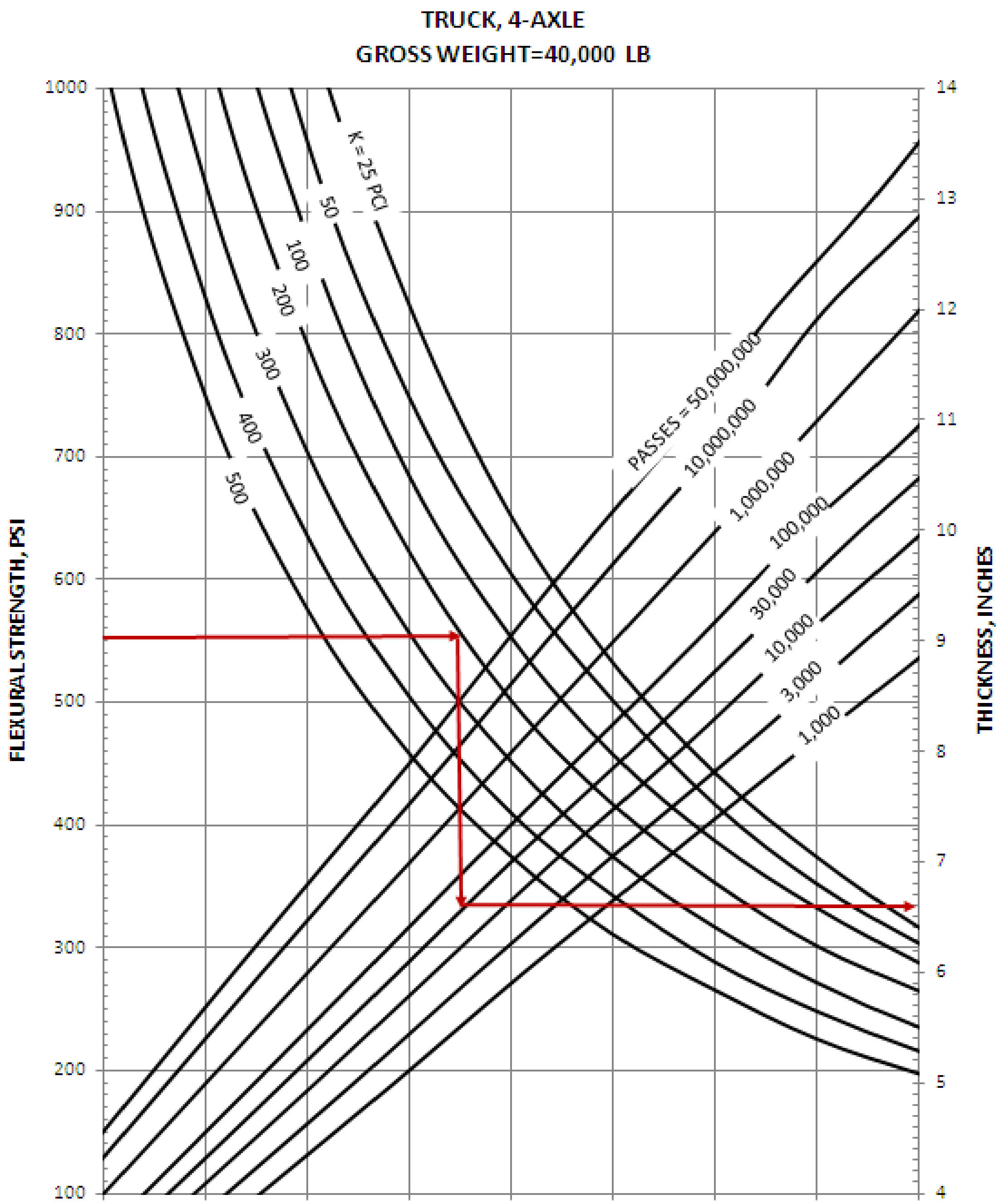


**Figure F-28 Truck 5 –Axle
Plain Concrete and RCCP**

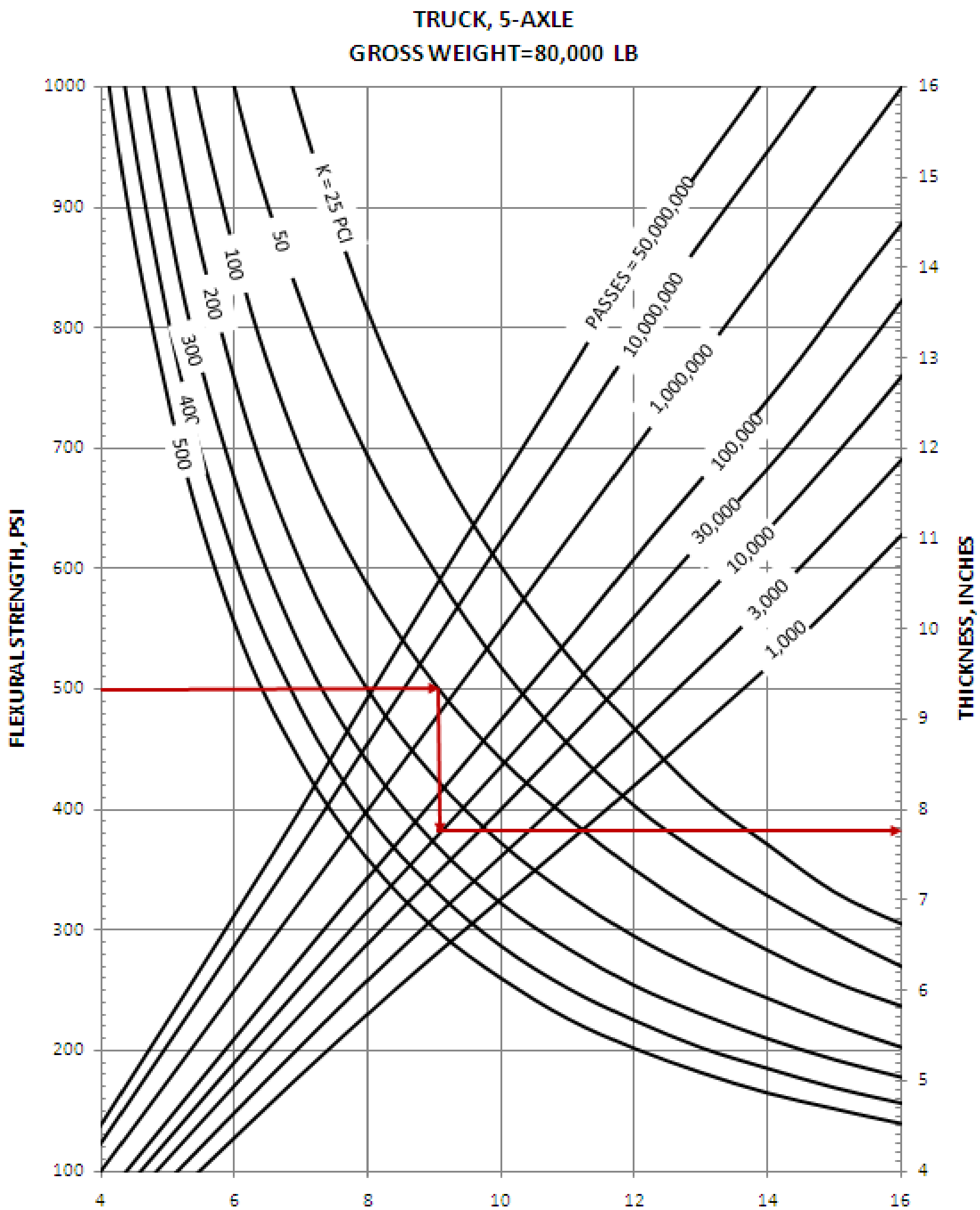


**Figure F-29 Truck 2-Axle, 6-Tire
Plain Concrete and RCCP**

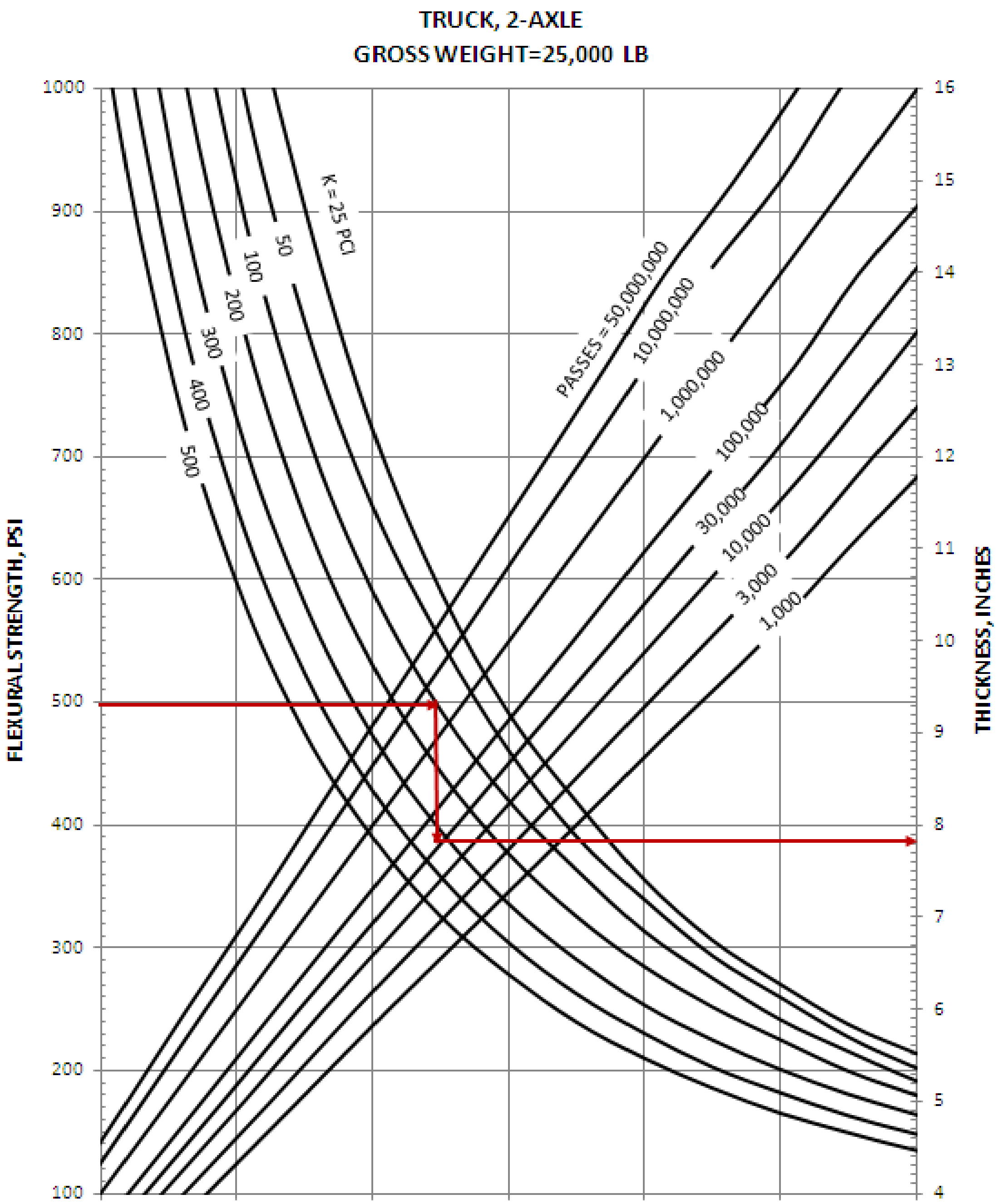


**Figure F-30 TYC-850L Container Truck
Plain Concrete and RCCP**

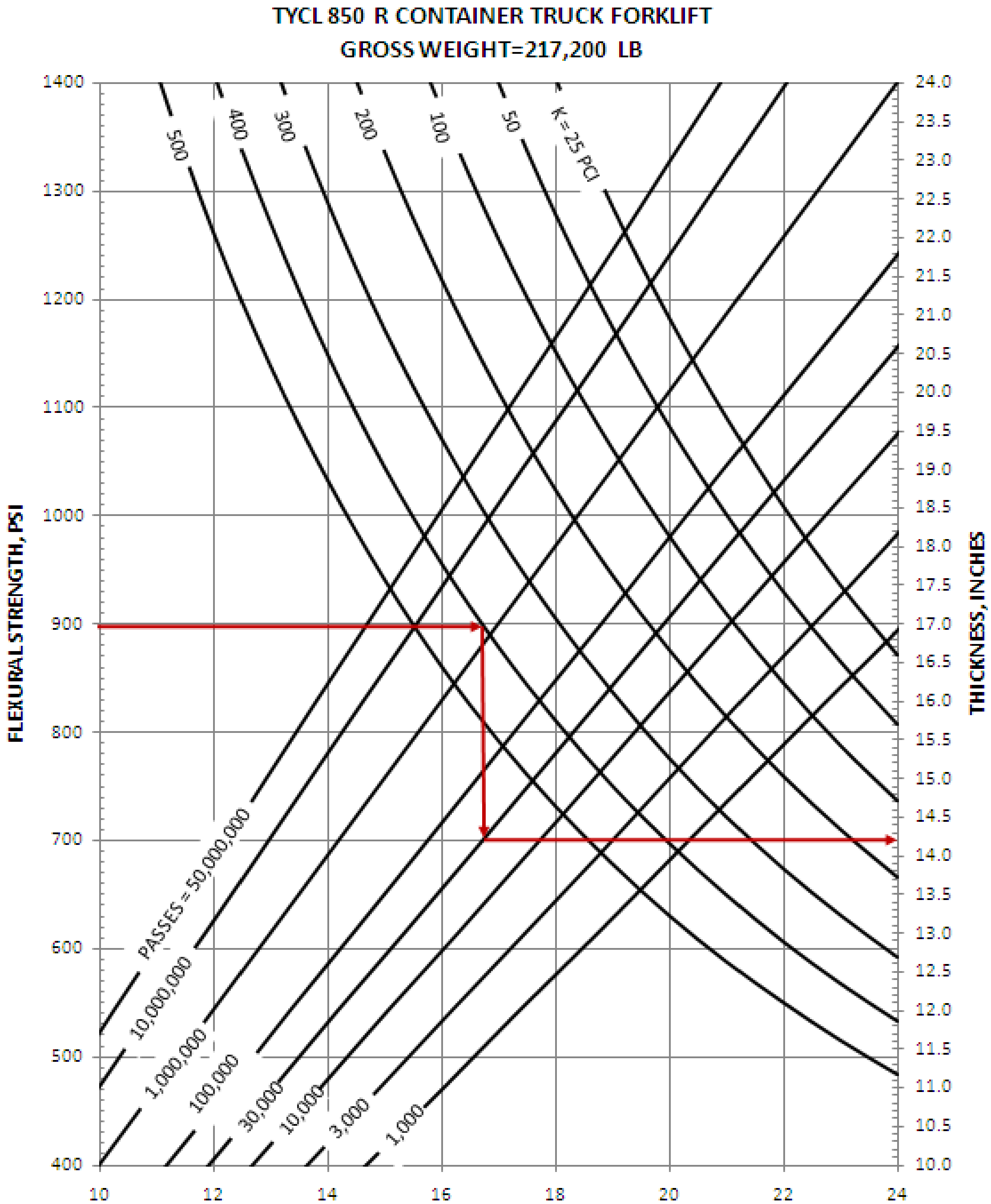
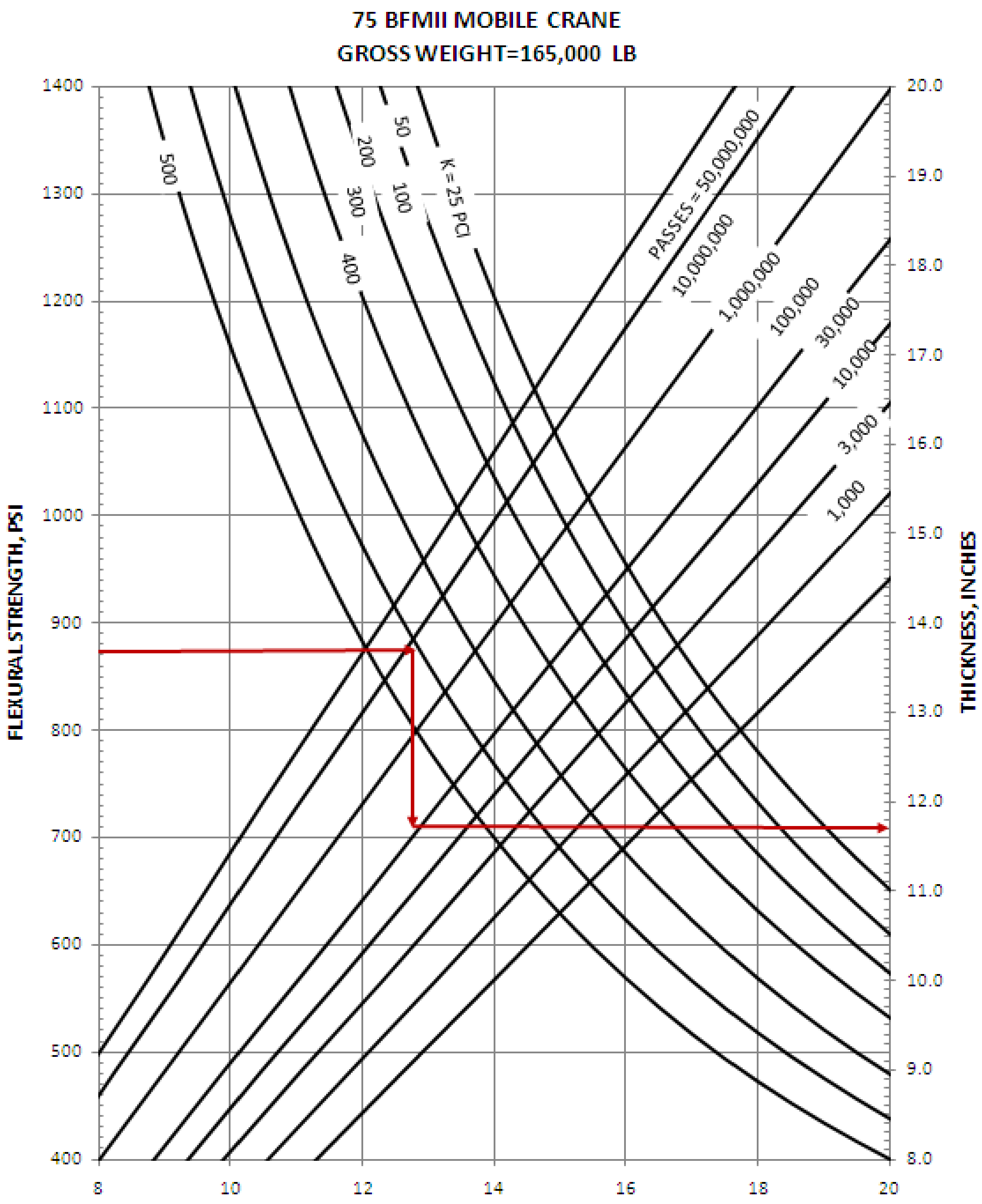


**Figure F-31 75 BFMII Mobile Crane
Plain Concrete and RCCP**



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APPENDIX G EXAMPLES

Solutions of the problems using PCASE software differ slightly from the solutions determined through the use of the pavement design charts. The difference is due to the higher level of numerical accuracy in the PCASE software. When using the pavement design charts, round the thickness up using 0.5 in (10 mm) increments.

G-1 MIXED TRAFFIC CALCULATION.

The mixed traffic calculations described by this example apply only to flexible pavements; a similar procedure can be followed for rigid pavements. The mixed traffic includes a truck with a single axle load of 18,000 lb (8,200 kg), passenger cars, 5-axle trucks, and 3-axle trucks. A design subgrade CBR of 4 was established from field tests. A CBR of 4 corresponds to a subgrade category D, as instructed in Table 4-1. Therefore, only for the purpose of traffic calculations, the representative CBR of 3 should be used. Table G-1 gives the corresponding design vehicle weights and total number of passes for the entire life of the pavement. It is assumed that the required thicknesses of cover material above the subgrade have already been determined from the procedures described in Chapter titled Flexible Pavement Design. Once the subgrade category has been established (Category D with a representative CBR = 3), the first step is to determine the total thickness of cover over the subgrade for each vehicle. This is accomplished by going to the design curves, shown in Appendix E, corresponding to each vehicle in the mix with a CBR = 3 and the assigned number of passes and reading the required thickness in Column 4 of Table G-1. The second step involves selecting the controlling vehicle based on the largest thickness requirement. In this example, the controlling vehicle is the 18-kip axle with a thickness of 16.4 in (420 mm). The third step is to determine the number of allowable passes of the other vehicles in the mix as if they were operating on pavement with a thickness of 16.4 in. This is determined using the same design charts, but working in reverse and reading the passes with the subgrade CBR = 3 and the controlling thickness of 16.4 in (420 mm). The fourth step is to determine the ratio of design passes in terms of the controlling vehicle. This is done by dividing the allowable passes for the thickness section (of the controlling vehicle) by the allowable passes of each vehicle (shown in Column 5). The corresponding fractions shown in Column 6 are then multiplied by the design passes (Column 3) to determine the equivalent passes in terms of the controlling vehicle. From Table G-1, 1,395,400 passes of the 18-kip axle operating at 18,000 lb (8200 kg) is equivalent or will have about the same thickness requirements as the traffic mix shown on Table G-1. From Figure E-1, an 18-kip axle loaded to a gross weight 18,000 lb (8200 kg), 1,395,400 passes and a design subgrade CBR equal to 4 will require a pavement thickness of 14 in (350 mm). It is actually not necessary to select the vehicle with the larger thickness requirements to perform a mixed traffic calculation. For example, the 5-axle truck could have been used as the controlling vehicle, but all the calculations would have to be referenced to the passes of this vehicle. These calculations are shown in Table G-2. This mixed traffic procedure, using the 18,000-lb (8200 kg) equivalent vehicle is used for PCASE to establish minimum pavement thicknesses and compaction requirements.

G-2 COMPACTION REQUIREMENTS.

Two examples illustrating the application of subgrade compaction requirements are as follows:

G-2.1 Example 1: Cohesionless Subgrade.

Assume clean cohesionless sand and a design CBR of 18, with a natural in-place density of 90 percent of maximum density to beyond the depth of exploration of 6 ft (1.8 m). From Table 5-1 for less than 5.7 million equivalent 18,000 lb (8,200 kg) single axle loads, it is found that 100 percent density must extend to a depth of 12 in (300 mm) below the pavement surface. Below this depth, fill sections must be compacted to 95 percent maximum density throughout, and cut sections to 95 percent of maximum density to a depth of 22 in (560 mm) below the pavement surface. The designer must decide from previous experience or from test pavement section data whether or not these percentages of compaction in cut sections can be obtained from the top of the subgrade. If they cannot, a part of the subgrade must be removed, the underlying layer compacted, and the material replaced, or the thickness of select material or subbase must be so increased that the densities in the un-compacted subgrade will be adequate.

Table G-1 Example of Mixed Traffic Calculations for a Flexible Pavement

(1) Vehicle	(2) Gross Weight, lb (kg)	(3) Design Total Passes	(4) Required[1] Thickness in (mm)	(5) Allowable Passes	(6)=1,000,000/(5) Ratio of Passes in Terms of Controlling Vehicle	(7)=(6)*(3) Equivalent Passes of Controlling Vehicle
18,000 lb (8,200 kg) ESAL	18,000 lb (8,200 kg)	1,000,000	16.4 (420)	1,000,000	1.000	1,000,000
Passenger Car	3,000 (1,400)	20,000,000	6.1 (160)	Unlimited	0.000	0
5-Axle Truck	80,000 (27,000)	100,000	15.8 (401)	252,915	3.954	395,400
3-Axle Truck	35,000 (16,000)	500,000	12.8 (325)	Unlimited	0.000	0
Equivalent Passes in Terms of 18-kip ESAL =						1,395,400
[1] Required thickness based on CBR=3 (Subgrade Category D).						

Table G-2 Example of Mixed Traffic Calculations with the 5-axle Truck as Controlling Vehicle

(1) Vehicle	(2) Gross Weight, lb (kg)	(3) Design Total Passes	(4) Required[1] Thickness in (mm)	(5) Allowable Passes	(6)=100,000/(5) Ratio of Passes in Terms of Controlling Vehicle	(7)=(6)*(3) Applied Passes in Terms of Controlling Vehicle
18,000 lb (8,200 kg) ESAL	18,000 (8,200)	1,000,000	16.4 (420)	362,788	0.253	253,000
Passenger Car	3,000 (1,400)	20,000,000	6.1 (160)	Unlimited	0.000	0
5-Axle Truck	80,000 (27,000)	100,000	15.8 (401)	100,000	1.000	100,000
3-Axle Truck	35,000 (16,000)	500,000	12.8 (325)	Unlimited	0.000	0
Equivalent Passes in Terms of 5-Axle Truck =						353,000
[1] Required thickness calculations for mixed traffic are based on CBR = 3 (Subgrade Category D)						

G-2.2 Example 2: Cohesive Subgrade.

Assume a lean clay, a design CBR of 7, and a natural in-place density of 83 percent of maximum density extending below the depth of exploration of 6 ft (1.8 m). Compaction of the subgrade from the surface would be impracticable with ordinary equipment beyond the 6 (150 mm) to 8 in (200 mm) depth that could be processed; therefore, the minimum depth of cut would be limited by the in-place density. From Table 5-1 for 5.7 million equivalent 18,000 lb (8,200 kg) axle loads, it is found that the 83 percent in-place natural density would be satisfactory below depths of about 25 in (625 mm) from the pavement surface. From CBR design curves (explained subsequently), the top of the subgrade will be 14 in (370 mm) below the pavement surface; therefore, a zone 11 in (275 mm) thick below the top of the subgrade requires treatment. The bottom 7 - 8 in (180 - 200 mm) of this can be processed in place; so about 4 in (100 mm) of material must be removed and replaced. Compaction to 95 percent of maximum density is required for all cohesive material that lies within 12 in (300 mm) of the pavement surface. Since the subgrade does not fall within this zone, compaction requirements in the replaced material should be 90 percent to conform to fill requirements, and the layer processed in place should be 85 percent of maximum density to conform to fill requirements.

G-3 THICKNESS DESIGN FOR CONVENTIONAL FLEXIBLE PAVEMENTS.

This example illustrates a design by the CBR method when the subgrade, subbase, or base course materials are not affected by frost. Assume that a design is to be prepared for a road that will support 200,000 passes per year of an equivalent 18,000 lb (8,200 kg) single axle dual-tire load for a period of 25 year (Total Design Passes = 200,000 ×

25 = 5,000,000). Further, assume that compaction requirements will necessitate an increase in subgrade density to a depth of 6 in (150 mm) below the subgrade surface and that a soft layer occurs within the subgrade 24 in (600 mm) below the subgrade surface. The CBR design values of the various subgrade layers and the materials available for subbase and base course construction are as follows:

Material	Soil Classification	Design CBR
Base	GM (limerock)	80
Subbase	GP	25
Compacted subgrade	CL	10
Natural subgrade	CL	7
Weak layer in subgrade	CH	4

The total pavement thickness and thicknesses of the various subbase and base layers are determined according the following procedure.

G-3.1 Total Thickness.

The total thickness of subbase, base, and bituminous surface will be governed by the CBR of the compacted subgrade. From the flexible pavement design curves shown in Figure E-1, the required total thickness above the compacted subgrade (CBR of 10) is 7.8 in (195 mm) to protect from 5,000,000 passes of 18,000 lb (8,200 kg) equivalent single axle. A check must be made of the adequacy of the strength of the natural subgrade and of the weak layer within the subgrade. From the curves in Figure E-1, the required cover for these two layers is 9.8 in and 14.5 in (245 mm and 370 mm), respectively. If the design thickness is 7.8 in (195 mm) and the subgrade is compacted to 6 in (150 mm) below the subgrade surface, the natural subgrade will be covered by a total of 7.8 in (195 mm) + 6 in (150 mm) = 13.8 in (345 mm) of higher strength material. Similarly, the soft layer occurring 24 in (600 mm) below the subgrade surface will be protected by 7.8 in (195 mm) + 24 in (600 mm) = 31.8 in (795 mm) of total cover. Thus, the cover is adequate in both cases.

G-3.2 Minimum Base and Pavement Thicknesses.

As indicated in Table 7-2 for 5,000,000 passes of an 18,000 lb (8,200 kg) equivalent single axle, dual-tire load, the minimum base thickness is 4 in (100 mm) and the pavement thickness is 3.5 in (89 mm).

G-3.3 Thickness of Subbase and Base Courses.

The design thickness of the base and subbase will depend upon the CBR design value of each material. The total thickness of subbase, base, and pavement, as determined above, is 7.8 in (195 mm). The thickness required above the subbase (CBR = 25), as determined from Figure E-1, is 3.4 in (83 mm); therefore, the required thickness of subbase is 7.8 in (195 mm) – 3.4 in (83 mm) = 4.4 in (112 mm). The 3.4 in (83 mm) layer required above the subbase will be composed of a base course and pavement; however, adjustments must be made in the thicknesses of the base and the pavement to comply with minimum thickness requirements, which is a combined thickness of pavement and base of 7.5 in (183) = 3.5 in (83 mm) of asphalt surface and 4 in (100 mm) of base. Therefore, the final design will consist of a 4 in (100 mm) subbase course, a 4 in (100 mm) base course, and a 3.5 in (83 mm) pavement.

G-4 THICKNESS DESIGN FOR STABILIZED SOIL LAYERS.

To use the equivalency factors requires that a conventional flexible pavement be designed to support the design load conditions. If it is desired to use a stabilized base or subbase course, the thickness of conventional base or subbase is divided by the equivalency factor for the applicable stabilized soil.

G-4.1 Example 1.

Assume a conventional flexible pavement has been designed which requires a total thickness of 16 in (410 mm) above the subgrade. The minimum thickness of AC and base is 2 and 4 in (50 and 100 mm), respectively, and the thickness of subbase is 10 in (250 mm). It is desired to replace the base and subbase with a cement-stabilized gravelly soil (GP) having an unconfined compressive strength of 890 psi (6.1 MPa). The material qualifies for application as base course since its strength is greater than 750 psi (5.2 MPa), as required by the UFC 3-250-11. From Table 9-1 the equivalency factor for a base is 1.15. Therefore, 4 in ÷ 1.15 = 3.5 in (100 mm ÷ 1.15 = 87 mm) of stabilized base course. Since the minimum required thickness is 4 in (100 mm), the excess of stabilized base course of 4 in – 3.5 in = 0.5 in (100 mm – 87 mm = 13 mm) is computed as equivalent thickness of non-stabilized subbase material, which is equal to 0.5 in. * 2.3 = 1.1 in (13 mm * 2.3 = 30 mm). This equivalent subbase thickness is accounted in the stabilized base; therefore the needed non-stabilized subbase is thinner than 10 in (250 mm) and equal to 10 in – 1.1 in = 8.9 in (250 mm - 30 mm = 220 mm). The next step includes the calculation of the equivalent thickness of subbase stabilized material, as 8.9 in ÷ 2.3 = 3.86 in (220 mm ÷ 2.3 = 96 mm). The required minimum thickness for stabilize subbase is 4 in (100 mm). Therefore, the total thickness of the cement-stabilized pavement is 2 in (50 mm) of AC, 4 (100 mm) in of cement-stabilized gravelly soil base, and 4 in (100 mm) of cement-stabilized gravelly soil subbase.

G-4.2 Example 2.

Assume a conventional flexible pavement has been designed which requires 3.5 in (89 mm) of AC surface, 4 in (100 mm) of crushed stone base, and 18 in (460 mm) of subbase. It is desired to construct bituminous pavement. The equivalency factor from Table 9-1 for a base course is 1.15 and for a subbase 2.30. The thickness of AC required to replace the base is 4 in. ÷ 1.15 = 3.5 in (100 mm ÷ 1.15 = 87 mm). Since the minimum required thickness is 4 in, the excess of stabilized base course of 4 in – 3.5 in = 0.5 in (100 mm – 87 mm = 13 mm) is computed as equivalent thickness of non-stabilized subbase material, which is equal to 0.5 in. * 2.3 = 1.1 in (13 mm * 2.3 = 30 mm). This equivalent subbase thickness is accounted in the stabilized base; therefore the needed non-stabilized subbase is thinner than 18 in (460 mm) and equal to 18 in – 1.1 in = 16.9 in) (460 mm – 30 mm = 440 mm) The next step computes the equivalent thickness of subbase stabilized material, as 16.9 in. ÷ 2.3 = 7.3 in (440 mm ÷ 2.3 = 190 mm). The total thickness of the ABC pavement is 3.5 in + 4 in + 7.3 in = 14.8 in~ 15 in (87 + 100 + 190 = 377 mm ~ 380 mm)

G-5 THICKNESS DESIGN FOR RIGID PAVEMENTS.

G-5.1 Example 1: Non-Stabilized.

A road is to be designed on a non-stabilized foundation for the following traffic and subgrade conditions:

Traffic:

Passenger Cars, 3,000 lb (1,400 kg) 2,400 passes/day

3-Axle Truck, 35,000 lb (16,000 kg) 120 passes/day

5-Axle Truck, 80,000 lb (27,000 kg) 80 passes/day

M1A2 Tank, 139,000 lb (63,000 kg) 16 passes/day

Subgrade:

k-value = 100 psi/in (27 kPa/mm)

Concrete:

28-day Flexural strength = 750 psi (5.2 MPa)

Modulus of Elasticity = 4,000,000 psi (27,600 MPa)

Design Life: 25 years

For these design conditions and using the mixed traffic procedures described in Chapter titled Vehicular Traffic with a subgrade category C (k-value equal to 147 psi/in (40 kPa/mm)), the equivalent passes in terms of the M1A2 tank are computed and are shown in Table G-3. From Figure F-5, 147,295 passes of an M1A2 tank results in a required thickness of 7.8 in (198 mm). Rounding up in 0.5 in (10 mm) increments to a final thickness will be 8 in (200 mm).

G-5.2 Example 2: Stabilized Soil.

A rigid pavement, functioning as road is to be designed over a 6 in (150 mm) stabilized soil having an E_f = 650,000 psi (4,500 MPa) for the following traffic and subgrade conditions:

Traffic:

M1A2 Tank, 139,000 lb (63,000 kg) 40 passes/day

M2A3 Tank, 58,200 lb (26,400 kg) 16 passes/day

M923 5-Ton, 32,500 lb (14,700 kg) 80 passes/day

M978 HEMMT, 59,000 lb (26,800 kg) 80 passes/day

M998 HMMWV, 7,900 lb (3,600 kg) 160 passes/day

Subgrade:

k-value = 100 psi/in (27 kPa/mm)

Concrete:

28-day Flexural strength = 750 psi (5.2 MPa)

Modulus of Elasticity = 4,000,000 psi (27,600 MPa)

Design Life: 25 years

Table G-3 Mixed Traffic with M1A2 Tank, 63,049 kg (139,000 lb) as Controlling Vehicle Non-Stabilized Foundation

(1) Vehicle	(2) Gross Weight, lb (kg)	(3) Design Total Passes	(4) Required[1] Thickness in (mm)	(5) Allowable Passes	(6)=146000/(5) Ratio of Passes in Terms of Controlling Vehicle	(7)=(6)*(3) Equivalent Passes of Controlling Vehicle
Passenger Car	3,000 (1,400)	21,900,000	2.6 (66)	Unlimited	0.000	0
3-Axle Truck	35,000 (16,000)	1,095,000	5.5 (140)	Unlimited	0.000	0
5-Axle Truck	80,000 (27,000)	730,000	6.5 (165)	8,230,570	0.001	1,295
M1A2 Tank	139,000 (63,000)	146,000	7.2 (183)	146,000	1.000	146,000
						147,295

[1] Required thickness based on k-value = 147 psi/in (40 kPa/mm) (Subgrade Category C).

For the design conditions stated, using the mixed traffic calculations shown in Table G-4, and disregarding the presence of the stabilized layer (which will be considered at a second step), this pavement is to be designed for 365,444 passes of an M1A2. From the design chart in Figure F-5, the required thickness would be 8.3 in (210 mm). For this example, if the plain concrete is to be placed on 6 in (150 mm) of cement stabilized soil having an E_f = 650,000 psi, then the thickness of plain concrete required would be as follows: using equation 13-1,

$$h_o = \sqrt[1.4]{h_d^{1.4} - \left(0.0063 \times \sqrt[3]{E_f}\ h_s\right)^{1.4}}$$

$$h_0 = \sqrt[1.4]{8.3^{1.4} - (0.0063\sqrt[3]{650000} * 6)^{1.4}}$$

This calculation results in a thickness h_o = 6.6 in., therefore use 7 in (180 mm) for design.

Table G-4 Mixed Traffic with M1A2, 63,049 kg (139,000 lb) as Controlling Vehicle Stabilized Foundation

(1) Vehicle	(2) Gross Weight, lb (kg)	(3) Design Total Passes	(4) Required[1] Thickness in (mm)	(5) Allowable Passes	(6)=365000/(5) Ratio of Passes in Terms of Controlling Vehicle	(7)=(6)*(3) Equivalent Passes of Controlling Vehicle
M1A2 Tank	139,000 (63,000)	365,000	7.6 (190)	365,000	1.000	365000
M2A3 Tank	58,200 (26,400)	146,000	5.7 (150)	Unlimited	0.00	0
M923 5-ton	32,500 (14,700)	730,000	4.3 (110)	Unlimited	0.00	0
M978 HEMMT	59,000 (26,800)	730,000	6.6 (170)	6×10^8	0.0006	444
M998 HMMWV	7,900 (3,600)	1,460,000	3.4 (86)	Unlimited	0.00	0
						365,444
[1] Required thickness based on k-value = 147 psi/in (40 kPa/mm) (Subgrade Category C).						

G-6 REINFORCED CONCRETE PAVEMENTS.

A design example for a reinforced concrete pavement requires a plan concrete thickness of 7.9 in (200 mm) for given traffic and subgrade conditions. The percentage of longitudinal reinforcing steel ***S*** required to reduce the pavement thickness to 7 in (180) mm) is obtained from Figure 14-1 as 0.10 percent. Similarly, the percentage of longitudinal reinforcing steel required to reduce the pavement thickness to 6 in (150 mm) is 0.30 percent. From paragraph titled Thickness Design On Unbound Base Or Subbase, the percentage of transverse reinforcing steel would be either 0.05 for a design thickness of 7 in or 0.15 for a design thickness of 6 in. The choice of which percentage of steel reinforcement to use should be based on economic factors, foundation, and climatic conditions peculiar to the project area. If the yield strength of the steel is assumed to be 60,000 psi (410 MPa), the maximum allowable spacing of the transverse contraction joints would be 49 ft (15 m) for 0.10 percent longitudinal steel, and 97 ft (30 m) as the maximum spacing for 0.30 percent longitudinal steel. In the latter case, the maximum permissible spacing of 75 ft (25 m) would be used.

G-7 OVERLAY DESIGN.

Design an overlay for an existing road having a plain concrete thickness of 6 in (150 mm), a flexural strength of 650 psi (4.5 MPa), a subgrade **k** value of 100 pci (27 kPa/mm), and a projected design traffic of 20 million of an 18,000 lb (8,200 kg) ESAL. The concrete overlay will also have a flexural strength of 650 psi. The factor for projecting cracking in a flexible overlay is 0.93 from Figure 15-1. The existing pavement is in good condition with little or no structural cracking. The condition factor C is therefore equal to 1.0 for concrete and flexible overlay. From Figure F-1, h_d is 8.1 in

(206 mm.). Overlay thickness requirements for the various types of overlays are as follows:

G-7.1 Bonded Overlay

$h_o = h_d - h_E$

h_o = 8.1 – 6 in (206 - 150 mm)

h_o = 2.1 in (56 mm); round up in 0.5 in (10 mm) increments to 2.5 in. (60 mm)

G-7.2 Partially Bonded Overlay

$$h_o = \sqrt[1.4]{h_d^{1.4} - C\left(\frac{h_d}{h_e} \times h_E\right)^{1.4}}$$

$$h_o = \sqrt[1.4]{8.1^{1.4} - 1.0\left(\frac{8.1}{8.1} \times 6.0\right)^{1.4}}$$

h_o = 3.7 in. (94 mm); round up in 0.5 in (10 mm) increments to 4 in. (100 mm)

G-7.3 Un-bonded Overlay

$$h_o = \sqrt{h_d^2 - C\left(\frac{h_d}{h_e} \times h_E\right)^2}$$

$$h_o = \sqrt{8.1^2 - 1.0\left(\frac{8.1}{8.1} \times 6.0\right)^2}$$

h_o = 5.4 in. (137 mm); round up in 0.5 in (10 mm) increments to 5.5 in. (140 mm)

G-7.4 Flexible Overlay

$$t_o = 3 \times (F \times h_d - C \times h_E)$$

t_o = 3.0 (0.93 × 8.1- 1.0 × 6)

t_o = 4.6 in (117 mm); round up in 0.5 in (10 mm) increments to 5.0 in. (120 mm)

G-8 DESIGN FOR SEASONAL FROST CONDITIONS.

Design a flexible and a rigid pavement for the following conditions:

G-8.1 Site and Traffic Characteristics.

Class B (rolling terrain within the "built-up area").

Category III.

Design Traffic. 1,200,000 18-kip ESAL.

Design Freezing Index. 700 degrees Fahrenheit-days.

G-8.2 Subgrade Material.

Uniform sandy clay, CL

Plasticity index, 18

Frost group, F3

Water content, 20 percent (average) Normal-period CBR, 10

Normal-period modulus of subgrade reaction

k = 200 psi/in (54 kPa/mm) on subgrade and 325 psi/in (88 kPa/mm) on 22 in 560 mm) of base course.

G-8.3 Base Course Material.

Crushed gravel (GW), normal-period CBR = 80, 30 percent passing No. 10 sieve, 1 percent passing No. 200 sieve, and water content = 5%.

G-8.4 Subbase Course Material.

Coarse to fine silty sand (SP-SM), normal period CBR=20, 11 percent passing No. 200 sieve, 6 percent finer than 0.02 mm, frost classification 52, meets filter criteria for material in contact with subgrade.

G-8.5 Average Dry Unit Weight

(good quality base and subbase, 135 pounds per cubic feet (2160 kg/m^3))

G-8.6 Average Water Content after Drainage

(good quality base and subbase, 5 percent)

G-8.7 Highest Groundwater.

About 4 ft (1.2 m) below surface of subgrade.

G-8.8 Concrete Flexural Strength.

4.5 MPa (650 psi).

G-8.9 Flexible Pavement Design by Limited Subgrade Frost Penetration Method.

From Figure 19-4, the combined thickness ***a*** of pavement and base to prevent freezing of the subgrade in the design freezing index year is 45 in (1140 mm). According to criteria in Table 7-2, the minimum pavement thickness is 3.0 in (75 mm) over a CBR = 80 base course that must be at least 4 in (100 mm) thick. The base thickness for zero frost penetration is 45 - 3.0 = 42 in (1140 – 75 = 1065 mm). The ratio of subgrade to base water content is r = 20/5 =4. Since this is a highway pavement, the maximum allowable ***r*** of 3 is used in Figure 19-5 to obtain the required thickness of base b of 26 in (660 mm), which would allow about 6 in (150 mm) of frost penetration into the subgrade in the design year. Subgrade preparation would not be required since the combined thickness of pavement and base is more than one-half the thickness required for complete protection.

G-8.10 Flexible Pavement Design by Reduced Subgrade Strength Method.

From the REDUCED SUBGRADE STRENGTH section, paragraph titled Reduced Subgrade Strength, the frost-area soil support index is 3.5, which, from the design curve (Figure E-1) yields a required combined thickness of pavement and base of 16 in (410 mm). Since this is less than the limited subgrade frost penetration method required thickness of 29 in (740 mm), of which 3 in (75 mm) is the required AC layer and 26 in (665 mm.) is granular material,, the 16 in thickness would be used. The pavement structure could be composed of 3 in of AC, 6 in (150 mm) of crushed gravel (since the crushed gravel contains only 1 percent passing the No. 200 sieve, it also serves as the free-draining layer directly beneath the pavement), and 7 in (180 mm) of silty sand subbase material. Subgrade preparation would be required to a depth of 26 – 16 = 10 in (665 – 410 = 255 mm).

G-8.11 Rigid Pavement Design by Limited Subgrade Frost Penetration Method.

From Figure F-1, the required concrete slab thickness p, based on the normal period k = 325 psi per inch (88 kPa/mm), the concrete flexural strength of 650 psi (4.5 MPa) and 1,200,000 ESAL, is 6.3 in (use 6.5 in (165 mm)). From Figure 19-4, the combined thickness of pavement and base for zero frost penetration is 45 in (1140 mm), equivalent to that for the flexible pavement. By use of r = 3 and a thickness of base for zero frost penetration of 45 – 6.5 = 38.5 in (1140 – 165 = 975 mm) in Figure 19-5, the required thickness of base b is 22 in (560 mm), which would allow about 5.5 in (140 mm.) of frost penetration into the subgrade in the design year. No subgrade preparation would be required.

G-8.12 Rigid Pavement Design by the Reduced Subgrade Strength Method.

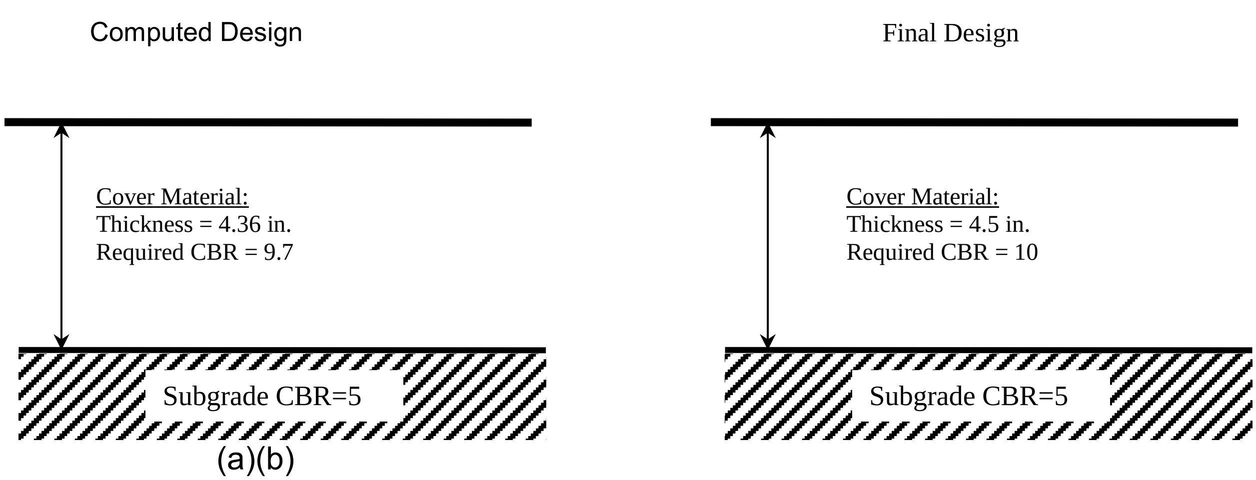
Since frost heave has not been a major problem, a minimum of 4 in (100 mm) of the free-draining base course material could be used, plus 4 in of the subbase that will serve as a filter material on the subgrade. For this case (8 in (200 mm) of base and subbase, from Figure F-1), the frost-area index of reaction would be 50 psi per inch (13.6 kPa/mm)) (Figure 19-6), requiring a pavement slab 8 in thick. As indicated in paragraph titled Subgrade Requirements, the depth of subgrade preparation must be 24 in (600 mm) or two-thirds of the frost penetration less the actual combined thickness of pavement, base course, and subbase course, whichever is less. Therefore, in this case, the required depth of subgrade preparation is 24 in (600mm) – 16 in (400 mm) = 8 in (200 mm).

G-9 DESIGN OF AGGREGATE SURFACED ROADS.

G-9.1 Example 1: Non-Frost Design.

An aggregate surfaced road is to be designed for 20,000 passes of a M923, 5-ton cargo truck 32,500 lb (14700 kg). The subgrade is cohesive material with a CBR equal to 5. Frost is not a consideration. Inputting these data into the PCASE design module results in the thickness and required CBR of cover material as shown in Figure G-1. The solution indicates that the cover material is to be built to a thickness of 4.36 in (111 mm.) and with a required CBR of 10 and it must meet the gradation and compaction requirements as dictated in Tables 21-1 and 21-2. The granular material should conform to the material requirements for NFS areas previously discussed.

Figure G-1 Results for Example 1-Non-frost design, M923, 5-Ton Cargo Truck (mm = 25.4 x inches)



G-9.2 Example 2: Frost Design.

An aggregate surfaced road is to be designed for 10,000 passes of a M977, 10-ton cargo truck 62,000 lb (28,100 kg) (or about 29.8 million ESAL). The subgrade is frost susceptible cohesive material classified as F3 with a natural CBR equal to 6. As specified in paragraph titled Frost Area Considerations, for areas where frost effects are expected, it is recommended that the pavement structure be built of a series of layers to ensure the stability of the pavement system. It is also recommended that the system be designed based on the reduced subgrade strength method using the frost area soil support indices FASSI values listed in Table 19-3 (for F3 soil FASSI is equal to 3.5). Therefore for construction purposes, the pavement structure will consist of:

- A wearing surface of fine-graded crushed rock

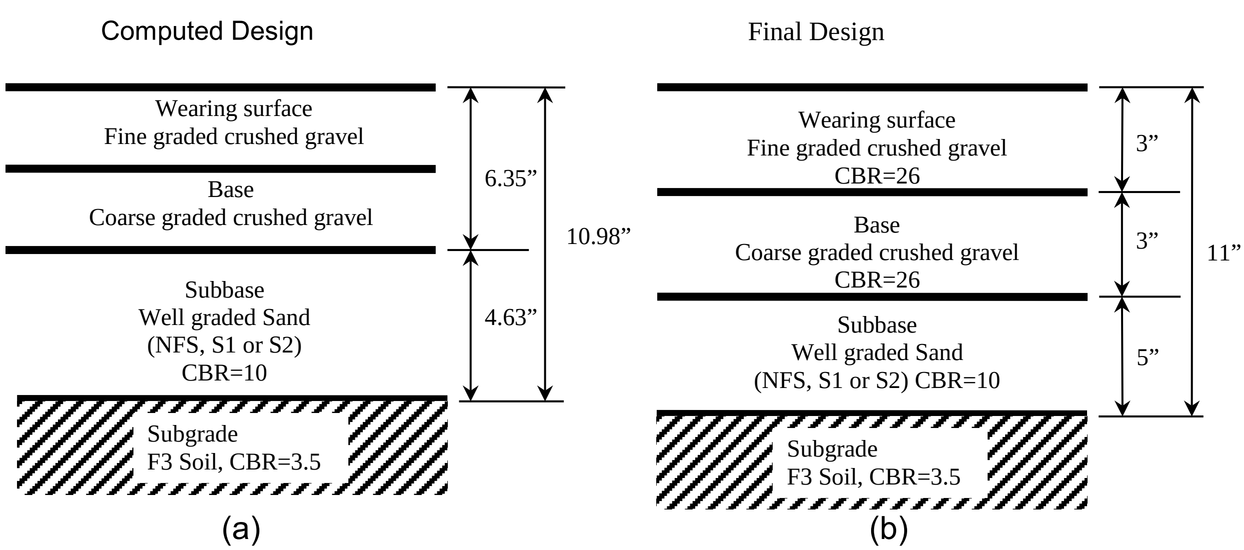
- A base course of coarse-graded crushed rock

- A subbase of well-graded sand (Frost group F1 and S2) with a CBR = 10

The wearing surface and the base course materials will be crushed aggregate with the same CBR value, then in PCASE these two layers can be treated as a unique layer.

The total required thickness of cover material above the subgrade, using a FASSI value of 3.5, is 10.98 in (279 mm) with a CBR of 21 for the top layers. The required thickness above the subbase (CBR equal to 10) is 6.35 in (161 mm); therefore the layers with CBR equal to 21 require a total thickness of 6.35 in. The subbase thickness is determined by subtracting the thickness required over the 10 CBR from total thickness required over the 3.5 CBR. The resulting subbase thickness is 4.63 in (116 mm). The layer thicknesses results are shown in Figure G-2. As mentioned, the top layer can be divided into two layers constituted of material with the same CBR but different characteristics. The resulting pavement structure may be proportioned by using the minimum of 3 in (75 mm) for wearing, base course, and sand subbase as shown in Figure G-2 (b). Again, each pavement layer must meet the gradation and compaction requirements dictated in Tables 21-1 and 21-2.

Figure G-2 Results for Example 2-Frost design, M977, HEMTT, 10-TON Cargo Truck (1 mm = 25.4 x inches)



APPENDIX H DETERMINATION OF FLEXURAL STRENGTH AND MODULUS OF ELASTICITY

H-1 FLEXURAL STRENGTH TEST PROCEDURE.

Use ASTM C78/78M to compute flexural strength.

H-1.1 CALCULATIONS.

H-1.1.1 Modulus of Rupture

Use modulus of rupture equation from ASTM C78/78M.

H-1.2 REPORT.

Provide a test report. Include report items in ASTM C78/78M.

H-2 MODULUS OF ELASTICITY TEST PROCEDURE

Soil stabilization is a method of improving soil properties by blending and mixing other materials. The modulus value for stabilized soils is determined according to the procedures in AASHTO MEPDG.

UFC 3-250-03
30 May 2018

UNIFIED FACILITIES CRITERIA (UFC)

O&M MANUAL: STANDARD PRACTICE FOR FLEXIBLE PAVEMENTS

UNIFIED FACILITIES CRITERIA (UFC)

O&M MANUAL: STANDARD PRACTICE FOR FLEXIBLE PAVEMENTS

U.S. ARMY CORPS OF ENGINEERS (Preparing Activity)

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER CENTER

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

Change No.	Date	Location

This UFC supersedes UFC 3-250-03, dated 15 May 2001, Air Force ETL 01-7, dated 5 June 2017, and Air Force ETL 01-9, dated 17 July 2001.

FOREWORD

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

UFC are living documents and is periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale should be sent to the respective service proponent office by the following electronic form: Criteria Change Request (CCR). The form is also accessible from the Internet sites listed below.

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

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

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

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UNIFIED FACILITIES CRITERIA (UFC)
REVISION SUMMARY SHEET

Document: UFC 3-250-03, *O&M Manual: Standard Practice For Flexible Pavements*

Superseding: UFC 3-250-03, *Standard Practice Manual for Flexible Pavements,* 15 May 2001; AF ETL 01-7, *Large Aggregate Asphalt Mixtures, 5 Jun 2017*; and AF ETL 01-9, *Procedures to Retard Reflective Cracking, 17 Jun 2001.*

Description: This UFC provides guidance for the preparation of drawings and specifications for road and airfield flexible pavements using asphalt cement materials. It also provides useful information for design engineers, laboratory personnel, and project managers concerning mix design, materials, production, and placement of the various asphalt mixtures.

Reasons for Document: This UFC provides engineers with current changes in technology to outline materials, equipment, techniques, and cautions required to produce a cost-effective and durable flexible asphalt pavement. Additionally, a number of editorial changes were needed to improve readability. Figures and tables were also improved.

Impact: Cost impact is negligible; improved guidance results in improved performance and reduced life cycle cost.

Unification Issues: None

TABLE OF CONTENTS

FIGURES

TABLES

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CHAPTER 1 INTRODUCTION

1-1 PURPOSE.

This UFC provides guidance for the preparation of drawings and specifications for road and airfield flexible pavements using asphalt cement materials. The term "asphalt" is used herein instead of bitumen or bituminous (a generic term for both asphalt and tar materials) because asphalt is the material typically used in pavement construction. In the past, tar or coal tar was used only in instances where fuel resistance was required. Due to problems with emissions, tar is no longer used in flexible pavement construction except occasionally as a sealer. This UFC also provides useful information for design engineers, laboratory personnel, and project managers concerning mix design, materials, production, and placement of the various asphalt mixtures.

1-2 SCOPE.

This UFC prescribes materials, mix design procedures, and construction practices for flexible pavements.

1-3 REFERENCES.

Appendix A contains a list of references cited within this UFC.

1-4 UNITS OF MEASURE.

The primary system of measurement used in this UFC is the International System of Units (SI). In some cases, inch-pound (IP) measurements are the governing critical values because of applicable codes, accepted standards, industry practices, or other considerations where the IP measurements govern. The IP value is shown in parentheses following a comparable SI value.

1-5 SPECIAL TERMS.

Special terms used in this UFC are explained in Appendix C.

1-6 BACKGROUND.

Asphalt mixtures (hot-, cold-, and warm-mix asphalt and other asphalt surfaces) provide a resilient, relatively waterproof, load-distributing medium that protects the base course and underlying pavement structure from the harmful effects of water and abrasion from traffic. Asphalt pavements wear, weather, and deteriorate from aging; therefore, maintenance of these pavements extends pavement life. The flexibility of asphalt mixtures allows a pavement structure to adjust slightly to consolidation of underlying layers or deflection due to load without affecting pavement performance. Flexible pavements also allow stage construction and use a range of construction materials, often leading to substantial savings through the use of locally available materials. Additional pavement courses are placed on existing pavements to provide additional structural strength as total loads increase or as traffic intensity increases. Design and construct the economical pavement that satisfy the objective of long pavement life.

1-7 SAFETY CONSIDERATIONS.

Department of Defense's (DoD) objective is to construct pavements that provides traffic safety. A non-skid surface is essential, and grade control is required to provide rapid removal of surface water to minimize the potential for hydroplaning. All pavement surfaces normally exhibit a sufficiently coarse texture to provide skid resistance. Avoid aggregate types known to have a history of polishing because they are probably the greatest cause of low skid resistance, prevalent in surface treatments and seal coats. Avoid aggregates having friable particles, as these tend to break down and form foreign object debris (FOD). Construction techniques are important for surface treatments and seal coats to ensure good bond between the asphalt and aggregate, providing aggregate retention. Pavement surfacing such as sealers that do not include aggregate are not applied in areas of high-speed traffic.

CHAPTER 2 HOT-MIX ASPHALT

2-1 INTRODUCTION.

Hot-mix asphalt (HMA) is often used for high-performance pavements. Select the degree of performance required based on traffic conditions and the availability of materials. HMA mixtures consist of mineral aggregate and asphalt cement. These HMA mixtures are meet the design requirements for airfield pavements, roads and streets, and storage areas. In general, from 4 to 6.5 percent asphalt cement content is required for asphalt base, intermediate courses, and surface courses and 5 to 7 percent asphalt cement content for porous friction course (PFC) and stone matrix asphalt (SMA); however, determine the optimum asphalt content according to mix design procedures. The term “hot-mix asphalt” refers to any hot asphalt mixture produced in a hot-mix plant; however, unless referred to directly by a specific name, it refers to dense-graded HMA with aggregate gradations shown in Table 2-1. Much of the information discussed in this section is found in report AATP 05-01 developed by Auburn University.

2-1.1 Advantages.

The hot-mix method of preparing paving mixtures provides for thorough coating of the aggregates with a uniform film of asphalt cement and accurate control of aggregate sizes and quantity of asphalt cement. Hot-mix pavements require no curing period after being laid and are used as soon as the pavement has cooled. Roll the paving mixture to compact the mix while it is sufficiently hot because rolling is ineffective after the mixture has cooled, making the mix design density unachievable. Hot-mix asphalt pavements are constructed rapidly minimizing the probability of damage to the HMA due to weather conditions that occur immediately after construction is completed. Immediately after adequate rolling and a cooling period, the pavement has a high degree of stability from the interlocking of the coarse and fine aggregate and adhesion of the asphalt cement, as well as a high resistance to moisture penetration and frost damage.

2-1.2 Gradations and Layer Thickness.

Selection of a gradation from Table 2-1 is based on the layer thickness of the HMA to be placed and the need to limit aggregate segregation. Segregation occurs more quickly in mixes with coarser aggregates; therefore, do not use aggregate gradation No. 1 on the surface. Ensure the layer thickness for gradation No.1 is at least 57 millimeters (2.25 inches), the layer thickness for gradation No. 2 is at least 37.5 millimeters (1.5 inches), and the layer thickness for gradation No. 3 is at least 28.5 millimeters (1.1 inches). Use 25-millimeter- (1 inch) thick layers of HMA only in unusual situations, such as level courses, since these thin layers tend to cool quickly and are difficult to place and compact properly. The preferred thickness of the surface layer for an airfield pavement is 51 millimeters (2 inches). Design and/or construct underlying layers with a thickness no greater than 76 millimeters (3 inches). The thickness of underlying layers is determined by the total designed thickness of the asphalt mixture. Surface layers for airfields are not less than 37.5 millimeters (1.5 inches) thick.

Table 2-1 Aggregate Gradations for HMA Pavements

Sieve Size, mm	Gradation 1 19 mm Nominal Max Agg Size by Mass	Gradation 2 12.5 mm Nominal Max Agg Size by Mass	Gradation 3 9.5 mm Nominal Max Agg Size by Mass
25.0	100	–	–
19.0	90-100	100	–
12.5	68–88	90-100	100
9.5	60–82	69–89	90-100
4.75	45–67	53–73	58–78
2.36	32–54	38–60	40–60
1.18	22–44	26–48	28–48
0.60	15–35	18–38	18–38
0.30	9–25	11–27	11–27
0.15	6–18	6–18	6–18
0.075	3–6	3–6	3–6
Sieve Size, inch	**Gradation 1 3/4 inch Nominal Max Agg Size by Mass**	**Gradation 2 1/2 inch Nominal Max Agg Size by Mass**	**Gradation 3 3/8 inch Nominal Max Agg Size by Mass**
1	100	–	–
3/4	90-100	100	–
1/2	68–88	90-100	100
3/8	60–82	69–89	90-100
No. 4	45–67	53–73	58–78
No. 8	32–54	38–60	40–60
No. 16	22–44	26–48	28–48
No. 30	15–35	18–38	18–38
No. 50	9–25	11–27	11–27
No. 100	6–18	6–18	6–18
No. 200	3–6	3–6	3–6

When a leveling course is applied, ensure layers are at least 37.5 millimeters (1.5 inches) thick except in areas where it is tapered to tie into the underlying layer. Ensure areas of leveling course that require tapering (it's better not to use tapering techniques) of the mix are at least 19 millimeters (0.75 inch) thick in the thinnest part of the taper to allow sufficient thickness for minimal compaction. Before overlaying, mill the asphalt surface to a grade resulting in no need for a leveling course. This allows each layer to be placed at a constant thickness throughout which is preferred.

Mixes with maximum aggregate size tend to have lower optimum asphalt content so these mixes are potentially a little cheaper for the contractor to produce but these mixes are more difficult to handle and compact and tend to segregate during handling. Use gradation 2 for all surface course mixtures for airfields unless the thickness is less than 37.5 millimeters (1.5 inches); in this case, use gradation 3. Provide good justification to use asphalt layer thicknesses less than 37.5 millimeters (1.5 inches). Use gradation 2 for intermediate layers as well unless the layer thickness exceeds 57 millimeters (2.25 inches); then gradation 1 is allowed to be used. Use gradation 3 for shoulders and for any layer that is constructed less than 37.5 millimeters (1.5 inches) thick.

2-1.3 Uses.

If properly designed, HMA paving mixtures are used for an asphalt base course, intermediate course, surface course, porous friction or stone matrix asphalt course. Wheel loads, wheel spacing, tire pressures, intensity of traffic, and subgrade strength (California Bearing Ratio (CBR)) dictate the thickness of the pavement (UFC 3-260-02). For airfield pavement applications, HMA is used for intermediate and surface courses on types A, B, C, and D traffic areas, blast areas, and any other areas (including non-traffic) where their use is economical. The four types of airfield traffic areas (A, B, C, and D) and their relationship to other methods of traffic area nomenclature are described in UFC 3-260-02. HMA is often used on any road or street, classification A through F. PFCs have been used in the past to prevent hydroplaning but have not been used in recent years on airfields primarily due to potential for raveling of the surface resulting in FOD. Gain approval from the Pavements Discipline Working Group (DWG) or their designated representative before using a PFC on an airfield. Grooving is used on runways in place of PFCs to facilitate removal of the water from the pavement surface. SMA is used in applications requiring a rut- and abrasion-resistant surfacing. SMA mixtures are more expensive than HMA, so they are not used. Areas subjected to fuel spills require an application of a fuel-resistant sealer to protect the HMA pavement or the use of a fuel resistant binder. When possible, investigate the use of a rigid pavement for areas with expected fuel spillage.

HMA is used for new construction and for rehabilitating existing pavements. For new construction it is important to ensure that the existing subgrade meets the strength requirements used for design. It is also essential that the quality of materials in the subbase and base courses meet the design requirements. Ensure a condition survey of existing pavements is made in order to develop a design for existing pavement repairs. During construction, it is essential that the design for materials and thicknesses be followed. Immediately address any construction issues prior to placement of material to avoid ultimately having to remove and replace such.

2-2 EQUIPMENT.

2-2.1 Plant Equipment.

The purpose of an asphalt plant is to produce the mixture using mix design proportions of aggregate materials and asphalt cement and mix the materials so that all aggregates are thoroughly coated and the mixture is uniform throughout. HMA is produced in both batch and drum mix asphalt plants. Drum mix plants are common in the U.S. Either type of asphalt plant is used to produce high quality HMA. Initiate asphalt mixture quality control at the aggregate stockpiles. Manage each aggregate stockpile to prevent segregation or mixing with adjacent stockpiles or contamination from other materials including underlying material.

2-2.1.1 Batch Plant.

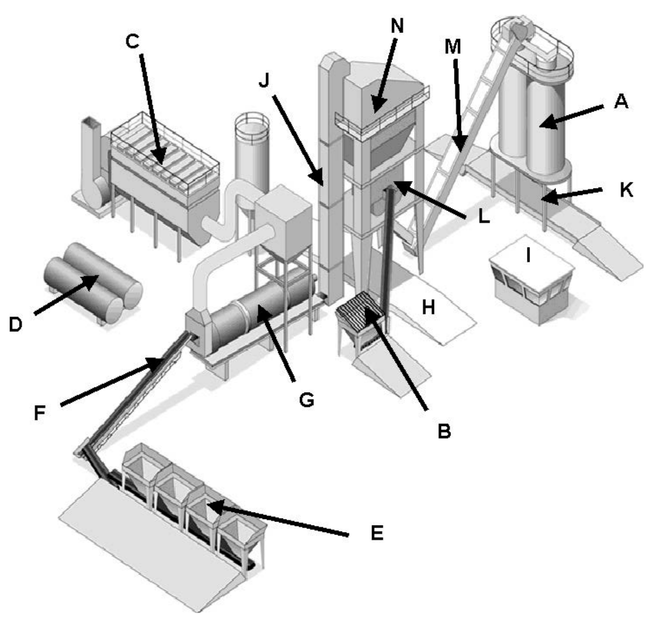
The components of a batch plant are illustrated in Figure 2-1. Cold feed hoppers have individual feeders for each of the aggregates used in the mixture. Set feeders so that the desired percentage of each aggregate as specified in the job mix formula is fed into the plant. Rate of feed is controlled by the gate opening, belt speed, or other methods, depending on the type of cold feed. If aggregate feeders are not set as specified in the job mix formula, the following problems occur:

a. One of the aggregate hot bins overflows with material while another hot bin runs low on material.

b. The gradation of the aggregate in the mix being produced does not meet the design gradation.

c. The amount of natural sand varies from the design proportion and exceeds the amount allowed in the specifications.

Figure 2-1 Batch Plant



A-Storage Silo
B-Reclaimed Asphalt Pavement (RAP) Feeder
C-Baghouse
D-Binder Storage
E-Cold Feed Hoppers
F-Cold Elevator
G-Dryer
H-Plant Scales
I-Control House
J-Hot Elevator
K-Silo Truck Scales
L-Pug Mill
M-Mix to Silo
N-Hot Bins

(Courtesy of National Asphalt Pavement Association (NAPA))

2-2.1.1.1 Cold Feed Bins.

Before the start of a project, calibrate the cold feed bins so that each bin feeds the desired rate of material. The cold feed calibration involves feeding one aggregate at a time onto a belt that is common to all aggregates. Determine the speed of this belt prior to calibration of the feeders. One way to do this is to divide the belt length by the time required for one revolution. After the material is fed onto the belt, completely remove and weigh the material over a given length (for example; 2 meters (6.5 feet)). To convert the weight of the sample taken to kilograms per hour (pounds per hour) and later to metric tons (tons) per hour, use the following relationship:

$$R = \frac{3600\ WS}{L}$$

Where:
R = rate of feed, kilograms per hour (pounds per hour)
W = weight of sample, kilograms (pounds)
S = speed of belt, meters per second (feet per second)
L = length of belt sampled, meters (feet)

Feed each aggregate at four to five different feeder settings and determine the rate of feed for each setting. Develop a plot of this data showing the relationship between the rate of feed (kilograms or metric tons (pounds or tons) per hour) and the feeder setting (gate opening, feeder belt speed, or other method for setting the aggregate feeder) for each aggregate. Use these plots to set each cold feed bin to feed at the desired rate.

2-2.1.1.2 Dryer.

After the aggregate cold feed bins have been properly set, the aggregate feeders are set to provide the desired percentages, and the aggregate is fed up the cold elevator and through the dryer. The dryer removes the moisture from the aggregate down to less than 0.5% and heats the aggregate to the desired temperature for mixing and handling.

2-2.1.1.3 Dust Collector.

A dust collector collects the dust created in the dryer and at other plant locations and adds all or any portion of it back into the mix at the hot elevator. Ensure the plant has the capability to remove any desired portion of the collected dust or to return it back to the mixture.

2-2.1.1.4 Screens.

The aggregate exits the dryer and is carried, along with the returned dust, up the hot elevator, over the screening deck, and into the hot bins. Screen sizes are selected such that the oversize material is rejected and the remaining aggregates are separated into various sizes. Ideally, select the screen sizes so that the amount of material going into each hot bin is proportional to the relative volume of that hot bin. For example, suppose that hot bin No. 1 has a volume of 3 cubic meters (4 cubic yards), hot bin No. 2 has a volume of 1.5 cubic meters (2 cubic yards), and hot bin No. 3 has a volume of 1.5 cubic meters (2 cubic yards). Select screens so that 50 percent of the material goes into bin No. 1, 25 percent into bin No. 2, and 25 percent into bin No. 3. This is not done for each mix since it takes effort to change the screens and asphalt batch plants produce a range of mixes during a normal workday.

2-2.1.1.5 Hot Bins.

Determine the percentage of each hot bin to be used in the mixture. Take samples of each hot bin and the gradation for each sample determined. Select the percentage of each bin so that the gradation of the combined materials from the hot bins is equal to the gradation of the job-mix formula (JMF). Variations occur in the combined hot bin gradation and that sent through the drier due to possible aggregate degradation or loss of fines in the dust collection system; however, ensure the gradation of the blended aggregate is equal to that originally developed in the mix design.

2-2.1.1.6 Mixer.

After the cold feed and hot bins are properly set, the combined aggregate from the hot bins is mixed with the approved mix design amount of asphalt binder. Select the mixing time, 5 seconds for dry mixing and 25 to 40 seconds for wet mixing, so that all aggregate particles are coated. Ensure the plant produces a uniform asphalt mixture having approved mix design aggregate gradation, asphalt content, and temperature. The batch plant weighs in approved mix design percentage of the various nominal size aggregates stored in the hot bins and asphalt binder to produce a batch of material that is then mixed in a pugmill.

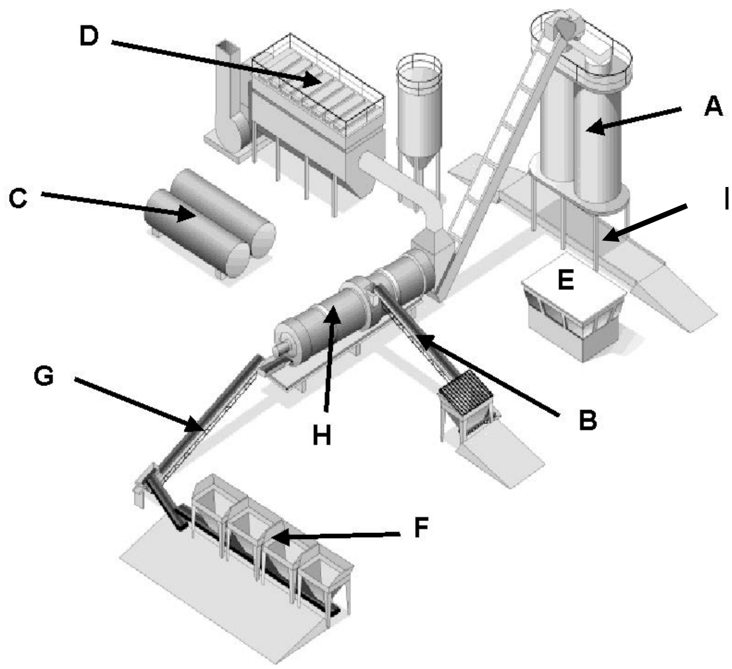
2-2.1.1.7 Storage Silo.

A storage silo is not required in a batch plant but almost all asphalt plants have one or more storage silos to temporarily store material during production. Ensure the storage silo in a batch plant meets the same requirements as that for a drum mix plant discussed below.

2-2.1.2 Drum Mix Plant.

The drum mix plant is illustrated in Figure 2-2. The drum mix plant is generally produces HMA at a higher production rate compared to a batch plant. When a drum mix plant is used, the gradation is completely controlled at the cold feed bins since no additional screening of the mixture occurs. The asphalt cement is either added to the aggregate while inside the drum or added to the aggregate immediately after passing through the drum. This plant type is used to readily produce HMA containing reclaimed asphalt pavement as well as HMA containing no reclaimed asphalt pavement.

Figure 2-2 Drum Mix Plant



A-Storage Silo
B-RAP Feeder
C-Binder Storage
D-Baghouse
E-Control House
F-Cold Feed Hopper
G-Cold Elevator
H-Dryer and Mixer
I- Truck Scales

(Courtesy of NAPA)

2-2.1.2.1 Cold Feed Bin

The cold feed bins in a drum mix plant are set up much the same way as for the batch plant, but the drum mix plant has a weight sensor on the aggregate feed belt that weighs the aggregate on the run prior to being fed into the dryer. Adjust this aggregate weight based on moisture content since there is moisture in the aggregate that is removed during the drying process. The asphalt pump adds binder based on the belt-measured weight of aggregate which is more asphalt binder than desired unless the aggregate weight is corrected based on the measure moisture content.

2-2.1.2.2 Dryer.

For the drum mix plant, the burner for the dryer is normally located on the high side (parallel flow) or the low side (counter flow) of the drum. In the parallel flow dryer, the aggregate enters the dryer on the high end of the drum and helps to shield the asphalt binder being added inside the drum from direct contact with the flame. The asphalt cement is added to the dryer at the midpoint to two-thirds the length to prevent close contact with the flame, which causes over-heating and damage to the asphalt binder. A counter-flow drum mix plant has the burner on the low end of the drum and is more energy efficient than a conventional drum mixer and produces less emissions during plant operations. With a counter flow plant, various techniques are used to protect the asphalt from the flame as it passes through the plant. Examples of techniques used include double barrels (where the aggregate is heated in the inner drum and the asphalt cement is added in the outside drum), coaters (where the asphalt cement is added to the aggregate after it passes through the dryer), and heat shields (shield the asphalt cement from the flame).

2-2.1.2.3 Dust Collector.

The dust collector in a drum mix plant operates similar to that in a batch plant.

2-2.1.3 Asphalt Mixture Storage Silo.

Asphalt storage silos are used to store HMA mixture before loading it onto trucks. Ensure the storage silo volume is maintained for the drum mix plants continuous flow production. The silos allow plants to run continuously even when there is a temporary shortage of trucks. Material is stored in silos for short periods of time, but if stored too long, the material cools excessively or oxidizes excessively, causing the asphalt binder to become hard and brittle. The asphalt binder has the potential to drain from the aggregate during long-term storage. This draindown is more likely to occur with mixes having high coarse aggregate content such as open-graded friction course and stone matrix asphalt. Hence for these mixture types storing the mixture in the silo for more than 30 minutes is not allowed.

Meet the stored mixture specification requirements when sampled and tested after storage. As a general rule, HMA dense-graded mixtures are not stored more than 3 hours in a non-insulated storage silo or for more than 8 hours in an insulated storage silo. If segregation of aggregate or draindown of asphalt binder occurs in the silo, disallow use of the silo or make changes in the equipment or process to prevent segregation and draindown.

2-2.2 Placement Equipment.

2-2.2.1 Asphalt Spreader (Paver).

2-2.2.1.1 Types of Spreaders.

An asphalt spreader is used to place mixture types, such as hot mix, cold mix, and base course material. Spreaders currently in use operate on either tracks or rubber tires, and have a vibrating screed to strike off and smooth the paving mixture. Spreaders use a tamping bar in conjunction with the screed, or an oscillating screed with a vibrating compactor, and others use a vibrating screed for both strike-off and initial compaction. Conventional paving machines are place HMA, provided these machines are maintained in good mechanical condition, kept adjusted, and operated by experienced personnel. Poor pavement surfaces result if the screed plates are worn or rusty or if the tamping bars (when used) are worn or not properly adjusted.

2-2.2.1.2 Automatic Grade Control.

Ensure asphalt spreaders have a means of automatically controlling the grade. In many cases the grade of the base course or underlying layers is controlled and the desired thickness of asphalt mixture is placed resulting in the desired grade on the surface. When directly controlling grade of an asphalt layer, grade control is used on both sides of the paver for the first pass. For additional passes, the existing edge is matched on one side of the paver while grade control is used on the opposite side of the paver. For roads, slope control in the paver is often used to control the desired grade. In this case one side of the paver matches the existing pavement and the opposite side is controlled by setting the screed of the paver to provide the desired slope. Controlling the grade by utilizing the transverse slope with the paving machine is not acceptable when multiple lanes are to be placed since the error using the transverse slope approach increases as the number of lanes placed is increased. Methods of grade control that have been used include stringline, laser, and Global Positioning System (GPS)/automation. The asphalt mixture is placed to a desired grade with the asphalt paver but after compaction the mix rolls down 20 to 25 percent of the loose thickness. Hence, if 63.5 millimeters (2.5 inches) of loose mix is placed, this results in 51 millimeters (2.0 inches) of mix after compaction. This results in the initial placement of the asphalt mixture being 13 millimeters (0.5 inch) higher than the desired grade after compaction.

2-2.2.2 Material Transfer Vehicle.

Segregation and lack of smoothness are problems that occur on many paving projects. The use of a material transfer vehicle (MTV) has been shown to minimize segregation and improve pavement smoothness. The MTV is used to transfer the HMA paving mixture from the transport truck to the hopper of the paver. These devices hold a substantial amount of paving mixture, allowing more freedom in mixture transport, and they remix the paving mixture to help reduce segregation that often occurs during placement. In addition to helping prevent segregation, the MTV improves pavement smoothness by allowing a paver to operate continuously (less stopping and starting) without having to be concerned with trucking operations. MTVs receive mixtures directly into a hopper from dump trucks. State's Department of Transportation (DOT) require that an MTV be used on critical projects, such as interstate highways, so MTVs are readily available. All MTVs are not the same. MTVs work better for reducing segregation and improving performance. As a minimum, specify an MTV that has an articulating arm and one that is self-propelled and operated independently from the paver. Ensure the MTV has remixing capability to minimize segregation. There are many machines that simply transfer the mix from the truck to the paver. Many of these do not remix the asphalt mixture. One method of remixing is to have an auger inside the MTV that has auger blades at varying spacing (closer together near the end and further apart near the middle of the auger where the material is fed to the paver) which results in mixing of the materials as they are being fed to the paver.

2-2.2.3 Joint Heaters.

Joint-heating devices that are attached to asphalt spreaders have been used on a number of HMA construction projects. The joint heaters are used to heat the edge of an adjacent pavement lane during placement so that a hot joint is obtained. The hot joint allows for higher compaction. Experience with joint heaters has shown that there is a danger of overheating the existing asphalt mixture. Accordingly, do not use joint heaters on airfields.

2-2.2.4 Asphalt Distributor.

Asphalt distributors are used to apply asphalt material evenly over a pavement surface. Clean the openings of all nozzles of any blockages. Ensure nozzles are the same size and turned at the same angle with reference to the spray bar to produce a uniform fan of bituminous material. The height of the spray bar above the surface being sprayed is important for uniform application. When the bar is too high or too low, a difference in application rate across the spray bar occurs, causing streaking. Adjust the height of the spray bar so that a double or triple overlap of the spray fan is obtained. The Asphalt Institute's Manual Series No. 19 (MS-19) offers guidance for calibrating and checking application equipment. American Society for Testing and Materials (ASTM) Standard D2995 (ASTM D2995) details a method for the determination of the application rate of asphalt (bituminous) distributors. Fully calibrate a distributor before being allowed to be used on a project.

2-2.2.5 Rollers.

A number of roller types are used for paving operations. Rollers used to compact asphalt mixtures are static steel-wheel, vibratory steel-wheel, and rubber-tired rollers. Occasionally rollers have a steel drum on one end of the roller and rubber tires on the other end of the roller. These types of rollers are not allowed for use on HMA because the rubber tires tend to pick up the asphalt mixture resulting in damage to the HMA surface.

2-2.2.5.1 Static Steel-Wheel Rollers.

Static steel-wheel rollers are available in two-wheel (tandem) and three-wheel (tricycle) versions. These two wheel tandem rollers are used for finish rolling but have been used for breakdown rolling as well. Static steel-wheel rollers leave a smooth finish on the pavement surface, but excessive rolling with steel wheel rollers results in lateral movement of the mixture as it’s being rolled, causing surface cracking and a general loss in density. Equip these rollers with a system for watering the drums and ensure they have scrapers to remove any material that sticks to the drums. The three-wheel rollers, tricycle rollers, are not used as often, partially due to their tendency to push and shove the asphalt mixture, which results in surface problems.

2-2.2.5.2 Vibratory Steel-Wheel Rollers.

Vibratory steel-wheel rollers are commonly used for breakdown and intermediate rolling of HMA mixtures. They consist of dual-drum vibration, single-drum vibration and single-drum static, or single-drum vibration and rubber tires on the rear axle; however, use of rubber tires on the vibratory steel wheel rollers for asphalt is not normally recommended due to the potential for pickup of the HMA. These vibratory steel wheel rollers are used for breakdown, intermediate, and finish rolling. Breakdown rolling is performed in either static or vibratory mode, although almost everyone now uses a vibratory roller for breakdown rolling. Intermediate rolling is almost always performed in the vibratory mode, while finish rolling is performed in the static mode. Limited data that indicates that excessive rolling with a vibratory roller results in bleeding of the asphalt surface resulting in excessive loss of friction. Therefore, limit the maximum number of passes to three in the vibratory mode. Ensure the vibratory roller has a watering system along with scrapers on the steel drums. Although the vibratory roller is used for intermediate rolling, it does not replace a rubber-tired roller.

2-2.2.5.3 Rubber-Tire Rollers.

Rubber-tired rollers are used commonly for intermediate rolling of HMA mixtures. They are also used as breakdown rollers when mixtures are excessively tender. Whether used as breakdown or intermediate rollers, these rollers provide for an increase in compaction and produce a watertight surface. Ensure a rubber-tired roller consisting of nine tires, four on one end of the roller and five on the end of the roller and with a minimum total mass load of 18,180 kilograms (40,000 pounds) or 2,020 kilograms (4,440 pounds) per tire and a minimum tire inflation pressure of 620 kilopascals (90 pounds per square inch (psi)), is available for construction of heavy-duty pavements on roads or airfields. Ensure the rubber-tired roller has a watering system for the tires and has scrapers and pads in good shape to prevent accumulation of materials on tires. Commercially available products are available that when applied to the rubber tires keep the HMA mixture from sticking to tires. An effective method for preventing pickup is to get the tires hot and keep them hot. In cold climates or in windy conditions, apply skirts to protect the tires from excessive cooling caused by wind. While roller types are not in the specifications, it is recommended that a rubber-tired roller be included in the train of rollers for compaction of all heavy-duty HMA pavements, and these rubber tire rollers have tires containing the minimum pressures and weights as described above. The rated weight for a rubber tire roller is the loaded weight for the roller. If the roller is not filled with ballast (sand and water), the weight is less than the rated weight. If the actual weight of the roller is needed, weigh it. Rubber tire rollers always yield the best results for longitudinal cold joints and transvers transition joints between asphalt and concrete vs. vibratory or non-vibratory steel rollers.

2-2.2.5.4 Operation of Rollers.

Operate rollers at or below a rate of 4.8 to 8 kilometers per hour (3 to 5 miles per hour) (fast walking speed). Ensure starts and stops are gradual to avoid damaging the freshly laid mixture. Quick turns or any turns that cause cracking on freshly laid mixture is not allowed.

2-3 MATERIALS.

2-3.1 Asphalt Materials.

Asphalt materials used in hot-mix paving operations include the products conforming to the specifications listed in Table 2-2. Asphalt cements for use in pavement design and construction are graded or classified in one of two ways. They are graded on the basis of penetration (ASTM D946) or by the performance grading system (ASTM D6373). Currently, in the continental United States (CONUS) and many other countries, the performance grading system is used; however, in many countries, penetration grades of asphalt are obtained more easily. If performance graded asphalt is available, specify it for any airfield project. In general, use the softest grade of asphalt cement consistent with traffic and climate. Base selecting a grade of asphalt cement on several considerations, such as climate, traffic conditions, economics of asphalt availability, and previous regional experiences. Traffic conditions and economic considerations vary from project to project, but environmental conditions and regional experiences are normally similar. For example, in warm and hot regions, primarily select a grade of asphalt cement to ensure that the mix is stable during the summer months, and in cold regions, primarily select a grade of asphalt cement to ensure that the mix is not prone to cracking during winter months. These requirements are discussed in the following subparagraphs.

Table 2-2 Specification References for Asphalt Materials

Bitumen Type	Specification
Asphalt cement (performance-graded asphalt binder)	ASTM D6373
Asphalt cement (penetration-graded)	ASTM D946
Cutback asphalt (slow-curing type)	ASTM D2026
Cutback asphalt (medium-curing type)	ASTM D2027
Cutback asphalt (rapid-curing type)	ASTM D2028
Asphalt, emulsified (anionic)	ASTM D977
Asphalt, emulsified (cationic)	ASTM D2397

2-3.1.2 Performance Graded (PG) Asphalt Cements.

The performance grading system (ASTM D6373) classifies asphalt binders using performance-related properties according to the upper and lower temperatures that are expected during the life of the pavement. American Association of State Highway and Transportation Officials (AASHTO) R29 provides information for grading or verifying the performance grade of asphalt cement. PG asphalts have replaced penetration- and viscosity-graded asphalts in the United States. Unlike the viscosity and penetration grading systems, the performance grading system is used to classify unmodified as well as polymer modified asphalt binders.

2-3.1.3 Classification Method for PG Graded Asphalt Cements.

Specify PG graded asphalt binders wherever available. Consider the same PG binder grade as that used by the state highway department in the specific geographic area as the base grade for the project (e.g., the PG grade specified in that specific location for dense-graded mixes on highways with design equivalent single axle loads (ESAL) less than 10 million). The exception is that grades with low temperature requirements higher than PG XX-22 are not to be used (e.g., PG XX-16 or PG XX-10), unless the engineer or the local DOT has had successful experience with these grades.

Rutting is not a problem on airport runways but there have been issues on taxiways where the traffic is slower moving. At airfields with a history of stacking on ends of runways and taxiway areas, rutting has occurred due to the slow speed of loading on the pavement. If there has been rutting on the project or if stacking occurs regularly during the design life of the project, then apply the following grade "bumping" for the top 125 millimeters (5 inches) of paving in the end of runway and taxiway areas: for aircraft tire pressure between 0.7 and 1.4 megapascals (100 and 200 psi), increase the high temperature grade by one grade; for aircraft tire pressure greater than 1.4 megapascals (200 psi), increase the high temperature grade by two grades. For those projects used by aircraft and missions intended to primarily support air operations on ships, a high temperature increase of two grades is required for all HMA projects.

PG grades are provided in 6 degree increments, for example PG 64-22, PG 70-22, PG 76-22 on the high temperature side and PG 64-22, PG 64-28 on the low temperature side. However, many state DOTs, in the southern climates, have selected a mid-range grade on the high end, PG 67-22, as the primary grade of asphalt binder to use. When in these states specify the mid-range grade, PG 67-22, unless the high temperature grade needs to be bumped to be more resistant to rutting.

Polymer-modified asphalt (PMA) has been shown to perform well for improving the resistance to rutting. Using PMA results in a bumped grade of asphalt binder. When bumping the high temperature grade, ensure the low temperature grade remains the same as that for the base grade asphalt. A rule of thumb is that any asphalt binder, having the sum of the high and low temperature grades exceeding 90, is likely to contain a polymer. For example a PG 64-22 has a sum of 86 and this is likely not modified; however, a PG 76-22 has a sum of 98 and this asphalt binder is almost certainly modified. Changing from a PG 64-22 to a PG 76-22 provide much improved resistance to rutting but substantially increase the cost of the asphalt mixture (by 15%, but this varies considerably).

2-3.1.3.1 Polymer Modification of Asphalts.

Many polymers greatly improve the stiffness and flow characteristics of asphalts at high temperatures and are being demonstrated in pavement applications to significantly reduce rutting where this has been a problem in the past. These modified mixtures are produced at higher mixing temperatures to facilitate mixing, placement, and compaction. Polymers improve the low temperature characteristics of an asphalt binder and improve the ability of the pavement to resist low temperature cracking.

Many agencies bump the grade of asphalt binder to provide a binder that is more resistant to rutting and to help ensure that the binder contains a polymer. This bumping results when the high temperature grade is increased. For example, the grade of asphalt binder to be used in a certain area is identified as PG 64-22. However, to minimize rutting potential and to help ensure that a polymer is used, the agency elects to bump the grade to a PG 76-22. This provides increased stiffness at high temperatures without increasing the stiffness at low temperatures thus producing a more rut resistant mixture without increasing the potential for cracking. When the PG grade is bumped, the agency desires that a polymer be used in the binder. However, the grade is bumped in other ways, such as air blowing, but the asphalt binder won't perform as well when a polymer is used to bump the binder grade.

Ensure that a polymer is used to bump the asphalt binder grade by modifying the binder specification. The modifications to the binder specifications that have been used include, but are not limited to, elastic recovery, forced ductility, phase angle requirement. This has resulted in agencies adopting different requirements thus creating a problem for asphalt binder producers. As a result there has been a lot of work to standardize the binder test to ensure polymer modification resulting in development of the multiple stress creep recovery (MSCR) test. This test is being finalized and is eventually a part of the binder specification requirements but is not yet included as part of the specifications. If the PG binder grade is bumped, it is recommended that additional PG binder requirements (PG plus) specified by the local state DOT be adopted as part of the binder specification. Once the MSCR test procedure is completed and adopted as a part of the ASTM binder specifications, it becomes part of the requirements.

2-3.1.4 Asphalt Cement Selection by Temperature Region.

2-3.1.4.1 Determining the Temperature Region.

Table 2-3 gives guidance for selecting penetration-graded and performance graded asphalt binder by temperature region. When local experience suggests a specific grade of asphalt binder be used, local experience controls. For example, in the U.S., the local state DOT has requirements for selecting the grade of asphalt binder to use. If local experience cannot be used, climatological data are required to provide input into the selection method. First, average monthly maximum temperature data are required to compute a pavement temperature index (PTI). When project locations have average monthly maximum temperatures above 23.9 degrees Celsius (C) (75 degrees Fahrenheit (F)), the PTI is defined as the sum of the monthly increments exceeding 23.9 degrees C (75 degrees F). Conversely, when no average monthly temperature exceeds 23.9 degrees C (75 degrees F), the PTI is defined as the difference between the highest average maximum temperature for the warmest month and 23.9 degrees C (75 degrees F).

Table 2-3 Asphalt Binder Base Grade Selection Criteria Based on Pavement Temperature Index*

Pavement Temperature Index, Cumulative °C (°F)	Temperature Region	Asphalt Cement Selection Criteria
< 16.7 (30)	Cold	120-150 penetration, PG (52,58)-xx**
16.7–44.4 (30–80)	Warm	85–100 penetration, PG 64-(22 or 28)
> 44.4 (80)	Hot	60–70 penetration, PG (64, 70 or 76)-22

*Use only if there is no local guidance on asphalt cement grade to use)

**Use cold region requirements described in paragraph 2-3.1.3.3 for low temperature grade.

2-3.1.4.2 Example of Calculations for PTI.

This example shows the method for calculating the PTI for two construction sites. The average monthly maximum temperature and the difference above 23.9 degrees C (75 degrees F) for Site A and Site B are provided in Table 2-4.

Table 2-4 Example PTI Data

	Site A		Site B	
Month	**Average Maximum Temperature °C (°F)**	**Difference Above 23.9 °C (75 °F)**	**Average Maximum Temperature °C (°F)**	**Difference Above 23.9 °C (75 °F)**
January	15.8 (60.4)	--	-1.2 (29.8)	--
February	20.3 (68.5)	--	-2.3 (27.9)	--
March	23.2 (73.8)	--	6.1 (43.0)	--
April	26.6 (79.9)	2.7 (4.9)	14.6 (58.3)	--
May	31.4 (88.5)	7.5 (13.5)	19.6 (67.3)	--
June	34.7 (94.5)	10.8 (19.5)	21.3 (70.3)	--
July	36.4 (97.5)	12.5 (22.5)	25.0 (77.0)	1.1 (2.0)
August	33.3 (91.9)	9.4 (16.9)	23.4 (74.1)	--
September	32.3 (90.1)	8.4 (15.1)	19.4 (66.9)	--
October	26.8 (80.2)	2.9 (5.2)	14.2 (57.6)	--
November	23.3 (73.9)	--	6.3 (43.3)	--
December	15.7 (60.3)	--	2.7 (36.9)	--
Cumulative Total		**54.2 (97.6)**		**1.1 (2.0)**

The temperature index at these sites is the sum of the increments of average monthly maximums above 23.9 degrees C (75 degrees F); therefore, these are the PTIs for each site:

Site A = 54.2, cumulative degrees Celsius (97.6 cumulative degrees Fahrenheit).
Site B = 1.1, cumulative degrees Celsius (2.0 cumulative degrees Fahrenheit).

Based on the criteria in Table 2-3, Site A is a hot region, and Site B is a cold region.

2-3.1.4.3 Cold Region Requirements -- Determining the Design Air-Freezing Index.

When it is determined that a project exist in a cold region, as defined in Table 2-3, additional climate data are required. For the project area under consideration, a design air-freezing index (DFI) is also required to meet cold region requirements. (Reference UFC 3-260-02 for determination of DFI.) DFIs are used to differentiate between climates in cold temperature regions. A DFI of 1,667 degree Celsius-days or 3,000 degree Fahrenheit-days (degree-days) is used as the delineation between moderately cold and severely cold (extremely cold) climates. Moderately cold climates have DFIs up to 1,667 degree-days, and severely cold climates have DFIs greater than 1,667 degree-days. After the DFI is determined, select the grade of asphalt from Table 2-5. The minimum pavement temperature is estimated as a function of DFI as shown in Figure 2-3. Knowing the minimum pavement temperature is helpful in selecting the best low temperature grade of the asphalt binder. Ensure the low temperature grade is lower than the estimated low temperature from the figure. For example if the estimated low pavement temperature is -26 degrees C (-14.8 degrees F) then the PG grade is -28 or lower.

2-3.1.4.4 Examples of Asphalt Cement Selection in the Three Regions.

a. **Asphalt cement selection in a hot region.** A parking lot is to be built in a region that has a PTI of 54.4, cumulative degrees Celsius (97.6, cumulative degrees Fahrenheit). Assume that the DOT requires a grade of PG 67-22 for routine traffic and PG 76-22 for heavy traffic such as an Interstate Highway. In this case select a PG 67-22 or select a PG 76-22 in areas of known potential rutting issues such as slow moving airfield traffic areas including taxiways and runway ends and roads with high volume and/or slow moving traffic.

If no local guidance is available use Table 2-3 for selecting the asphalt cement grade. An asphalt cement that is graded as a 60-70 penetration or use a PG (64, 70, 76)-22. If rutting has been a problem or if aircraft stacking is expected then PG 76-22 is preferred. However, if this is for shoulder or other areas with little or no traffic, select PG 64-22. A PG 70-22 works reasonably well in traffic or non-traffic areas.

b. **Asphalt cement selection in a warm region.** A street is to be constructed in a region that has a PTI of 23.3, cumulative degrees Celsius (42, cumulative degrees Fahrenheit). Based on Table 2-3, select 85-100 penetration asphalt cement or PG 64-(22, 28) unless local guidance suggests a different grade. The -28 is more resistant to cracking and the -22 is more economical.

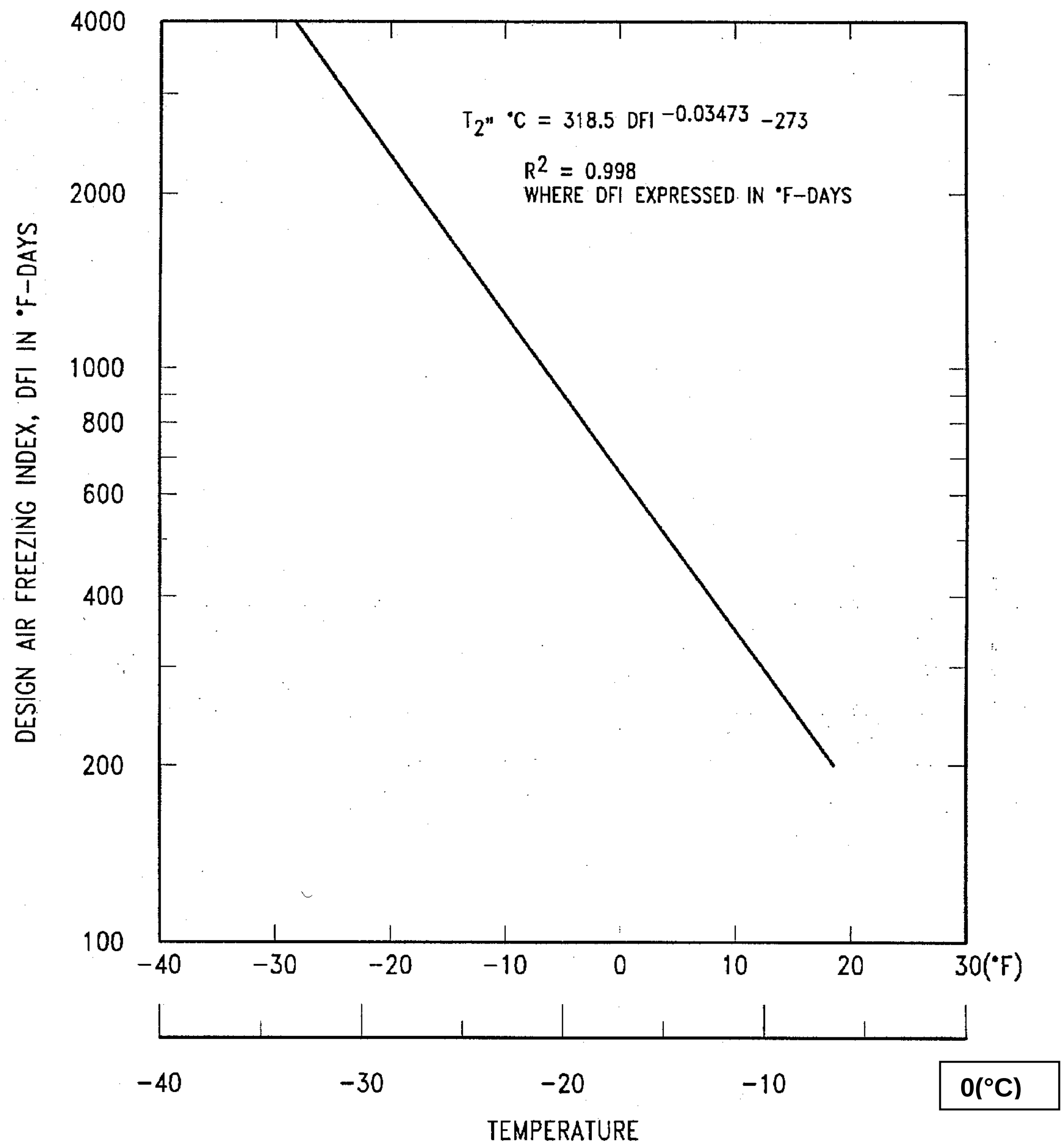
c. **Asphalt cement selection in a cold region. C**onstruct a heavy-duty open storage area (design index of 0) for use by 22,680-kilogram (50,000-pound) forklift trucks in a region with a PTI of 1.1, cumulative degrees Celsius (2, cumulative degrees Fahrenheit) and a DFI of 1,278 degree Celsius-days (2,300 degree Fahrenheit-days) calculated using UFC 3-260-02. Use penetration 120-150 if penetration graded asphalt is used or use PG (52, 58)-(28, 34) based on Tables 2-3 and 2-5. Again use local guidance for selecting grade of asphalt binder if available. Grade 58 is more resistant to rutting and Grade -34 is more resistant to cracking.

Table 2-5 Asphalt Cement Selection Criteria Based on Design Air-freezing Index*

Pavement Temperature Index, Cumulative °C (°F)	Temperature Region	Asphalt Cement Selection Criteria
< 1,667 (3,000)	Moderately Cold	PG (52, 58)-(28, 34)
> 1,667 (3,000)	Severely Cold	PG(52, 58)-(34, 40)

*Use only if there is no local guidance on asphalt cement grade to use)

Figure 2-3 Minimum Anticipated Pavement Temperature as a Function of DFI



2-3.2 Aggregates.

Use clean, hard, and durable aggregates for use in HMA. Angular aggregates provide more stable HMA mixtures than do rounded aggregates. Natural sands and gravels tend to be rounded and need to be limited or the gravel crushed to provide angular properties. Remove the fine aggregate from the source stone material before crushing to remove soft particles and potential clay balls that develop in the seams of the rock. Remove the fine aggregate from the gravel source before crushing to remove potential soft particles and clay balls, and to ensure that after crushing, particles are fractured and angular.

2-3.2.1 Sieve Analysis.

Subject aggregates to be used in a paving mix, as listed in Table 2-1, to a sieve analysis. From an aggregate's grading curve, an experienced engineer obtains information concerning the suitability of the aggregate for a paving mix, the quantity of asphalt cement required, and whether to add mineral filler. Conducted sieve analyses of fine and coarse aggregates according to ASTM C136. Washed sieve analysis are needed to get accurate measure of dust but for quality control (QC) testing during construction dry gradations are conducted to reduce test time. Use washed gradations for acceptance testing.

2-3.2.2 Specific Gravity.

Bulk specific gravity values for aggregates used in paving mixture are required in the computation of percent VMA. The method to determine the bulk specific gravity of aggregate is provided in ASTM C127 for coarse aggregate and ASTM C128 for fine aggregate.

2-3.2.3 Abrasion and Impact Resistance of Coarse Aggregate.

The determination of percent loss for coarse aggregates is not required if the aggregate has been found to meet the project mix design by previous tests or performance; however, test coarse aggregates obtained from new or doubtful deposits for resistance to degradation by evaluating the conformance to specification requirements for percent loss as measured using the Los Angeles Abrasion Machine (ASTM C131).

2-3.2.4 Soundness Test.

The soundness test is used where damage from freezing is a potential problem. Do not perform the soundness test on aggregate that has been found to meet the mix design by previous tests or performance data; however, aggregate obtained from new or doubtful deposits is tested for conformance to specification requirements using the sodium sulfate or magnesium sulfate solution tests (ASTM C88).

2-3.2.5 Percent Crushed Pieces.

Ensure the percentage of crushed pieces in both the coarse aggregate and fine aggregate fractions are sufficiently high to promote stability in the HMA mix design. Use

CRD-C 171 to determine the percentage of crushed aggregate particles for coarse aggregate (particles retained on a 4.75 millimeter (No. 4) sieve). Ensure a description for a crushed face and the required percentage of crushed aggregate particles is specified in the contract specifications. Natural gravels require crushing to produce the mix design percentage of fractured faces. Crushed stone, on the other hand, almost always meet the fractured face requirement.

2-3.2.6 Particle Shape.

The particle shape of crushed aggregates is required to be essentially cubical. Flat and elongated aggregate particles are susceptible to breakage under compaction and subsequent traffic. This breakdown of aggregate results in a change in volumetric properties of the mixture often resulting in a mix that does not meet the specification requirements. Determine the quantity of flat and elongated particles for conformance to specification requirements using ASTM D4791.

2-3.2.7 Clay Lumps and Friable Particles.

Some aggregates tend to have clay balls and soft particles. This test requirement (ASTM C142) evaluates the aggregate to ensure that aggregate containing clay balls or other friable particles that tend to breakdown during handling or during traffic is not allowed in the asphalt mixture. While these particles don’t normally result in disintegration of the pavement, they do result in blemishes that are unsightly and lead to FOD which is a significant problem for airfield pavements.

2-3.2.8 Sand Equivalent.

Some aggregates contain a significant amount of clay particles distributed throughout the aggregate. These particles that are not identified in the clay lumps and friable particles test present a problem. The sand equivalent test (ASTM D2419) evaluates a fine aggregate to determine the ratio between sand size and clay size particles. When a fine aggregate fails the sand equivalent test, it is not acceptable for use.

2-3.2.9 Natural Sand Content.

Natural sand is defined as any fine aggregate material that occurs naturally and has not been crushed. Natural sands tend to be rounded particles which, when used in excess, cause instability in the HMA mixture. The limit of 15 percent natural (uncrushed) sand in airfield mixtures assures a strong and stable pavement under aircraft. Natural sand also tends to have a smooth surface often resulting in poor bond between the asphalt binder and the sand particles. When reclaimed asphalt pavement (RAP) is used, determine the amount of natural sand in the RAP and included in the total amount of natural sand in the recycled mixture.

2-3.2.10 Fine Aggregate Angularity.

The fine aggregate angularity (FAA) test method (ASTM C1252, Method A) measures the uncompacted void content in the fine aggregate portion of a mix and is related to the angularity of the fine aggregate portion of the mixture. Generally crushed fine aggregates have an FAA value greater than 45 while natural sands have FAA values between the high 30s and the low 40s. The minimum specified value of FAA is 45 unless local experience indicates that aggregates with a lower value provide better performance. Occasionally, the FAA of a fine aggregate portion of the total aggregate is less than 45 even when it contains 100 percent crushed stone particles.

2-3.2.11 Voids in Mineral Aggregate (VMA).

The VMA is the volume of intergranular void space between the aggregate particles of a compacted paving mixture expressed as a percent of the total volume; it includes the air voids and the volume of the asphalt not absorbed into the aggregates. While VMA is not an aggregate property, it is a measure of the packing ability of an aggregate. The VMA is a function of bulk specific gravity of the aggregate, bulk specific gravity of the mix, asphalt content, and specific gravity of the asphalt binder. The VMA requirement is used to establish the minimum amount of asphalt binder added to the asphalt mix design. Without the VMA requirement, laboratories design asphalt mixes to have less asphalt binder to reduce mix cost. These low asphalt content mixes are difficult to place and compact and often result in reduced pavement durability. The VMA requirement indirectly controls the minimum asphalt content.

2-3.2.12 Combining Aggregates.

When asphalt mixtures are produced, combine aggregates from two or more sources. This UFC provides methods and procedures for determining the aggregate blend available and prescribes the asphalt content for the aggregate blend. Whenever an asphalt mixture does not meet established criteria, improve the gradation of the aggregate, use another aggregate, or make adjustments in the mix. Option choice is a matter of engineering judgment by the contractor and involves an analysis of the available aggregate supplies and costs.

2-3.3 Mineral Fillers.

Mineral filler refers to the material passing the 0.075 mm (No. 200) sieve. Most asphalt mixtures have enough mineral filler in the crushed aggregates and no additional filler is required. In fact, many mixtures have too much filler in the aggregates and procedures have to be used to waste some of the filler prior to or during the plant production operations. Some mineral fillers are more desirable to use in asphalt paving mixtures than others. For example, fine sands are less suitable fillers than limestone filler or some other by-product of crushed stone. Design asphalt pavement mixtures using commercial fillers that conform to ASTM D242.

2-3.3.1 Addition of Mineral Filler.

Additional filler is seldom needed in asphalt mixtures since the aggregates typically contain sufficient filler. The quantity of mineral filler to be added or removed depends on the amount of filler naturally present in the aggregate. In most cases the amount of filler in the aggregate produces a mixture meeting the specification requirements. With some aggregates, washing is performed to remove the excess filler in the aggregate before producing an asphalt mixture. High filler contents reduce the VMA in the mixture making it difficult to meet the specification requirements for VMA. The addition of satisfactory mineral filler, when needed, results in lower optimum asphalt content and increased stability of a paving mixture. Mixtures with low filler contents typically require additional asphalt binder to fill the voids resulting in a mixture that tends to be less stable if the filler is too low. Higher amounts of filler result in lower optimum asphalt content and reduced film thickness causing loss in mixture durability. Practical considerations and optimum performance usually dictate quantities of approximately 5-6 percent passing the 0.075 mm (No. 200) sieve for HMA and approximately 10 percent passing for sand-asphalt mixtures.

2-3.4 Antistrip Agents.

Several antistrip agents have been used successfully to reduce the probability of the asphalt stripping from the aggregate. Antistrip agents are added to the asphalt binder before it leaves the refinery, while others are added directly into the mixer as mineral filler. Hydrated lime is a commonly used antistrip agent and is one material with a history of success in preventing stripping. The liquid antistrip agents are easier to work with since these materials are mixed into the asphalt at the refinery and don’t require any extra effort by the contractor. When hydrated lime is added at the plant, have a silo to hold the lime and meter it into the mix thus requiring more effort by the contractor. Other available antistripping agents fall into these general groups: cationic surfactants, iron naphthenate, organosilane, and Portland cement. The tensile strength ratio (TSR) (ASTM D4867/D4867M) is used to evaluate the stripping property of a dense-graded asphalt mixture.

2-3.4.1 Recommended Antistrip Agent.

The recommended procedure for improving the resistance of an aggregate to stripping is to add 1 percent by weight hydrated lime to the mixture. Include this 1 percent lime in the determination of the aggregate gradation. Exact amounts are determined through trial and error on test specimens with various amounts of antistripping materials. Research has shown that lime provides better resistance to stripping than other materials. Some state DOTs are considered lime states and others are not. When in a state that does not use lime, local contractors are not set up to add lime increasing cost to set up equipment to store lime and feed it into the mix.

2-3.5 Antifoam Agents.

Silicone additives or modifiers reduce foaming of asphalt mixes when they come in contact with moisture. Silicone additives have been used successfully to suppress foaming of asphalt in asphalt plants. The silicone that has been used for this purpose is mixed at a rate of 1 milliliter per 640 liters (1 ounce per 5,000 gallons) of asphalt binder. The recommended range is also given as 1 to 2 parts per million. Silicones have been used to reduce the hardening of HMA while it is in storage silos. Silicone additives have successfully prevented slumping of mixes in trucks, which occurs when the hot-mix gradation is such that the mix traps escaping steam. In addition, silicones have provided better finishing qualities to pavement mixtures. These qualities include improved workability, reduced tearing during placement, and a reduction in the amount of effort required for compaction. Testing by several agencies has revealed no detrimental effects on the properties of asphalts when silicone is used in the recommended concentrations. Silicones are persistent materials, and their effects potentially carry over from one tank of asphalt to another. Mixing and control is best achieved by addition of the silicone at the refinery. (If silicone is added to the asphalt binder to prevent foaming, the asphalt binder cannot be used with the foaming process to produce warm mix asphalt).

2-4 DENSE-GRADED HMA.

Dense-graded HMA consists of a mixture of well-graded aggregate and asphalt cement. The HMA is produced at a central plant, laid to the desired grade with an asphalt spreader, and compacted with steel wheel and rubber tire rollers. HMA provides a high-strength, water resistant, smooth riding surface.

2-4.1.1 Aggregate Considerations.

Dense-graded HMA mixtures have several aggregate requirements and considerations. For airfield mixtures that support high-pressure tires, ensure the percentage of natural sand does not exceed 15 percent of the combined weight of the total aggregate. This percentage is 25 percent for roadway (low-pressure) mixtures, but needs to be validated with the mix design. The amount of filler that exists naturally in aggregates is sufficient to produce HMA meeting the mix design but needs to be validated. Usually, practical considerations and optimum performance dictate 5 to 6 percent filler, which is almost always available in the aggregates being used. Ensure the aggregates used meet the specification requirements for the aggregate properties discussed in paragraph 2.3.2.

2-4.2 Marshall Mix Design.

2-4.2.1 Contractor-provided Job Mix Formula (JMF).

Current practice is for the contractor to design the mixture and develop the JMF for the aggregates and asphalt used in the paving project. Supply a sufficient amount of aggregate and asphalt to the contracting officer or the contracting officer’s representative for possible verification tests. If verification tests are not performed, keep these material samples until the project is completed and accepted. Ensure the JMF supplied contains, as a minimum, the following information:

- Percent passing each sieve size for each aggregate and combined gradation.
- Optimum asphalt content.
- Percent of each aggregate and mineral filler to be used.
- Asphalt penetration grade, or performance grade.
- Number of blows of hammer per side of molded specimen (if Superpave is used, then show the number of gyrations).

- Laboratory mixing temperature.
- Lab compaction temperature.
- Temperature-viscosity relationship of the asphalt cement.
- Plot of the combined gradation on the 0.45 power gradation chart, stating the nominal maximum size.
- Graphical plots of stability, flow, air voids, VMA, and unit weight versus asphalt content.
- Bulk specific gravity and absorption of each aggregate.
- Percent natural sand.
- Coarse aggregate test results including: Los Angeles (LA) abrasion, sulfate soundness, percent fractured faces, flat and elongated particles, clay lumps and friable particles.
- Fine aggregate test results including: sand equivalent, uncompacted void content, clay lumps and friable particles.
- Tensile strength ratio and wet/dry specimen test results.
- Antistrip agent (if required) and amount.
- List of all modifiers and amounts.
- Percentage and properties (asphalt content, binder properties, and aggregate properties) of RAP in accordance with specifications when RAP is used.

The JMF likely needs to be adjusted based on plant-produced materials but only adjusted within the limits allowed in the specifications. Adjustments that exceed these specified limits are not be performed without a revised mixture design. Adjust the JMF only when changes in materials or procedures occur or to improve the JMF. It is common to adjust the mix design after construction of the test section and as needed during mixture production.

2-4.2.2 Procedure.

Laboratory tests are conducted on laboratory-compacted samples compacted with the effort identified in the specifications. These samples are tested to identify air voids, voids filled with asphalt, and VMA. Based on these properties (primarily air voids) the optimum asphalt content is selected. A final selection of aggregate blend and asphalt content is based on these data with due consideration to relative costs of the various mixes. The procedure set forth in paragraph 2-4.2.3 apply directly to all mixes containing not more than 10 percent by weight of total aggregate retained on the 25-millimeter (1-inch) sieve.

2-4.2.3 Preparation of Test Specimens.

Selection of materials for use in designing the paving mix is addressed in section 2-3. As an example, suppose that an aggregate gradation for a hot-mix design is required to meet the requirements of the 19-millimeter (3/4-inch) maximum (high-pressure) aggregate gradation band (gradation No. 2, 12.5 mm [1/2 inch] nominal) shown in Table 2-1. Design data are required on this blend. The initial mix design tests is usually conducted in a central testing laboratory on samples of stockpile materials taken by the laboratory. The procedure for proportioning stockpile samples to produce a blend of materials to meet a specified gradation is outlined in paragraphs 2-4.2.3.1 and 2-4.2.3.2 Adjustments to the mix design is based on samples taken from the asphalt plant and is usually conducted in a field laboratory near the plant.

2-4.2.3.1 Proportioning of Stockpile Samples.

As a preliminary step in mixture design and manufacture, determine the proportions of the different available stockpiled materials required to produce the mix design gradation of aggregate. This step is required to determine whether a blend is produced meeting the mix design and, if so, determine the proportion of each aggregate to be fed from the cold feeder bins into the dryer. Sieve analyses are conducted on material from each of the stockpiles, and the data are shown graphically in Figure 2-4. Another method of plotting or graphically illustrating the data is through the use of the 0.45 power curve. This was developed in the early 1960’s by the Federal Highway Administration (FHWA) using a formula developed in a study by Fuller and Thompson. The equation developed by Fuller is:

$$P = 100 \ (d/D)^n$$

where d is the opening of the sieve size in question, P is the total percent passing or finer than the sieve, D is the maximum size of the aggregate, and n is equal to 0.45. The FHWA recommends that this chart be used as part of the hot-mix design process. Combine the four aggregate fractions to produce the desired blend. The estimated percentage of each fraction needed to produce this blend is determined by trial-and-error calculations. Normally, two or three trials are required to obtain the desired blended gradation.

2-4.2.3.2 Proportioning of Bin Samples from Batch Plants.

Once it is demonstrated that a blend is prepared from the available materials, samples of these materials are processed through the asphalt plant for verification of the mix design or during construction of the test section. Conduct sieve analyses for each batch of processed aggregate. The data are shown graphically in Figure 2-5. Blend the hot-bin aggregates to produce the same gradation as that produced in the JMF. The percentage of each bin is estimated, and calculations are made to determine the gradation produced from these estimated percentages. The gradation of this recombined blend is then checked against the desired gradation. Two or three trials are usually sufficient to produce a combined mixture having a gradation equal to the job mix formula. This step is not needed when a drum mix plant is used since the aggregate is not rescreened in the plant.

Figure 2-4 Gradation Curves for Stockpile Samples

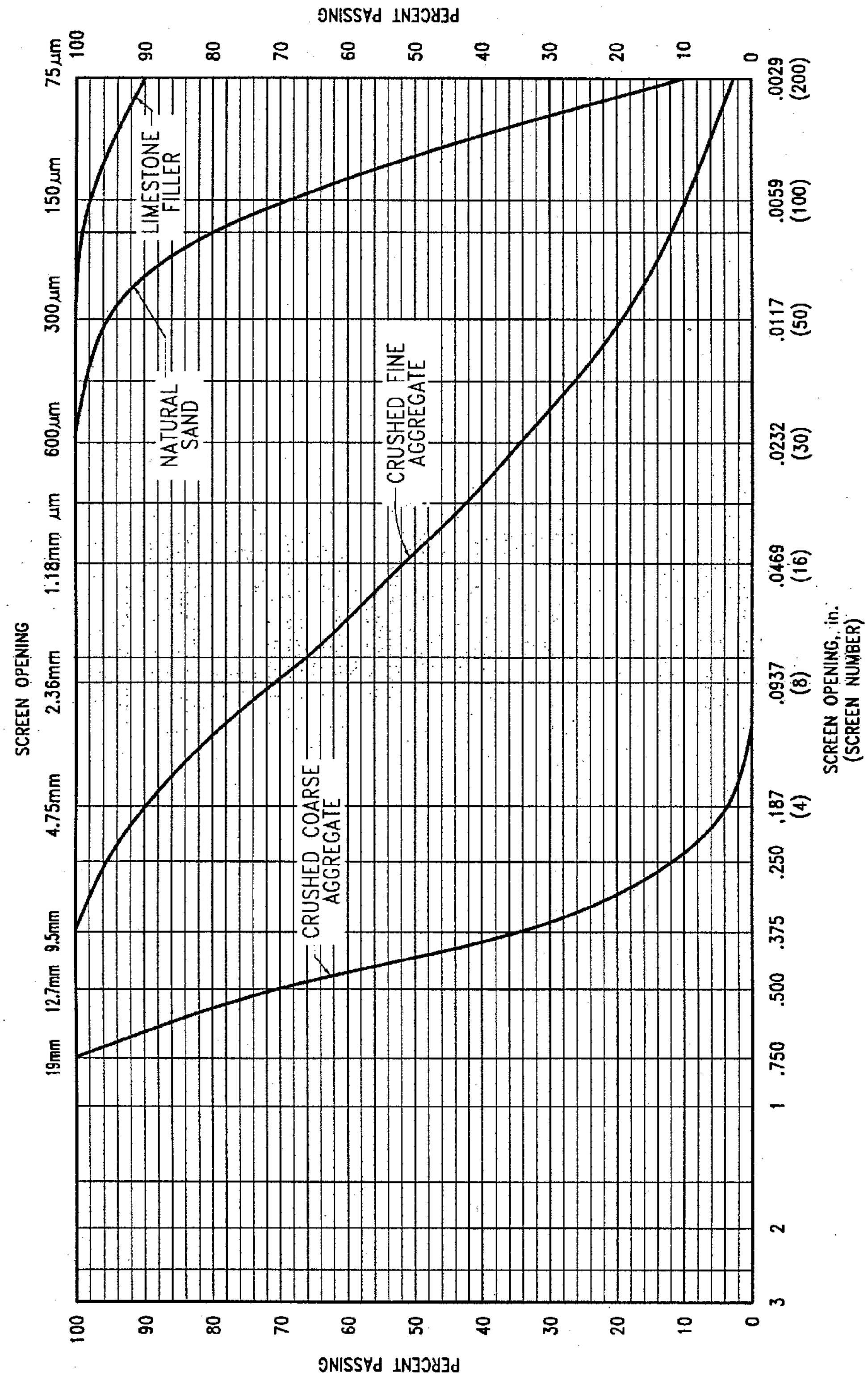
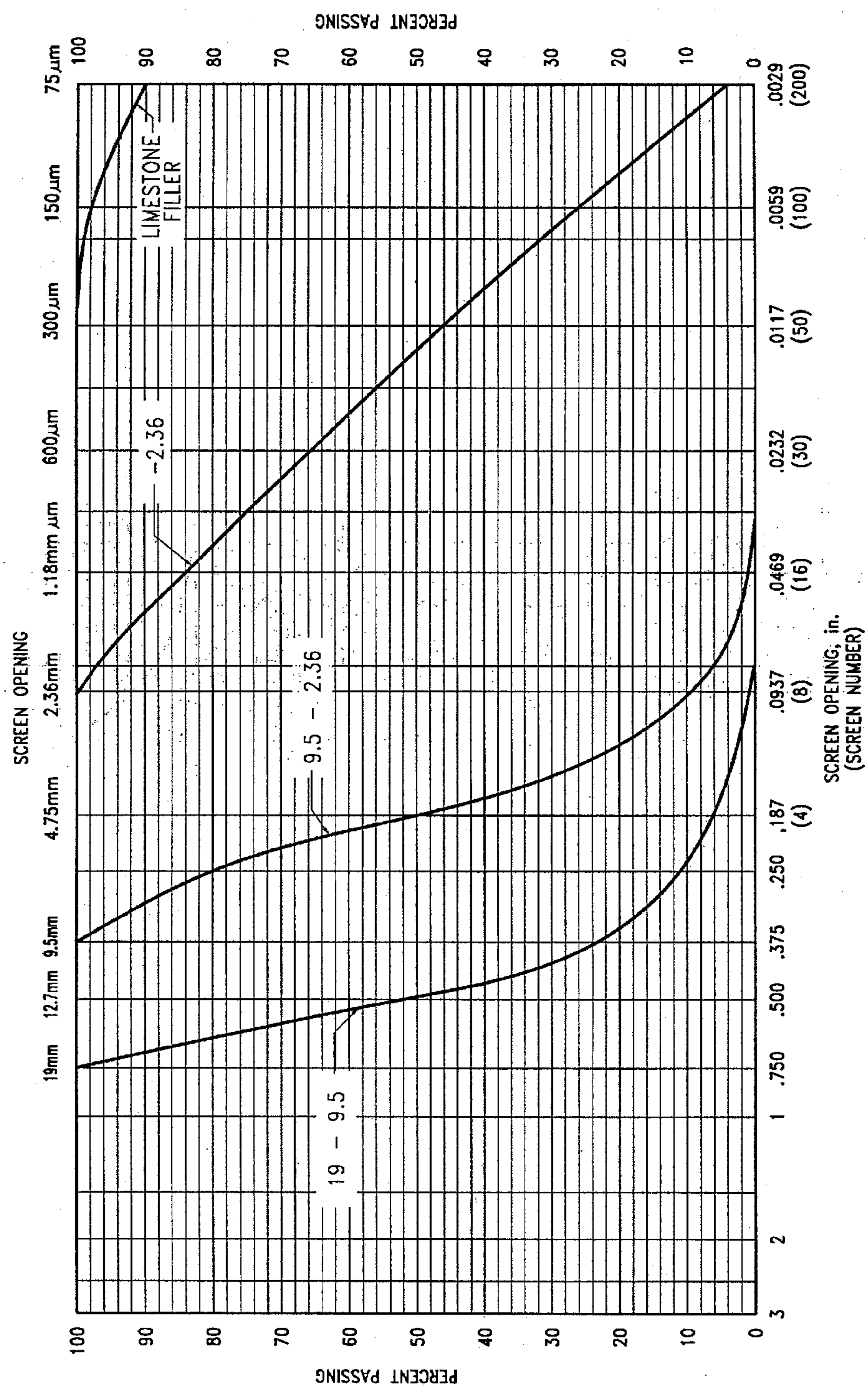


Figure 2-5 Gradation Curves for Bin Samples



2-4.2.4 Asphalt Contents for Specimens.

The quantity of asphalt binder required for an aggregate is important to ensure performance. Procedures are described in paragraph 2-4.2.5. Normally, to start the laboratory tests, an estimate is made of the optimum amount of asphalt binder based on total weight of mix. Laboratory tests usually are conducted for a minimum of five asphalt contents: two above, two below, and one near the estimated optimum asphalt content. Incremental changes of 1 percent of asphalt are used for preliminary work, but increments of 0.5 percent are used for final design.

2-4.2.5 Selection of Design Compaction Method.

DoD use the Marshall mix design method. Specifications have also been prepared for using Superpave mix design procedures which use the Superpave Gyratory Compactor. Procedures for conducting the Marshall mix design tests are described in the Asphalt Institute's Manual Series No. 2 (MS-2) and CRD-C649. The primary difference between the Marshall method and the Superpave method is the method of compaction. A Marshall hammer is used for the Marshall method and a gyratory compactor is used for the Superpave method.

When using CRD-C649, establish the mixing temperature to provide the asphalt binder with a kinematic viscosity of 280±30 centistokes, determined according to the procedure provided in ASTM D2493. A manual hammer is required. When a mechanical hammer is used, calibrate it to provide the same specified density as that obtained with the effort with a manual hammer. It is easier to use a manual hammer for mix design and to use a mechanical hammer once full scale production begins. Compact samples produced at the asphalt plant using 50/75 blows as specified with a manual hammer and a variable number of blows with a mechanical hammer. Then select the number of blows required with the mechanical hammer to produce the specified density equal to that with the required number of blows with the manual hammer. Use this correlation only on the one project and not on additional projects since the correlation varies for different mixes. Verify the accuracy of the calibration weekly during the conduct of the project.

2-4.2.6 Tabulation of Data.

After selecting the laboratory design method and preparing test specimens, tabulate the data on forms similar to those shown in MS-2 or CRD-C649 and CRD-C650 for the Marshall procedure and for Superpave. Arranging data as shown in Table 2-6 facilitates tabulation of specimen test property data. Other material properties needed to make calculations include the bulk specific gravity of the aggregate, which is 2.700 (for this example), and the specific gravity of asphalt binder, which is 1.02 (for this example). Make plots of data from Table 2-6 for stability, flow, unit weight, percent voids total mix (VTM), percent VMA, and percent voids filled with asphalt (VFA) as shown in Figure 2-6(a-f). The desired values of VMA depend on the size of the aggregate particles in the mixture as shown in Table 2-6. The average actual specific gravity of the mixture is obtained for each set of test specimens, as shown in column G of Table 2-6. The unit weight values are determined in accordance with ASTM D2726 and provided in grams per cubic centimeter (g/cm^3) at 25 degrees C (77 degrees F). At this temperature, the average values are multiplied by 997 to convert to kilograms per cubic meter (kg/m^3)(62.24 to obtain the density conversion in pounds per cubic foot (lb/ft^3). Enter these data in column M. Plot the density conversion values as shown in Figure 2-6, and draw the best-fit smooth curve. The data from columns J, K, and L are used to plot curves for percent VTM, VMA, and VFA, respectively, in Figure 2-6. The corrected (converted) stability values in column O and the flow values in column P of Table 2-6 are plotted on Figure 2-6 to evaluate the stability and flow properties of the mixture. For Superpave, flow and stability are not used.

2-4.2.7 Relationship of Test Properties to Asphalt Cement Content.

Test property curves, plotted as described in paragraph 2-4.2.6, have been found to follow a reasonably consistent pattern for mixes made with non-modified grades of asphalt cement. Polymer-modified asphalt cements exhibit less consistent trends. Standard trends shown in Figures 2-6 (a-f) are noted in the following sub-paragraphs:

2-4.2.7.1 Flow.

The flow value increases at an increasing rate with increasing asphalt content. Flow is part of Marshall procedure but not used in Superpave.

2-4.2.7.2 Stability.

The Marshall stability increases with increasing asphalt content up to a point, after which it decreases. Stability is part of Marshall procedure but not used in Superpave.

2-4.2.7.3 Unit Weight.

The curve for unit weight of total mix is similar to the curve for stability, except that the peak of the unit-weight curve is normally at a slightly higher asphalt content than the peak of the stability curve.

2-4.2.7.4 VTM.

VTM decreases with increasing asphalt content. The void content of the compacted mix approaches a minimum void content as the asphalt content of the mix is increased.

2-4.2.7.5 VMA.

The VMA decreases with increasing asphalt content as the mixture becomes better lubricated and easier to compact. As the asphalt content continues to increase, the asphalt occupies space and begins to push apart aggregate particles, thereby increasing the VMA.

2-4.2.7.6 VFA.

The percent VFA increases with increasing asphalt content and approaches a maximum value in much the same manner as the VTM (above) approaches a minimum value.

Table 2-6 Computation of Properties of Asphalt Mixtures (page 1 of 2)

		Weight - Grams				Specific Gravity		Voids - Percent			Unit Weight Total Mix kg/m^3 (lb/ft^3)	Stability - N (lb)		Flow of Units of 0.25 mm (0.01 in.)
Specimen No.	Asphalt Cement %	In Air	In Water	SSD	Volume cc	Actual	Theo	Total Mix	VMA	Filled		Measured	Converted	
A	B	C	D	E	F	G	H	J	K	L	M	N	O	P
						Note 1		Note 1	Note 1	Note 1	Note 1		Note 2	
A-3.5 1	3.5	1228.3	719.3	1231.3	512.0	2.399						8985 (2020)	8985 (2020)	11
2		1219.5	716.2	1223.5	507.3	2.404						8283 (1862)	8612 (1936)	10
3		1205.5	708.3	1208.5	500.2	2.410						8100 (1821)	8425 (1894)	8
4		1206.2	714.4	1212.2	497.8	2.423						8416 (1892)	8754 (1968)	8
Avg						2.409	2.579	6.6	15.2	69.7	2,402 (149.9)		8694 (1954)	9
A-4.0 1	4.0	1276.9	751.3	1280.9	529.6	2411						9386 (2110)	9012 (2026)	10
2		1252.6	736.3	1255.6	519.3	2.412						9008 (2025)	9008 (2025)	9
3		1243.5	734.0	1246.8	512.8	2.425						8874 (1995)	8874 (1995)	9
4		1230.4	726.8	1234.4	507.6	2.424						8985 (2020)	9346 (2101)	9
Avg						2.418	2.559	5.5	14.9	73.0	2,411 (150.5)		9060 (2037)	9
A-4.5 1	4.5	1254.4	741.2	1257.4	516.2	2.430						9119 (2050)	9119 (2050)	12
2		1238.3	729.0	1240.5	511.5	2.421						9319 (2095)	9319 (2095)	9
3		1239.0	727.1	1241.2	514.1	2.410						9386 (2110)	9386 (2110)	10
4		1273.5	754.4	1275.9	521.5	2.442						9097 (2045)	9097 (2045)	10
Avg						2.426	2.539	4.5	14.6	76.4	2,419 (151.0)		9230 (2075)	10
Sp. Gr. of Bit. = 1.020														

- No flow or stability results when Superpave used.

Table 2-6 Computation of Properties of Asphalt Mixtures (page 2 of 2)

Specimen No.	Asphalt Cement %	Weight - Grams In Air	Weight - Grams In Water	Weight - Grams SSD	Volume cc	Specific Gravity Bulk	Specific Gravity Theo	Voids - Percent Total Mix	Voids - Percent VMA	Voids - Percent Filled	Unit Weight Total Mix kg/m^3 (lb/ft^3)	Stability - N (lb) Measured	Stability - N (lb) Converted	Flow of Units of 0.25 mm (0.01 in.)
A	B	C	D	E	F	G	H	J	K	L	M	N	O	P
						Note 1		Note 1	Note 1	Note 1	Note 1		Note 2	
A-5.0 1	5.0	1237.9	729.3	1240.2	510.9	2.423						8985 (2020)	8985 (2020)	14
2		1300.0	766.0	1302.3	536.3	2.424						8283 (1862)	8612 (1936)	10
3		1273.6	749.9	1276.6	526.7	2.418						8100 (1821)	8425 (1894)	12
4		1247.9	733.8	1249.9	516.1	2.418						8416 (1892)	8754 (1968)	12
Avg						2.421	2.519	3.9	14.8	79.1	2,414 (150.7)		8694 (1954)	12
A-5.5 1	5.5	1237.3	726.3	1239.5	513.2	2.411						9386 (2110)	9012 (2026)	12
2		1264.0	743.0	1264.0	521.0	2.415						9008 (2025)	9008 (2025)	14
3		1286.4	754.4	1288.4	534.0	2.409						8874 (1995)	8874 (1995)	13
4		1253.5	738.2	1255.5	517.3	2.412						8985 (2020)	9346 (2101)	16
Avg						2.412	2.500	3.5	15.1	81.2	2,405 (150.1)		9060 (2037)	14
Sp. Gr. of Bit. = 1.020														

- No flow and stability values when Superpave used.

Figure 2-6(a-f) Asphalt Paving Mix Design for Typical Mix

Figure 2-6a VTM vs. Asphalt Content

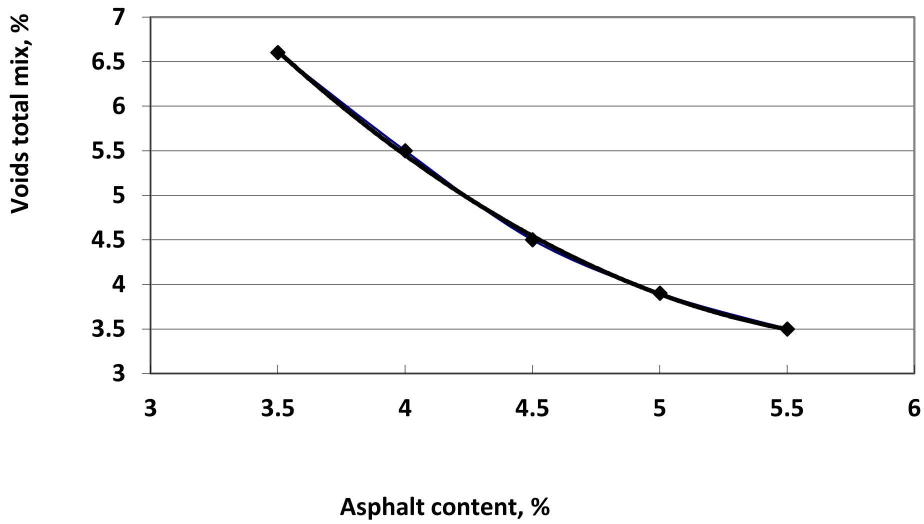


Figure 2-6b Unit Weight vs. Asphalt Content

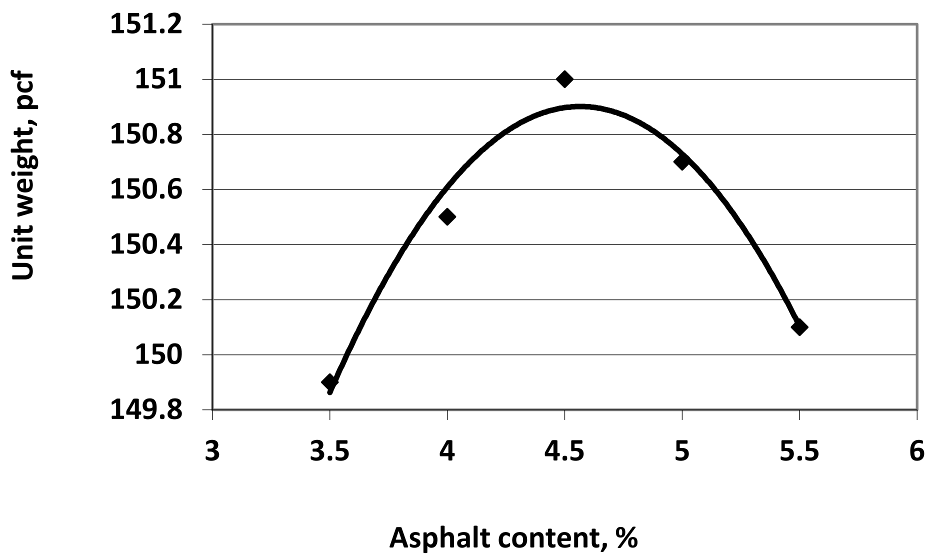


Figure 2-6c VMA vs. Asphalt Content

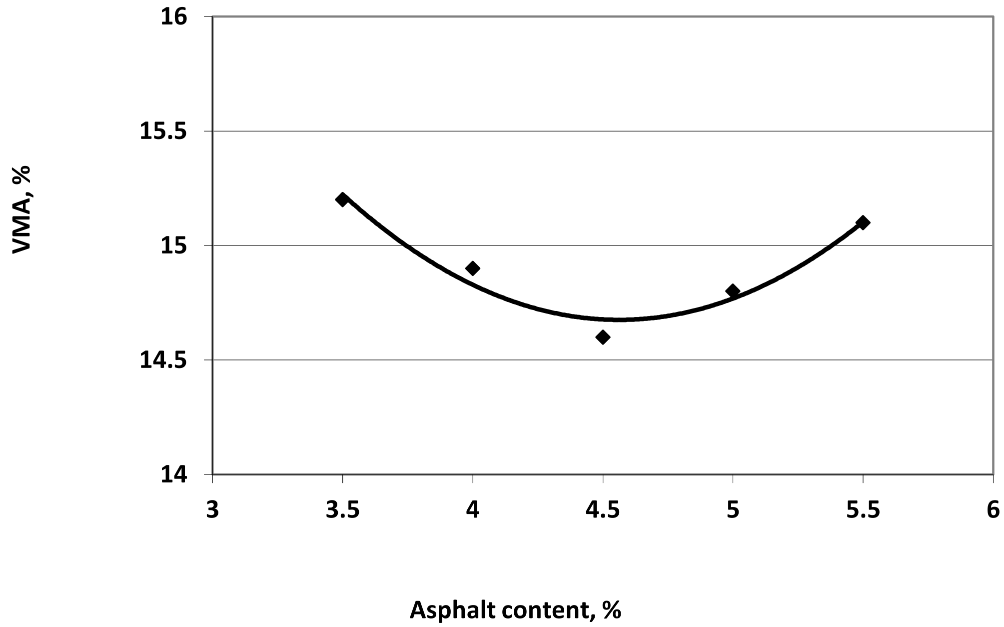


Figure 2-6d Voids Filled vs. Asphalt Content

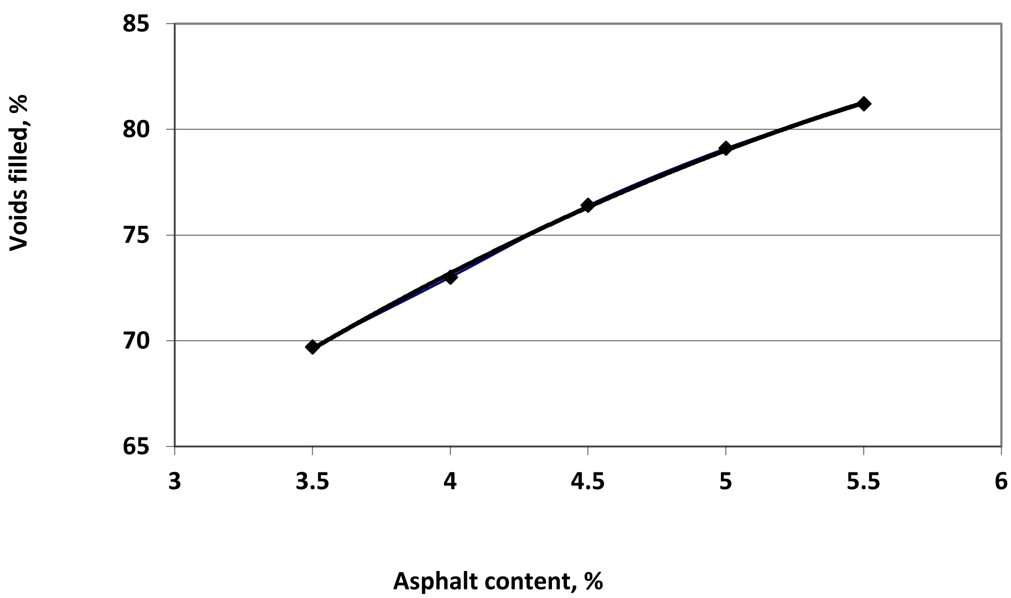


Figure 2-6e Stability vs. Asphalt Content

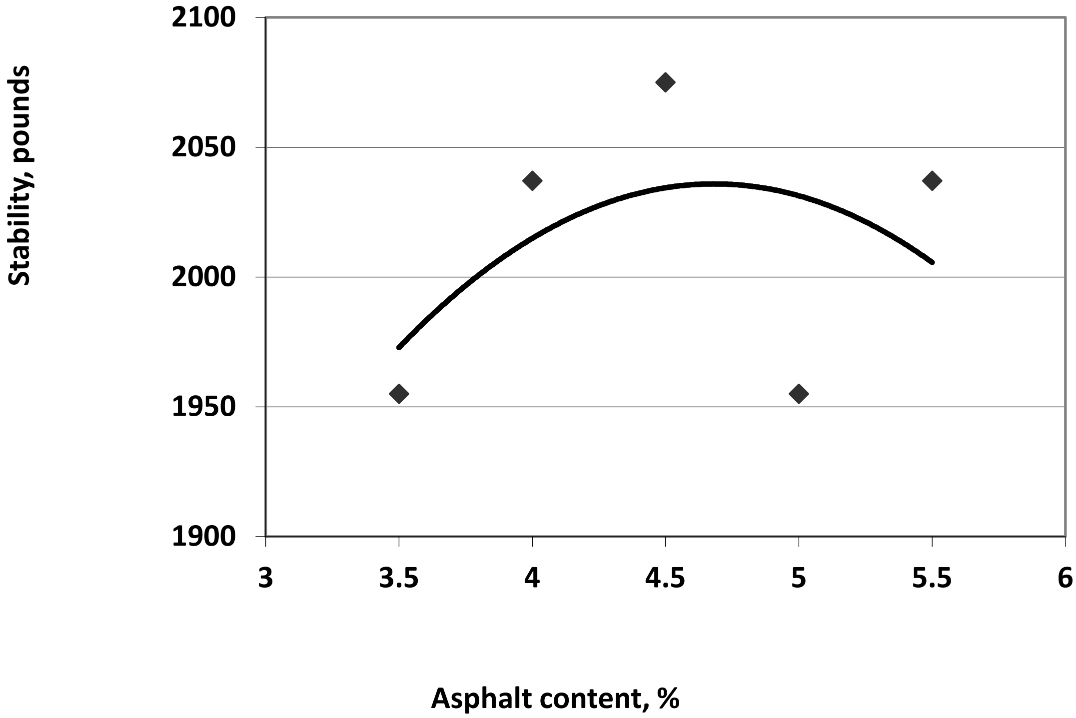


Figure 2-6f Flow vs. Asphalt Content

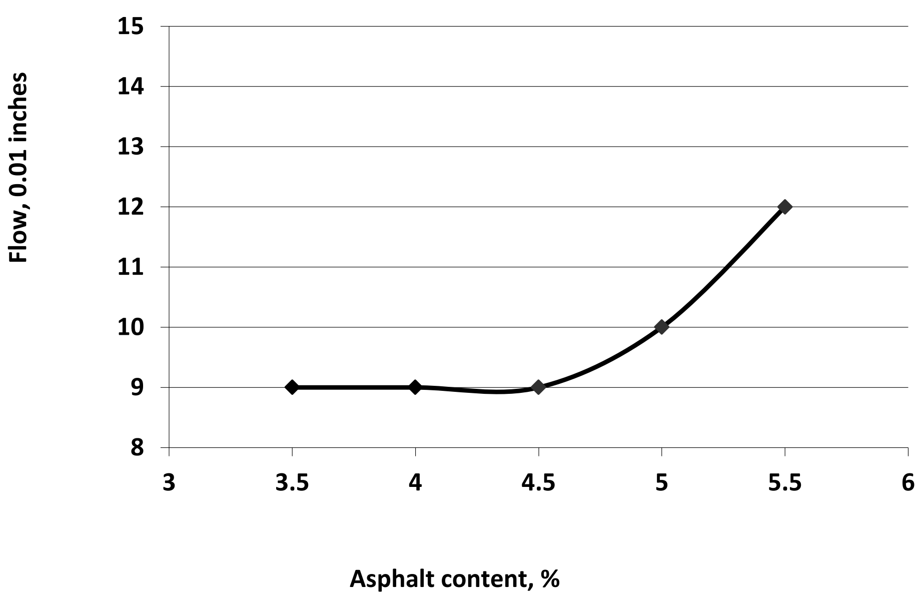


Table 2-7 Minimum Percent Voids in Mineral Aggregate (VMA)

Gradation Type[1]	Minimum VMA, percent
Gradation 1, 25 mm (1-in.) maximum particle size	13.0
Gradation 2, 19 mm (3/4-in.) maximum particle size	14.0
Gradation 3, 12.5 mm (1/2-in.) maximum particle size	15.0
[1] Gradation designations given in Unified Facilities Guide Specification (UFGS) 32 12 15.13	

2-4.2.8 Requirement for Additional Test Specimens.

The curves in Figure 2-6 are typical of those normally obtained when non-modified grades of asphalt cement are used with aggregate mixes. Some aggregate blends furnish erratic data that make plotting the typical curves difficult. In these cases, an increase in the number of specimens tested at each asphalt content normally results in data that plots as typical curves.

2-4.2.8.1 Equations Used for Calculation of Mixture Properties.

These are the mixture properties:

G_b = specific gravity of binder, ASTM D70
G_{sb} = bulk specific gravity of aggregate, ASTM C127 and C128
P_b = percent of total asphalt by weight
G_{mb} = bulk specific gravity of mixture, ASTM D2726
G_{mm} = theoretical maximum specific gravity of mixture, ASTM D2041
V_v = air voids in mixture, percent of total mixture
VMA = voids in mineral aggregate, percent of total mixture
VFA = voids filled with asphalt
W_{dry} = weight of sample after compaction in dry condition
$W_{submerged}$ = weight of sample submerged in water for 3 to 5 minutes
W_{SSD} = weight after removing from water and blotting dry, often called the saturated surface dry (SSD) weight

Determination of bulk specific gravity of mixture: $G_{mb} = \dfrac{Wdry}{W(SSD) - W(submerged)}$

Determination of air voids: $V_v = 100(1 - \dfrac{G_{mb}}{G_{mm}})$

Determination of VMA: $VMA = 100 - \left(\dfrac{G_{mb}(1-Pb)}{G_{sb}}\right)100$

Determination of VFA: $VFA = \dfrac{100(VMA - V_v)}{VMA}$

2-4.2.8.2 Determination of Stability and Flow

Stability and flow are determined by measuring the load and deformation of a sample at failure (ASTM D6927). The adjusted stability is needed to correct samples that are taller or shorter than 6.35 centimeters (2.5 inches) in height to get an equivalent stability to that of a 6.35 centimeters (2.5-inch)-tall sample. The stability is the load to failure, and the flow is the deformation at failure. The samples are corrected for height based on the height of the sample or the volume of the sample, which is determined when evaluating the volumetric properties of the mixture.

Example: Using the data for Specimen No. 1 at 5.0 percent asphalt in Table 2-6, the calculations are shown below for determining the mixture properties. The specific gravity of the binder is known to be 1.02. The bulk specific gravity of the aggregate is 2.70. A sample of the loose mix is obtained and the theoretical maximum density (TMD) is determined. For this example, the theoretical maximum density was determined to be 2.519. Samples of the remaining mixture are compacted using a specified effort and the mixture properties determined. After compaction, the sample is weighed dry, weighed while submerged in water, and weighed in a SSD condition after being removed from the water bath and the surface water blotted.

The sample volume is determined by:

$$Volume = Wssd - Wsubmerged = 1240.2 - 729.3 = 510.9\ cc$$

The bulk specific gravity of the sample is determined by:

$$G_{\mathrm{mb}} = \frac{Wdry}{W(SSD) - W(submerged)}$$

$$G_{mb} = \frac{1237.9}{1240.2 - 729.3}$$

$$G_{mb} = 2.423$$

Multiply this bulk specific gravity by 62.24 (since the test is conducted at 25 degrees C (77 degrees F)) to convert to pounds per cubic foot.

The VTM is determined to be:

$$V_{\mathrm{v}} = 100(1 - \frac{G_{mb})}{G_{mm}})$$

$$V_v = 100(1 - \frac{2.423}{2.519})$$

$$V_v = 3.8 \text{ percent}$$

The VMA is determined to be:

$$VMA = 100 - \left(\frac{G_{mb}(1-Pb)}{G_{sb}}\right)100$$

$$VMA = 100 - \frac{2.423(1-0.05)}{2.70}100$$

$$VMA = 14.8 \text{ percent}$$

The VFA is determined to be:

$$VFA = \frac{100(VMA - V_v)}{VMA}$$

$$VFA = \frac{14.7 - 3.8}{14.7}$$

$$VFA = 79.6 \text{ percent}$$

2-4.2.9 Importance of Asphalt Content.

Previous testing has indicated that optimum asphalt content is an important factor in meeting the specified design of an asphalt paving mixture. Extensive research has resulted in criteria for determining the optimum asphalt content for a given blend of aggregates. Criteria have also been established to determine whether the aggregate furnishes the design paving mix at the selected optimum asphalt content.

2-4.2.10 Determination Optimum Asphalt Content & Acceptability of Mix.

The data plotted in graphical form in Figure 2-6(a-f) is used to illustrate the determination of optimum asphalt content. In addition to the data from Figure 2-6, optimum asphalt content and acceptability of the mix are determined based on Table 2-8. Separate criteria are shown for use where specimens were prepared with 50- or 75-blow compactive efforts. As shown in Table 2-9, the optimum asphalt content is determined at 4 percent air voids for surface or intermediate mixtures and is determined to be 4.9 percent. Table 2-10 shows that at the optimum bitumen content of 4.9 percent, this mixture meets the minimum criteria for acceptability of the mix for a 75-blow compactive effort.

2-4.2.11 Dust/Asphalt Ratio

One check of the design mixture is the dust proportion. This is the ratio of the mass of the aggregate passing the 0.075 mm (No. 200) sieve, divided by the effective asphalt content, in percent of total mass of the mixture. The normal range is 0.8 to 1.2. The ratio is intended to ensure that dust is added to the mix to provide good stability but not so much that results in excessively low asphalt content and subsequent durability problems.

Table 2-8 Design Criteria

Section 1. Procedure for Determining Optimum Asphalt Content					
	Point of Curve				
Property	Type of Mix	50 Blows	75 Blows	50 Gyrations	75 Gyrations
Marshall stability	HMA surface or intermediate course	NA	NA	NA	NA
	Sand asphalt	NA	NA	NA	NA
Unit weight	HMA surface or intermediate course	NA	NA	NA	NA
	Sand asphalt	NA	NA	NA	NA
Flow	HMA surface or Intermediate course	NA	NA	NA	NA
	Sand asphalt	NA	NA	NA	NA
Percent[b] VTM	HMA surface or intermediate course	4	4	4	4
	Sand asphalt	6	NA	6	NA
Percent[b] VMA	HMA surface or intermediate course	NA	NA	NA	NA
	Sand asphalt	NA	NA	NA	NA
Percent[b] VFA	HMA surface or intermediate course	NA	NA	NA	NA
	Sand asphalt	NA	NA	NA	NA
Section 2. Procedure for Determining Acceptability of Mix					
Test Property	**Criteria**				
	Type of Mix	**50 Blows**	**75 Blows**	**50 Gyrations**	**75 Gyrations**
Marshall stability	HMA surface or intermediate course	6.0 kN (1350 lbf) or higher	8.0 kN (1800 lbf) or higher	NA	NA
	Sand asphalt	500 lbf or higher	NA	NA	NA
Unit weight	--	NA	NA	NA	NA
Flow	HMA surface or intermediate course	20 (0.25 mm (0.01 in.)) or less	16 (0.25 mm (0.01 in.)) or less	NA	NA
	Sand asphalt	20 (0.25 mm (0.01 in.)) or less	NA	NA	NA
Percent[b] VTM	HMA surface or intermediate course	3–5 percent	3–5 percent	3-5 percent	3-5 percent
	Sand asphalt	5–7 percent	NA	5-7 percent	NA
Percent VMA	HMA surface or intermediate course	See Table 2-7	See Table 2-7	See Table 2-7	See Table 2-7
	Sand asphalt	NA	NA	NA	NA
Percent VFA	HMA surface or intermediate course	75–85 percent	70–80 percent	75-85 percent	70-80 percent
	Sand asphalt	65–75 percent	NA	65-75 percent	NA

[a] Sand asphalt is not to be used for pavements having traffic with tire pressures above 690 kPa (100 psi).
[b] The theoretical maximum specific gravity is determined by the use of ASTM D2041.

Table 2-9 Determination of Optimum Asphalt Content[1]

Criteria	Asphalt Content, Percent
Flow curve	NA
Stability curve	NA
Unit-weight curve	NA
4 percent air voids from VTM curve	4.9
VMA curve	NA
VFA curve	NA

[1] Based on data in Figure 2-6.

Table 2-10 Evaluation for Acceptability of Design Mix

Test Property	4.9 Percent Asphalt	Criteria for Acceptability
Flow 0.025 centimeters (0.01 inch)	10	< 16
Stability, kN (lbf)	9.0 (2,030)	> 8.0 (1,800)
Percent VTM	4.0	3–5 percent (HMA)
Percent VMA	14.8	14 min
Percent total VFA	78	70–80 percent (HMA)

2-4.2.12 Moisture Susceptibility.

The final evaluation of the design mixture involves a test for moisture susceptibility. The TSR of the mixture at the selected optimum is performed according to ASTM D4867. A TSR value of less than 75 percent requires the use of an antistrip additive in the mixture.

2-4.2.13 Superpave Mix Design.

Superpave mix design is acceptable for airfield pavements. UFGS 32 12 15.13 provides for use of Superpave mix design as an option for the designer. Marshall mix design and Superpave mix design share common guidance. The aggregate and asphalt binder requirements are the same whether Marshall or Superpave is used. A difference is the way samples are compacted. For Marshall, samples are compacted with a Marshall hammer. For Superpave, samples are compacted with a Superpave gyratory compactor. Samples for Marshall are 102 millimeters in diameter (4 inches) and 64 millimeters tall (2.5 inches). For Superpave, samples are 150 millimeters in diameter (6 inches) and 115 millimeters tall (4.6 inches); hence, sample material is larger for a Superpave mix design than for a Marshall mix design. For Superpave, the number of gyrations is set at 75 for high tire pressures greater than 1380 kPa (200 psi) and 50 for low tire pressures for less than 1380 kPa (200 psi).

The asphalt content is varied in 0.5 percent increments just as with Marshall mix design. Stability and flow tests are not conducted for Superpave designed mixes. Plots of the data that obtained with a Superpave mix design are provided in Figure 2-6, a-d. The quality of the mix is based on air voids, VMA, and voids filled with asphalt. The specification requirements for air voids, VMA, and voids filled with asphalt are the same for Superpave as for Marshall. These properties are determined for Superpave mixtures in the same way that they are determined for Marshall mixes. The optimum asphalt content is selected at 4 percent air voids. Moisture susceptibility testing is performed to ensure acceptability of the mixture, just like with Marshall.

Hence, the Superpave mix design and Marshall mix design procedures are almost identical except for the type of compactor used, the size of sample, and the fact that flow and stability are not part of the Superpave mix design procedure. The Superpave mix design compactive effort (number of gyrations) was selected to match that for Marshall (75 blows with Marshall hammer is equal to 75 gyrations with the Superpave gyratory machine and 50 blows with the Marshall hammer is equal to 50 gyrations with the Superpave gyratory machine). Hence for a specific aggregate, it is expected that the mix design provide the same results whether using Marshall or Superpave.

2-4.3 Mixture Control.

2-4.3.1 JMF Production at Asphalt Plant.

After the aggregate and asphalt binder qualities have been determined to meet the required mix design has been completed, the next step is to ensure that the JMF is produced at the asphalt plant. To evaluate the quality of the material produced and to ensure the required paving mixture is produced, a complete plant laboratory is required. Locate the laboratory at the plant site and ensure it contains the same equipment as that listed in MS-2 or CRD-C649 and CRD-C650. Because of the capacity of asphalt plants, assign at least two technicians to conduct control tests; otherwise, all testing cannot be completed in a timely manner.

2-4.3.2 Asphalt Plant Laboratory Burden.

The heaviest demands on plant laboratory facilities occur at the initiation of plant production. Feed aggregates and asphalt binder through the plant at a relatively constant rate and at the correct proportions. The gradation of the aggregate supplied by the plant often does not precisely reproduce the job mix formula developed in mix design. This often requires that the job mix formula be modified slightly. The specifications provide guidance on how much the mix is modified without requiring a new mix design. Feed the aggregates and asphalt binder through the plant at a constant rate to obtain efficient plant operation and to produce a mixture conforming to requirements.

2-4.3.3 Mix Adjustments.

The aggregates obtained from the hot bins of batch plants cannot be proportioned to exactly reproduce the gradation of the aggregate used in the laboratory design. Similarly, the gradation of the aggregates that have passed through a drum-mixer plant do not entirely duplicate the gradation used in the mixture design. This occurs because fines are generated during handling and production operations. Usually only slight adjustments are required to the original mix design and a completely new design is not required. If the change in gradation is substantial to prevent the contractor from meeting the mix design gradation (i.e., the gradation does not meet the job mix formula), it is necessary to adjust or redesign the mix using plant-produced aggregates. Specimens are prepared and tested for the new design in the same manner as for the original design tests. The optimum asphalt content and acceptability of the mix produced by the plant are determined. Perform sufficient additional tests to establish the optimum asphalt requirements and to ensure that the mix meets the applicable criteria.

2-4.3.4 Production & Laydown Quality Control & Quality Assurance.

Control several items routinely during the production and laydown operation to provide the specified pavement. As part of the quality control program, test for and control, at a minimum, asphalt content, aggregate gradation, temperatures, aggregate moisture, moisture in the asphalt mixture, laboratory air voids, VMA, stability, flow, in-place density, grade, and smoothness. As part of a quality assurance program, test mixture items including: aggregate gradation, asphalt content, voids, and VMA. The laydown items include density, smoothness, and final grade. Measure and analyze these items statistically. These items are air voids, density (mat and joint), and final grade. When these items do not meet the specified requirements, the contract unit price is reduced or the mixture is rejected. Projects of less than 1,000 metric tons (1,000 tons) of hot-mix are constructed without the pay reduction clause for economic reasons.

2-4.3.4.1 QA Methodology.

To evaluate the quality of a job, the work is divided into lots. Each lot is considered as a separate job and as such is evaluated solely on the test results for that lot. Ensure a lot does not exceed 2,000 metric tons (2,000 tons) of production or one normal day’s production. Subdivide the lot into four equal sublots, and take a random sample from each sublot for evaluation of air voids, asphalt content, and density. The random sublot sample for these properties includes one sample of uncompacted asphalt mixture, one field core from a pavement joint area, and one field core from the compacted HMA.

ASTM D3665 provides detailed information on how to determine sampling locations within a sublot. As an example, suppose that 1,000 metric tons (1,100 tons) (one lot) of HMA were placed in two adjacent lanes, one lane 2,000 meters (6,600 feet) long and the other 1,000 meters (3,300 feet) long. The width of each paving lane was 3 meters (10 feet). The joint length between the two lanes is 1,000 meters (3,300 feet); thus, one sample is taken at random for each 250 meters (825 feet) of joint length to evaluate joint density. The total length of the two lanes is 3,000 meters (9,900 feet); therefore, take one random sample from the mat for each 750 meters (2,475 feet) of HMA. Ensure the mat core samples are at least 0.3 meter (1 foot) away from any joint, the effective width of the paving lanes is 2.4 meters (8 feet). Obtain two random numbers and multiply the first one times the length and the second times the width to give the location for the core within the sublot. In this case, with random numbers of 0.108 and 0.485, the location of the core from the beginning of the sublot is 750 meters (2,500 feet)×0.108 = 81 meters (270 feet) and 2.7 meters (9 feet)×0.485 = 1.31 meters (4.3 feet) from 0.3 meter (1 foot) inside the designated left or right edge of the pavement. The random samples do not have to be precisely located, but it is important that the procedure being used to locate the sampling location is based on a standard form of measurement and is not affected by surface appearance.

2-4.3.4.2 QC Methodology.

The asphalt content and aggregate gradation is determined from samples of the asphalt mix taken between the production and the laydown operation. It is preferred that samples be taken from the back of loaded trucks before they leave the asphalt plant. It is also acceptable to take samples from other locations such as truck at laydown site or from behind the paver. Take samples from the paver hopper or at the paver auger during production. This is not acceptable since this practice is unsafe and it is extremely difficult to obtain a sample in this way. ASTM D979 and D3665 provide information needed for obtaining samples.

If a lot size equal to 1,000 metric tons (1,000 tons) is selected, ensure a sample of asphalt mix is taken for each 250 metric tons (250 tons) produced. Obtain a random number of each 250 metric tons (250 tons) produced. As an example, suppose that a random number is selected between 1 and 250 and is determined to be 200. This selection means that the 200th ton batched is sampled.

2-4.3.4.3 Air Void and Asphalt Content Deviations from JMF.

After the four asphalt contents and corresponding void values are determined for a lot, these results are compared with the JMF and the absolute difference is determined. Suppose the design air void content is 4.0 percent and the four air void contents of the sampled mixtures are determined to be 3.5, 3.0, 4.0, and 3.7. The mean absolute deviation from the JMF is determined to be:

$$\text{Mean absolute deviation} = (0.5+1.0+0.0+0.3)/4 = 0.45$$

The same procedure is used to determine the mean absolute deviation for asphalt content. After the mean absolute deviation is determined for the air void content and asphalt content for a lot, the maximum percent payment for that lot is determined from the tables provided in the specification requirements.

2-4.3.4.4 Density Measurements.

Determine density within the mat and at the joints between mats. Density measurements for acceptance is measured from cores taken from the pavement. Density gauges are not acceptable for acceptance testing. Obtain one sample in the mat and one in the joint for each sublot. The total linear length of joint constructed for a given lot is divided into quarters and one random sample taken for each sublot. These sample locations are determined in a similar way as that for aggregate gradation and asphalt content. Take all mat samples at least 0.3 meter (1 foot) from the edge of mat or joint. Use ASTM D3665 to determine sample locations in the mat and joint. ASTM D5361 provides information on obtaining the pavement sample.

The mat density and joint density for each sublot is expressed as a percentage of the theoretical maximum density (TMD) for that sublot. When a joint core sample is taken across two sublots, the density is determined using an average of the TMD for each of the two sublots. Suppose that the TMD for four consecutive sublots within a lot was 2,408 kilograms per cubic meter, 2,398 kilograms per cubic meter, 2,389 kilograms per cubic meter, and 2,421 kilograms per cubic meter, yielding an average TMD value of 2,404 kilograms per cubic meter. Further assume that the corresponding four sublot mat samples have individual densities of 2,324 kilograms per cubic meter, 2,356 kilograms per cubic meter, 2,348 kilograms per cubic meter, and 2,373 kilograms per cubic meter, and that the four corresponding sublot joint samples have individual densities of 2,311 kilograms per cubic meter, 2,324 kilograms per cubic meter, 2,343 kilograms per cubic meter, and 2,325 kilograms per cubic meter. Based on these results, the mat lot density is determined as:

$$\text{Mat density} = \frac{2{,}324 + 2{,}356 + 2{,}348 + 2{,}373}{4(2{,}404)} = 97.8\ \text{percent}$$

and the average joint density is:

$$\text{Joint density} = \frac{2{,}311 + 2{,}324 + 2{,}343 + 2{,}325}{4(2{,}404)} = 96.8\ \text{percent}.$$

The average density in the mat and the average density in the joint are used along with the tables in the specifications to determine the maximum percent payment for the lot of material being evaluated.

2-4.3.4.5 Evaluation of Grade and Smoothness.

The surface of the completed pavement is evaluated on a systematic basis to determine the acceptability of grade and smoothness. The results are compared with the specification requirements to determine the percent payment for grade and smoothness.

2-4.3.4.6 Quality Control Charts.

To properly evaluate the quality control of a mixture and maintain up-to-date records of test results, maintain control charts. It is recommended that the control charts be plotted for the critical sieves in the gradation requirements. The critical sieves include the 4.75 millimeters (No. 4) and 75 micrometers (No. 200) sieves. The plots are also to be made for asphalt content, laboratory density, stability, flow, VTM, VFA, mat density, and joint density. Make a plot of individual values and for the running average of four samples.

Subparagraphs a through c provide an example of the use of control charts. Assume that the density results shown in Table 2-11 were obtained from the in-place mat.

Table 2-11 Lot Density as a Percent of Laboratory Density

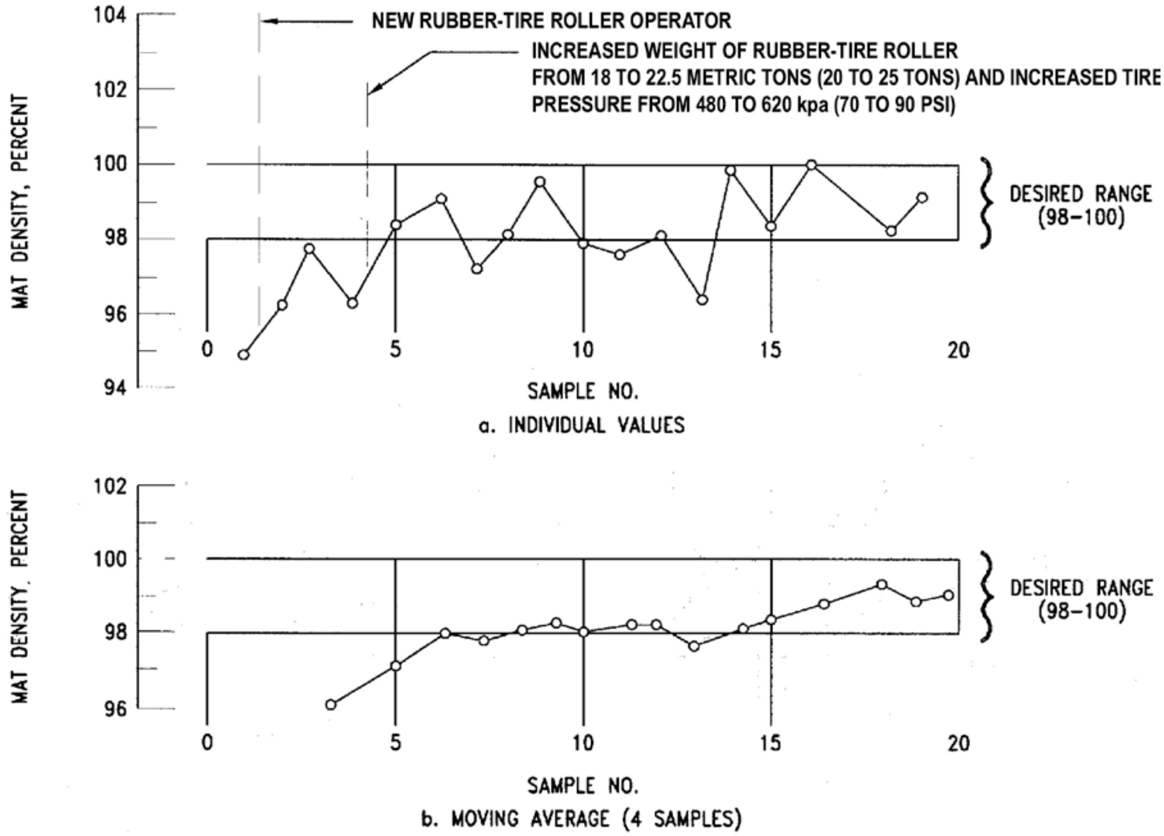
Lot 1	Lot 2	Lot 3	Lot 4	Lot 5
95.2	98.4	99.5	98.1	100.0
96.4	99.1	98.0	96.8	99.1
97.8	97.3	97.5	99.8	98.3
96.6	98.1	98.3	98.6	98.9
Average				
96.5	98.2	98.3	98.3	99.1

a. Figure 2-7 shows the control charts for mat density. The first test result obtained is plotted in Figure 2-7, a. Note that this measurement falls below the desired range. At this point, it is concluded that the process is out of control; thus, stop the operation until the cause of the deficiency is identified and corrected.

b. The second, third, and fourth samples are those obtained after corrections to the process, and they are higher but still below the desired range. At this point, the weight of the rubber-tired roller used to compact the mat was increased from 18 to 22.5 metric tons (18 to 22 tons), and the tire pressure was increased from 480 to 620 kilopascals (70 to 90 psi). After these changes, the density results were within the desired range.

c. The moving average is determined for the last four samples tested (Figure 2-7, b). Plotting the moving average smoothes out the plot of individual values and allows trends to be spotted more readily.

Figure 2-7 Mat Density Control Chart



2-4.4 Significance of Changes in Mixture Properties.

As a general rule, most of the QC test results (for example, air voids, VMA, asphalt content, gradation) are obtainable quickly and are reasonably reliable indicators of the consistency of the plant-produced mix. A measurable change in these properties or properties outside the specified limits indicates that there is a mixture problem. A review of the control charts normally indicates the problem. Adjust mix proportions whenever any test property consistently falls outside of the specified tolerances. In the case of batch plants, the use of faulty scales and the failure of the operator to accurately weigh the required proportions of materials are common causes for paving-mixture deficiencies. Improper weighing or faulty scales need to be detected readily and corrective measures taken by maintaining a close check of load weights. Figure 2-8 lists other probable causes of paving-mixture deficiencies. For drum mix plants, a mixture problem typically is an indication that the rate of feed of one or more of the materials into the plant is incorrect.

Figure 2-8 Types of HMA Deficiencies and Probable Causes

Probable Causes of Deficiencies in Hot Plant Mix Paving Mixtures / Types of Deficiencies That May Be Encountered in Producing Hot Plant Mix Paving Mixtures

Item	Probable Cause	Bitumen content fails to check job-mix formula	Gradation fails to check job-mix formula	Poorly mixed loads	Fat, rich mixtures	Lean or burned mixtures	Mixture temperature fails to check job mix	Smoking loads	Steaming loads	Overweight or underweight loads	Lack of uniformity of mixtures in loads
1	Aggregate scales out of adjustment	X	X		X	X					
2	Bridging of hot aggregate in bin		X							X	X
3	Bitumen scales out of adjustment	X			X	X				X	X
4	Lack of proper weighing by operator	X	X		X	X				X	X
5	Faulty pug mill dump gate	X	X	X	X	X				X	X
6	Bitumen temperature too high			X	X	X	X				X
7	Drum feed not uniform						X	X	X		
8	Improper dryer operation					X	X	X	X		
9	Too little bitumen	X				X					X
10	Too much bitumen	X			X						X
11	Sampling method not uniform	X	X		X	X					
12	Excessive moisture content of aggregate								X		X
13	Bin overflow pipes not functioning	X	X								X
14	Leaky bins	X	X		X	X					X
15	Segregation of aggregates in bins		X								X
16	Mixing time not uniform	X		X							X
17	Mineral filler feed not uniform	X	X		X						X
18	Aggregate temperature too high					X	X	X			
19	Temperature mechanism out of adjustment					X	X	X	X	X	X
20	Improper feed of aggregates to dryer	X	X		X	X		X	X		X
21	Overrated dryer capacity						X		X		X
22	Faulty screen operation		X								X
23	Overloaded pug mill			X							X
24	Improper set on pug mill	X	X	X							X
25	Bitumen and aggregate feed out of adjustment	X	X		X	X					X
26	Bitumen pump not functioning properly	X			X	X					
27	Not sufficient hot aggregate in storage bins	X	X								X
28	Aggregate gates not properly set	X	X		X	X					X

Items 6 to 23 are applicable to all types of plants. Items 1 to 5 and items 24 to 28 are applicable to batch plants and volumetric plants, respectively.

2-4.4.1 Hot-bin Gradations.

When batch plants are used, conduct the hot-bin gradation tests at least once daily during operation. Determine hot-bin gradations on all bins in conjunction with sampling of the pavement mixture. Determine washed sieve analyses initially.

2-4.4.2 Construction Control.

Well-designed mixes are compacted by adequate field rolling to about 98 percent or greater of the density obtained by compacting specimens with previously specified laboratory procedures (or at least 94 percent of theoretical maximum density). Roll asphalt intermediate, base course, or surface course mixes until the density specified is met.

2-4.4.3 Pavement Sampling.

Take samples for determining pavement density and thickness either with a coring machine (with a core barrel nominal diameter of at least 100 millimeters (4 inches)) or by cutting out a section of pavement at least 100 millimeters (4 inches) square with a concrete saw. When the compacted thickness of the pavement is less than 50 millimeters (2 inches), use a 150-millimeter (6-inch) -diameter core barrel to obtain the sample. Ensure these samples include the entire thickness of the layer of asphalt mixture being evaluated. Take density samples of each day’s production and have delivered to the project laboratory by noon of the following day, and make the density determinations by the end of the day. Any changes in placing technique to obtain the required density is made immediately prior to placing additional pavement.

2-4.4.4 Testing Pavement Samples.

Prepare pavement samples for testing by carefully removing all particles of base material or other foreign matter. Carefully trim broken or damaged edges of sawed samples for density tests carefully from the sample. Take thickness measurements before separating the sample into layers. Split a sample consisting of an intermediate course and surface course at the interface of these layers before testing. Usually these courses are separated with only a few blows of a sharp-edged chisel at the interface. When possible, use a concrete table saw to separate layers of pavement. This is true when the underlying surface was a milled layer or the asphalt was placed directly on a crushed stone base. Eliminating excess tack, uncoated aggregate, and voids from the bottom of a core sample greatly increase the accuracy of density measurements. Determine the density of the sawed samples by weighing them in air and in water and as described in paragraphs 2-4.2.6 and 2-4.2.8. Discard samples from which density measurements are desired if damage is apparent. Take additional samples from the same sublot.

Nuclear gauges and other nondestructive density tests are currently being used to check the density of HMA. These methods are fast, but the results are often questionable. Factors that affect the results of density measurements with the nondestructive gauges are the thickness of the asphalt mixture, the density of the material below the asphalt mixture, moisture, and smoothness at the test location. The nondestructive density gauges are useful for developing roller patterns, but conduct density tests for acceptance by removing samples from the pavement and weighing them in air and water to determine density.

2-4.4.5 Density Data.

Density data obtained from specimens in the manner described in paragraphs 2-4.2.6 and 2-4.2.8 is compared with the average laboratory density or theoretical maximum density for the same lot.

2-4.4.6 Pavement Imperfections and Probable Causes.

Pavement imperfections result from not following specified laying and rolling operations as well as not meeting specified mix designs or faulty plant operation. These imperfections are controlled only by inspection. Figure 2-9 presents these potential pavement imperfections result.

2-5 POROUS FRICTION COURSE.

A PFC is an open-graded, free-draining asphalt paving mixture that is placed on an existing pavement to minimize hydroplaning and to improve skid resistance in wet weather. PFC is just another name for open-graded friction course (OGFC) used by many state DOT agencies. Do not use this surface for low-speed applications or in areas subjected to tank traffic. The thickness of the finished course varies from approximately 19 millimeters (3/4 inch) to 25 millimeters (1 inch). A PFC has a coarse surface texture and is sufficiently porous to permit drainage of water internally as well as along the surface. A combination of water pressure relief through the internal and surface voids and the rough surface texture promotes tire-to-aggregate contact. PFC paving mixtures are produced in HMA plants and placed with conventional asphalt paving machines. Place them on pavements that are in good condition. Similar to Section 2-1.2, determine if a leveling course is required to achieve the desired surface conditions before construction of the PFC. Due to performance issues, FOD potential, PFCs have not been used on airfields in recent years.

2-5.1 Materials.

2-5.1.1 Aggregates.

High-quality aggregates are required for PFCs with a maximum Los Angeles (LA) abrasion loss (ASTM C131) of 25 percent and 40 percent for high and low tire pressure loadings, respectively. A crushed aggregate is required and has a minimum of 90 percent by total weight of aggregate with one crushed face and 70 percent with two crushed faces. Specify antistrip agents when required. Design, specify and use an antistripping agent not only in the PFC but also in the underlying HMA layer regardless of the results from the TSR test (ASTM D4867/D4867M). Table 2-12 presents the aggregate gradation requirements for PFCs.

Figure 2-9 Types of HMA Pavement Imperfections and Probable Causes

Probable Causes of Imperfections in Finished Pavements \ Types of Pavement Imperfections That My Be Encountered in Laying Hot Plant Mix Paving Mixtures	Bleeding	Brown, dead appearance	Poor surface texture	Rough uneven surface	Uneven joints	Roller marks	Shoving	Waves	Cracking	Honeycomb	Tearing of surface during laying
Excessive moisture in mixture		X					X				
Not cut back to uniform thickness					X						
Inadequate cross rolling				X		X					
Excess of bitumen in mixture	X						X				
Lack of bitumen in mixture		X							X		X
Mixture too coarse	X		X						X	X	
Roller standing on hot pavement				X				X			
Faulty allowance for compaction					X						
Unstable basecourse				X				X			
Poorly graded mixture	X		X				X		X		
Rolling mixture when too cold				X	X	X			X		
Rolling mixture when too hot				X			X	X			
Mixture too cold				X	X		X	X	X	X	X
Mixture too hot or burned		X					X				
Poor spreader operation				X	X			X		X	X
Inadequate rolling				X		X					
Excessive segregation in laying	X		X	X					X	X	
Poor handwork behind spreader				X	X			X		X	
Unsatisfactory batches in load	X		X	X			X		X	X	X
Improper proportioning	X		X	X			X		X	X	
Excessive primecoat	X										

Table 2-12 Aggregate Gradation for PFCs

Sieve Designation (Square Openings)	Percent Passing by Weight of Total Aggregates	
	Gradation "A" 19 mm (3/4-inch) Maximum (Compacted Nominal Thickness, 25 mm, 1 inch)	Gradation "B" 12.5 mm (1/2-inch) Maximum (Compacted Nominal Thickness, 19 mm, 3/4 inch)
19 mm (3/4 inch)	100	100
12.5 mm (1/2 inch)	70–100	100
9.5 mm (3/8 inch)	35–75	80–100
4.75 mm (No. 4)	25–40	25–40
2.36 mm (No. 8)	10–20	10–20
600 µm (No. 30)	3–10	3–10
75 µm (No. 200)	0–5	0–5

2-5.1.2 Asphalt Cement.

Test requirements for asphalt cements are outlined in specifications (ASTM D946, D3381, D6373, or AASHTO M320). Guidance on the selection of an asphalt type is provided in section 2-3.1. Historically, many PFCs were constructed using modified asphalt to improve the ability of the asphalt to hold the aggregate in place and reduce oxidation deterioration in the porous mat. When using PFC, specify polymer modified asphalt cement.

2-5.2 Mixture Design.

2-5.2.1 Proportioning of Aggregates.

For PFC use polymer modified asphalt and fibers. The modified asphalt and fibers help to reduce draindown when storing for a short period of time and during haul to the paving site. Select the aggregate gradation from Table 2-12.

2-5.2.2 Fiber Stabilizers.

Tables 2-13 and 2-14 provide the requirements and test procedures to be used with cellulose and mineral fibers, respectively. The dosage rates normally used for cellulose fibers is 0.3 percent by weight of the total mix and for mineral fibers is 0.4 percent by weight of the total mix. The recommended tolerance for the fibers is 10 percent of the required fiber weight.

Table 2-13 Properties of Cellulose Fibers (after NAPA 1999)

Properties	Requirement
Sieve Analysis Method A, Alpine Sieve[1] Analysis Fiber length Passing 150 μm (No. 100) sieve Method B, Mesh Screen[2] Analysis Fiber length Passing 850 μm (No. 20) sieve 425 μm (No. 40) sieve 106 μm (No. 140) sieve	 6 mm (0.25 in.) (max.) 70% (±10%) 6 mm (0.25 in.) (max.) 85% (±10%) 65% (±10%) 30% (±10%)
Ash Content[3]	18% (±5%) non-volatiles
pH[4]	7.5 (±1.0)
Oil Absorption[5]	5.0 (±1.0) (times fiber weight)
Moisture Content[6]	< 5% (by weight)

[1] Method A, Alpine Sieve Analysis. This test is performed using an Alpine air jet sieve (Type 200 LS). A representative 5-gram (0.18 oz) sample of fiber is sieved for 14 minutes at a controlled vacuum of 75 kPa (11 psi). The portion remaining on the screen is weighed.

[2] Method B, Mesh Screen Analysis. This test is performed using standard 850, 425, 250, 180, 150, 106 μm (No. 20, 40, 60, 80, 100, 140) sieves, nylon brushes, and a shaker. A representative 10-gram sample of fiber is sieved using a shaker and two nylon brushes on each screen. The amount retained on each sieve is weighed and the percentage passing calculated. Repeatability of this method is suspect and needs to be verified.

[3] Ash Content. A representative 2- to 3-gram (0.07 – 0.11 oz) sample of fiber is placed in a tared crucible and heated between 595 and 650 degrees C (1100 and 1200 degrees F) for not less than 2 hours. The crucible and ash are cooled in a desiccator and reweighed.

[4] pH Test. Five grams (0.18 oz) of fiber is added to 100 ml (0.106 quarts) of distilled water, stirred, and let sit for 30 minutes. The pH is determined with a probe calibrated with pH 7.0 buffer.

[5] Oil Absorption Test. Five grams(0.18 oz) of fiber is accurately weighed and suspended in an excess of mineral spirits for not less than 5 minutes to ensure total saturation. It is then placed in a screen mesh strainer (0.5 square millimeter [7.75×10^{-4} square inch] hole size) and shaken on a wrist action shaker for 10 minutes, 3.2 centimeter (1.25 inch) motion at 240 shakes per minute). The shaken mass is then transferred without touching, to a tared container and weighed. Results are reported as the amount (number of times its own weight) the fibers absorb.

[6] Moisture Content. Ten grams (0.35 oz) of fiber is weighed and placed in a 121 degrees C (250 degrees F) forced air oven for 2 hours. The sample is then reweighed immediately upon removal from the oven.

Table 2-14 Properties of Mineral Fibers[1] (after NAPA 1999)

	Properties	Requirement
Sieve Analysis	Fiber length[2]	6 mm (0.25 in.) max. mean text value
	Thickness[3]	5 μm (0.0002 in.) max. mean test value
Shot Content[4]	250 μm (No. 60) sieve	95 percent passing (min.)
	63 μm (No. 230)	65 percent passing (min.)

[1] The European experience and development of the above criteria are based on the use of basalt mineral fibers.

[2] The fiber length is determined according to the Bauer-McNett fractionation.

[3] The fiber diameter is determined by measuring at least 200 fibers in a phase contract microscope.

[4] Shot content is a measure of non-fibrous material. The shot content is determined on vibrating sieves. Two sieves, 250 μm (No. 60) and 63 μm (No. 230), are used; for additional information see ASTM C612.

2-5.2.3 Asphalt Content.

The asphalt content of PFCs is expressed as a percentage of the total mix by weight. A surface area constant, K_c, as described in the centrifuge kerosene equivalent (CKE) test (ASTM D5148), is used to determine the optimum asphalt content. The K_c value is used in the relation $2K_c+4.0$ to determine the estimate of asphalt (EOA). This asphalt content is valid for aggregates with an apparent specific gravity in the range of 2.60 to 2.80 and with a water absorption value less than 2.50 percent when tested by ASTM C127 for coarse aggregate and ASTM C128 for fine aggregate. A slight increase in asphalt content (up to 0.5 percent) is required when the absorption is greater than 2.50 percent. The EOA is inversely proportional to the specific gravity of the aggregate, ensure adjustments are made when the specific gravity is outside of the 2.60 to 2.80 range.

2-5.2.4 K_c Factor.

The K_c factor indicates the relative particle roughness and surface capacity based on the porosity of the aggregate to be used for the PFC. The K_c factor is determined from the percent of Society of Automotive Engineers (SAE) 10 oil retained, which represents the total effect of the coarse aggregate's absorptive properties and surface roughness. The K_c factor is determined from that portion of the aggregate sample that passes the 9.5-millimeter (3/8-inch) sieve and is retained on the 4.75-millimeter (No. 4) sieve using the procedure described in ASTM D5148. If the specific gravity for the aggregate is greater than 2.70 or less than 2.60, apply a correction to oil retained using the formula given in ASTM D5148. No correction need be applied for asphalt viscosity.

2-5.2.5 Mixing Temperature.

Mixing temperature to provide an asphalt viscosity of 275±25 centistokes is obtained by evaluating the temperature-viscosity relationship for the type of asphalt selected at a minimum of three temperatures (ASTM D2170 and ASTM D2171). ASTM D2493 provides details for plotting this information on a graph with temperature versus log viscosity. Plotting this information normally results in a straight-line relationship, and the temperature for the correct viscosity is chosen from the graph.

2-5.3 Plant Control.

2-5.3.1 Plant Laboratory.

A plant laboratory is needed to ensure that the aggregate is properly graded and the mix contains the prescribed percentage of asphalt binder. Locate the laboratory at the plant to minimize the time between production and testing.

2-5.3.2 Sieve Analysis.

Conduct all sieve analyses by the method described in ASTM C136. Recommended sieve sizes for plant sieve analysis are: 19 millimeter (3/4 inch), 12.5 millimeter (1/2 inch), 9.5 millimeter (3/8 inch), 4.75 millimeter (No. 4), 2.36 millimeter (No. 8), 600 micrometers (No. 30), and 75 micrometers (No. 200). For batch-mix plants, accomplish sieve analyses on material from each plant hot bin. Obtain samples for these sieve analyses after a few tons of aggregate have been processed through the dryer and screens so that the sample is representative. For drum mixers, make the sieve analysis directly from the cold feeds. Final mix proportions are determined on the basis of these analyses. For both types of plants, aggregate gradations will also be conducted on the aggregate recovered from the asphalt mixture.

2-5.3.3 Asphalt Content Tests.

Accomplish extraction tests in accordance with ASTM D2172. A nuclear gauge is used to determine the asphalt content, when tested in accordance with ASTM D4125, provided the gauge is calibrated. The asphalt content is also determined by the ignition method in accordance with ASTM D6307. Follow procedures specified in ASTM D5444 for sieve analysis. If the nuclear gauge is used to measure asphalt content, there is no way to recover the aggregate from the mixture for testing.

2-5.3.4 Mix Proportions.

Adjust mix proportions whenever tests indicate that specified tolerances are not being met. In the case of batch plants, common causes for mixture deficiencies are faulty scales and the failure of the operator to accurately weigh the required proportions of materials. Detect failure of accurate weighing or faulty scales and take corrective measures by maintaining a close check of load weights. Figure 2-8 presents other probable causes of mixture deficiencies due to plant operations.

2-5.3.5 Controlling Plant Production.

Normally the plant inspector obtains a sample of the PFC mix after the plant has been in production for 30 minutes. Test the sample as rapidly as possible for compliance with gradation and asphalt content requirements. If plant is too far from the construction site, draindown potentially occurs during haul due to the extended period of haul time.

2-5.4 Construction.

2-5.4.1 Pavement Control.

A PFC pavement has no density requirements. A characteristic of this overlay is its rapid cooling. If minimum asphalt drainage is desired, ensure the roller closely follows the paver to initially set the PFC so that asphalt drainage is minimized. If drainage in the truck or the paver causes a rich spot (excess asphalt cement) in the pavement, and warm weather conditions exist (high temperatures), rolling is delayed to allow the asphalt to drain into the PFC. Two passes with a 10-metric ton (10-ton) steel-wheel roller (in static mode if a vibratory roller) is required to properly seat the PFC mix.

2-5.4.2 Pavement Sampling.

Samples for determining thickness (ASTM D979) are taken either with a coring machine or by cutting out a sample of pavement at least 100 millimeters (4 inches) square with a concrete saw. Ensure the sample includes the entire thickness of the PFC.

2-5.4.3 Storage Silos.

Avoid storage of PFC mix whenever possible; the maximum allowable storage time under any circumstance is not to exceed 1 hour. Excessive storage time allows the asphalt to drain, causing segregation of the mixture. Coordination between the plant and the laydown operations eliminates the need for extended storage.

2-5.4.4 Pavement Operations under Normal Conditions.

Guide specifications do not permit placement of PFC when the surface temperature of the existing pavement is below 16 degrees C (60 degrees F). Ensure the contractor applies the specified rolling before the mixture becomes too cool to be properly seated. Generally, perform all rolling before the PFC mixture cools to 80 degrees C (175 degrees F). A PFC cools quickly because of the thin layer of material and high void content in the thin PFC layer.

2-6 STONE MATRIX ASPHALT.

SMA is a mixture of aggregate, mineral filler, asphalt cement, and a stabilizer (modified asphalt with or without the addition of cellulose or mineral fiber). SMA is designed to minimize rutting and abrasions even under high loads and high tire pressures. SMA mixtures depend on aggregate-to-aggregate contact to support traffic loads, therefore their mix design requires a higher percentage of coarse aggregate than HMA. Excess fine aggregate or too much mastic prevents the coarse aggregate particles from obtaining full contact and therefore lowers the mixture's resistance to rutting. The high void content of the mix is occupied by fine aggregate, mineral filler, asphalt cement, and a stabilizer (polymer, cellulose, or mineral fiber), which forms a mastic portion of the SMA mixture. This mastic stabilizes the coarse aggregate and reduces the final air voids in the SMA to 3 to 4 percent. SMA is comparable to HMA in regards to structural design, mix design, and construction. SMA originated in Europe and has recently been placed by state and federal agencies on projects throughout the country. The design and construction of SMA pavements are described in this chapter.

2-6.1 Materials.

2-6.1.1 Aggregates.

The gradation used for SMA is gap-graded for the coarse aggregate retained on the 4.75-millimeter (No. 4) sieve. This coarse aggregate makes up from 72 to 80 percent of the aggregate in the mix. Ensure 100 percent of the coarse aggregate passes the 19-millimeter (3/4-inch) sieve, and the amount of the fine material passing the 75-micrometer (No. 200) sieve is from 8 to 10 percent. Table 2-15 lists the gradation as recommended by the NAPA and FHWA. This gradation is based on the recommendations of a technical working group jointly representing NAPA and FHWA that reviewed the performance of SMA mixtures in place. Table 2-16 lists the recommended coarse and fine aggregate properties for SMA. Another test that is often used for airfield specs is ASTM C142, *Clay Lumps and Friable Particles*, which might be used in place of ASTM D3744, coarse and fine durability index.

2-6.1.2 Filler.

As presented in Table 2-15 for SMA mixtures, the recommended amount of aggregate filler (dust) passing the 75-micrometers (No. 200) sieve is 8 to 10 percent. This amount of filler in the SMA is higher than that usually found in dense-graded HMA. The amount of filler is important in obtaining the desired mixture air voids and in affecting the optimum asphalt content. The SMA asphalt content is sensitive to the aggregate fines and filler content. SMA mixtures commonly employ a filler-to-asphalt ratio of 1.5 and higher. In contrast, conventional dense-graded hot mix recommends a filler-to-asphalt ratio of less than 1.2. A well-graded filler with less than 20 percent of the total filler smaller than 20 micrometers (0.001 inch) is required. Commercial fillers are added by mineral filler feeder systems. Fly ash, limestone dust, and other types of rock dust have been used successfully as fillers for SMA applications.

2-6.1.3 Stabilizer.

There is a tendency for the asphalt binder to drain from the aggregate during storage, transportation, or placement because of the high asphalt content in the mix, the thick asphalt coating on the coarse aggregate, and the high voids in the aggregate skeleton. To reduce this drainage potential, stabilizers are used to stiffen the mastic or to increase the asphalt binder viscosity. These stabilizers are categorized into two groups: (1) either cellulose fibers or mineral fibers, and (2) polymers. When SMA has been placed with a combination of fibers and asphalt polymer, the fibers have been shown to perform better at reducing draindown than polymers.

Table 2-15 SMA Gradation Guideline (after NAPA 1999*)

Sieve Size	Percent Passing
19 mm (3/4 in.)	100
12.7 mm (1/2 in.)	85–95
9.5 mm (3/8 in.)	75 maximum
4.75 mm (No. 4)	20–28
2.36 mm (No. 8)	16–24
600 μm (No. 30)	12–16
300 μm (No. 50)	12–15
75 μm (No. 200)	8–10
*National Asphalt Pavement Association, publication QIP-122	

2-6.1.3.1 Fiber Stabilizers.

Tables 2-13 and 2-14 provide the requirements and test procedures to be used with cellulose and mineral fibers, respectively. The dosage rates normally used for cellulose fibers is 0.3 percent by weight of the total mix and for mineral fibers is 0.4 percent by weight of the total mix. The recommended tolerance for the fibers is 10 percent of the required fiber weight.

2-6.1.3.2 Asphalt-Polymer Stabilizers.

SMA mixtures have been placed using a polymer to modify the asphalt cement and stabilize the mixture so that fibers are not required. There have also been instances where a polymer and a fiber have been used in conjunction to stabilize SMA mixtures. Follow the manufacturer’s design and construction recommendations when the standard SMA guidelines are not applicable for asphalt-polymer stabilizers.

Table 2-16 Recommended SMA Coarse and Fine Aggregate Properties (after NAPA 1999)

Property	Specifications	Requirement
Coarse aggregate:		
LA abrasion, %	ASTM C131, AASHTO T96	30 max.
Flat and elongated, +No. 4 3 to 1 (length to thickness), % 5 to 1 (length to thickness), %	ASTM D4791	 20 max. 5 max.
Fractured faces, +No. 4 One fractured face, % Two fractured faces, %	CRD-C171	 100 min. 90 min.
Absorption, %	ASTM C127, AASHTO T85	2 max.
Coarse and fine durability index	ASTM D3744, AASHTO T210	40 min.
Sulfate soundness loss, 5 cycles Sodium sulfate, % or Magnesium sulfate, %	ASTM C88, AASHTO T104	 15 max. 20 max.
Fine aggregate:		
Crushed manufactured fines, %		100 min.
Sulfate soundness loss, 5 cycles Sodium sulfate, %		 15 max.
Liquid limit	ASTM D4318, AASHTO T89	25 max.

2-6.1.4 Asphalt.

Ensure the asphalt cement complies with the requirements of ASTM D946, ASTM D3381, or ASTM D6373, and the asphalt cement used is the grade normally used in the area by the local DOT or on previous Department of Defense (DoD) projects. When using ASTM D6373, the grade is normally bumped to be equal to that specified for heavy traffic. Ensure the temperature of the asphalt cement at the time of mixing is that required to achieve a viscosity of 170±20 centistokes. Where polymer modified asphalt cement is used, manufacturer’s recommendations for mixing temperature are to be followed.

2-6.2 Mixture Design.

Determine optimum asphalt content with procedures similar to those outlined in section 2-4.3. Table 2-17 contains the recommended mix design requirements for SMA, which are based on the requirements in AASHTO MP8.

Table 2-17. SMA Mix Design Requirements (after NAPA 1995)

Design Parameter	Value
Marshall[1]	
(1) VTM, percent[2]	3–4
(2) Asphalt content, percent[3]	6.0 min.
(3) VMA[4]	17 min.
(4) Stability, N (lbf)	6200 (1400) suggested minimum
(5) Flow, 0.25 mm (0.01 in.)	8–16
(6) Compaction, number of blows on each side of test specimen	50
(7) Draindown, percent[5]	0.3 max. (1 hour reading)

[1] Marshall procedures are in accordance with AASHTO T245 (ASTM D6927).
[2] VTM (voids in total mix or air voids) is based on AASHTO T166, T209 (ASTM D2041), and T269 (ASTM D3203). Maximum density is based on AASHTO T209 (ASTM D2041).
[3] Based on weight of total mix.
[4] VMA (see Asphalt Institute MS-2).
[5] ASTM D6390

2-6.2.1 SMA Draindown Test.

For the purpose of this test method (ASTM D6390), draindown is considered to be that portion of the asphalt cement that separates itself from a sample of uncompacted SMA mixture as a whole and is deposited outside the wire basket during the test. This test method is used to determine whether the amount of draindown measured for a given SMA mixture is within acceptable levels. This test method also provides an evaluation of the draindown potential of an SMA mixture produced in the field.

2-6.2.2 JMF Requirements.

It is the contractor's responsibility to ensure that, in addition to meeting the aggregate gradation requirements, the produced material provides an asphalt mixture that conforms to the applicable design parameters listed in Table 2-17. Submit in writing the proposed JMF in accordance with contract specifications, including:

a. The percentage (in units of 1 percent) of aggregate passing each specified sieve (except the 75-micrometer (No. 200) sieve), based on the total dry weight of aggregate as determined by ASTM C117 and C136.

b. The percentage (in units of 1/10th of 1 percent) of aggregate passing the 75-micrometer (No. 200) sieve, based on the dry weight of aggregate as determined by ASTM C117.

c. The percentage (in units of 1/10th of 1 percent) of aggregate finer than 0.020 millimeter (7.87×10^{-4} inch) in size, based on the dry weight of aggregate as determined by AASHTO T 88-13 (2017).

d. The percentage (in units of 1/10th of 1 percent) of asphalt material to be added based upon the total weight of mixture.

e. The proposed percentage of each stockpile to be used, the average gradation of each stockpile, and the proposed target value for each sieve size. Ensure the target values and the combined average gradation of all the stockpiles when combined in accordance with the contractor's recommended stockpile combinations are within the gradation ranges for the designated grading in Table 2-12.

f. The type and amount by weight of mix of stabilizer additive to be used.

g. Additional information required as part of the JMF includes:

(1) The material sources for all ingredients.

(2) The material properties, as listed, for all ingredients:

(a) The specific gravities of the individual aggregates and asphalt.

(b) The LA abrasion of the aggregates.

(c) The sand equivalent value of the combined aggregate.

(d) The flat and elongated percent of the coarse aggregate (3-to-1 and 5-to-1 ratios) retained above the 4.75 millimeter (No. 4) sieve.

(e) The plasticity index of the aggregate.

(f) The absorption of the aggregates.

(g) The asphalt temperature/viscosity curves.

(3) The mixing temperature.

(4) The mix design test property values and curves used to develop the job mix in accordance with those provided for HMA in this chapter and also in the Asphalt Institute's MS-2.

(5) The plot of the gradation on the FHWA 0.45 power gradation chart.

2-6.3 Mixing Plants.

SMA has been mixed in both batch and drum-mix plants. However, make required adaptations to meet the SMA components mix design.

2-6.3.1 Batch Plants.

The mineral filler is added directly into the weigh hopper. Batch plants have an existing mechanism for accomplishing this; however, attention is required to assure accurate proportioning of the amounts of filler required for SMA. The fiber is also added directly into the weigh hopper, which occurs when the hot aggregate is also being placed into the hopper. An alternative method of adding the fibers directly to the pugmill as the hot aggregates are added has also been used successfully.

2-6.3.2 Drum-Mix Plants.

The mineral filler is added directly into the drum mixer. Attention is required to assure accurate proportioning of the amounts of filler added. The fiber is also added directly into the drum mixer. A separate feeding system is usually employed, in the case of loose fibers. Ensure these fibers are added to the aggregates to avoid direct contact with the burner flame.

2-6.3.3 Mixing Time.

The time required to mix SMA is usually greater than that to mix dense-graded HMA. For batch plants, the dry-mixing time is increased from 5 to 15 seconds, and wet-mixing is increased at least 5 seconds for cellulose fibers and up to 5 seconds for mineral fibers.

2-6.3.4 Storage.

Temporary (less than 1 hour) storage of SMA in surge bins is used only for balanced production capacity. Limit storage in heated and insulated storage bins to 4 hours unless laboratory testing indicates that additional time is acceptable. Base acceptability on no adverse changes in binder properties and excessive draindown not occurring. Do not store mixture overnight.

2-6.4 Test Section.

The construction of a test section is important to allow examination of the contractor’s mixing and placement procedures. This is true if the contractor has not had experience in mixing or placing SMA.

2-6.5 Placement.

2-6.5.1 Equipment.

The trucks, pavers, distributors, and other general equipment are the same as those used for any asphalt concrete (AC) construction. Only steel-wheel rollers are used for SMA. Rubber-tire rollers are not used since they tend to pick up the rich mix excessively. Vibratory rollers are used, but take care to prevent breakdown (fracture) of the aggregate.

2-6.5.2 Surface Preparation.

Clean the surface of all loose or deleterious material. Apply a tack coat as described in section 3-3. A minimum atmospheric temperature of 7 degrees C (45 degrees F) and rising is required at the time of placement.

2-6.5.3 Paving.

Ensure the SMA mixture, when delivered to the paver, is at a temperature sufficiently high for good compaction but not so high as to damage the asphalt binder. Never exceed 177 degrees C (350 degrees F) for the mixture temperature.

2-6.5.4 Compaction.

Compact the SMA to a minimum of 94 percent of maximum theoretical density. Use steel-wheel rollers for rolling. Vibratory rollers are used provided that the aggregate is not excessively crushed. Rubber-tire rollers do not perform well with SMA due to the high amounts of asphalt cement in the mixture causing asphalt buildup on the wheels. Continue rolling until the required density is obtained. This is usually controlled through the use of a nuclear density gauge. Due to the amount of binder coating the aggregate particles, it is important that the roller drums be properly moistened with water containing small amounts of detergent to prevent adhesion. Ensure traffic remains off the SMA surface until it has cooled below a minimum of 60 degrees C (140 degrees F). One method that has been used to increase the rate of cooling to allow for earlier trafficking is flooding with water from a truck after the completion of all rolling.

2-7 WARM-MIX ASPHALT.

In recent years, processes that allow mixtures to be constructed at lower temperatures have been developed, and these lower temperature mixtures are referred to as warm-mix asphalt. A number of processes have been used, but specific processes are not discussed here. These processes allow the asphalt mixture to be mixed and placed at temperatures of 132 degrees C (270 degrees F) down to 110 degrees C (230 degrees F). The techniques involve using additives to change the viscosity of the asphalt at the higher temperatures or a foaming process. Generally, these warm mixes meets the requirements for HMA. While there has been little use on airfields, there has been significant use on highways. It is anticipated that use of warm-mix asphalt (WMA) increases significantly on airfields in future years. Early performance of WMA has been good. Use UFGS 32 12 15.13 as the guide specification for WMA. Prior to using WMA, contact the Pavements Discipline Working Group (DWG) or their designated representative.

The primary purpose of WMA is to reduce emissions during production. The additional cost for producing WMA is often offset by the savings in fuel cost. Hence, WMA potentially is a little lower cost than HMA or it might be a little higher depending on location and other factors. Besides reducing emissions, WMA also has other benefits including improved workability and ability to provide a mixture easier to compact during cooler weather. There have been a number of studies for roads and for airfields comparing the performance of WMA and HMA. So far, studies have shown that WMA and HMA have similar performance characteristics. One thing that has to be monitored, when WMA is used just as with HMA, is the moisture in the mix. Since mix temperatures are lower with WMA, the amount of moisture tends to be a little higher as specified in the mix design. So far, this has not been a significant problem but it is one that has to be monitored.

There are approximately 30 products/techniques for producing WMA. All of these have not been determined to be viable for airfields. UFGS 32 12 15.16 provides an approach for determining viable products. There are no significant differences in production, placement, and compaction of WMA and HMA.

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CHAPTER 3 SPRAY APPLICATIONS

3-1 INTRODUCTION.

“Spray application” is a term used to describe many different types of asphalt applications. An economical maintenance and repair method for flexible pavements is accomplished using spray applications of an asphalt material. When properly constructed, asphalt spray applications are economical as well as long lasting and are beneficial in treating or improving the pavement condition and increasing the life of the pavement. Where additional thickness is needed to increase the structural strength of pavements, spray applications are not considered helpful because they don’t contribute the structural strength. The different types of spray applications to be discussed in detail in this chapter are prime coats, tack coats, and fog seals and rejuvenators.

Note: The main cause for concern with fog seals and rejuvenators is reduced skid resistance, which is discussed in detail in sections 3-4 and 3-5. The amount of application is greater in lower-trafficked areas, such as pavement shoulders, the outer edges of runway and taxi pavements, and parking areas. Application rates are greatest where traffic, such as high-speed traffic, is not expected to occur. Due to a possible decrease in skid resistance, obtain approval from the Pavements Discipline Working Group (DWG) or their designated representative prior to using fog seals and rejuvenators.

3-2 PRIME COAT.

Asphalt prime coat consists of a low-viscosity liquid asphalt material applied by a pressure distributor to an unbound base course before placement of a HMA pavement. The purposes of the prime coat are to prevent lateral movement of the unbound base during pavement construction, to waterproof during pavement construction, and to form a tight, tough base to which an asphalt pavement adheres. To accomplish these purposes, ensure the prime material penetrates into the unbound base and fills the void spaces. A completed unbound base is susceptible to serious damage from rain, wind, and traffic. A prime coat is insurance against this water and traffic damage. Apply prime coat material to a dust-free, unbound base as soon as the base has been thoroughly compacted and before construction or other traffic loosens surface material in the compacted base. For best penetration of emulsions, the application of water (saturation or ponding) improves the wetability of the emulsion and improves penetration. Allow sufficient time to permit prime material to penetrate thoroughly into the compacted base. In instances where construction of an asphalt layer is to follow in less than 7 days upon completion of base course compaction, the application of a prime coat is not mandatory if it improves construction scheduling, but the use of a prime coat is preferred. When construction of an asphalt layer does not occur for at least 7 days, the compacted base is primed. Whether the compacted base is primed or not, take steps to protect the surface from any damage (e.g., from water, traffic) until an asphalt layer is placed. Generally, it is required that a prime coat be allowed to cure for 48 hours to withstand construction traffic, and cool or wet weather further increases the required time. Construction traffic on an uncured or improperly cured prime coat causes base movement. Local conditions, local experience, the type of base material, and the type of prime coat material available are all to be considered when deciding on the application of a prime coat.

3-2.1 Materials.

3-2.1.1 Asphalt.

Use low-viscosity asphalt material as prime material, but ensure the selection of type and grade is given consideration. These following items are consider in selecting the priming material:

- Air temperature
- Humidity
- Void content of the base course
- Curing time of the prime material
- Environmental restrictions
- Available materials

3-2.1.2 Prime Coats.

Recommended priming materials include emulsified asphalts and cutback (liquid) asphalt. Table 3-1 shows the recommended types and grades.

Table 3-1 Prime Coat Materials

Type	Grade
Cutback	SC-70 SC-250 MC-30 MC-70 MC-250 RC-70 RC-250
Emulsion	SS-1 SS-1h CSS-1 CSS-1h

A prime coat works only if it penetrates into the base course. Open-textured (high void content) bases are primed easily, but a tight surface (low voids) cannot be penetrated readily. In cases of low voids, consider the less viscous cutbacks such as RC-70, MC-30, MC-70, and SC-70. If penetration does not occur, an asphalt film is left on the surface of the base, causing slippage of the bituminous surface during and after construction. Use caution in using RC-70 or RC-250 because the solvent in the cutback evaporates rapidly or is absorbed by the base course fines and leaves an asphalt film on the surface. Undiluted emulsions cause asphalt film problems if the base course surface is tight. When emulsions are used for prime coat it is recommended that the emulsion be diluted with 1 part water to 1 part emulsion. Generally, cutback asphalts penetrate better and are better prime coat materials than asphalt emulsions. However, many areas do not allow the use of cutback asphalts. Also, emulsions are specially formulated to improve their penetrating ability. So, many asphalt suppliers produce an asphalt emulsion that is specially formulated for prime coats.

3-2.1.2.1 Influence of Weather.

Weather influences the choice of the correct priming materials. Since emulsions are dependent on the evaporation of water for curing, low temperature or high humidity slow or stop the curing process. Cutbacks are not as dependent on weather conditions as emulsions. In cold weather, however, the rapid-curing cutbacks (RCs) cure quicker than the slower curing cutbacks (MCs and SCs).

3-2.1.2.2 Considerations for Use of Cutbacks.

Cutback materials are available in locations throughout the United States and the world. Environmental, safety, and cost considerations have led to increased use of emulsions as prime coat materials. Environmental restrictions, under certain conditions, have begun to limit the use of cutback prime coat materials. This plus concerns that flammability and the cost of cutbacks have led to an increased used of asphalt emulsion prime coats. Dilute asphalt emulsions with water before applying as a prime coat, and exercise handling and storage considerations to prevent freezing, settling, and breaking.

3-2.2 Application Rate.

Prime coats are usually applied in quantities of 0.45 to 1.13 liters per square meter (0.10 to 0.25 gallons per square yard) of residual asphalt. The optimum amount of prime is highly dependent on the plasticity index of the base material, the amount of fines in the base, the nature of the fines, the tightness of the surface, and the moisture content of the base; therefore, determine the optimum amount of prime required by field trial. Test sections at various application rates are recommended for determining the optimum amount of prime. After 48 hours of curing, if there is free or excess bitumen on the surface or if the base continues to appear shiny, the base is probably overprimed. Generally, the prime is absorbed into the base within 2 to 3 hours. When excessive prime is used, the surplus probably is absorbed into the overlying asphalt layers. In turn, the absorption of the excess contributes to pavement slippage or rutting. Where excessive prime is applied, blot the excess with an application of clean fine sand or mineral dust. The ideal end result is to obtain maximum penetration without leaving free prime on the surface.

3-2.3 Placement.

Lightly broom surfaces to be primed that contain appreciable amounts of loose material or are dusty. A dusty surface cause prime to “freckle,” that is, have areas with no prime and adjacent areas with drops of excess prime. A light application of water just before applying the prime aids in reducing freckles and getting good distribution of the prime. Ensure the primer is uniformly applied with a pressure distributor at the required application rate and at the specified temperature for the asphalt used. The minimum curing time varies according to the grade and type of asphalt being used, the nature of the base, the temperature, and the humidity, but curing takes place within 48 hours.

3-2.4 Control.

Since prime coat material is applied with a pressure distributor, calibrate and check the distributor for the specified application rate before applying the prime. ASTM D2995 offers a method for determining the application rate of bituminous distributors. In addition, ensure all nozzles are free and open, the same size, and to the same angle in reference to the spray bar to produce a uniform fan of prime. The height of the spray bar above the surface is important because a bar too high or too low gives an unequal application across the spray bar, causing streaking. Ensure the height of the spray bar is such that a double or triple lap of the spray fan is obtained.

3-3 TACK COAT.

A tack coat is a light application of asphalt material to an existing paved surface immediately prior to placing the next pavement layer or course. The purpose of the tack coat is to provide a bond between the two pavement layers. The tack coat is applied by pressure distributor to cleaned surfaces. Apply the tack coat in a light and uniform application.

3-3.1 Materials.

Emulsions are common types of asphalt material used as tack, but cutbacks and asphalt cements are also used. For tack coats, the asphalt emulsion is not to be diluted. Obtain the correct spraying viscosities (temperatures) for the type of material used. Recommended tack coat materials and spray application temperatures are shown in Table 3-2. Cutbacks and emulsions are sprayed at low temperatures, but asphalt cements require considerable heating to reach a viscosity for spraying. A tack coat is always to be used when adding an asphalt mixture on top of a bound layer such as HMA or Portland cement concrete (PCC).

In cold weather, cutbacks are used with less concern than with emulsions; however, concerns with cutbacks, as mentioned before for prime coats, make them unavailable. Use of an emulsion requires that consideration be given to weather conditions, storage and handling requirements, and curing time. Ensure all tack coats are completely cured before placing the new pavement layer.

3-3.2 Application Rate.

Tack coats are usually applied in quantities of 0.23 to 0.68 liter per square meter (0.05 to 0.15 gallon per square yard) of residual asphalt, but adjust the exact quantities to suit field conditions. Light applications are preferred since heavy applications cause serious pavement slippage and bleeding problems; however, failure to use any tack coat also causes pavement slippage problems.

Table 3-2 Tack Coat Materials and Spray Application Temperatures

Type	Grade	Application Temperature °C (°F)
Cutback	RC-70	49-93(120–200)
	RC-250	74-121(165–250)
Emulsion	RS-1	21-60(70–140)
	MS-1	21-71(70–160)
	HFMS-1	21-71(70–160)
	SS-1	21-71(70–160)
	SS-1h	21-71(70–160)
	CRS-1	52-85(125–185)
	CSS-1	21-71(70–160)
	CSS-1h	21-71(70–160)
Asphalt cement	200–300 pen	129(265)+
	120–150 pen	132(270)+
	85–100 pen	138(280)+
	AC-2.5	132(270)+
	AC-5	138(280)+
	AC-10	138(280)+
	AR-1000	135(275)+
	AR-2000	141(285)+
	AR-4000	143(290)+
	PG 58-22, 64-22	143(290)+

3-3.3 Placement.

Apply tack coats to clean, dust-free asphalt pavement courses prior to placement of the overlying pavement layer. Apply the tack coat immediately before placement of the overlay; therefore, unless an asphalt cement is used, allow the tack coat time to cure. A tack coat is required on a base course when the prime coat on that surface has been subjected to construction traffic or other traffic. User a pressure distributor to apply tack coats at an application temperature that produces a viscosity between 10 and 60 seconds, Saybolt Furol, or between 20 and 120 centistokes, kinematic viscosity. The suggested spray application temperatures in degrees Fahrenheit for tack coat materials are shown in Table 3-2. When an even or uniform coating is not obtained, an improved coverage is possible by making several passes over the freshly applied tack coat with a pneumatic-tired roller. However, take steps to ensure a uniform application from the asphalt distributor. Ensure the tack coat is completely cured (volatiles or water evaporated) before the overlying layer is placed. A properly cured surface feels tacky. Plan work so that the amount of tack coat placed on the surface is equal to the amount required for one day of operation. Keep all nonessential traffic off the tack coat so that dust, mud, or sand is not tracked onto the surface. There are tack coats that are tack free when cured. These products were developed to prevent tracking of the tack by the trucks to areas outside the work area. Guidance for using these products is provided in UFGS 32 12 13.

3-3.4 Control.

The control of tack coat application is the same as that for prime coat application, as discussed in paragraph 3-2.2.

3-4 FOG SEALS.

A fog seal is a light spray application of diluted emulsified asphalt to an existing asphalt pavement surface. Fog seals are used to maintain old pavements, reduce raveling, waterproof, and in general extend the life of existing pavements. Fog seals are good for treating pavements that carry little or no traffic; however, there are several considerations when using fog seals:

- The pavement skid resistance is possibly reduced.
- The pavement air voids or permeability is possibly reduced.
- Close the pavement to traffic for 12 to 24 hours to allow for curing of the seal material.

3-4.1 Materials

In the past, asphalt emulsions and cutbacks were used for fog seals, but in recent years, the materials used are emulsions and rejuvenators. The emulsions often used are SS-1, SS-1h, CSS-1, and CSS-1h. Use only slow-setting emulsions, to allow for maximum penetration of the asphalt into the pavement. Several products are marketed as rejuvenators; they are proprietary products and their use is discussed in section 3-5.

3-4.2 Application Rate.

The application and dilution rate for fog seal varies with the absorption characteristics of the existing pavement surface. Rates vary between 0.14 to 0.36 liters per square meter (0.03 to 0.08 gallons per square yard of residual asphalt). Place test sections on the pavement to determine the best application rate. Adjust the application rate so that the pavement does not become slick or unstable and does not have excess free material on the surface after curing 12 to 24 hours. Asphalt emulsion are applied at full strength or are diluted as much as 1 part emulsion to 5 parts or more of water; however, normal application dilution is 1 part emulsion to 1 part water. Evaluate the amount of dilution for each job using a test section similar to application rate.

3-4.3 Placement.

Use only a pressure distributor that has been calibrated to deliver the fog seal at the specified rate to apply the seal material. Clean all surfaces to which the seal is applied. Apply the fog seal when the ambient temperature is above 4.5 degrees C (40 degrees F), but warmer temperatures are preferable because the material breaks and cure faster. The seal material is applied to a damp pavement if the dilution material is water, but ensure the pavement is not be too wet or the seal does not break properly and does not penetrate into the pavement. Blot excess seal left on the surface with clean sand and broom.

3-5 REJUVENATION.

Rejuvenation is the spray application of a material on an asphalt surface for the purpose of rejuvenating an aged asphalt cement binder. This rejuvenation is intended to extend the life of the asphalt pavement by softening or rejuvenating the surface asphalt toward the properties it had shortly after construction. The application of a rejuvenator is effective when the pavement has not aged to the point at which block cracking or substantial raveling has occurred. Depending on the climatic conditions, pavement rejuvenation is required within 3 to 6 years after placement. Rejuvenators are spray applied to the pavement surface and allowed to penetrate into the pavement. Rejuvenators are not to be used on runways without fine aggregate cover due to their tendency to reduce the surface friction. Obtain approval from the Pavements Discipline Working Group (DWG) or their designated representative prior to the use of rejuvenators or rejuvenators-sealers on airfields.

3-5.1 Testing.

Test results have shown that the viscosity test is effective in determining a change in asphalt properties compared to a penetration test. The viscosity test identifies changes in asphalt properties regardless of amount of rejuvenator applied, while the penetration test potentially identifies no change in asphalt property. The dynamic shear rheometer (DSR) test method is also used to produce results for evaluation; however, while the test requires less asphalt than the other methods, current extraction methods normally recover the amount of material required to perform the preferred viscosity test. If the DSR test method is used, select the phase angle test parameter for comparison since it has been shown to be statistically consistent that the G* parameter.

3-5.2 Materials.

Rejuvenation materials are not currently specified by ASTM or any other organization. The various rejuvenators available are proprietary products. Available rejuvenator materials are classified into two major types according to their major components, either asphalt or coal tar bases. Ensure the rejuvenator selected for use has a proven record of performance; however, if performance data on a rejuvenator are not available, apply the rejuvenator to a test area on the pavement and evaluated to determine its potential performance. Fog spray applications of emulsified asphalt cannot be considered to act as a rejuvenator as they don't normally have significant penetration into the pavement surface.

3-5.3 Application Rate.

The rate of application varies greatly with the condition, dry, oxidized, and open-textured, of the pavement surface. Ensure the application rate of total liquid is within the range of 0.18 to 0.9 liters per square meter (0.04 to 0.2 gallons per square yard). The application rate is selected as the amount of material that is absorbed into the pavement surface within 12 to 24 hours of application depending on the trafficking needs of the rejuvenated pavement. Follow the manufacturer's recommendations concerning dilution and other factors. Depending on the amount of solids or residual material within the rejuvenator, as evidenced by materials remaining on the pavement surface after curing, sand-sized aggregate are used to provide initial skid resistance after placement. The rejuvenators that leave material on the surface to hold aggregate are also classified or referred to as rejuvenator-sealer because they rejuvenate the surface asphalt and also, at least temporarily, seal the pavement surface. Coal tar- and asphalt-based rejuvenator-sealers leave residue on the pavement surface to hold aggregate for at least a short time. The sand used is a fine-grained aggregate that passes the 1.18 mm (No. 16) and usually the 600 μm (No. 30) sieve. The amount of aggregate applied varies with the type of rejuvenator-sealer and the condition of the pavement surface, usually within the range of 0.27 to 0.54 kilogram per square meter (0.5 to 1.0 pound per square yard).

3-5.4 Placement.

Prior to placement of the rejuvenator, thoroughly clean all the lose material from the pavement surface. Rejuvenators are usually placed with an asphalt distributor truck or any other type of specially designed application spray vehicle. Manufacturers and contractors have added a feature to immediately apply aggregate directly on top of the rejuvenator (rejuvenator-sealer). Follow manufacturer recommendations concerning application temperature and dilution of the material. When a rejuvenator is applied to the pavement, ensure clean dry sand is available to blot areas that received too much rejuvenator. Spread the sand evenly over these areas, broom into a pile, and remove.

Rolling the pavement surface with a rubber tire roller 1 or 2 days after rejuvenator has been applied helps to knead and close hairline cracks. The minimum application temperature is normally 10 degrees C (50 degrees F); however, temperatures at or above 21 degrees C (70 degrees F) results in improved penetration and curing.

3-5.5 Control.

Calibrate the asphalt distributor and check all nozzles according to ASTM D2995. When a rejuvenator-sealer is applied, the aggregate distribution system is calibrated and checked according to ASTM D5624. Conduct test sections of the pavement to be rejuvenated to test various application rates and the function of the distribution equipment.

3-5.6 Skid Resistance.

Rejuvenators normally reduce the skid resistance of treated pavement surfaces. Any excess rejuvenator that is not removed reduces skid resistance. Rejuvenator materials, when applied in the correct amounts, have skid resistance values approaching pretreatment values within a few days. Rejuvenator-sealer materials, those leaving substantial amounts of material on the pavement surface, provide skid resistance values when the application of aggregate has been applied to them. As the rejuvenator-sealer cures and traffic is applied, this thin layer of sand is worn off along with the material, and the skid resistance approaches that of the untreated pavement.

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CHAPTER 4 SEAL COATS

4-1 INTRODUCTION.

Seal coats are one of several types of applications that consist of a relatively thin layer of aggregate cemented together with an asphalt (bituminous) material. The types of seal coats addressed in this chapter include surface treatments, slurry seals, fuel-resistant sealers, and micro-surfacing. Seal coats are widely used because of their low cost and usefulness in light to medium traffic roadways and parking areas. These treatments are normally used to seal or waterproof the pavement, provide wear resistance, and increase skid resistance. All seal coats are relatively thin coatings of material and do not add structurally to the pavement. Contact Pavements Discipline Working Group (DWG) or their designated representative prior to using surface treatments on airfield pavements due to FOD potential. Surface treatments have a FOD potential in that they use aggregate particles that are 9.5 to 19 millimeters (3/8 to 3/4 inches) in diameter. Slurry seals and micro-surfacing use aggregates with maximum sized particles less than 4.75 millimeter (No. 4) in diameter and fuel-resistant sealers use sand sized particles less than 1.18 millimeter (No. 16) in diameter. The major FOD potential from slurry seals, micro-surfacing, and fuel-resistant sealers occur when sections of the seals were not completely bonded to the underlying HMA. The individual aggregate particles are too small (1.18 to 19 millimeters) to cause a potential FOD threat.

4-2 SINGLE AND DOUBLE BITUMINOUS SURFACE TREATMENTS.

A single bituminous surface treatment (SBST) consists of an application of bituminous material on a prepared surface followed immediately by a single layer of cover aggregate. “Chip seal” is a commonly used term for the same process. Double bituminous surface treatment (DBST) is similar to a SBST except that two applications of bitumen and cover aggregate are used. The first application of aggregate uses a coarser aggregate than the second application and usually determines the DBST thickness. The second application of aggregate partially fills the surface voids and keys into the aggregate in the first aggregate course. SBSTs and DBSTs are used on prepared base courses and on new or old pavements. The DBSTs with additional layers are used to provide greater wearing resistance and potential structural strengthening (minimal).

4-2.1 Materials.

4-2.1.1 Binder.

The functions of the asphalt binder are to hold the aggregate in place, bond it to the underlying surface, and seal the underlying surface to prevent the entrance of moisture and air. The binders specified for SBST and DBST are cutback asphalts, emulsified asphalts, and asphalt cements. The types and grades are shown in Table 4-1. ASTM D1369 also provides a list of binder materials based on aggregate size and expected temperatures at application.

Table 4-1 Surface Treatment Asphalt Materials

Type	Grade
Cutback (seldom used currently due to environmental issues)	RC-250
	RC-800
	RC-3000
Emulsion	RS-1
	RS-2
	CRS-1
	CRS-2
Asphalt cement	120–150 pen
	200–300 pen
	AC-2.5
	AC-5
	PG 58-22
	PG 64-22

4-2.1.1.1 Selecting Type and Grade.

Select the type and grade of binder carefully. Consider these factors:

- Climatic conditions.
- Curing time of the binder.
- Environmental restrictions.
- Available materials.
- Temperature of the surface.
- Condition of the surface.
- Condition of the aggregate.

4-2.1.1.2 Cutback Asphalts.

Historically, rapid-curing cutback asphalts were used for surface treatments. RC-250 was used when cooler temperatures were anticipated and RC-3000 when warmer temperatures were anticipated. Currently, environmental requirements limit the availability of cutback asphalts, and as a result, emulsified asphalt binders are widely used binders.

4-2.1.1.3 Emulsions.

Emulsions require handling and storage considerations to prevent freezing, settling, and premature breaking, but they are applied with little or no additional heating. In selecting the type of emulsion, consider the compatibility of the aggregate and emulsion. As a general rule, anionic emulsions adhere better to limestone and other aggregates composed of predominantly calcium minerals. Cationic emulsions adhere better to aggregates high in silica, such as chert and quartz gravels. Cationic and anionic emulsions both adhere well to damp aggregates.

4-2.1.1.4 Asphalt Cements.

Asphalt cements harden quickly so that the cover aggregate is held in place better than other binders provided the asphalt cement does not chill before the cover aggregate is applied. Chilling of the binder before applying the aggregate is one major disadvantage with asphalt cement binders. To ensure good bond, the aggregates are often heated when asphalt cements are used. Another disadvantage with the use of asphalt cements is the high amount of heat required for spraying. Because of the difficulties encountered with asphalt cements, carefully consider using cutbacks or emulsions instead of asphalt cement.

4-2.1.2 Aggregates.

The aggregate has an effect on the degree of wear resistance, riding quality, and skid resistance of the surface treatment. Use only clean, dry, aggregate fragments that are free from dust or dried films of harmful material. Ensure the aggregate has a single-size (uniform) gradation and is composed of hard, angular, polish-resistant material. Flat and elongated aggregate particles and wet or dusty aggregates are not used. Quantities of moisture up to 1 percent do not create a problem, in warm weather, but dust prevents the adhesion of the binder to the aggregate. When an emulsion is used as the binder, aggregate with up to 3 percent moisture are commonly used. ASTM D1139 offers additional physical requirements for aggregates to be used in surface treatments.

Tables 4-2 and 4-3 provide the recommended aggregate gradations for SBST and DBST, respectively. The correlating size number designation from ASTM D448 is also provided. For DBST, gradation Nos. 1 and 2 and gradation Nos. 3 and 4 from Table 4-3 is used in combination.

4-2.2 Design.

The type and amount of aggregate and bitumen to be used for surface treatments is determined in accordance with ASTM D1369. This standard provides guidance on typical rates of aggregate and bitumen for the various types of surface treatments, and cites other ASTM standards that are applicable for measuring both bituminous and aggregate quantities. D1369 lists recommended grades of various asphalt and tar materials for use with surface treatments. Similar guidance is also available in the Asphalt Institute’s Educational Series No. 11 (ES-11) and ES-12.

Table 4-2 Gradations for SBST

Sieve Size	Percent Passing by Weight, Gradation Designation		
	No. 1 (No. 6[1])	No. 2 (No. 7[1])	No. 3 (No. 8[1])
25 mm (1 in.)	100	--	--
19 mm (3/4 in.)	90–100	100	--
12.5 mm (1/2 in.)	20–55	90–100	100
9.5 mm (3/8 in.)	0–15	40–70	85–100
4.75 mm (No. 4)	0–5	0–15	10–30
2.36 mm (No. 8)	–	0–5	0–10
1.18 mm (No. 16)	–	–	0–5
[1] Number size designations from ASTM D448.			

Table 4-3 Gradations for DBST

Sieve Size	Percent Passing by Weight, Gradation Designation			
	No. 1 (No. 6[1]) (First Spreading)	No. 2 (No. 8[1]) (Second Spreading)	No. 3 (No. 7[1]) (First Spreading)	No. 4 (No. 9[1]) (Second Spreading)
25 mm (1 in.)	100	--	--	--
19 mm (3/4 in.)	90–100	--	100	--
12.5 mm (1/2 in.)	20–55	100	90–100	--
9.5 mm (3/8 in.)	0–15	85–100	40–70	100
4.75 mm (No. 4)	0–5	10–30	0–15	85–100
2.36 mm (No. 8)	--	0–10	0–5	10–40
1.18 mm (No. 16)	--	0–5	--	0–10
300 μm (No. 50)	--	--	--	0–5
[1] Number size designation from ASTM D448.				

4-2.3 Construction.

Field construction practices determine the success or failure of a well-designed surface treatment; therefore, equipment, surface preparation, and construction techniques are important.

4-2.3.1 Equipment.

Among the equipment used in placing a surface treatment, the asphalt distributor and the aggregate spreader are important. Aggregate spreaders are used during the construction of bituminous surface treatments to apply the aggregate to the surface being treated. Design and calibrate the spreader to apply a predetermined amount of aggregate uniformly over the surface. Aggregate spreaders are self-propelled; others are propelled by the truck hauling the aggregate. The self-propelled aggregate spreaders are desirable because they allow for a uniform application of material and a smoother operation. Ensure calibration and operation of the distributor and aggregate spreader meet the specified results.

4-2.3.2 Surface Preparation.

Without surface preparation, the life expectancy of a pavement is reduced; therefore, repair all soft or failed areas and remove all loose material, dirt, and vegetation prior to placing the surface treatment. Also sand or remove a bleeding surface before construction of the surface treatment.

4-2.3.3 Application.

Give attention to the application rates of both binder and aggregate. Too much binder causes bleeding or low skid resistance, and too little binder results in the loss of cover aggregate. Apply 5 to 10 percent excess aggregate, although too much aggregate results in a waste of materials and damage to windshields.

Apply the aggregate immediately after the binder application to obtain a good bond between asphalt and aggregate. Rolling with a rubber-tired roller immediately after applying the aggregate seats the aggregate in the binder and improve the bond.

4-2.3.4 Control.

Since the distributor and aggregate spreader are important for the successful application of materials, calibrate and check them to ensure that the specified application rate is obtained. ASTM D2995 offers a method for determining the application rate of asphalt (bituminous) distributors. In addition, ensure all nozzles are free and open, the same size, and at the same angle with reference to the spray bar to produce a uniform fan of asphalt. The height of the spray bar above the surface is important. A bar too high or too low produces a variable application across the spray bar, causing streaking. Ensure the height of the spray bar is such that a double or triple lap of the spray fan is obtained. ASTM D5624 offers a method for determining the application rate of aggregate transversely across the width of the spreader.

A test section is another method to evaluate the construction techniques and the application rates required for surface treatment. Construct at least one test section before allowing surface treatment applications on a full scale.

4-3 SLURRY SEAL.

A slurry seal is a mixture of asphalt emulsion, well-graded fine aggregate, water, and mineral filler. These materials are combined in proportions to produce a homogeneous, fluid-like slurry. Ensure the consistency of the slurry is spreadable to be squeegeed over an existing pavement surface. A thick, sealed surface results after evaporation of the water and curing of the mix. When properly designed, constructed, and cured, the slurry seal improves the qualities of an existing pavement surface, but the structural strength of the pavement structure is not significantly improved. Slurry seals are used to protect worn, weathered, or cracked pavements from the adverse effects of weather conditions and traffic wear. With use of aggregates, the slurry seal is also used to reduce skid or slipperiness problems. Slurry seals have application to roads and streets, parking lots, and bridge decks. This type of seal coat is best suited for pavements that are not subjected to heavy traffic. Because aircraft normally causes a rapid deterioration of the slurry seal and there is a high potential for FOD, do not apply slurry seals to airfields.

4-3.1 Equipment.

Various types of equipment are needed on a slurry seal project, but the basic pieces of equipment required include a truck-mounted continuous-mix slurry machine, spreader box, power broom, front-end loader, distributor, and pneumatic-tired roller. The truck-mounted continuous-mix slurry machine, which serves as a portable mixing plant, is an important piece of equipment. It is the only type of mixing equipment recommended for mixing a slurry seal. A slurry seal machine is used to mix aggregate, filler, asphalt emulsion, and water in the correct proportions and to uniformly apply the material to the surface to be sealed. The slurry seal machine contains storage for the aggregate, filler, emulsion, and water. Before use, calibrate and set the machine to deliver the job materials in the correct proportions. The machine manufacturer's instructions usually offer the best guidance for calibrating the slurry machine; however, a calibration method based on a revolution counter is applicable to all machines. By attaching a revolution counter to any shaft that is mechanically interlocked with the emulsion pump, water pump, fines feeder, and aggregate conveyor, the relative quantities of each of these components per revolution is determined for various gate openings, metering valve openings, or sprocket sizes. The materials are mixed and deposited into a squeegee box, which applies the slurry seal onto the surface at a thickness equal to the maximum aggregate size.

4-3.2 Material Requirements.

4-3.2.1 Emulsion.

The binder used in a slurry seal is asphalt emulsion. The emulsion is often either slow-set anionic (SS-1 or SS-1h) or slow-set cationic (CSS-1 or CSS-1h). The slow-set emulsions are best suited for slurry seals, but quick-set emulsions are specifically designed for slurry seals. The use of quick-set emulsions requires that an experienced slurry seal contractor perform the job because of the amount of time available for handling the slurry seal before it cures. Slow-set cationic emulsions cure faster than slow-set anionic emulsions because the curing process is partly a chemical reaction that expels water from the mix. Anionic emulsions cure primarily by evaporation of the water from the mix; therefore, they are greatly influenced by weather conditions. Low temperatures, high humidity, or rain slows or stops the curing process. Emulsion break; that is, the asphalt separates from the water upon contact with certain types of aggregates. If a break occurs, change either the emulsion or aggregate type.

Aggregates have a slightly negative or positive charge. A cationic emulsion bonds better with a negatively charged aggregate and an anionic emulsion bonds better with a positively charged aggregate. Aggregates that have a minimum charge, and in this case, an anionic or cationic aggregate works.

4-3.2.2 Aggregate.

Give close attention to the aggregate as well as the emulsion used in a slurry seal. Clean all aggregates, and crush the particles to produce an angular shape. Do not use aggregates that contain plastic fines. These fines absorb excessive amounts of emulsion, not allowing the required amounts of binder to coat the remaining aggregate. The fines also promote low-wear characteristics and premature break of the emulsion. Better performance is expected from slurry seals that are produced using crushed aggregate. Natural sands such as dune, river, and beach sands and other rounded aggregates tend to have poor skid resistance and wear characteristics and therefore do not use these in slurry seal coatings.

4-3.2.2.1 Gradations for Aggregates.

Ensure the aggregates are dense-graded so that the particles lock themselves together. Table 4-4 shows the gradations for use with slurry seals. Gradation type 1 is normally used for filling and sealing cracks in a pavement surface, and it provides a thin wearing surface. Gradation type 2 is widely used, and is used to fill voids, correct moderate surface irregularities, seal cracks, and provide a wearing surface for traffic. Aggregate gradation type 3 assures a thicker seal and provides a coarser surface texture. This gradation might be used as the first course in a two-course slurry seal surface treatment.

4-3.2.3 Mineral Filler.

When stability or segregation problems occur, mineral filler at a rate of 0.5 to 4.0 percent by weight of the total mixture is used to solve the problem. When mineral filler is needed, Portland cement (PC) or hydrated lime (HL) is often used in slurry seals. The filler is used to improve the mix stability, that is, to suspend heavier aggregate particles throughout the slurry seal mixture, to reduce segregation of materials, and to meet gradation requirements. Take care to ensure that the fines content, including mineral filler, does not exceed the gradation limits. Excessive fines or mineral filler causes shrinkage cracking to occur in the seal coat.

4-3.2.4 Water.

Water controls the workability of the slurry seal mixture. Ensure the mixture contains the required amount of water to produce a smooth, creamy, homogeneous, fluid-like appearance. If more water is used than required, the resultant mixture is soupy, and segregation or bleeding of the mixture occurs. On the other hand, if less water is used than required, the slurry mixture is stiff and neither spreads smoothly nor performs. Use only potable water in a slurry seal mixture.

Table 4-4 Slurry Seal Aggregate Gradations

Sieve Size	Percent Passing		
	Type 1	Type 2	Type 3
9.5 mm (3/8 in.)	–	100	100
4.75 mm (No. 4)	100	90–100	70–90
2.36 mm (No. 8)	90–100	65–90	45–70
1.18 mm (No. 16)	65–90	45–70	28–50
600 µm (No. 30)	40–65	30–50	19–34
300 µm (No. 50)	25–42	18–30	12–25
150 µm (No. 100)	15–30	10–21	7–18
75 µm (No. 200)	10–20	5–15	5–15

4-3.3 Design.

The method of developing a JMF for slurry seals selects the optimum asphalt content based on a desired film thickness of asphalt and the absorption characteristics of the aggregate. The water and mineral filler content requirements are determined by a cone test, and the wear characteristics are determined by the wet track abrasion test (WTAT) as described in ASTM D3910. Appendix C contains a summary design method and an example problem for slurry seals. The method is intended to furnish a starting point for field application. Adjust the proportions of the mixture to field conditions; however, construct a field test section using the laboratory-developed JMF.

4-3.4 Factors Affecting Design.

Consider these important factors before using a slurry seal:

- The cost of placing a slurry seal is relatively small, but this mixture does not provide additional strength to the pavement and does wear rapidly under a high volume of traffic.
- Slurry seal fills and seals many surface cracks.
- Slurry seals are used to seal a pavement surface to retard oxidation and raveling or to provide a thin (6-millimeter (1/4-inch)) wearing surface.

- Skid resistance is improved if crushed aggregates are used in the mix.
- Uncured slurry seal is adversely affected by changes in weather conditions.
- Close treated pavement to traffic to allow the slurry seal to cure (sometimes as long as 24 hours, but usually 6 hours).
- Slurry seal is better suited for a pavement subjected to low or moderate traffic because heavy traffic causes a rapid deterioration of the thin layer.
- Only structurally sound pavements are suited for a slurry seal.
- Design and application are important for meeting job required job performance.
- Generally, slurry seals have a three- to five-year life.
- Slurry seals fills cracks and coats the surface of the pavement to a depth of 3 to 6 millimeters (1/8 to 1/4 inch).

4-3.5 Surface Preparation.

Without surface preparation, the life expectancy of a slurry seal surface is reduced. Remove all loose material (including loose or flaky paint), dirt, and vegetation. Treat cracks wider than 3 millimeters (1/8 inch) before applying the seal coat. After the surface is cleaned, apply a light tack coat to improve the bond and to reduce the asphalt absorption of the old surface.

4-3.6 Application.

The surface texture of the fresh slurry seal is affected by the condition of the flexible lining of the spreader box, fragments of cured slurry adhering to the edges of the lining or to the squeegee, and the condition of the burlap drag. Worn lining results in an uneven thickness of the seal coat. Fragments of cured slurry seal or aggregate particles caught in the lining produce gouges and streaks. Wash or replace the burlap drag as needed to ensure that accumulations or crusts of mix do not cause scars or streaks. Empty and clean the mesh basket screen that is hung at the end of the discharge chute. Check the slurry seal for lumps or balling, which is caused by inadequate mixing or premature break of the asphalt emulsion. Deviation of the mix from the specified gradation potentially results in a product not meeting required job performance.

4-3.6.1 Joints.

Whenever possible, make joints while the slurry seal mixture applied in the first pass is still semi-fluid and workable. If operations preclude fresh working joints, allow the previously laid pass to set and cure sufficiently to support the spreader box without scarring, tearing, or being scraped from the pavement surface.

4-3.6.2 Hand Application.

Give close attention to spreading of the slurry seal mixture by hand squeegee. Overworking causes partial breaking of the emulsion before the final spreading is completed, which results in a nonuniform material that has poor appearance and durability.

4-3.7 Curing.

Slurry seals, depending on the emulsion characteristics in relation to the aggregate with which the emulsion is used, cure primarily by evaporation of water from the surface, by deposition of asphalt on the aggregate that frees the water, or by a combination of both. If curing is from the surface downward, the surface presents a cured appearance, but the material below possibly is still uncured. Therefore, assure thorough curing of the slurry seal before traffic is permitted.

4-3.8 Rolling.

Rolling is advantageous in reducing voids in the slurry seal, smoothing out surface irregularities, and increasing the resistance to water. Begin rolling as soon as the slurry seal has cured to support the roller without any pickup of the slurry seal mixture. Use a rubber-tired roller for rolling the slurry seal mixture.

4-4 FUEL-RESISTANT SEALER.

Fuel-resistant sealer (FRS) material is a combination of coal-tar emulsion, fine aggregate, water, and occasionally other additives. These materials are mixed in batches and applied to HMA surfaces by hand, sprayer, or mechanical squeegee. Coal-tar emulsion binder provides a fuel-resistant surface, and the fine aggregate provides skid resistance. The FRS is placed in thin layers, usually 2 millimeters (1/16 inch) or less. Particle size affects the minimum thickness that is applied by squeegee. An FRS does not significantly enhance the structural strength of the pavement structure.

4-4.1 Areas of Application.

Apply FRS to any HMA surface subjected to fuel drippage or spillage. This includes vehicle maintenance and parking areas.

4-4.2 Considerations for Use.

Important factors to consider before using an FRS:

- Use FRS only where a fuel-resistant surface is required.
- FRSs do not have as long a service life as surface treatments with asphalt cement binder, but they last up to 4 years, depending on traffic and climate conditions.

- Parking areas with low vehicle turnover or low usage rates (therefore lower instances of fuel spillage) are better served with a single or double bituminous surface treatment or a slurry seal.
- FRSs provides a seal to protect the underlying HMA pavement to retard oxidation and weathering.
- Close the pavement to traffic during the curing of FRS layers (usually 4 to 8 hours).
- Uncured FRS is adversely affected by changes in weather conditions such as rain or freezing temperatures.
- Only structurally sound pavements are suited for an FRS.
- Mixture design and application are important for obtaining a required job performance.

4-4.3 Material Requirements.

4-4.3.1 Coal-tar Emulsion.

The binder material used in an FRS is a coal-tar emulsion. The coal-tar emulsion is usually specified as having to meet the requirements of ASTM D5727.

4-4.3.2 Aggregates.

Ensure aggregates are either natural or manufactured angular aggregate, are clean, free of organic and other objectionable material, and meet the gradation requirements in Table 4-5.

4-4.3.3 Water.

Use only potable water in an FRS mixture. Determine the amount of water required from laboratory testing prior to construction. Additional water normally is required under high temperature pavement conditions.

4-4.3.4 Additives.

Additives used in FRSs include various types of polymer and silicon materials. These materials are added to the FRS mixture in the field or added to the coal-tar emulsion during the emulsifying process. The polymer materials often used are latex combinations of acrylonitrile and butadiene. Ensure additives used are compatible with the coal-tar emulsion.

Table 4-5 FRS Minimum Application Rates and Corresponding Aggregate Gradations

Gradation Type		Coarse	Medium	Fine
Minimum Application Rate, L/m² (gal/yd²)		**1.35 (0.3)**	**1.0 (0.22)**	**0.72 (0.16)**
Sieve Size	1.18 mm (No. 16)	100	100	100
	850 µm (No. 20)	85–100	98–100	100
	600 µm (No. 30)	25–85	85–100	98–100
	425 µm (No. 40)	5–25	25–85	85–100
	300 µm (No. 50)	2–10	5–25	25–85
	212 µm (No. 70)	---	2–10	5–25
	150 µm (No. 100)	0–2	0–4	2–10
	106 µm (No. 140)	--	0–2	0–2

4-4.4 Design.

Historically, the design of FRS mixtures has been based on the selection of materials (sand, water, and additives) from an allowable range based on a gallon of coal-tar emulsion. The current guide specification requires that the final FRS mixture developed be required to meet two test requirements. These tests are curing time and resistance to kerosene.

4-4.4.1 Application Rate.

The rate of application of sealer depends, to a great extent, on the gradation of the aggregate used. The coarser the gradation, the thicker the application required. This ensures that the aggregate is embedded in the sealer and does not wear off under traffic. The rates given are for general guidance and vary depending on the final proportions (solids content) of the sealer that is applied. Recent research suggests that thinner coatings of FRS are not as susceptible to cracking with age; therefore, when possible, use the fine gradation (smaller size aggregate particle). This decreases the occurrence of cracking and increases the life span of the FRS.

4-4.4.2 Requirements.

The FRS mixture is required to meet the requirements provided in Table 4-6. Ensure the amount of sand added to the FRS mixture does not exceed 480 to 720 grams per liter (4 to 6 pounds per gallon) of coal-tar emulsion. Sand loads of greater amounts are not normally fuel resistant and fail the resistance to kerosene test.

Table 4-6 Physical Properties of Sealer Mixtures

Property	Requirement	Referenced ASTM Test Method
Curing time, firm set	8 hours maximum	D2939
Resistance to kerosene	No penetration or loss of adhesion	D2939

4-4.5 Equipment.

Various types of hand-held squeegees, brooms, and other non-mechanical equipment are needed on the typical FRS project. Depending on the job size, they are completed with only mixers sized to job size and hand-held squeegees; however, the basic equipment required for mechanical application on an FRS project includes a truck-mounted batch-mix machine, squeegee blades, power broom, and front-end loader or fork truck. The truck-mounted batch-mix machine is where the FRS mixtures are proportioned and mixed and then taken to the project site and applied to the pavement surface. FRS mixtures are always batch mixed and then applied, unlike slurry seals that are made in a continuous mix operation. The batch-mix machine usually has a manufacturer-supplied calibration sheet showing the number of gallons per depth in the tank. The depth is usually monitored with a marked dipstick. The squeegee blades apply the FRS material to the pavement surface. The power broom cleans the pavement surface prior to application. The front-end loader is used for aggregate handling; however, a forklift is often needed because bagged and manufactured aggregate is often used.

4-4.6 Surface Preparation.

Remove all loose material from the pavement surface prior to application of the FRS. Clean and seal cracks wider than 3 millimeters (1/8 inch) or with vegetation prior to application of the FRS.

4-4.7 Application.

After sufficient mixing, pour the FRS mixture directly on the pavement surface and squeegee across the pavement surface. In hot weather conditions where the pavement surface gets hot, applying a fog spray of water prior to application of the FRS material assists in bonding the FRS to the pavement surface. Use a minimum of two applications of the FRS material to eliminate the possibility of any continuous, full-depth voids in the FRS. When possible, make each additional application perpendicular to the previous one. Whenever possible, place consecutive lanes while the sealer mixture applied in the first lane is still semi-fluid and workable. If operations preclude fresh working joints, allow the previously laid pass to set and cure sufficiently so that it is not scarred, torn, or scraped from the pavement surface during the placement of the adjoining pass.

4-4.8 Curing.

FRSs cure by evaporation of the water from the sealed pavement surface. Sunlight and warmer temperatures increase the rate of curing. Curing time varies from 2 to 24 hours depending on the thickness of FRS applied and the existing climatic conditions. Ensure FRSs are not applied when freezing temperatures (<0 degrees C, <32 degrees F) are possible within the required curing time.

4-5 MICRO-SURFACING.

Micro-surfacing, also known as micro-texturing, macro-seal, or macro-pavement, is a latex-modified asphalt emulsion slurry paving system. This system was originally developed in West Germany in the 1970’s and has been used in the United States since 1980. The total system consists of a latex-modified asphalt emulsion, a chemical set control additive, high-quality crushed aggregate and mineral filler (usually Type 1 Portland cement), and water.

4-5.1 Equipment.

Some of the methods of mixing and application are similar to those of a slurry seal. Equipment such as brooms, loaders, and asphalt distributors are the same as for a slurry seal. However, other equipment required for mixing and application of micro-surfacing mixtures are different than those required for slurry seals. Mixing is accomplished in a multi-bladed, twin-shaft, pugmill mixer. Application equipment with constant agitation within the slurry box is required to achieve a uniform placement of slurry. Micro-surfacing mixtures are placed with self-propelled mixing and placement vehicles. These vehicles have bins and tanks to carry all the aggregate, filler, asphalt emulsion, water, and additives required to make the mixture. Two basic types of vehicles are used to place micro-surfacing -- those that do so with the help of nurse or resupply trucks and those that place and then leave for resupply. These vehicles have the ability to apply a fog spray of water to the pavement directly in front of the spreader box. The spreader box contains blades to continually agitate the slurry. On relatively smooth surfaces, the rear seal is rubber and acts as a strike-off (screed). On rough surfaces, normally a steel strike-off is used to form an intermediate leveling course, with another slurry then placed over the leveling course. Rut boxes are used to fill ruts in individual traffic lanes. These boxes are V-shaped, with the point of the V toward the rear of the box. They have two shafts with multiple blades on each side of the V to continuously agitate the slurry. The box is designed to push aggregate to the center and is equipped with two metal leveling plates and a rubber strike-off.

4-5.2 Material Requirements.

4-5.2.1 Emulsion.

The binder used in micro-surfacing is a latex-modified asphalt emulsion. The base asphalt emulsion used is normally a cationic slow-setting emulsion with a hard base asphalt (CSS-1H) as specified in ASTM D2397. The latex polymer is combined with the asphalt cement during the emulsifying process, at a rate of 3.0 percent by weight of residual material.

4-5.2.2 Additives.

Liquid additives are added during the field mixing process to provide control of the set properties of the micro-surface mixture. The amount of additive used increases with decreasing temperatures. This is because the additive acts to cause the emulsion to break or cure faster. Obtain these additives from the emulsion manufacturer to assure compatibility with all components of the mixture.

4-5.2.3 Aggregates.

Ensure the aggregate used is a high-quality, 100 percent crushed aggregate. Aggregates previously used for micro-texturing include granite, flint, slag, limestone, basalt, chert, and gravel. The aggregate is required to meet one of the gradation types listed in Table 4-7. The gradations used for micro-surfacing are the same as those of an asphalt slurry seal, except that type 1, the finest gradation used for a slurry seal (Table 4-4), is not used for micro-surfacing.

Table 4-7 Gradation Types for Micro-Surfacing

Sieve Size	Type 2 Percent Passing	Type 3 Percent Passing
9.5 mm (3/8 in.)	100	100
4.75 mm (No. 4)	90–100	70–90
2.36 mm (No. 8)	65–90	45–70
1.18 mm (No. 16)	45–70	28–50
600 μm (No. 30)	30–50	19–34
300 μm (No. 50)	18–30	12–25
150 μm (No. 100)	10–21	7–18
75 μm (No. 200)	5–15	5–15

Mineral filler is added to the mixture to obtain the desired dispersion (reduce segregation) and working characteristics (speed-up or slow-down the rate of cure of the system) of the micro-surfaced mixture. Determine the amount of mineral filler added from laboratory testing, normally not to exceed 3.0 percent of the weight of the aggregate. Mineral filler is non-air entrained Portland cement, hydrated lime, or another mineral additive.

4-5.2.4 Water.

Use potable water free of soluble salts or any other harmful materials. Limit the amount of water used to that required to produce a mixture of the desired consistency. The amount of water required increases slightly with increasing temperatures.

4-5.3 Design.

A method of mix design for military pavements has not been developed. Instead, procedures developed by the International Slurry Surfacing Association (ISSA) are recommended for use and are detailed here. These procedures are broken down into three parts. The first is the evaluation of materials to verify that they meet the requirements described in section 4-5.2. These materials include the aggregates and the polymer-modified asphalt cement. The second part involves testing the effects of mixing and application characteristics, water content, filler, and additives, and determining the optimum asphalt content through the preparation of trial mixes. The third part involves performance-related tests on the mixture to ensure good long-term performance. ASTM D6372 provides information on standard practices in the design, testing, and construction of micro-surfacing.

4-5.3.1 Mix Characteristics.

Trial mixes are used to determine if the emulsion and aggregate are compatible, if a mineral filler or field control additive is needed, and if used, the concentration and the range of water that produces homogeneous mixtures. Trial mixes are also prepared to determine the optimum filler content and the effects of mineral filler on wet cohesion. These mixes are prepared with constant asphalt emulsion contents and incremental changes in the amount of mineral filler, usually either hydrated lime or Portland cement. Once the desirable mineral filler content has been determined, trial mixes are again prepared, this time keeping the mineral filler content constant and making incremental changes in the asphalt emulsion content.

4-5.3.1.1 Cohesion Test (ISSA Technical Bulletin 139 (TB-139)).

The cohesion test is the method used to classify the set and traffic time of micro-surfacing systems. The cohesion tester is a power steering simulator that measures the torque required to tear apart a 6- or 8-millimeter-thick (0.236- or 0.315-inch-thick) by 60-millimeter (2.36-inch) in diameter specimen under the action of a 32-millimeter-diameter (1.26-inch-diameter) rubber foot loaded to 200 kilopascals (4,177 pounds per square foot). A system is defined as “quick set” if it develops a torque value of 12 to 13 kilograms per centimeter (67.1 to 72.6 pounds per inch) within 20 to 30 minutes. A torque of 12 to 13 kilograms per centimeter (67.1 to 72.6 pounds per inch) is considered the cohesion value at which the mixture is set, water-resistant, and cannot be remixed. A system is defined as "quick traffic" if the mixture develops 20 to 21 kilograms per centimeter (111.9 to 117.6 pounds per inch) torque within 60 minutes. At 20 to 21 kilograms per centimeter (111.9 to 117.6 pounds per inch), sufficient cohesion has developed to allow rolling traffic. Figure 4-1 provides a method to classify various slurry seals and micro-surfacing systems. All micro-surfacing mixtures are designed as quick set, quick traffic systems. Cohesion test results are also used to optimize mineral filler by the use of the “Benedict Curve” (see Figure 4-2), in which the effect of an incremental addition of mineral filler versus cohesion is plotted. The optimum filler content is the value that gives the highest cohesion value. The shape of the curve shows the sensitivity of the system to changes in mineral filler. This helps determine the range of mineral filler that give acceptable laboratory results.

Figure 4-1 Classification of Mix Systems by Cohesion Test Curves

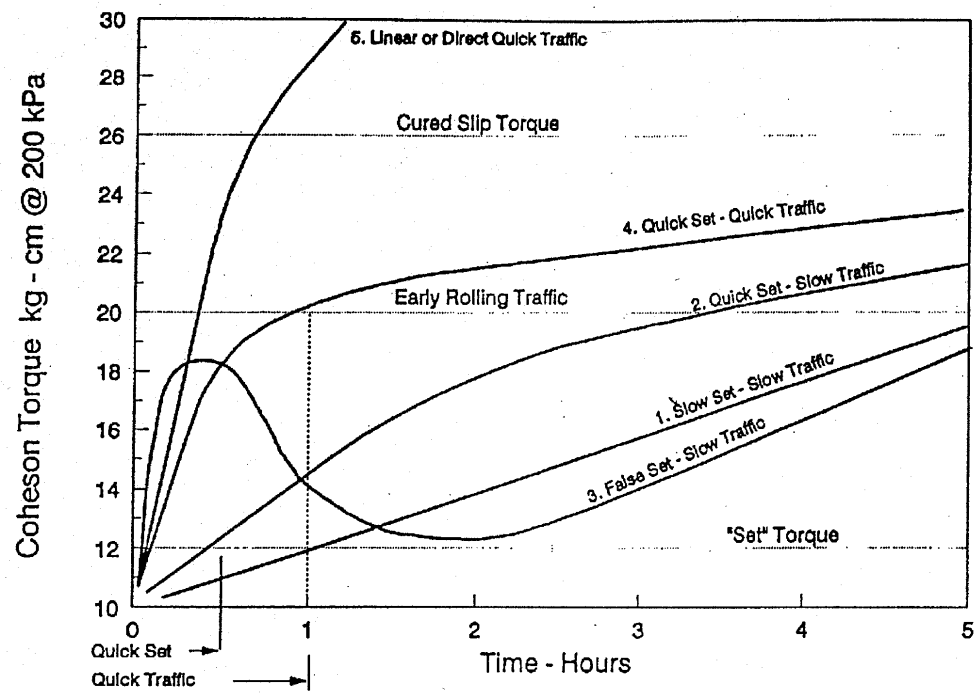
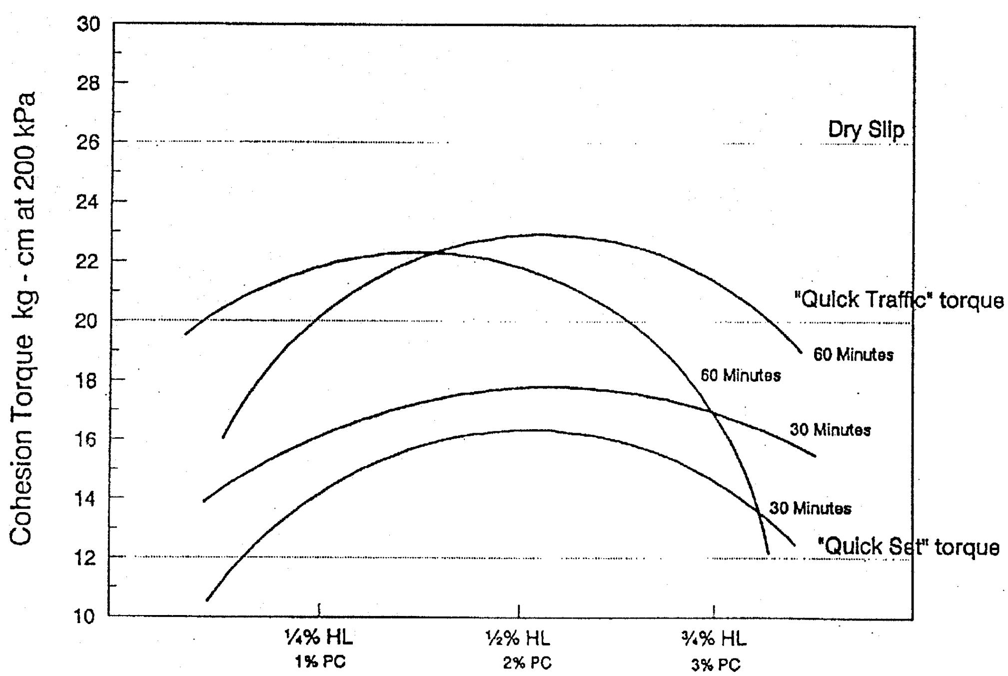


Figure 4-2 Mineral Filler Content Optimization "Benedict Curve"



4-5.3.1.2 Stripping.

Two tests used to evaluate the potential for stripping are: the Wet Stripping Test (ISSA TB-114) and the Boiling Test (ISSA TB-149). The Wet Stripping Test is performed on 60 degrees C (140 degrees F) cured cohesion specimens that are boiled in water for 3 minutes to determine the asphalt adhesion to the aggregate. A coating retention of 90 percent or greater is considered meeting required specifications, with 75 to 90 percent being marginal and less than 75 percent not meeting required specifications. The Boiling Test is similar to the Wet Stripping Test. Either test is also used as an early compatibility indicator test.

4-5.3.2 Determination of Optimum Asphalt Content.

There are several ways to determine the optimum asphalt cement content. One way is to use ISSA test procedures, and another is to use a modified Marshall procedure. A few states also specify requirements for Hveem stability test.

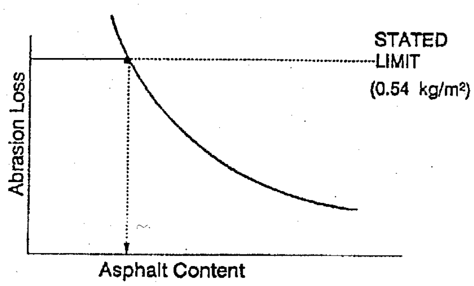
4-5.3.2.1 ISSA Procedure.

The optimum asphalt content is determined from ISSA procedures by graphically combining the results of a WTAT and a loaded wheel test (LWT). Figure 4-3 (a, b, and c) shows how the optimum asphalt content along with an acceptable range is determined by graphically combining WTAT and LWT data. Ensure the minimum and maximum asphalt content falls within the range usually provided in the specification. The ISSA recommends that residual asphalt content be within a range of 5.5 to 9.5 percent.

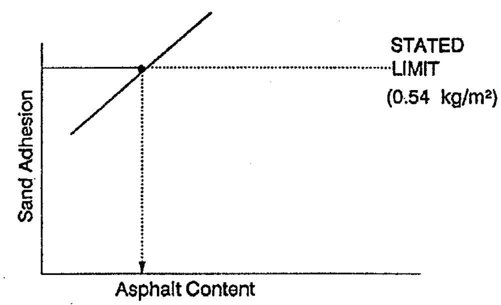
a. **Wet Track Abrasion Test (ASTM D3910/ISSA TB-100).** This test determines the abrasion resistance of micro-surfacing mixture relative to asphalt content and is one of two ISSA tests used for determining optimum asphalt content. This test simulates wet abrasive conditions such as vehicle cornering and braking. A prepared and cured sample of mixture 6 millimeters (0.24 inch) thick by 280 millimeters (11.0 inches) in diameter that has been soaked for periods of either 1 hour or 6 days is immersed in a 25 degrees C (77 degrees F) water pan and is wet abraded by a rotating weighted (2.3-kilogram [5.1 pounds]) rubber hose for 5 minutes. The abraded specimen is dried to 60 degrees C (140 degrees F) and weighed. The maximum allowed weight losses for 1-hour and 6-day soaks are 0.54 kilogram per square meter (0.11 pound per square foot) and 0.8 kilogram per square meter (0.16 pound per square foot), respectively. Asphalt contents that result in these weight losses are considered the minimum asphalt contents. The WTAT on a 6-day soaked sample is not required; however, due to the increased severity of the 6-day soak, it is preferred by laboratories and user agencies for predicting the performance of the system.

b. **Loaded Wheel Test (ISSA TB-109).** This test is used to determine the maximum asphalt content to avoid asphalt flushing in micro-surfacing systems. This is accomplished by specifying and measuring fine sand that adheres to the sample subjected to simulated wheel loadings. The ISSA recommends a maximum sand adhesion value of 0.54 kilogram per square meter (0.11 pound per square foot) for heavy traffic loadings. If the sand adhesion is below this maximum value, mixture bleeding does not occur. In this test, a 50-millimeter-wide (1.97-inch-wide) by 375-millimeter-long (14.76-inch-long) specimen of desired thickness (25 percent thicker than the coarsest particle) is fastened to the mounting plate and is compacted with one thousand 57-kilogram (125.6-pound) cycles at 25 degrees C (77 degrees F). At the end of compaction, the specimen is washed, and then dried at 60 degrees C (140 degrees F) to a constant weight. A measured quantity of sand is then placed on the sample, and the LWT is repeated for a specified (usually 100) number of cycles. The specimen is then removed and weighed. The increase in weight due to sand adhesion is noted.

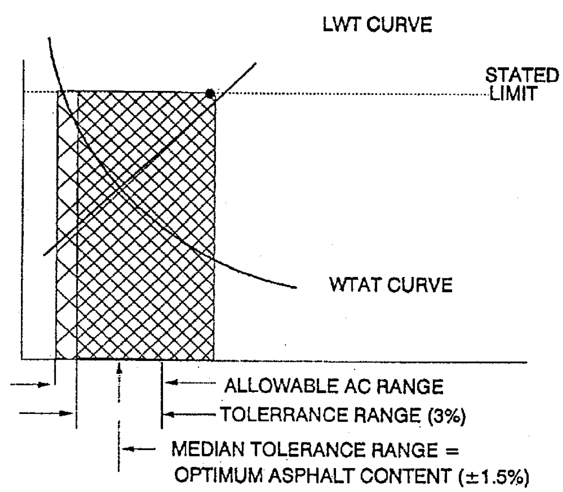
Figure 4-3 Determination of Optimum Asphalt Content



(a) Minimum asphalt content by wet track abrasion test



(b) Maximum asphalt content by loaded wheel test



(c) Combined WTAT and LWT curves

4-5.3.2.2 Marshall Procedure (Modified CRD-C649 or ASTM D6927).

The Marshall HMA mixture criteria is used to determine the optimum asphalt content. Since these are cold polymer-modified emulsion systems, the stability and flow test procedures have been modified to allow for air and low temperature drying (at least 3 days of air curing, 18 to 20 hours of drying in an oven at 60 degrees C (140 degrees F) before compaction at 135 degrees C (275 degrees F)). The mixes are usually compacted with 50 blows per side. Under this procedure, several test specimens are prepared for combinations of aggregate and asphalt content. The asphalt contents are selected to provide VTM of 4.5 to 5.5 percent. The compacted test specimens are tested for the bulk specific gravity (ASTM D2726), stability, and flow values. Finally, the optimum asphalt cement content is determined using results from these tests. For thin micro-surfacing applications, the stability is not considered a primary factor in determining the optimum asphalt cement content. The surface characteristics of aggregates require adjustments in the VTM requirement to achieve the desired flow values.

4-5.3.2.3 Design Limitations.

a. **ISSA Design.** Torque values are measured in the laboratory under specific conditions; no correlation has been established with pavement performance in the field. Perform the mixing and wet cohesion test at various moisture contents, relative humidity, and temperatures to simulate the expected field conditions. In addition, it has been reported that aggregates that met ISSA torque standards for 60 minutes have failed to meet the torque values for 30 minutes. Laboratories also use a subjective analysis to determine torque. The sample is examined after the torque is applied, and if it fails, the torque value is determined from a visual examination of the condition of the sample; however, this analysis appears to negate the objectivity of the cohesion test. This indicates an area where the industry reexamines its procedures for cohesion tests and consider the effect of various aggregates on test results. The WTAT was correlated to field performance for only 6-millimeter (0.24-inch) thickness and Type 2 gradation. Accordingly, values of 0.54 kilogram per square meter (0.11 pound per square foot) are not used for other thicknesses and aggregate gradations. Further tests are needed to verify or establish new values. Also, limestone materials meet the WTAT standard for 1-hour soak periods but fail to meet maximum abrasion loss when a sample with a 6-day soak is tested. While the WTAT on a 6-day soak specimen is used for information only, industries review and adjust their current design standards. The reproducibility of the LWT is questionable. The arm that moves the wheel does not stay horizontal, but rather moves up and down during the test. This changes the pressure on the sample. Modify the arm to stay horizontal. At the present time, the weights used to apply pressure are bags of lead shot. These bags shift during the test and affect the applied pressure. Plates that are attached to the machine replace the bags. Sample preparation has been shown to affect the LWT results by a factor of as much as two. The test specimen flushes if water levels are not carefully controlled. This condition affects the sand adhesion. Improve current laboratory procedures for sample preparation so that samples are molded consistently. For aggregates, the LWT has shown to permit excessive amounts of binder, resulting in unacceptable mixtures. This is true for applications in high shear areas such as intersections. Performance data indicates that mixtures produced with these aggregates using a lower binder content (than required by the LWT) have performed well in extending the pavement service life. The specific gravity specification is subjective due to the sampling procedure. The entire LWT specimen is weighed wet and dry to obtain the specific gravity. After compaction, the same test is repeated. The problem is that only 50 to 60 percent of the specimen is compacted. Variations in the specific gravities of samples also skew LWT results.

b. **Marshall Design.** The applicability of this HMA test for micro-surfacing is questionable. The Marshall series uses specimens of varying asphalt contents that are dried, reheated to 135 degrees C (275 degrees F), and compacted to low void content. Micro-surfacing mixtures do not reach low void levels during the life of the mixture. Field observation has noted air voids of 10 to 15 percent after 1 to 2 years of placement. There is a need to correlate the voids measured during the design using the Marshall method with the actual field voids. One materials laboratory that has developed a cold Marshall test procedure to estimate field voids is currently correlating the field voids with the voids obtained by the modified HMA procedure. The HMA samples are prepared by compacting in a mold. Also, for reliable results, cure the sample in a uniformly distributed film throughout the thickness of the lift.

4-5.4 Surface Preparation.

Ensure the pavement surface has all loose material removed prior to application of the micro-surfacing material. Repair any structurally deficient pavement areas. Clean and seal cracks wider than 3 millimeters (1/8 inch) or filled with vegetation prior to application of the micro-surfacing.

4-5.5 Application.

Apply a tack coat to the pavement surface prior to application of the micro-surfacing. Immediately prior to application, wet the pavement surface with a water fogging. This fogging leaves the surface damp but with no free water. Ensure the minimum thickness of micro-surfacing material application at least exceeds the maximum nominal size of the aggregate in the mixture (usually 1¼ to 1½ times the maximum nominal size). This relates to minimum thicknesses of from 10 to 13 millimeters (3/8 to slightly over 1/2 inch). Where wheel ruts exceed 6 millimeters (1/4 inch) in depth, place a separate rut-filling layer prior to the complete overlay. The emulsion is usually heated to within 27 to 49 degrees C (80 to 120 degrees F) prior to mixing. Micro-surfacing applications are designed to be opened to traffic within 1 hour after placement. Temperature and humidity are the controlling factors for curing micro-surfacing after placement. As the temperature increases and the humidity decreases, the cure time decreases. Construction of a test section is very important for micro-surfacing due to changes in field conditions from lab conditions. Micro-surfacing is a quick-set system; therefore, changes or variations in field conditions require moisture, additive, or basic mix design changes to meet field conditions. Where possible, accomplish placement utilizing “nurse trucks” to allow for continuous placement. Nurse trucks are vehicles that are intended to carry aggregate, emulsion, and water to the application vehicle, whereby application of the micro-surfacing is a continuous operation. Whenever placement of the micro-surfacing is stopped, lift and clean the spreader box and ensure the transverse joint is squared. Paper strips or metal flashing is used to improve transverse joints. Construct longitudinal joints with a 50-millimeter (2-inch) overlap to assure complete coverage and to reduce rigid development. Use of an operator to control the rate of material flow along with careful control of the placement vehicle’s speed allows for accurate placement of the micro-surfacing.

CHAPTER 5 ASPHALT STABILIZATION

5-1 INTRODUCTION.

This chapter contains information for use of asphalt cement for stabilization of soil/aggregate materials and on stabilization of drainage layers. When any subsurface layer receives an asphalt treatment, the treatment is considered asphalt stabilization. In general, asphalt stabilization is utilized where good base course materials are not readily available and where the existing subgrade materials are sands or silts which meet design requirements for stabilization. Asphalt stabilization is used when a drainage layer is trafficked with construction equipment. UFC 3-250-11 contains detailed information on the design and construction of asphalt stabilized soils.

5-2 MATERIALS.

5-2.1 Soil/Aggregate.

There are a number of requirements for determining soil suitability for asphalt stabilization. The stabilization of fine-grained soils depends on the plasticity characteristics and amount of material passing the 75 μm (No. 200) sieve. Recommended gradations of materials for various types of asphalt stabilization are given in UFC 3-250-11. Soils with high plasticity are not stabilized with asphalt because of difficulty in thoroughly mixing the asphalt into the soil. These soils are only stabilized if pretreated with lime or cement to decrease the plasticity of the soil.

5-2.2 Asphalt.

The asphalt used for stabilization is either emulsified or cutback asphalt. Normally, the emulsions used are slow setting (SS) or possibly some medium setting (MS) emulsions. Rapid set (RS) emulsions are not used. Any type of cutback from rapid (RC) to medium (MC) to slow (SC) cure is used for asphalt stabilization. The use of emulsions versus cutbacks is dependent on the availability of materials, soil type, climate, and construction practice. The availability of cutbacks is limited in areas due to environmental concerns.

5-3 COMPOSITION AND MIXTURE.

For stabilized materials, the type of asphalt used is as important as how much is used. UFC 3-250-11 contains information on the type and amount of liquid asphalt to use. Design procedures for determining optimum asphalt content are given for both cutback and emulsified asphalts.

5-4 CONSTRUCTION.

Methods and procedures for constructing asphalt-stabilized materials are given in UFC 3-250-11.

5-5 DRAINAGE LAYERS.

Guidance for the design and construction of subsurface drainage features is given in FAA Advisory Circular 150/5320-5E, *Airport Drainage Design*. Open graded material (OGM) is the drainage feature that normally requires stabilization for construction stability or for structural strength to serve as a base for a flexible pavement.

5-5.1 Design.

Ensure the amount of asphalt used coats the aggregate and holds it in place but does not fill any voids. Normally 2 to 2.5 percent (by weight of total mixture) asphalt is sufficient for stabilization. As a rule, the more open graded the material is, the lower the asphalt content required for stabilization. The asphalt used is similar to the grade normally used in that location. Use a higher viscosity (stiffer) asphalt to provide increased stability.

5-5.2 Construction.

Place a stabilized OGM with a paver to minimize segregation and achieve the design grade and thickness. Usually asphalt cement is used as the binder and the OGM is run through a HMA plant to achieve required coating and to allow for placement. Liquid asphalts (emulsions or cutbacks) are used if conditions warrant. An OGM requires rolling the mixture only to seat the aggregate in place.

CHAPTER 6 MISCELLANEOUS MIXTURES

6-1 RECYCLED ASPHALT MIXTURES.

See UFC 3-250-07.

6-2 SAND-ASPHALT MIXTURES.

In regions such as coastal areas where sand of good quality (clean and angular) is the only local aggregate available, the sand is used to produce an economical base or surface course. Sand mixtures, produced from these clean angular sands, are considered for paving roads and streets where light loads are anticipated and where considerable savings are realized by using locally available sand. Mineral filler is often added to increase the density and stability of the mixture, but mineral filler is omitted in designing sand-asphalt mixtures for asphalt-stabilized base courses. Asphalt cement, cutback asphalt, or emulsified asphalt is used for binder. Cold-laid asphalt mixtures are mixed at a central plant, mixed with a travel plant, or mixed in place. HMA is mixed at a central plant. Sand mixes are fine textured, dense, and relatively impermeable. The stability and durability of the sand mixes depend on the quality and grading of the fine aggregate, the amount and grade of asphalt binder, and the degree of control exercised in construction operations. Ensure the sand is sufficiently well-graded to meet the specified aggregate requirements for the type of course to be constructed and is free from excessive amounts of foreign matter. In many cases, the design gradation is obtained by selecting and blending locally available sands.

6-2.1 Advantages and Disadvantages.

Sand-asphalt mixes are produced with locally available materials at a relatively low cost; however, the use of sand mixes is limited due to their relative lack of strength and durability. Sand asphalt mixtures normally require a relatively high asphalt content thus resulting in a high mixture cost.

6-2.2 Uses.

Sand mixes are not to be used as surface or intermediate courses for airfield and heliport pavements designed for high-pressure tires or for pavements designed for solid-rubber tires, steel wheels, or tracked vehicles. High-pressure truck tires and all-terrain vehicle (ATV) tires are not to be allowed on sand-asphalt mixes. Sand mixes are considered for asphalt-stabilized base courses for all types of traffic areas and for any course in non-traffic areas. Sand mixes are considered for surface and intermediate courses for pavements subjected to low-pressure tires (690 kilopascals (100 psi) or less) and low traffic volumes. In this case, make and test trial mixes in the laboratory. Sand-asphalt mixes have been used to provide temporary travel paths for construction vehicles over completed AC pavements. Ensure the maximum sized aggregate particle are 9.5 millimeters (3/8 inch) or less to prevent the traffic from making indentations on the underlying AC pavement.

6-3 SHEET ASPHALT.

Sheet asphalt is a refined type of hot sand-asphalt pavement in which the grading, quality of sand, amount of mineral filler, and asphalt cement content are carefully controlled. The percentage of asphalt required is higher than that used for sand asphalt. Sheet asphalt provides a smooth, impermeable, homogeneous surface course that gives the best service when traffic is spread evenly over the pavement. Normally, sheet asphalt is used for surface courses only and is constructed 38 to 50 millimeters (1½ to 2 inches) thick over an intermediate course.

6-4 ROCK ASPHALT.

Rock asphalt pavement is composed of crushed, natural asphalt-impregnated limestone or sandstone, or a combination of these, used alone or mixed with additional asphalt or flux oil. Rock asphalt pavement is laid cold in the same manner as cold-laid asphalt mixture. Rock asphalt is used only in surface courses for roads and are not to be constructed over 37.5 and 50.0 millimeters (1½ and 2 inches) thick for blended and fluxed rock-asphalt, respectively. Kentucky, Alabama, Texas, New Mexico, Oklahoma and Utah have natural rock-asphalt deposits where paving material is produced commercially. The character and quantity of the aggregate and asphalt in the material vary among the different deposits and vary within the same deposit. Rock asphalt pavement is prepared by blending into the natural asphalt a crushed impregnated limestone or sandstone or a combination of the two in proportions to produce a properly graded mixture with a specified asphalt content. Ensure the natural rock asphalt is enriched (that is, add more asphalt to the mixture) if the material does not contain asphalt in its natural state to produce a mixture meeting design requirements. Hot mixes are produced by heating crushed limestone impregnated with relatively hard asphalt, alone or with added sand, and mixing with additional asphalt cement in a conventional plant.

6-4.1 Advantages and Disadvantages.

The advantages and disadvantages are the same as those for plant-mix cold-laid asphalt mixtures. In addition, the use of rock asphalt pavement reduces cost because this mixture already contains binder material.

6-4.2 Uses.

Rock asphalt pavements are used for roads and streets not subjected to traffic by tracked vehicles. Rock asphalts are used as the aggregate in slurry seals, but only use predominantly sandstone rock asphalts in slurry since limestone rock asphalts polish under traffic and thus produce a slick pavement surface.

6-5 COLD-MIX ASPHALT.

Cold-mix asphalt pavements are used as a low-cost surface for low-volume roads or as a base course for high-volume roads and airfields. While cold mixes do not provide pavements with the same quality as hot mixes, cold mixes do perform for the purposes intended. Cold mixes are capable of being stored for several months and are useful for patching. Because fuel is not needed to heat cold mixes, these pavements are constructed at lower cost than hot mixes. Two disadvantages of using cold mixes are that usually a lower density is obtained in cold mixes than in the construction of hot mixes and that a curing period is needed to allow water or volatiles to evaporate so that shear strength is obtained.

6-5.1 Design.

6-5.1.1 Preliminary Work.

The first step in designing a paving mixture is to make a survey to ensure that the materials needed are available in quantities meeting job requirements and their use is economical in the pavement construction. Obtain sufficient samples of material during the survey to accomplish the tests described in this section of this UFC. Materials normally required for the paving mix are coarse aggregate, fine aggregate, mineral filler, and bitumen.

6-5.1.1.1 Sampling.

Test reports reflecting the results of sampling and testing of the aggregates and bituminous materials are prepared. Conduct a gradation analysis on the aggregates to determine whether the aggregates when blended meet the contract gradation specifications. Furnish representative samples of materials for laboratory testing. Divide samples into sizes meeting testing requirements in the laboratory, in a way that represents field conditions. Sufficient quantities of materials are obtained at the time of sampling to meet the ASTM requirements and for laboratory pavement design tests described in this section of this UFC. Normally, aggregates that produces 90 kilograms (200 pounds) of the desired gradation and 19 liters (5 gallons) of bitumen is sufficient for these tests.

6-5.1.2 Materials.

6-5.1.2.1 Tests on Aggregates.

Ensure aggregates for use in an asphalt mixture are clean, hard, and durable. Angular aggregates provide an increased stability in pavements compared to rounded aggregates. Tests of aggregates required in the design of HMA mixtures are also applicable to the cold-mix type. Table 6-1 lists typical aggregate gradation requirements for both dense- and open-graded mixtures. The gradation used depends on the application and the binder. Dense-graded mixtures are used in most applications; open-graded mixtures provide more workability in colder weather. Many proprietary cold-patch materials use an open grading along with a modified binder. The dense-graded aggregate gradations correspond to those recommended in this text for hot-mix, hot-laid asphalt mixtures, which are provided in Table 2-1 for HMA.

Generally, combine aggregates for paving mixes from a minimum of two stockpiles. Mathematical equations are available for making such combinations but are not presented in this UFC because they are lengthy and because trial-and-error procedures are normally easier. The method of combining stockpile sample gradations is described in section 2-4 on dense-graded HMA. Ensure the gradation of the aggregate falls within the limits of the gradation for the project specifications, such as those provided in Table 6-1. Ensure the final gradation presents a smooth curve when plotted with sieve size versus percent passing.

Table 6-1 Typical[1] Aggregate Gradations for Plant-Mix Cold-Laid Asphalt Mixtures

Sieve Size	Percent Passing Sieve by Weight			
	Dense-Graded		Open-Graded	
12.5 mm (1/2 in.)	100	--	100	100
9.5 mm (3/8 in.)	86±9	100	90–100	90–100
4.75 mm (No. 4)	66±9	85±9	20–55	40–75
2.36 mm (No. 8)	53±9	71±9	5–30	25–55
1.18 mm (No. 16)	41±9	57±9	0–10	10–30
600 µm (No. 30)	31±9	43±9	---	---
300 µm (No. 50)	21±8	31±8	0–5	3–15
150 µm (No. 100)	13±6	19±6	---	---
75 µm (No. 200)	4.5±1.5	6±3	0–2	0–6

[1] Actual gradations used depend on the application; open gradations provide for greater workability in colder weather.

6-5.1.2.2 Tests on Asphalt Cement.

Know the specific gravity of the asphalt cement to determine the percent by volume of bituminous materials in the mix. Because only the residual asphalt is used in calculating the percent binder, the amount of residual asphalt cement in cutback asphalts and asphalt emulsions are determined as specified in ASTM D402 and ASTM D244 for cutback and emulsified asphalts, respectively. Determine the specific gravity of the residual asphalt as described in ASTM D70.

In addition to cutback asphalts and emulsified asphalts, cold-mix asphalt pavements are made with asphalt cement and liquefier (cutback) produced to meet a project’s design requirements. This cutback asphalt is produced, usually for remote projects, by using kerosene to liquefy an asphalt cement. The type of asphalt cement used to make this liquid binder is varied easily to meet various climate conditions. The cutback binder produced has a relatively long shelf life, depending on the amount of cutback material (kerosene) that is added. When cutback asphalts are contained in a single tank, then only the standard pipelines and spray bar are required. Additional equipment is used for handling the kerosene and asphalt cement when this type of cutback binder is produced. Asphalt emulsions are advantageous in that damp aggregate is allowed to be used in the mixing process, whereas dry aggregates are required for the other binder materials. Normally, mixes made with asphalt emulsions cannot be stockpiled unless the emulsion has been specifically formulated for stockpiling purposes. The choice of asphalt material type depends primarily on economics and the type of equipment to be used. Table 6-2 provides a guide to the selection of the type and grade of asphalt cement. The table provides information on asphalt for mixes to be used immediately and on asphalt for mixes to be stockpiled for later use.

Table 6-2 Selection of Asphalt Type and Grade

Asphalt Parameter	Climatic Conditions During Construction or Storage		
	Cold (less than 16 °C, 60 °F)	Moderate (16–27 °C, 60–80 °F)	Hot (above 27 °C, 80 °F)
Kerosene, liters/metric ton (gallons/ton mix) to asphalt cement	8.3 (18.8[1]) (2.0 (4.5[1])) added to AC-20, 85–100 pen, and PG 58-22	7.1 (15.4[1]) (1.7 (3.7[1])) added to AC-20, 85–100 pen, and PG 58-22	6.3 (12.5[1]) (1.5 (3.0[1])) added to AC-20, 85–100 pen, and PG 58-22
Cutback asphalts	RC-70–RC-250	RC-250–RC-800	RC-800–RC-3000
Emulsified asphalts[2]	MS-2h SS-1h	MS-2–MS-2h SS-1–SS-1h	MS-2 SS-1

Note: RC = rapid curing; MS = medium set; SS = slow set.
[1] Amount of kerosene to be added when mixture is to be stockpiled for future use.
[2] Emulsified asphalts are available that are specifically formulated for stockpile use.

6-5.1.3 Design.

The following procedure is recommended for determining the amount of asphalt cement to be used in the paving mix for cold-mix pavements. This procedure is applicable only for dense-graded mixtures. This design procedure is similar to the procedure used for designing HMA mixes for roads and streets. Laboratory equipment and test procedures are required to conform to CRD-C 649 and CRD-C 650. There is no widely accepted standard method for the design of all types of cold mixes. The Asphalt Institute provides information on design and construction procedures for cold mixes in MS-14. Information specific to emulsions is available in MS-19. Base the selection of the design method on past experience and local practices.

6-5.1.3.1 Asphalt Contents for Specimens.

The quantity of asphalt cement required for an aggregate is an important factor in the design of a paving mixture. To start the laboratory tests, make an estimate of the optimum amount of asphalt cement for the aggregate to be tested. Laboratory tests normally are conducted for a minimum of five asphalt cement contents: two above, two below, and one at the estimated optimum content. Incremental changes of 1 percent are used for preliminary work, but increments of 0.5 percent are used where the optimum asphalt cement content is known and for final designs.

6-5.1.3.2 Proportioning of Aggregates.

As a preliminary step in mixture design and manufacture, determine the proportions of the different available stockpiled materials required to produce the desired gradation of aggregate. This step determines whether a blend is produced meeting design requirements and, if so, the proportion of aggregates to be fed from the cold feeders into the dryer. Sieve analyses are conducted on material from each of the stockpiles. The aggregates are combined as described in CHAPTER 2. After a blend has been prepared from the available materials meeting design requirements, samples of these materials are processed for use in the laboratory design tests as specified in CRD-C 649.

6-5.1.3.3 Determination of Optimum Asphalt Cement Content.

The optimum asphalt cement content is taken as the average of the asphalt contents corresponding to the mix properties in Table 6-7. The optimum asphalt cement content is the amount of asphalt cement that is incorporated into the mix. The percent of cutback asphalts and emulsified asphalts are corrected to give a residual asphalt content equal to the optimum asphalt content determined by the tests. Because all of the volatiles do not evaporate, decrease slightly the amount of bitumen to be added as determined by this mix design procedure. When the asphalt cement and kerosene-type mix is to be used, add the desired amount of kerosene to the actual paving mix in addition to the optimum asphalt content determined from the laboratory design.

Table 6-3 Selection of Optimum Asphalt Content

Mix Property	Value for Determining Optimum Asphalt Content
Unit weight of mix, lb/ft^3	Peak of curve
VTM, percent	4±1
VFA, percent	75±5

6-5.2 Plant Mix.

Quality control is increased for mixtures produced in a plant Vs mixtures mixed in place in the field. This increased control results in a much tighter gradation and binder content control, although overall costs are greater compared to in-place mixing.

6-5.2.1 Plant Operation.

The plant operation varies with the type of asphalt material used in the mix. For mixes using asphalt cement and kerosene, introduce the kerosene and asphalt cement onto the aggregate at different times. Drying of the aggregate is not a design requirement with asphalt emulsions, but for cutback binders, heat the aggregates. Ensure aggregates are not hotter than 93 degrees C (200 degrees F) when mixed with RC cutback asphalts and not hotter than 121 degrees C (250 degrees F) for mixing with MC grades or asphalt cement and kerosene. Ensure the asphalt materials are in the temperature ranges provided in Table 6-8 when introduced into the pugmill.

Table 6-4 Mixing Temperatures for Asphalt Materials

Bituminous Material Type	Grade	Temperature Range, °C (°F)
Emulsified asphalts	MS-2	38–71 (100–160)
	MS-2h	38–71 (100–160)
	SS-1	24–54 (75–130)
	SS-1h	24–54 (75–130)
Cutback asphalts (not used much due to environmental issues)	RC-70	38–57 (100–135)
	RC-250	57–79 (135–175)
	RC-800	77–96 (170–205)
	MC-70	38–57 (100–135)
	MC-250	57–79 (135–175)
	MC-800	77–96 (170–205)
Note: MC = medium curing; RC = rapid curing; MS = medium set; and SS = slow set.		

6-5.2.2 Plant Laboratory.

Use of a plant laboratory ensures that the aggregate meets design gradation requirements and that the mix contains the prescribed percentage of asphalt material. The plant laboratory contains this major equipment:

a. A hand- or power-driven mechanical sieve shaker. The sieve shaker is required to have a capacity of not less than eight full-height, 200-millimeter (8-inch) -diameter sieves.

b. A full-height, 200-millimeter (8-inch) -diameter sieve for each of the following sieve openings: 12.5 millimeter (1/2 inch), 9.5 millimeter (3/8 inch), 4.75 millimeter (No. 4), 2.36 millimeter (No. 8), 1.18 millimeter (No. 16), 600 micrometer (No. 30), 300 micrometer (No. 50), 150 micrometer (No. 100), and 75 micrometer (No. 200). The sieves are required to have square openings and conform to the requirements of ASTM E11.

c. An extractor or ignition test for measuring bitumen content within close tolerances.

d. A balance having a capacity of 2 kilograms (4.4 pounds) and sensitive to 0.1 gram (0.0035 ounce).

e. Marshall equipment for compacting and testing samples to verify mixture design.

6-5.2.3 Adjusting Mix Proportions.

Adjust mix proportions whenever tests indicate that specified tolerances are not being met. Fully automated plants produce consistent mixtures, provided that the equipment is calibrated and in good working condition. Variations in weighing techniques or faulty scales are detected readily and corrective measures taken by maintaining a close check on load weights. Ensure the total weight of each load of mixture produced only varies between plus or minus 2 percent from the total of the batch weights dumped into the truck.

6-5.2.4 Preparation of Construction Specifications.

6-5.2.4.1 Specifications.

Cold-laid asphalt mixtures are produced according to the provisions of guide specifications except when mix quantities, less than 100 metric tons (100 tons), are specified for limited use in repairs. In these cases, the procedures specified in the guide specification are not economical. When such an exception is allowed, locally available cold-laid bituminous mix produced according to local state highway department specifications are used. Contact the Pavements Discipline Working Group (DWG) or their designated representative for these exceptions. When the quantity equals or exceeds 100 metric tons (100 tons), approval from the Pavements DWG or their designated representative is required. Provide a copy of the specification or reference thereto and information regarding traffic conditions and facilities to be paved to facilitate discussions

6-5.2.4.2 Placing.

Although closer control of layer thickness and better prevention of segregation of the mix is achieved with a mechanical spreader, a motor grader is desirable for spreading plant-mix cold-laid pavements. Aeration of the mix to remove volatile material is often required to bring the mix to the design condition for compaction. A motor grader aerates the mix by blading it back and forth across the roadbed.

6-5.2.4.3 Compaction of Mixture.

At the time of compaction, the asphalt material in the mixture is required to provide the specified amount of cohesion so that the design density is reached. Cohesion of the mixture is controlled by the type of asphalt material, volatile content, and temperature of the mixture. Low cohesion causes the mix to be unstable under the roller, while high cohesion causes the mix to be too stiff to be compacted. Compact the mixture as soon as it supports the roller without undue displacement.

6-5.3 Road Mix.

Asphalt road mixes are normally mixed in place by travel plants or common types of road-building equipment, such as blade graders, disk harrows, drags, and pressure distributors. When allowed by design, the existing subgrade materials, loosened existing subgrade materials blended with imported materials, or properly processed imported materials placed on the existing base or subgrade have been used as aggregate in road mixes. When the amount of material passing the 75 microns (No. 200) sieve exceeds 20 percent, processing with asphalt is difficult and this material benefits from the addition of imported materials. A wide range of aggregates are used, and the gradation requirements are less strict than those for hot or cold plant-mixed types. The bitumen is often applied by a pressure distributor to the processed aggregate on the base or subgrade and then thoroughly mixed with the aggregate. A travel-type mixing plant combines the aggregates with an asphalt material and continuously discharges the mixture at the rear of the machine as the plant travels along the strip being paved. Using a travel plant permits accurate proportioning of the bitumen and aggregate and produces a uniform and higher quality mixture vs. a mixed-in-place method. Further, because viscous types of cutback asphalt are used, the curing time is reduced. Curing is usually required to reduce the volatiles in the cutback asphalt or water in the asphalt emulsion prior to spreading and compacting because excessive amounts of volatiles and water affect the compatibility of the mixture and the stability of the finished pavement. Manipulation with blades or other road machines speed curing.

6-5.3.1 Advantages and Disadvantages.

Much less equipment is required for construction using asphalt road mix than is required using AC, thus resulting in cost savings. Using locally available materials also results in significant cost savings. Asphalt road mix, however, does not have the strength or durability of HMA. The road-mix type of pavement provides an economical means of obtaining a surface for roads and streets when the required amount of pavement is small, when the natural soil meets aggregate design requirements, or when aggregates meeting design requirements are nearby. Apply seal coats with aggregate cover as a part of road-mix construction since road mixes are often open graded or of relatively low density and are therefore susceptible to oxidation and abrasion.

6-5.3.2 Uses.

When an asphalt road mix is properly designed and constructed on an existing subgrade meeting design requirements or using locally available aggregates, the quality of road-mix construction approaches that of cold mix produced in a central plant. Road mix is used for intermediate or surface courses, but because of the less accurate control, road mix is often considered inferior to plant mixtures. Road mix is not allowed for use above the base course for airfields. Road mix is used as a wearing course for temporary roads and streets or as the first step in stage construction for permanent roads and streets when these are to be supplemented by plant-mix surfaces as the demands of traffic increase and warrant the increased thickness. Seal coats reduce infiltration of air and water and thus improve the durability of road-mix pavements.

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CHAPTER 7 RESIN MODIFIED PAVEMENT (RMP)

7-1. OVERVIEW.

RMP is a tough and durable surfacing material that combines the flexible characteristics of HMA with the fuel, abrasion, and wear resistance of PCC. RMP is best described as a cross between AC and PCC and is categorized between these two common types of paving materials. RMP is basically an open-graded AC mixture containing 25 to 35 percent voids that are filled with a resin modified Portland cement grout. The open-graded asphalt mixture and resin modified cement grout are produced and placed separately. The production of the materials and the mixture requirements for both the open-graded asphalt mixture and the cement grout differ slightly from conventional procedures. The open-graded asphalt mixture is designed to be the support layer and to determine the thickness of the RMP, which is 50 millimeters (2 inches). The open-graded mixture is placed with standard AC paving equipment but is not compacted. After placement, the open-graded asphalt material is simply smoothed over with a steel-wheel roller, a 3-metric ton (3-ton) maximum. Compaction of the open-graded AC material adversely decrease the voids and hinder grout penetration. After the asphalt mixture has cooled, the cement grout is poured onto the open-graded asphalt material and squeegeed over the surface. The cement grout is then vibrated into the voids with the steel-wheel roller to ensure full penetration of the grout. This process of grout application and vibration continues until all voids are filled with grout, which essentially completes the construction process.

RMP was developed in France in the 1960’s as a fuel and abrasion resistant surfacing material. The RMP, or Salviacim® process as it is known in Europe, was developed by the French construction company, Jean Lefebvre Enterprises, as a cost-effective alternative to PCC. The RMP process has been used on various types of pavements, including warehouse floors, tank hardstands and roads, and aircraft parking aprons. This surfacing material is best suited for pavements that are subjected to abrasive traffic, heavy static point loads, heavy fuel spillage, and channelized traffic. RMP has been constructed successfully in numerous countries, including France, Great Britain, South Africa, Japan, Australia, Saudi Arabia, and the United States.

7-2 MATERIALS

7-2.1 Open-Graded Asphalt Mixture

7-2.1.1 Aggregates

The required aggregate physical properties and the gradation limits for aggregates in the open-graded asphalt portion of RMP are listed in Table 7-1 and Table 7-2, respectively.

Table 7-1 Aggregate Physical Properties

Test	Specification Requirements
LA Abrasion (ASTM C131)	< 40 percent
Percent Fractured faces +4.75 mm (No. 4) -4.75 mm (No. 4)	 > 70 percent > 70 percent
Percent flat and elongated (ASTM D4791)	< 8 percent

Table 7-2 Gradation Limits for Open-Graded Asphalt Mixture

Sieve Size	Specified Limits, Percent Passing
19 mm (3/4 inch)	100
12.5 mm (1/2 inch)	54–76
9.5 mm (3/8 inch)	38–60
4.75 mm (No. 4)	10–26
2.36 mm (No. 8)	8–16
600 µm (No. 30)	4–10
75 µm (No. 200)	1–3

7-2.1.2 Asphalt Cement.

The asphalt cement used is required to be of the same grade as that normally used in the area. When possible, specify the stiffest (highest viscosity) asphalt cement available in that area to assist in providing a stable surface for the subsequent grouting operations. Ensure the asphalt cement meets the requirements of ASTM D946, ASTM D3381, or ASTM D6373/AASHTO M 320.

7-2.2 Cement Slurry Grout.

7-2.2.1 Aggregate.

The cement slurry grout requires silica sand meeting the gradation provided in Table 7-3. Silica sand is specified because of its soundness and durability. Ensure the silica sand meets the requirements for wear and soundness specified for the aggregate in the open-graded AC. Deviations from these aggregate requirements have resulted in significant constructability problems in the past. To date, no problems or distresses associated with possible alkali-silica reactivity (ASR) have been reported in any RMP. No information has been found on investigations of this possible phenomenon.

Table 7-3 Aggregate Gradation for Slurry Grout

Sieve Size	Percentage by Weight Passing Sieves
1.18 mm (No. 16)	100
600 μm (No. 30)	95–100
75 μm (No. 200)	0–2

7-2.2.2 Filler.

Normally, filler or material passing the 75 μm (No. 200) sieve is present in the aggregate used in the cement grout. When additional filler is required, ensure it is a Class F (ASTM C618) fly ash with a limit on the calcium oxide content of 5 percent by weight maximum. Ensure the fly ash has a minimum of 95 percent by weight of material passing the 75 micron (No. 200) sieve.

7-2.2.3 Cement.

Ensure the Portland cement used conforms to ASTM C150. Ensure the Portland cement used is Type I, II, III, or IV. Type I cement is commonly used for RMP applications. The other types are used where moderate to high sulfate resistance or high early strength is required.

7-2.2.4 Cross Polymer Resin Additive.

Cross polymer resin additives are available on the commercial market, Table B-4. Typical composition is five parts water, two parts cross polymer resin of styrene and butadiene, and one part water reducing agent. This product is used as a plasticizing and strengthening agent.

7-3 MIXTURE DESIGN.

7-3.1 Open-Graded Asphalt Mixture.

The optimum asphalt content for the open-graded asphalt mixture is determined through a modified Marshall mix design procedure. Marshall laboratory samples

152.4 millimeters (6 inches) in diameter by 63.5 millimeters (2½ inches) in height are produced using the determined JMF aggregate gradation and a series of asphalt contents ranging below and above an estimated optimum asphalt content value. The estimated optimum asphalt content is determined using a procedure developed in France and based on aggregate properties. The procedure is outlined below:

$$\text{Optimum asphalt content} = 3.25\,\alpha\,\Sigma_{0.2}$$

where

α = $\frac{2.65}{SG}$ where SG = apparent specific gravity of the combined aggregates

Σ = conventional specific surface area

= $0.21G+5.4S+7.2s+135f$

G = percentage of material retained on the 4.75 millimeter (No. 4) sieve

S = percentage of material passing the 4.75 millimeter (No. 4) sieve and retained on the 600 µm (No. 30) sieve

s = percentage of material passing the 600 µm (No. 30) sieve and retained on the 75 µm (No. 200) sieve

f = percentage of material passing 75 µm (No. 200) sieve

If, for example, the estimated optimum asphalt content calculated for a given aggregate gradation was 4.2 percent, then the asphalt contents used for the subsequent laboratory Marshall sample evaluation normally is 3.8, 4.0, 4.2, 4.4, and 4.6 percent. The 152.4-millimeter (6-inch) -diameter Marshall samples are compacted in the laboratory using a 4.536-kilogram (10-pound) hand hammer with a 152.4-millimeter (6-inch) -diameter impact plate. The samples are compacted at 121 degrees C (250 degrees F) using 25 blows on one side of the sample. Three samples are produced for each of the five asphalt contents used, and the resulting average voids data of percentage of VTM and voids filled are used to finalize the selection of optimum asphalt content. As a general rule, as the percent of asphalt increases, the VTM fluctuates over a relatively small range. Also, the voids filled increase slowly until the percentage shows a significant increase, indicating that further increases in asphalt content are working to fill the void spaces rather than coating the aggregate particles. This is an undesirable condition since an excess amount of asphalt cement in the RMP void structure hinders the slurry grout's penetration upon its application. Ensure the asphalt content selected is below the point where voids filled shows a significant increase and where the VTM is within the 25 to 35 percent range of values. The VTM of laboratory specimens and field cores prior to grouting are calculated using this formula:

$$VTM = \left[100 - \frac{WT_{air}\,(1)}{Volume\ SG_T} \times 100\right]$$

Where:

VTM	=	*voids total mix*
WTair	=	*dry weight of specimen*
Volume	=	*π/4 D^2H (measured)*
D	=	*diameter*
H	=	*height*
SG_T	=	*theoretical specific gravity*

7-3.2 Cement Grout.

The slurry grout JMF is developed using the range of properties listed in Table 7-4. Using these proportions, the following procedure is used. The slurry grout samples are prepared in the laboratory by first dry mixing the cement, sand, and fly ash in a blender until they are thoroughly mixed. Then the specified amount of water is added meeting viscosity requirements, and the grout mixture is blended for 5 minutes. After this 5-minute mixing period, the cross polymer resin additive is added and mixed with the grout for an additional 3 minutes. Immediately after the 3-minute mixing period, the grout is poured into the Marsh flow cone and tested for viscosity. A Marsh cone has dimensions of 155 millimeters (6.2 inches) base inside diameter, tapering 315 millimeters (12.6 inches) to a tip inside diameter of 10 millimeters (0.4 inch). The 10-millimeter (0.4-inch) -diameter neck has a length of 60 millimeters (2.4 inches). The viscosity, in seconds, is measured for each sample, and three different batches of each blend are tested to obtain an average viscosity value. The requirements for viscosity of the grout are provided in Table 7-5. The individual components of the grout are adjusted within the prescribed tolerances listed in Table 7-4 to obtain a desired grout viscosity.

Table 7-4 Resin Modified Cement Slurry Grout Mixture Proportions

Material	Percent by Weight
Silica sand	16–20
Fly ash	16–20
Water	22–26
Type I cement	34–40
Cross polymer resin	2.5–3.5

Table 7-5 Slurry Grout Viscosity

Time Elapsed After Addition of Polymer	Viscosity (Marsh Cone Flow Time)
0–30 minutes	8–10 seconds
After 30 minutes	9–11 seconds

7-4 EQUIPMENT.

The equipment used to place, transport, and mix the open-graded asphalt mixture is the same as that used to place dense-graded asphalt mixture, except for smaller steel-wheel rollers. This equipment includes sweepers, distributors, pavers, AC plants, and transport trucks. The equipment used to place the cement slurry grout consists of transit trucks, vibratory steel-wheel rollers, and hand tools.

7-4.1 Rollers.

The rollers used to seat the open-graded asphalt mixture and to vibrate the cement slurry grout into the open-graded mixture are (3 metric tons (3 tons) maximum) vibratory rollers. These rollers are used in the static mode only while seating the open-graded asphalt mixture and in the vibratory mode while placing the cement grout. During placing of the grout, ensure that a minimum of two vibratory rollers are available at the job site in case of breakdowns.

7-4.2 Hand Tools.

Hand squeegees are used to spread the cement grout over the pavement surface during application and to remove excess grout from the pavement surface once the grout application is completed. Hand brooms are used to smooth the texture of the joints during grout application and are used to roughen the texture of the entire grouted pavement surface immediately after the grout application.

7-5 PLACEMENT.

7-5.1 Open-Graded Asphalt Mixture.

The open-graded mix is mixed, transported, and placed by the same methods and procedures used to place dense-graded asphalt mixture. A light tack coat of asphalt material is first applied on the existing AC on which the RMP is to be placed. After the mixture has been placed with a standard asphalt paver, the mixture is not compacted but is rolled to seat or smooth the surface. This is accomplished with a (3-metric ton (3-ton) maximum) tandem steel-wheel roller once the freshly placed open-graded asphalt layer has cooled to 71 degrees C (160 degrees F). Only use a vibratory roller of this size when it is operated in the static mode, in other words the vibratory mode of vibration is turned off. One pass of the roller is usually sufficient for seating. With another single pass, the same or a similar-sized roller is used as a finishing roller to remove roller marks once the asphalt layer has cooled to 38 degrees C (100 degrees F).

7-5.2 Cement Slurry Grout.

7-5.2.1 Mixing and Transport.

The slurry grout is mixed in either a batch plant, portable mixer, or in a ready-mix truck. The cross polymer resin is added to the mixture after all other ingredients have been mixed thoroughly. Generally, add the cross polymer resin to the grout mixture at the batch plant if the haul distance is less than 30 minutes. If the haul distance is greater than 30 minutes, add the cross polymer resin to the grout mixture at the job site. When using ready-mix trucks for transporting slurry grout, mix the grout mixture thoroughly at the job site immediately before application for a minimum of 10 minutes. Thorough mixing is best accomplished by rotating the mixing drum at the maximum allowable revolutions per minute. The final control on the acceptability of the mixing process is the mixing of a consistent grout that meets the viscosity requirements.

7-5.2.2 Placement.

7-5.2.2.1 Application of Grout.

Ensure the surface temperature of the bituminous mixture is less than 38 degrees C (100 degrees F) before the application of grout. On hot days, this requires the use of a fog spray of water to reduce the temperature immediately prior to grouting. Do not use excessive amounts of water, which causes ponding. Test each batch of grout at the job site immediately before placement and use in the finished product only if the batch meets the viscosity requirements listed in Table 7-5. The cement grout is poured over the bituminous mixture from the ready-mix truck by means of a pivoting delivery chute and then spread around with the hand squeegees. Ensure the application of the cement grout is sufficient to fill the internal voids of the open-graded bituminous mixture. 10 to 13 kilograms (22 to 28 pounds) of mixed slurry grout fills 0.8 square meter (1 square yard) for each 25 millimeters (1 inch) of thickness of open-graded asphalt mixture with 25 to 35 percent VTM. Begin the grouting operation at the lowest side of the sloped cross-section and proceed from the low side to the high side. Note that slopes up to 2 percent are considered the practical limit for RMP. Sections with slopes up to 5 percent have been placed, but excess handwork and grout overruns are expected at slopes greater than 2 percent. Place the slurry grout in successive paving lanes with a maximum width of 6 meters (20 feet). The use of 50-millimeter (2-inch) by 100-millimeter (4-inch) strips of lumber as wooden battens separating each of the grouting lanes and the RMP from adjacent pavements facilitates an orderly grouting operation. Secure the wooden battens to the surface of the bituminous mixture before grout application to help prevent excessive grout runoff and to prevent overworking the grouting crew. Ensure the grouting operation is in the same direction as the paving operation for the open-graded bituminous mixture. Use the small, 3-metric ton (3-ton) maximum tandem steel-wheel roller (vibratory mode) passing over the grout-covered bituminous mixture to promote full penetration of the slurry grout into the void spaces. Once the open-graded layer is fully saturated with grout, all excess grout is removed by squeegeeing. This process exposes the rough surface of the open-graded material and improve skid resistance.

7-5.2.2.2 Joints.

Make the formation of all joints between successive lanes of RMP in such a manner as to ensure a continuous bond between the paving lanes. Remove the wooden battens as soon as the grout has been applied to the surrounding area and the area underneath them vibrated or reworked with additional grout and hand brooms to assure full penetration and smoothness in these joint areas. There are no time restrictions for placing successive lanes of grout to create joints. Ensure all RMP joints have the same texture, density, and smoothness as other sections of the course. Saw cut the joints between the RMP and any surrounding pavement surfaced with PCC to the full depth of the RMP thickness and filled with a joint sealant material meeting project specifications. Curing.

Curing of a new RMP surface is accomplished with a light coating of a white-pigmented, membrane-forming curing compound. Apply the curing compound to the finished pavement surface while the surface is still damp but without excessive moisture on the surface, normally within 2 hours of the completed slurry grout application. Apply curing compound with a pressurized spraying machine, using one or two coats with a total application rate of 4.5 square meters per liter (183.4 square feet per gallon).

7-5.2.3 Covering Pavement Surface.

7-5.2.3.1 Prior to Grouting.

Protect the pavement and its appurtenances prior to grouting against contamination from mud, dirt, windblown debris, waterborne material, or any other contamination that enters the void spaces of the open-graded asphalt mixture before grout application. Protection against contamination by keeping the construction site clean and free of such contaminants and by covering the pavement prior to grouting with a protective material such as rolled polyethylene sheeting. The sheeting is mounted on either the paver or a separate movable bridge from which it is unrolled without dragging over the pavement surface.

7-5.2.3.2 After Grouting.

Protect the pavement and its appurtenances against both public traffic and traffic caused by the contractor’s employees and agents for a period of 14 to 21 days. This time period depends on the environmental conditions during curing, with 14 days required for warm and dry weather curing and 21 days required for cool and damp weather curing. To properly protect the pavement against the effects of rain before the pavement is sufficiently hardened (the first 24 to 48 hours), materials for the protection of the edges and surfaces of the unhardened RMP are required to be available, at all times,. Use the same protective materials and method of application as described in paragraph 7-5.2.3.1. When rain appears imminent, stop all paving operations, and cover the surface of the hardened RMP with protective covering.

APPENDIX A REFERENCES

U.S. ARMY CORPS OF ENGINEERS

http://wbdg.org/ffc/army-coe/standards

U.S. Army Corps of Engineers Handbook for Cement and Concrete (CRD)

CRD-C649-95, *Standard Test Method for Unit Weight, Marshall Stability, and Flow of Bituminous Mixtures*

CRD-C650-95, *Standard Test Method for Density and Percent Voids in Compacted Bituminous Paving Mixtures*

CRD-C171-94, *Standard Test Method for Determining Percentage of Crushed Particles in Aggregate*

UNIFIED FACILITIES CRITERIA

http://www.wbdg.org/ccb/browse_cat.php?o=29&c=4

3-250-07, *Standard Practice for Pavement Recycling*

3-250-11, *Soil Stabilization for Pavements*

3-260-02, *Pavement Design for Airfields*

UNIFIED FACILITIES GUIDE SPECIFICATIONS

https://www.wbdg.org/ffc/dod/unified-facilities-guide-specifications-ufgs

32 12 13, *Bituminous Tack and Prime Coats*

32 12 15.13, *Asphalt Paving for Airfields*

32 12 15.16, *Warm Mix Asphalt Airfield Paving*

AIRFIELD ASPHALT PAVEMENT TECHNOLOGY PROGRAM

https://eng.auburn.edu/research/centers/ncat/files/aaptp/Report.Final.05-01.pdf

AAPTP 05-01, *Airfield Asphalt Pavement Construction Best Practices Manual*

AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS

https://bookstore.transportation.org/

M320-17-UL, *Standard Specification for Performance-Graded Asphalt Binder*

MP-8, *Standard Specification for Stone Matrix Asphalt (SMA)*

R029-15-UL, *Standard Practice for Grading or Verifying the Performance Grade (PG) of an Asphalt Binder*

T088-13-UL, *Standard Method of Test for Particle Size Analysis of Soils*

T089-13-UL, *Standard Method of Test for Determining the Liquid Limit of Soils*

T096-02-UL, *Standard Method of Test for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine*

T104-99-UL, *Standard Method of Test for Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate*

T166-16-UL, *Standard Method of Test for Bulk Specific Gravity (Gmb) of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens*

T209-12-UL, *Standard Method of Test for Theoretical Maximum Specific Gravity (Gmm) and Density of Hot Mix Asphalt (HMA)*

T210-15-UL, *Standard Method of Test for Aggregate Durability Index*

T245-15-UL, *Standard Method of Test for Resistance to Plastic Flow of Asphalt Mixtures Using Marshall Apparatus*

T269-14-UL, *Standard Method of Test for Percent Air Voids in Compacted Dense and Open Asphalt Mixtures*

ASPHALT INSTITUTE

http://www.asphaltinstitute.org/

ES-11, *Asphalt Surface Treatments Specifications*

ES-12, *Asphalt Surface Treatments – Construction Techniques*

MS-2, Asphalt *Mix Design Methods*

MS-14, *Asphalt Cold Mix Manual*

MS-19, *Basic Asphalt Emulsion Manual*

AMERICAN SOCIETY FOR TESTING AND MATERIALS

www.astm.org

C88-13, *Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate*

C117-17, *Standard Test Method for Materials Finer than 75-μm (No. 200) Sieve in Mineral Aggregates by Washing*

C127-15, *Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate*

C128-15, *Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate*

C131/C131M-14, *Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine*

C136/C136M-14, *Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates*

C142/C142M-17, *Standard Test Method for Clay Lumps and Friable Particles in Aggregates*

C150/C150M-17, *Standard Specification for Portland Cement*

C612-14, *Standard Specification for Mineral Fiber Block and Board Thermal Insulation*

C618-17a, *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete*

C1252-17, *Standard Test Methods for Uncompacted Void Content of Fine Aggregate (as Influenced by Particle Shape, Surface Texture, and Grading)*

D70-17, *Standard Test Method for Density of Semi-Solid Bituminous Materials (Pycnometer Method)*

D242/D242M-09, *Standard Specification for Mineral Filler for Bituminous Paving Mixtures*

D244-09, *Standard Test Methods and Practices for Emulsified Asphalts*

D402/D402M-14, *Standard Test Method for Distillation of Cutback Asphalt*

D448-12, *Standard Classification for Sizes of Aggregate for Road and Bridge Construction*

D946/D946M-15, *Standard Specification for Penetration-Graded Asphalt Binder for Use in Pavement Construction*

D977-17, *Standard Specification for Emulsified Asphalt*

D979/D979M-15, *Standard Practice for Sampling Bituminous Paving Mixtures*

D1139/D1139M-15, *Standard Specification for Aggregate for Single or Multiple Bituminous Surface Treatments*

D1369-84(2012), *Standard Practice for Quantities of Materials for Bituminous Surface Treatments*

D2026/D2026M-15, *Standard Specification for Cutback Asphalt (Slow-Curing Type)*

D2027/D2027M-13, *Standard Specification for Cutback Asphalt (Medium-Curing Type)*

D2028/D2028M-15, *Standard Specification for Cutback Asphalt (Rapid-Curing Type)*

D2041/D2041M-11, *Standard Test Method for Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures*

D2170/D2170M-10, *Standard Test Method for Kinematic Viscosity of Asphalts (Bitumens)*

D2171/D2171M-10, *Standard Test Method for Viscosity of Asphalts by Vacuum Capillary Viscometer*

D2172/D2172M-17, *Standard Test Methods for Quantitative Extraction of Asphalt Binder From Asphalt Mixtures*

D2397/D2397M-17, *Standard Specification for Cationic Emulsified Asphalt*

D2419-14, *Standard Test Method for Sand Equivalent Value of Soils and Fine Aggregate*

D2493/D2493M-16, *Standard Practice for Viscosity-Temperature Chart for Asphalt Binders*

D2726/D2726M-17, *Standard Test Method for Bulk Specific Gravity and Density of Non-Absorptive Compacted Asphalt Mixtures*

D2995-14, *Standard Practice for Estimating Application Rate and Residual Application Rate of Bituminous Distributors*

D3203/D3023M-17, *Standard Test Method for Percent Air Voids in Compacted Asphalt Mixtures*

D3381/D3381M-13, *Standard Specification for Viscosity-Graded Asphalt Cement for Use in Pavement Construction*

D3665-12, *Standard Practice for Random Sampling of Construction Materials*

D3744/D3744M-11a, *Standard Test Method for Aggregate Durability Index*

D3910-15, *Standard Practices for Design, Testing, and Construction of Slurry Seal*

D4125/D4125M-10, *Standard Test Methods for Asphalt Content of Bituminous Mixtures by the Nuclear Method*

D4318-17, *Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils*

D4791-10, *Standard Test Method for Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate*

D4867/D4867M-09, *Standard Test Method for Effect of Moisture on Asphalt Concrete Paving Mixtures*

D5148-10*, Standard Test Method for Centrifuge Kerosine Equivalent*

D5361/D5361M-16, *Standard Practice for Sampling Compacted Asphalt Mixtures for Laboratory Testing*

D5444-15, *Standard Test Method for Mechanical Size Analysis of Extracted Aggregate*

D5624-13, *Standard Practice for Determining the Transverse-Aggregate Spread Rate for Surface Treatment Applications*

D5727/D5727M-00, *Standard Specification for Emulsified Refined Coal Tar (Mineral Colloid Type)*

D6307-16, *Standard Test Method for Asphalt Content of Asphalt Mixture by Ignition Method*

D6372-15, *Standard Practice for Design, Testing, and Construction of Micro-Surfacing*

D6373-16, *Standard Specification for Performance Graded Asphalt Binder*

D6390-11, *Standard Test Method for Determination of Draindown Characteristics in Uncompacted Asphalt Mixtures*

D6927-15, *Standard Test Method for Marshall Stability and Flow of Asphalt Mixtures*

INTERNATIONAL SLURRY SURFACING ASSOCIATION

www.slurry.org/

TB-100, *Laboratory Test Method for Wet Track Abrasion of Slurry Surfacing Systems*

TB-109, *Test Method for Measurement of Excess Asphalt In Bituminous Mixtures by Use of a Loaded Wheel Tester and Sand Adhesion*

TB-114, *Test Method for Wet Stripping of Cured Slurry Surfacing Mixtures*

TB-149, *Test Method for Boiling Compatibility of Slurry Seal Mixes*

NATIONAL ASPHALT PAVEMENT ASSOCIATION

QIP-122E, *Designing and Constructing SMA Mixtures - State of the Practice,* http://store.asphaltpavement.org/index.php?productID=776

APPENDIX B BEST PRACTICES

B-1 SUMMARY OF DESIGN METHODS FOR SLURRY SEALS

B-1.1 INTRODUCTION

The design method for determining the emulsion requirement consists of determining the surface area of the job aggregate and calculating the amount of asphalt required to coat the surface area with a film thickness of 8 microns (3.15×10^{-4} inch). The absorption characteristics of the aggregate are determined using the CKE test. The total asphalt is the asphalt required for coating the aggregate plus the required due to aggregate absorption.

The water required for a given mixture is determined by a cone test as described in ASTM D3910. Water is added to a slurry mixture until a flow of 25.4 millimeters (1 inch) is obtained on a reference plate. Ensure the consistency of the mixture when the 25.4-millimeter (1-inch) flow is obtained is such that there is no segregation in the mixture. Portland cement or hydrated lime is added to aid in overcoming the segregation; the cone test serves as an aid for determining the amount of Portland cement or hydrated lime required in the mixture.

B-1.2 SURFACE AREA DESIGN METHOD

The surface area design method includes three considerations: the calculation of the amount of asphalt required to coat the surface area of the job aggregate, the absorption characteristics of the aggregate, and the total asphalt content.

B-1.2.1 Surface Area Asphalt Calculation

The surface area of the job aggregate is determined by multiplying the percent of aggregate passing a given sieve by a surface area factor based on the sieve size. The surface area of the aggregate is determined for each particle size (group) and then summed to obtain the total surface area. The surface area units are given in square meters per kilogram (feet per pound) of aggregate. The surface area factors are shown in Table B-1. The total surface area (SA) is then corrected to obtain a corrected surface area (CSA): $CSA = SA \times 2.65 / ASG$, where ASG is the apparent specific gravity of the aggregate. When the surface area and the desired bitumen film thickness are known, the volume of asphalt required and thus the percent by weight of asphalt required is obtained. Equation B-1 is the equation for calculation of the percent asphalt by weight to provide a desired film thickness:

$$SAA = \begin{array}{c} \text{Metric: } CSA \times t \times 0.99941 \times SG_A \\ \text{U.S. Customary: } CSA \times t \times 0.02047 \times SG_A \end{array}$$

Where:

SAA = *asphalt content to cover surface area of aggregate, t micrometers thick, percent of dry aggregate weight*

CSA = *corrected surface area, square meters per kilogram (feet per pound) of dry aggregate*

T = *asphalt film thickness, micrometers*

SGA = *specific gravity of the asphalt*

0.99941 (0.02047) = *conversion coefficient for the units of the equation*

If the specific gravity of the asphalt is not known, the asphalt required to coat the aggregate is calculated by assuming SG_A = 1.0. The error that results from assuming SG_A = 1.0 does not greatly affect the final design requirements.

Table B-1 Factors Used in Calculating Surface Area of Slurry Seal Aggregate

Sieve Size	Surface Area Factors	
	Square Meters per Kilogram of Aggregate	Square Feet per Pound of Aggregate
9.5 mm (3/8 in.)	0.4	2
4.75 mm (No. 4)	0.4	2
2.36 mm (No. 8)	0.8	4
1.18 mm (No. 16)	1.6	8
600 µm (No. 30)	2.9	14
300 µm (No. 50)	6.1	30
150 µm (No. 100)	12.2	60
75 µm (No. 200)	32.8	160

B-1.2.2 Aggregate Absorption

The absorption requirements of the aggregate are determined by using the CKE described in ASTM D5148. In this test, 100 grams (0.22 pounds) of 4.75-millimeter (No. 4) material is centrifuged in the presence of kerosene for 2 minutes. The amount of kerosene retained by the aggregate is assumed to be the amount of asphalt that the aggregate absorbs. The kerosene absorbed (KA) by the aggregate is converted to a percentage of the dry weight of the aggregate.

B-1.2.3 Total Asphalt Content

The total asphalt requirement is obtained by adding the percent asphalt required for the film thickness and the percent asphalt required for absorption. All percentages are based on the dry weight of the aggregate. The total is obtained using equations B-2 and B-3:

$$AR = SAA + KA$$

$$AR = \begin{array}{r} \text{Metric:}\ \ (CSA \times t \times 0.99941 \times SG_A) + KA \\ \text{U.S. Customary:}\ \ (CSA \times t \times 0.02047 \times SG_A) + KA \end{array}$$

Where:

AR = *total asphalt required, percent of dry aggregate weight*

KA = *kerosene absorbed, percent of dry aggregate weight*

The required percentage of emulsion is calculated by dividing the total asphalt required for the aggregate by the percentage of asphalt residue in the emulsion. A sample calculation for determining the asphalt content is presented in section B-1.4.

B-1.3 CONE TEST

The cone test is used to determine the amount of water required to form a workable mixture as described in ASTM D3910. This test uses the sand absorption cone described in ASTM C128. The cone is placed over a base plate. The base plate has concentric circles inscribed in diameters that are equal to the large end of the cone and increase proportionally outward. The radius of each circle increases in 12.7-millimeter (1/2-inch) increments. The cone is loosely filled with a slurry mixture, struck off, and then removed to allow the slurry mixture to “flow” over the base plate. A mixture with a flow of 25.4 millimeters (1 inch) is considered to contain the right amount of water for field workability. Mixtures that do not flow 25.4 millimeters (1 inch) require additional water to obtain the desired flow. If the flow cannot be obtained without segregation of the mixture, the addition of 0.5 to 4 percent Portland cement or hydrated lime helps to reduce the segregation. Flows greater than 25.4 millimeters (1 inch) indicate excess water or segregation.

If Portland cement or hydrated lime is added to reduce segregation and its addition has not been included in the design gradation, correct the total bitumen content of the mixture to include the effects of the Portland cement or hydrated lime. As a rule, increase the asphalt content by 0.6 percent for every percent of additional Portland cement or hydrated lime added to the mixture.

B-1.4 SAMPLE CALCULATION OF ASPHALT REQUIREMENTS FOR A SLURRY SEAL AGGREGATE

B-1.4.1 Surface Area Calculation

The ASG equals 2.96, and the aggregate gradation includes 2 percent Portland cement.

Table B-2 Surface Area Calculation

Sieve Size	Percent Passing	Surface Area Factor square meters per kilogram (square feet per pound) of Aggregate	Surface Area square meters per kilogram (square feet per pound) of Aggregate
9.5 mm (3/8 in.)	100	0.00409 (0.02)	0.409 (2.00)
4.75 mm (No. 4)	99.5	0.00409 (0.02)	0.407 (1.99)
2.36 mm (No. 8)	95.6	0.00819 (0.04)	0.783 (3.82)
1.18 mm (No. 16)	77.8	0.01639 (0.08)	1.275 (6.22)
600 μm (No. 30)	52.0	0.02867 (0.14)	1.491 (7.28)
300 μm (No. 50)	24.5	0.06144 (0.30)	1.505 (7.35)
150 μm (No. 100)	10.7	0.12289 (0.60)	1.315 (6.42)
75 μm (No. 200	6.4	0.32771 (1.60)	2.097 (10.24)
		Total SA	**9.282 (45.32)**

The corrected SA (CSA) = SA×2.65/2.96 = 8.310 square meters per kilogram (40.57 square feet per pound) of aggregate.

B-1.4.2 Kerosene Absorption Calculation

The aggregate gradation includes 2 percent Portland cement.

Table B-3 Kerosene Absorption Calculation

Cup No. (a)	Tare Weight Grams (b)	Sample Weight Grams (c)	Weight before Centrifuging Grams (d = b+c)	Weight after Centrifuging Grams (e)	KA Percent (f = e - d)
1	215.3	100.0	315.3	321.0	5.7
2	215.9	100.0	315.9	321.6	5.7
				Average KA	**5.7**

B-1.4.3 Total Asphalt Requirements

These factors are involved in calculating the asphalt contents:

- Asphalt = SS-lh asphalt emulsion
- Design film thickness (t) = 8 micrometers
- Apparent specific gravity of aggregate (ASG) = 2.96
- Specific gravity of asphalt (SG_A) = 1.028
- Kerosene absorption (KA) = 5.7 percent
- Corrected surface area (CSA) =
- Metric: 8.310 square meters per kilogram of aggregate
- U.S. Customary: 40.57 square feet per pound of aggregate
- Total asphalt required (AR) =
- Metric: $(CSA \times t \times SG_A \times 0.99941) + KA$
- U.S. Customary: $(CSA \times t \times SG_A \times 0.02047) + KA$
- Metric: (8.310×8×1.028×0.99941)+5.7 = 6.83+5.7 = 12.53 percent.
- U.S. Customary: (40.57×8×1.028×0.02047)+5.7 = 6.83+5.7 =
- 12.53 percent
- AR = 12.53 percent of dry aggregate weight
- Residue asphalt content in emulsion = 63 percent by weight
- Emulsion required = $\dfrac{AR \times 100}{\text{Residue asphalt content in emulsion}}$
- Emulsion required = $\dfrac{12.53 \times 100}{63}$ = 19.9 percent of dry aggregate weight, that is, 19.9 kilograms of emulsion is required for every 100 kilograms of dry aggregate, or in inch-pound units, 19.9 pounds of emulsion is required for every 100 pounds of dry aggregate

B-2 POTENTIAL VENDORS

A list of potential vendors is summarized in Table B-1 to assist in the procurement of products. It is not intended to be a complete listing of vendors as there are numerous large and small companies that provide a wide range of materials for dust abatement. Inclusion on this list does not represent endorsement of any kind. The list is provided to assist the soldiers, sailors, marines, and airmen working in the field. Complete a small test section prior to using each product to evaluate the effectiveness and determine the placement details.

Table B-4 Product and Vendor Information

Vendor	Products	Website
Alyan Corporation	Prosalvia-7 (PL7)	http://www.alyancorp.com/

APPENDIX C GLOSSARY

C-1 ACRONYMS

AAPTP	Airfield Asphalt Pavement Technology Program
AASHTO	American Association of State Highway and Transportation Officials
AC	asphalt concrete
ASG	apparent specific gravity
ASR	alkali-silica reactivity
ASTM	American Society for Testing and Material
ATV	all-terrain vehicle
C	Celsius
CBR	California Bearing Ratio
CKE	centrifuge kerosene equivalent
CONUS	continental United States
CRD	Concrete Research Division
CSA	corrected surface area
cSt	centistoke
DBST	double bituminous surface treatment
DFI	design air-freezing index
DoD	Department of Defense
DOT	Department of Transportation
DSR	dynamic shear rheometer
EOA	estimate of asphalt
ERDC	U.S. Army Engineer Research and Development Center
ES	Educational Series
ESAL	equivalent single axle load

F	Fahrenheit
FAA	fine aggregate angularity
FAA	Federal Aviation Administration
FOD	foreign object debris
ft	foot, feet
FHWA	Federal Highway Administration
FRS	fuel-resistant sealer
gal	gallon
g/cm^3	grams per cubic centimeter
gal/yd^2	gallons per square yard
GPS	Global Positioning System
HL	hydrated lime
in.	inch
ISSA	International Slurry Surfacing Association
JMF	job-mix formula
KA	kerosene absorption
K_c	surface area constant
kg	kilogram
kg/m^3	kilograms per cubic meter
kN	kilonewton
kPa	kilopascal
L	liter
LA	Los Angeles
L/m^2	liters per square meter
lb	pound

lb/ft^3	pounds per cubic foot
LWT	loaded wheel test
m	meter
MAJCOM	major command (Air Force)
max, max.	maximum
MC	medium curing
µm	micrometer
min.	minimum
min	minute
mm	millimeter
MS	medium setting
MSCR	multiple stress creep recovery
MS	Manual Series (Asphalt Institute)
MTV	material transfer vehicle
N	newton
NA	not applicable
NAPA	National Asphalt Pavement Association
NAVFAC	Naval Facilities Engineering Command
No.	number
OGFC	open-graded friction course
OGM	open-graded material
P	poise
PC	Portland cement
PCC	Portland cement concrete
pcf	pounds per cubic foot

pen	penetration
PFC	porous friction course
PG	performance graded
PL7	Prosalvia L7
PMA	polymer-modified asphalt
psi	pounds per square inch
PTI	pavement temperature index
QA	quality assurance
QC	quality control
RAP	reclaimed asphalt pavement
RC	rapid curing
RMP	resin modified pavement
RS	rapid set
SA	surface area
SAE	Society of Automotive Engineers
SBST	single bituminous surface treatment
SC	slow-curing
SI	International System of Units
SMA	stone matrix asphalt
SS	slow setting
SSD	saturated surface dry
TB	technical bulletin
TM	technical manual
TMD	theoretical maximum density
TSR	tensile strength ratio

UFC	Unified Facilities Criteria
U.S.	United States
USACE	U.S. Army *Corps of* Engineers
TSMCX	USACE Transportation Systems Center
UFGS	Unified Facilities Guide Specification
VFA	voids filled with asphalt
VMA	voids in mineral aggregate
VTM	voids in total mix
WES	Waterways Experiment Station (USACE ERDC)
WMA	warm mix asphalt
WTAT	wet track abrasion test

C-2 DEFINITION OF TERMS

Common terms related to AC pavements are not defined here since they are found in flexible pavement references, primarily in ASTM D8. The terms defined for this UFC have definitions that have not been universally accepted or that have limited usage.

asphalt base course: A minimum of one course of asphalt mixture placed on a subbase or subgrade to serve as a base course. This mixture is called a black base. An asphalt base course is covered with an intermediate course and surface course.

coarse aggregate: The aggregate retained on the 4.75-millimeter (No. 4) sieve as described in ASTM E11.

cold-mix recycling: Involves reclaiming all of the existing bituminous pavement by breaking it to a maximum particle size of 4 centimeters (1½ inch), mixing it with virgin materials, if needed, and reusing the mixture as a pavement material. Cold-mix recycling material is used to surface secondary roads, if a seal coat is applied, and as a base course for high-quality pavements.

components of a compacted bituminous mixture: A given volume of compacted bituminous concrete consists of air, bitumen, and aggregate.

fine aggregate: Aggregate passing the 4.75-millimeter (No. 4) sieve and retained on the 75 μm (No. 200) sieve, often referred to as sand. Natural sand (fine aggregate) is that material found naturally and not manufactured by crushing.

flow: The deformation, measured in 25 hundredths-of-a-millimeter (hundredths-of-an-inch), that occurs in a compacted specimen of a paving mixture at the point at which maximum load begins to decrease when the specimen is subjected to the Marshall stability test.

hot-mix recycling: Process that involves removing the existing HMA, crushing it, and mixing it in a hot-mix plant with new aggregate, asphalt, and recycling agent, when required. The recycled HMA is designed for use in all types of pavements. Crushed PCC has also been used as aggregate for hot recycled mixtures.

intermediate course: That portion of a pavement placed on the base course to serve as a leveling or transition layer between the base and surface courses. Intermediate courses are called leveling or binder courses.

Marshall stability value: The maximum load in newtons (pounds) that is applied to a specimen of AC paving mixture when tested in the Marshall apparatus.

mastic asphalt: Mastic asphalt is an HMA mixture of fine aggregate and asphalt cement forming a mixture free of voids.

micro-surfacing: Micro-surfacing is the process of applying a latex-modified asphalt emulsion slurry to an existing pavement surface. The slurry is mixed and applied similarly to asphalt slurry seals, except for the specially-designed mixing and constant agitation application equipment required by the latex modifier. Micro-surfacing applications contain larger aggregate particles than conventional asphalt slurry seals. Micro-surfacing is used to fill ruts or for re-establishing skid resistance. Curing is normally completed in 1 to several hours depending on weather conditions.

mineral filler: Mineral aggregate particles passing a 75 micrometer (No. 200) sieve or commercially available materials such as lime or cement.

optimum asphalt content: The asphalt content of a paving mixture determined by the Marshall or gyratory methods of design that satisfies the applicable pavement mix design criteria.

percent VFA: Percentage of the VMA in the compacted aggregate mass that is filled with asphalt.

$$VFA = \frac{V_{bitumen}}{V_{air} + V_{bitumen}} \times 100$$

percent VMA: Percentage of the compacted bituminous mixture not occupied by the aggregate. The percentage of VTM plus the percentage of asphalt cement by total volume is equal to VMA.

$$VMA = \frac{V_{air} + V_{bitumen}}{V_{total}} \times 100$$

percent VTM: Percentage of the compacted AC mixture not occupied by the aggregate or asphalt cement.

$$VTM = \frac{V_{air}}{V_{total}} \times 100$$

porous friction course (PFC): An open-graded, free-draining asphalt paving mixture that is placed on an existing pavement to minimize hydroplaning and to improve skid resistance in wet weather. The course is placed in a layer usually varying from 20 to 25 millimeters (3/4 to 1-inch) in thickness. PFC paving mixtures are produced in asphalt hot-mix plants and placed with conventional asphalt paving machines.

resin-modified pavement (RMP): A composite pavement surfacing that uses a unique combination of HMA and PCC materials in the same layer. The RMP material is described as an open-graded AC mixture containing 25 to 35 percent voids that are filled with a resin-modified Portland cement grout. An RMP layer is 5 centimeters (2 inches) thick and has a surface appearance similar to a rough-textured PCC.

stone matrix asphalt (SMA): SMA, which is also referred to as stone mastic asphalt, is a mixture of aggregate, mineral filler, polymer-modified asphalt cement, and a mineral or cellulose fiber. SMA is designed to prevent rutting and abrasion under high loads or high tire pressures.

surface course: The top course of an AC pavement. The surface course is referred to as the wearing course by many pavement engineers.

surface recycling: Repaving, heater-planing-scarifying, cold milling, and rejuvenating are methods of surface recycling that are used to increase skid resistance, decrease permeability to air and water, and improve properties of the asphalt binder. Depending on the process used, surface recycling modifies from 5 to 50 millimeters (1/4 to 2 inches) of the pavement surface. Surface recycling does not increase the strength of the pavement. The cost to scarify and rejuvenate pavement is the same as the cost of an additional 25 millimeters (1 inch) of overlay, but the benefits of the scarification and rejuvenation usually exceed the benefits of the additional 25 millimeters (1 inch) of overlay.

warm-mix asphalt: Asphalt mixture that has been treated through additives or foaming to allow the mixture to be mixed, placed, and compacted at lower temperatures than HMA.

UNIFIED FACILITIES CRITERIA (UFC)

STANDARD PRACTICE FOR CONCRETE PAVEMENT CONSTRUCTION

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UNIFIED FACILITIES CRITERIA (UFC)

STANDARD PRACTICE FOR CONCRETE PAVEMENT CONSTRUCTION

Indicate the Military Department Preparing Activity responsible for the document.

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING SYSTEMS COMMAND (Preparing Activity)

AIR FORCE CIVIL ENGINEER CENTER

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

Change No.	Date	Location

This UFC supersedes UFC 3-250-04, *Standard Practice for Concrete Pavements*, dated 16 January 2004.

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FOREWORD

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

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

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

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

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

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CHAPTER 1 INTRODUCTION

1-1 REISSUES AND CANCELS.

This document replaces UFC 3-250-04, 16 January 2004.

1-2 PURPOSE AND SCOPE.

This UFC provides guidance for preparing drawings and specifications for roads and airfields to construct rigid pavements using portland cement concrete (PCC) materials. It provides useful information for military and civilian design engineers, laboratory personnel, and project managers concerning mix design, materials, production, and placement of concrete mixtures. This UFC documents the standard practice for rigid airfield pavement construction and follows the chapter outline of Innovative Pavement Research Foundation Report IPRF-01-G-002-1, *Best Practices for Airport Portland Cement Concrete Construction (Rigid Airport Pavement)*, April 2003. This UFC provides supplementary clarification, requirements, and specific guidance for DoD concrete pavements. If there is conflicting guidance, DoD standard practice for military airfields takes precedence over IPRF guidance. This standard practice document aids in the use, interpretation, and implementation of Unified Facility Guide Specifications (UFGS) for DoD concrete pavement construction efforts and aids in resolving field construction problems. The requirements in this UFC produce a pavement of quality sufficient to support all DOD and allies' aircraft and missions.

This UFC prescribes materials, mix design procedures, and construction practices for concrete pavements. This UFC includes discussion of the advantages and disadvantages of techniques, practices, or materials when several choices exist. This includes possible methods and materials to mitigate or eliminate distresses or premature failures. This UFC is specifically tailored for military airfields and other heavy-duty pavements. It may be used for PCC road pavements, but airfield pavement guidance and requirements are generally much more stringent than for road pavements. Commercial construction practices and material quality permissible in civilian roadway construction do not suffice to meet the demands placed on military airfields.

1-3 APPLICABILITY.

The requirements of this UFC should be used for all DoD-owned or -funded organizational airfield pavements, heavy-duty roads, and hardstands. State specification requirements may only be substituted for nonorganizational parking, roads, streets, and driveways where the design index is less than 5. This UFC applies to all DOD military engineering and construction units, Title II on DOD construction efforts, as well as civilian design and construction personnel and companies working on DoD-owned or -funded airfield and other heavy duty pavement construction or repair.

1-4 GENERAL BUILDING REQUIREMENTS.

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

1-5 ROLLER COMPACTED CONCRETE PAVEMENT.

Appendix E contains information regarding the construction of roller-compacted concrete pavement (RCCP). RCCP is prohibited for airfield pavement use unless approved by the USACE TSC or appropriate Tri-Service Pavements Discipline Working Group (TSPDWG) Service representative.

1-6 GLOSSARY.

Appendix F contains acronyms, abbreviations, and terms.

1-7 REFERENCES.

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

CHAPTER 2 CONSIDERATION OF DESIGN ISSUES

2-1 INTRODUCTION.

The factors affecting long-term concrete pavement performance are broadly divided into the following categories:

- Adequate design of pavement structure
- Use of quality materials
- Use of proper construction procedures
- Timely maintenance and repair

The pavement designer controls several parameters and details that greatly impact pavement construction. These will be discussed individually in the following paragraphs. When there is a conflict between design requirements and field conditions, any modifications to the design to accommodate field conditions should be reviewed by the original designer to ensure the modifications comply with the original design intent.

2-2 DESIGN CONSIDERATIONS.

Design procedures for airfield pavements are described in the UFC 3-260-02, *Pavement Design for Airfields*. Design procedures for other concrete pavements are described in UFC 3-250-01, *Pavement Design for Roads and Parking Areas*.

2-2.1 Pavement Foundation.

Provide a firm foundation to support concrete construction activities, such as slipform pavers, forms, concrete delivery truck traffic, and other heavy vehicles or equipment. Designers will consider the anticipated field soil support and moisture conditions during construction and select base courses to support concrete placement activities. UFC 3-260-02 mandates use of base courses on pumping susceptible subgrade soils, which generally include the silts and clays that are the most troublesome during construction. However, the designer may include a base course to ensure a viable construction platform for soils such as those classified as SM, SC, GC, or SP by the Unified Soil Classification System (ASTM D2487). These may not be stable under construction traffic or during wet construction conditions.

A designer assesses the characteristics of the subgrade soil at a project location to determine whether a base course is required to support construction activities. Extend base courses far enough beyond the edge of the pavement to accommodate construction activities such as slipform paver tracks or provide space to place and anchor forms. Only use stabilized bases on airfields when there is a specific need, such as lack of suitable local base material, all-weather construction platform, or other structural requirements. Verify that designers working on design-build contracts are aware of this difference at initial design meetings.

2-2.2 Concrete Strength.

Traditionally, calculating the design strength for pavement thickness equates to the ASTM C78/CRD-C 16 flexural strength at 90 days. While modern concrete mixtures can achieve very high strength, this can introduce adverse setting and handling characteristics or shrinkage. Therefore, specify no flexural strength less than 600 psi (4136 kPa) or greater than 700 psi (4826 kPa) for military airfields without prior approval from the TSPDWG. Specifying a 90-day strength allowed designers to take advantage of strength gains between 28 and 90 days before allowing traffic or for minimal traffic. Most modern portland cement chemistry and grinding produce very modest strength increases between 28 and 90 days; however, concretes that use supplemental cementitious materials such as fly ash and ground-granulated blast furnace slag can gain substantial strength after 28 days.

Projects often require reopening pavement to traffic early. A designer balances the desired strength, the time to achieve this strength, and other factors such as durability, against specific project requirements. For pavement that must open early to traffic, the designer should calculate the effect of the limited early age traffic on the total pavement life to select reasonable strengths before allowing traffic. Simply requiring the normal 90-day strength at some very early age can generate a concrete mixture possessing troublesome working characteristics.

2-2.3 Pavement Dimensions.

Concrete pavements for any application are normally jointed plain concrete pavements. Only reinforce odd-shaped slabs or for special circumstances or applications, such as continuously reinforced concrete. Airport concrete pavements are typically designed on the basis of mixed aircraft loadings to minimize maintenance service for multiple decades. The pavements are designed on the basis of expected aircraft repetitions over the design period. For many airfield pavements, the concrete thickness may range from 400 to 500 mm (16 to 20 in.) and transverse joint spacing may range from 4.6 to 6.2 m (15 to 20 ft). Typical longitudinal joint spacing can also range from 4.6 to 6.2 m (15 to 20 ft).

Current practice uses dowel bars for load transfer in all longitudinal construction joints. For concrete pavements subjected to only light aircraft loads, slab thickness may range from 125 to 300 mm (5 to 12 in.) and transverse and longitudinal joint spacing may range from 2.4 to 4.6 m (8 to 15 ft). Slab dimensions in design manuals are set to minimize curling stresses from non-load-associated factors. Failure to adhere to these limits leads to unwanted cracking due to the combined effect of curling stresses and load-related flexural stresses. For these reasons, common practice limits the maximum slab size to 6.1 m (20 ft) as research shows that slab joint spacing equal to or greater than 7.6 m (25 ft) increases the risk of uncontrolled cracking.

2-2.4 Legacy Slabs.

On older airfield pavements with 7.6 m (25 ft) slabs, strict adherence to this policy may create mismatched slab joints. Where joint patterns of abutting pavement facilities do not match, partial reinforcement of slabs may be necessary. Using reinforcement at mismatched joints in such junctures is based upon the type of joint between the two pavement sections. Designers should develop repair projects with a cost-effective joint pattern that minimizes and mitigates mismatch between larger slabs and smaller slabs by incorporating appropriate protective measures, such as expansion joints or reinforcing. See further discussion in UFC 3-260-02.

2-3 DESIGN PROCESS.

The terms “base” and “subbase” often designate the layer directly under the concrete slab. In this UFC, the layer immediately below the slab is called the base. The layer between the base and the subgrade is called the subbase. The overall process of designing a concrete pavement involves the following steps.

2-3.1 Soil Investigation.

Soil borings determine the properties of the subsurface strata and depth to groundwater. Soil samples are obtained for soil classification and laboratory testing (see UFC 3-260-02).

2-3.2 Evaluate Subgrade Support at Design Grade.

The information from the soil investigation indicates the subgrade conditions at and below the design grade.

2-3.3 Design Pavement Section.

After determining the appropriate base type (i.e., stabilized or non-stabilized) and thickness, use the appropriate design procedure to calculate the required PCC pavement thickness.

2-3.4 Select Jointing Plan.

Develop appropriate longitudinal and transverse joint details based on the calculated slab dimensions. Proper construction details are required for joints and transition slabs that tie-in to existing pavements.

2-3.5 Develop Plans and Specifications.

Further develop the design details into complete plans and specifications.

2-3.6 Critical Design Features.

Critical design features that influence long-term concrete pavement performance include:

- Subgrade support uniformity and stability
- Base and subbase uniformity (type and thickness), including drainage

- PCC pavement layer thickness
- PCC properties, as specified
- Uniformity (ability of concrete to produce consistent properties)
- Workability (ability of concrete to be placed, consolidated and finished)
- Strength (ability of concrete to support traffic & environmental conditions)
- Durability (ability of concrete to provide long-term service)
- Jointing details
- Slab dimensions
- Load transfer at joints
- Joint sealing provisions

2-3.7 Construction Variability.

Throughout the design process, recognize that variability in the properties of key design elements significantly affects pavement performance. While some variability is unavoidable, excessive variability during construction induces random pavement performance and higher contractor costs. Make effective use of quality management plans to control construction variability. For each project, the design engineer establishes the acceptable parameters for each design variable. Construction work must meet or exceed the specified quality. Typically, when several marginal features are incorporated into a pavement structure through a design deficiency, poor construction techniques, or a combination thereof, premature failure results or it performs poorly throughout its service life.

2-4 CRITICAL CONSTRUCTION OPERATIONS.

Examples of critical construction operation include the following.

2-4.1 Grading.

Grading is important. Proper grading facilitates drainage and placement of successive layers. Grading issues are discussed in Chapters 4, 5, and 6.

2-4.2 Jointing.

Jointing controls slab cracking, which minimizes the potential for random cracking. Random cracking is a maintenance concern and can reduce the load capacity of pavement. Shallow joint sawing and late sawing can induce random cracking. If dowel bars are misaligned or bonded to the concrete, joints do not function and adjacent slab panels can develop random cracking. Joint sawing, load transfer, and joint sealing practices are discussed in Chapter 9.

2-4.3 Subgrade, Subbase, and Base Quality.

If the compaction of the subgrade, subbase, and base is compromised, the pavement may deflect excessively under aircraft loading and develop corner cracking. Subgrade, subbase, and base construction practices are presented in Chapters 4 and 5, respectively.

2-4.4 PCC Strength.

Low-strength concrete results in early fatigue cracking of the pavement. Concrete flexural strength at 28 days for airfield paving is typically 4,100 to 5,200 kPa (600 to 750 psi). For fast-track construction, these strength levels may be required earlier. Concrete practices, including strength requirements, are discussed in Chapters 6 and 7.

2-4.5 Concrete Durability.

Concrete that is not durable (a result of poor or reactive materials, a poor air-void system, or due to over-finishing) deteriorates prematurely. Concrete durability issues are discussed in Chapters 7 and 8.

2-4.6 Concrete Curing.

Improperly cured concrete can deteriorate prematurely and generate early age spalling. Chapter 8 discusses concrete curing practices.

2-4.7 Concrete Finishability.

Concrete that is over-finished or requires excessive manipulation to provide an acceptable finish deteriorates prematurely. Poorly finished concrete may also generate poor surface conditions. See Chapter 8.

2-4.8 Paver Operation.

Paver operations significantly impact pavement smoothness and in-place concrete quality. Chapter 8 discusses paver operation practices.

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CHAPTER 3 PRE-CONSTRUCTION ACTIVITIES

3-1 CONSTRUCTION SPECIFICATION ISSUES.

Pavement construction specifications provide guidance and establish minimum requirements that, when adhered to, facilitate building a quality pavement. The acceptable level of quality for a rigid airfield pavement comprises desirable surface characteristics and a surface free from foreign object generators (FOG) for the service life of the pavement. FOGs result from distresses in the concrete pavement. A FOG that results in foreign object damage (FOD) is a very critical item for airfield concrete pavements. However, good design features, well-developed plans and specifications, and quality construction can minimize or eliminate FOG (and FOD) development.

As a result, it is important that construction specifications clearly define the requirements that promote long-term performance of concrete pavement and exclude arbitrary requirements. The UFGSs are detailed and cover all aspects of concrete paving, including materials and mixture design issues and required construction techniques and inspection requirements. It is important for the specifier and contractor to review military specifications in detail prior to construction.

3-2 PLANNING CONSTRUCTION LOGISTICS.

A successful construction project plans all logistical support in advance and pays attention to the smallest details, including the following:

- Ensuring readiness of all operations, including grade control
- Concrete plant set-up and traffic flow
- Concrete plant capacity and production rate
- Haul road availability and serviceability
- Security and site access requirements
- Availability of crews
- Availability of equipment and materials
- Construction and airfield traffic management
- Concrete placement needs (rate of placement)
- In-pavement structures
- Acquisition of in-pavement electrical items (affects fast track construction)
- Inspection and testing requirements
- Subcontractor readiness – crew and equipment availability
- Project phasing, if any
- On-site testing laboratory
- Other needs related specifically to fast-track paving

Include all parties involved in a construction project in the communication network. Regardless of project size, pavement construction is a team effort that includes operators and users.

3-3 EARLY PAVEMENT TRAFFICKING.

The UFGSs define when a concrete pavement may open to construction traffic and the design aircraft or vehicle traffic. Do not open pavement to aircraft or other design traffic for at least 14 days or longer, depending upon the loading, concrete mixture, and curing conditions. The requirement to allow equipment to operate on the pavement edges is for test specimens molded and cured in accordance with ASTM C31/CRD-C 11, attaining a minimum flexural strength of 400 psi (2.8 MPa) when tested in accordance with ASTM C78/CRD-C 16. Absent strength testing, use a 14-day aging requirement. Also, complete seven days of curing before allowing hauling equipment to use new concrete, and seal or otherwise protect all joints. Consider the following additional factors regarding construction traffic.

a. Develop specific criteria for typical construction equipment for different concrete pavement thicknesses and for edge and interior loading. For example, for large military facilities with concrete pavement thickness of 16 in. (400 mm) or greater, construction traffic may induce flexural stresses in the range of 100 to 150 psi (700 to 1,000 kPa). However, similar construction equipment may induce higher stresses on thinner pavements that are 12 in. (300 mm) or less in thickness.

b. Consider trade-offs between a higher strength requirement and extra thickness for critical areas that require fast track construction. Develop alternate designs for fast-track areas; for example, a thicker slab and cement-stabilized base without higher concrete strength versus use of an asphalt-treated base or a granular base and higher strength concrete.

Another consideration for early age strength levels is drilling to install dowel bars along the longitudinal joint face of pilot lanes. Drilling is typically not initiated until the concrete attains sufficient strength to reduce/eliminate micro-cracking and excess spalling around the drilled holes.

3-4 PRE-BID MEETINGS.

Pre-bid meetings allow the owner to review project requirements with contractors interested in bidding on a project. Although pre-bid meetings primarily tend to review administrative and contractual matters, it is important to highlight modifications of guide specifications implemented in the plans and specifications. Also address critical material supply and availability issues, the schedule, and specific acceptance testing requirements. It is good practice for contractors to attend pre-bid meetings. Distribute meeting minutes to all potential bidders (those requesting bid documents) whether they attend or not. Paving-related discussion items include:

- Owner and contractor organizational hierarchy
- Value engineering issues

- Project overview
- Phasing plan
- Scheduling criteria, including which areas are accessible and when
- Scheduling milestones, with incentives and disincentives
- Expected and unexpected delay resolution
- Alternate bid items
- Restrictions on site access and working hours
- Plant and staging area locations
- Paving sequence for cross-taxiway areas
- Access and egress locations, haul road locations, and construction traffic control
- QA, acceptance testing, and QC requirements
- Water, phone, and power connection locations
- Issuance of design and specification changes
- Provisions for protection of stabilized layers from freeze conditions
- Fast-track changes; thicker slab and stiffer base versus higher concrete strength
- Early age cracking, joint spalling, and edge slump
- Establish acceptability criteria
- Guidelines for corrective measures
- Dowel misalignment testing and resolutions
- Test strip construction requirements and acceptance criteria

3-5 PRE-AWARD MEETINGS.

Some agencies hold a pre-award meeting with the selected contractor. As part of these meetings, the contracting officer may perform an on-site survey of the contractor's facilities or previous projects. The survey helps to verify the data and representations submitted with the bid documents and determine if the contractor understands and has overall capabilities to adequately meet the contract requirements. A pre-award meeting is also an opportunity for the contracting officer and contractor to review the contract line items. Based on the discussions with the contracting officer, the contractor has an opportunity to withdraw the bid if it is determined that the bid may have included erroneous pricing.

3-6 PRE-CONSTRUCTION MEETINGS.

The contracting officer will host pre-construction meetings to review specific project requirements and project planning with the contractor. Review the following items:

- Issue resolution hierarchy – Appendix A
- Construction logistics – Appendix A
- Installation and airfield access and movement – Appendix A
- Security clearance requirements – Appendix A
- Checklist of critical material supply and availability issues – Appendix A
- Project specifications – Appendix A
- Approval of materials – Appendices A and B
- Schedule – Appendix A
- Inspection and testing requirements – Appendices A, B, and C
- Quality management (or contractor quality control) plan – Appendices A and B

Discuss concrete pavement-related items during the pre-construction meetings as a separate agenda. A concrete paving pre-construction meeting is the last opportunity to discuss concrete paving process issues before equipment starts moving. If items are discussed up front before construction begins, the parties can review potential problems and create solutions that work for everyone. Distribute meeting minutes to all parties. Pavement-related discussion items are listed in Appendix A. For projects involving more than 42,000 m^2 (50,000 yd^2) of concrete paving, conduct a half-day concrete pavement construction workshop using this UFC along with project-specific plans and specifications. Attendees at this workshop can include key staff from the contractor's field crew and the testing and inspection crews. Workshops ensure that all involved parties have the same understanding of project requirements and are committed to a successful project.

DoD installations or units can fund and schedule the USACE Transportation Systems Center (TSC) to conduct on-site airfield paving workshops and post-award teleconferences, provide on-site technical support during construction, review PCC mix designs, hot mix asphalt (HMA) job mix formulas (JMF), and warm mix asphalt (WMA) JMF. A list of services and required fees are described in USACE ER 1110-34-1, *Transportation Systems Mandatory Center of Expertise*.

3-7 QUALIFYING CONSTRUCTION MATERIALS.

In some localities, the state Department of Transportation (DOT) has information on materials approved for concrete pavement construction. Evaluate state DOT records for performance history and certification. State DOT certifications together with other documentation can facilitate the material approval review process. If current independent testing certificates cannot be obtained through material suppliers, DoD installations, DoD units, designers, or construction contractors may contract with third-party commercial laboratories accredited to perform the required materials testing. DoD installations, DoD units, designers, or construction contractors may alternatively contract with the U.S. Army Engineering Research and Development Center, (ATTN: CEERDC-GM-C), 3909 Halls Ferry Road, Vicksburg, Mississippi, 39180-6199, to qualify a cement or pozzolan for use in DoD pavement construction on a reimbursable basis. Prior to bid solicitation, the design engineer should address material availability and cost. If alternate materials are proposed in lieu of those specified, the contractor must ensure fulfillment of the specification testing requirements. Testing requirements for concrete aggregates may have long lead times and scheduling conflicts can arise if materials are not pre-qualified in a timely manner. Lead times for aggregate testing are discussed later in this chapter.

3-7.1 Evaluation of Local Aggregates.

The coarse and fine aggregates must meet the requirements of ASTM C33/CRD-C 133. However, for airfield and heavy-duty pavement additional restrictions and requirements exist. The fineness modulus of the fine aggregate, the limits on deleterious materials, the sample size, and order of testing differ from ASTM C33/CRD-C 133. Limits on deleterious materials are an order of magnitude lower than those in ASTM C33/CRD-C 133 for DoD airfields; thus, larger samples are required. Some key items follow.

a. The largest maximum size consistent with the requirements for placing the concrete will produce the most economical concrete with the least tendency to crack due to thermal effects or autogenous, plastic, or drying shrinkage.

b. The minimum nominal maximum aggregate (NMA) size is 38 mm (1.5 inch). For airfield and other heavy-duty pavements, the combined gradation must have a minimum of 10 percent mass retained on the 25mm (1 inch) sieve or must be a combination of #4, #67, and fine aggregate.

c. In areas where D-cracking in pavements is a known problem, use a smaller nominal maximum aggregate size or import aggregate from outside the area.

d. Aggregates for roads generally need to meet the requirements and contain no more than the specified percentages of deleterious materials listed in ASTM C33/CRD-C 133. For DoD airfield pavements, limits on deleterious materials are an order of magnitude lower than those in ASTM C33 (see Tables 3-1 and 3-2). Furthermore, the sample size and test sequence must meet additional requirements.

3-7.1.1 Airfield Coarse Aggregate Deleterious Materials Testing Sequence:

The minimum test sample size of the coarse aggregate is 90 kg (200 pounds) for the 19 mm (3/4 inch) and larger maximum size and 12 kg (25 pounds) for the 4.75 to 19 mm (No. 4 to 3/4 inch) coarse aggregate.

1. Step 1: Wash each full sample of coarse aggregate for material finer than the 0.075 mm (No. 200) sieve. Discard material finer than the 0.075 mm (No. 200) sieve.

2. Step 2: Test remaining full sample for clay lumps and friable particles and remove.
3. Step 3. Test remaining full sample for chert and cherty stone with SSD density of less than 2.40 specific gravity. Remove lightweight chert and cherty stone. Retain other materials less than 2.40 specific gravity for Step 4.
4. Step 4: Test the materials less than 2.40 specific gravity from Step 3 for lightweight particles (Sp. GR. 2.0) and remove. Restore other materials less than 2.40 specific gravity to the sample.
5. Step 5: Test remaining sample for clay-ironstone, shale, claystone, mudstone, siltstone, shaly and argillaceous limestone, and remove.
6. Step 6: Test a minimum of one-fifth of the remaining full sample for other soft particles.

3-7.1.2 Airfield Fine Aggregate Deleterious Materials Testing Sequence:

The minimum test sample size for fine aggregate is 5 kg (10 pounds). The fineness modulus must not be less than 2.50 nor more than 3.40.

1. Step 1: Wash each full sample of fine aggregate for material finer than the 0.075 mm (No. 200) sieve. Discard material finer than the 0.075 mm (No. 200) sieve.
2. Step 2: Test remaining full sample for clay lumps and friable particles and remove.
3. Step 3. Test remaining full sample for lightweight particles (Sp. GR.2.0).

Table 3-1 Categorization of Weather Severity

Weather Severity	Air Freezing Index, Coldest year in 30[1]	Average Precipitation for any Single Month During the Freezing Period
Moderate	500 or less	Any amount
Moderate[2]	501 or more	Less than 25 mm (1 in.)
Severe	501 or more	25 mm (1 in.) or more

[1] Calculated as described in UFC 3-260-02. See ASTM C33/CRD-C 133 for a simplified map of CONUS weather severity.

[2] In poorly drained areas, the weather should be considered severe even though the other criteria indicate a rating of moderate.

Table 3-2 Deleterious Material Limits in Airfield Aggregates - Percent Mass

Material	Coarse Severe Weather	Coarse Moderate Weather	Fine Aggregate All Weather
Clay lumps and friable particles (ASTM C142)	0.2	0.2	1.0
Shale[1] (ASTM C295/CRD-C 127)	0.1	0.2	-
Material finer than 0.075 mm (No. 200 sieve) [2] (ASTM C117)	0.5	0.5	3.0
Lightweight particles[3] (ASTM C123)	0.2	0.2	0.5
Clay ironstone[4] (ASTM C295)	0.1	0.5	-
Chert and cherty stone (SG less than 2.40 – SSD)[5] (ASTM C295/CRD-C 127)	0.1	0.5	-
Claystone, mudstone, and siltstone[6] (ASTM C295/CRD-C 127)	0.1	0.1	-
Shaly and argillaceous limestone[7], (ASTM C295/CRD-C 127)	0.2	0.2	-
Other soft particles (CRD-C 130)	1.0	1.0	-
Total of all deleterious substances, exclusive of material finer than 0.075 mm (No. 200) sieve	1.0	2.0	-
Total for fine aggregate including material finer than 0.075 mm (No. 200) sieve	-	-	3.0

[1] Shale is defined as a fine-grained, thinly laminated or fissile sedimentary rock. It is commonly composed of clay or silt or both. It has been indurated by compaction or by cementation, but not so much as to have become slate.

[2] Limit for material finer than 0.075 mm (No.200 sieve) will be increased to 1.5 percent for crushed aggregates if the fine material consists of crusher dust that is essentially free from clay or shale.

[3] The separation medium will have a density of 2.0 mg/m^3 (SG of 2.0). This limit does not apply to coarse aggregate manufactured from blast-furnace slag unless contamination is evident.

[4] Clay ironstone is defined as an impure variety of iron carbonate, iron oxide, hydrous iron oxide, or combinations thereof, commonly mixed with clay, silt, or sand. It commonly occurs as dull, earthy particles, homogeneous concretionary masses, or hard-shell particles with soft interiors. Other names commonly used for clay ironstone are “chocolate bars” and limonite concretions.

[5] Chert is defined as a rock composed of quartz, chalcedony, or opal, or any mixture of these forms of silica. It is variable in color. The texture is so fine that the individual mineral grains are too small to be distinguished by the unaided eye. Its hardness is such that it scratches glass but is not scratched by a knife blade. It may contain

impurities such as clay, carbonates, iron oxides, and other minerals. Other names commonly applied to varieties of chert are flint, jasper, agate, onyx, hornstone, porcellanite, novaculite, sard, carnelian, plasma, bloodstone, touchstone, chrysoprase, heliotrope, and petrified wood. Cherty stone is defined as any type of rock (generally limestone) that contains chert as lenses and nodules, or irregular masses partially or completely replacing the original stone.

[6] Claystone, mudstone, or siltstone is defined as a massive fine-grained sedimentary rock that consists predominantly of indurated clay or silt without laminations or fissility. It may be indurated either by compaction or cementation.

[7] Shaly limestone is defined as limestone in which shale occurs as one or more thin beds or laminae. These laminae may be regular or very irregular and may be spaced from a few inches down to minute fractions of an inch. Argillaceous limestone is defined as a limestone in which clay minerals occur disseminated in the stone in the amount of 10 to 50 percent by weight of the rock. When these make up from 50 to 90 percent, the rock is known as calcareous (or dolomitic) shale (or claystone, mudstone, or siltstone).

3-7.2 Alkali-Silica Reactivity.

Alkali-silica reaction is a deleterious chemical reaction between the reactive silica constituents in the aggregates and alkali in the cement. The product of this reaction can produce significant expansion and cracking of the concrete. The methodology to determine the susceptibility of aggregate to alkali-silica reactivity (ASR) and the effectiveness of mitigation measures is based on the Portland Cement Association's *Guide Specification for Concrete Subject to Alkali-Silica Reactions* (1998). However, for airfield pavements, the DOD doubles the immersion time of the test to 28 days versus the typical 14 days for roads and sets the expansion limit to 0.08 percent in lieu of 0.1 percent for roads. DoD requires these alterations to reduce the risk of false negative results and ensure deleterious expansion from slowly reactive materials is detected prior to incorporation into DoD airfield pavements.

3-7.3 Service History (Field Performance).

Performance history is a source of information on the susceptibility of an aggregate to ASR. When evaluating a service history as an indicator of the susceptibility of an aggregate to ASR, document the following (if this information cannot be affirmed and documented, the service history may be insufficient to evaluate the aggregate):

- The current supply of the aggregate is representative of that used in the existing historical placements.
- The existing historical placements are exposed to the same severity of exposure condition as the proposed placement.
- The existing historical placements have been exposed to this severity condition for at least 15 years.

- The existing historical placements have the same cement content with the same alkali content of the cement and the water/cementitious material (w/cm) ratio of the concrete equal to or greater than proposed concrete mix placement.
- The existing historical placements have the same pozzolans in both class and content as well as total equivalent alkali content and SiO_2 + Al_2O_3 + Fe_2O_3 content.

3-7.4 Laboratory Evaluation.

In the absence of an adequate history of field performance or for airfield or other heavy-duty paving, test both fine and coarse aggregates as follows.

3-7.4.1 ASTM C1260/CRD-C 174.

For roads, results per this test that yields a mean 14-day mortar bar expansion less than or equal to 0.10 percent contains acceptable aggregate and may be used for concrete production. When the mean 14-day expansion is greater than 0.10 percent, the aggregate is suspect and additional testing is warranted before the aggregate is approved for used. For military airfield and heavy-duty paving projects, expansion is limited 0.08 percent after 28 days of submersion for aggregate to be acceptable without mitigation.

3-7.4.2 ASTM C295/CRD-C 127.

This test supplements the results of ASTM C1260/CRD-C 174. This test identifies and quantifies the reactive mineral constituents in the aggregate. Reactive constituents include strained or microcrystalline quartz, chert, opal, and natural volcanic glass in volcanic rocks.

3-7.4.3 ASTM C1293/CRD-C 175.

This is an optional test to verify results of ASTM C1260/CRD-C 174. An aggregate that produces a mean expansion at one year exceeding 0.04 percent is considered potentially reactive. Although the time required for this test generally makes it impractical to use for a specific job, some aggregate suppliers can provide test results specific to their aggregates. The suppliers must demonstrate that the test results represent the aggregate currently being produced from their quarry.

3-7.4.4 ASTM C1567.

While similar to ASTM C1260/CRD-C 174, this test includes supplementary cementitious materials and is used to determine the proportioning of these supplementary cementitious materials to mitigate ASR. Furthermore, the limits and test length for airfield paving are 0.08 percent after 28 days of submersion for the mitigation to be acceptable.

3-7.4.5 CRD-C 662.

If evaluating lithium nitrate as a means to mitigate ASR expansion, with or without supplementary cementitious materials (SCM), test in accordance with CRD-C 662.

3-8 MITIGATION MEASURES.

For roads, if the aggregate demonstrates potential reactivity by ASTM C295/CRD-C 127, ASTM C1260/CRD-C 174, ASTM C1293/CRD-C 175, or by previous field performance, it may be used if an appropriate mitigation measure is effective. Specify and test several combinations of cementitious materials to allow the contractor as much flexibility as possible to meet the other requirements of the project. For military airfield construction, any combination that produces a mean 28-day expansion of 0.08 percent or less when tested according to ASTM C1567 is considered an acceptable method of controlling expansion due to ASR. The cement used for testing must be the same type and brand used on the project. Possible mitigation measures include incorporating a supplementary cementitious material. These materials include low-calcium Class F fly ash (calcium oxide [CaO] content less than 8 percent), slag, silica fume, or natural pozzolan in combination with portland cement.

3-8.1 D-Cracking.

D-cracking describes the distress in concrete that results from the disintegration of coarse aggregates after they become saturated and are subjected to repeated cycles of freezing and thawing. For pavements subject to freezing conditions in service, reject or beneficiate aggregate susceptible to D cracking to remove particles of susceptible size; generally, these are larger particles. Most rock types associated with D-cracking are of sedimentary origin. If the performance history of a proposed aggregate is unknown and the pavement is subject to numerous cycles of freezing during a season, test the aggregate using ASTM C 666/CRD-C 20 (either Procedure A or Procedure B). This method tests the durability of concrete under cycles of freezing and thawing in conditions likely to saturate the concrete. Modifications for testing aggregate for D-cracking include increasing the number of cycles to 350 and calculating the durability index from the expansion of the specimens.

3-8.2 Lead Time Required for Aggregate Testing.

Table 3-3 gives the time required for testing of ASR and freeze-thaw (D-cracking). Typically, about 60 days’ lead-time is available from contract award to start of work, so aggregate acceptance must be done within that time or before award. Design engineers must specify ASTM C1260/CRD-C 174 if ASR testing is required. Design engineers must emphasize the test time requirements if aggregate qualification tests are needed. ASTM C1260/CRD-C 174 can test the effectiveness of mitigation measures, as described in this UFC. Test several combinations of cementitious materials simultaneously to save time and allow flexibility to meet other job requirements.

Table 3-3 Testing Time Required

Test Method (ASTM)	Time for Test Result
C1260/CRD-C 174	16 days
C1293/CRD-C 175	1 year for potential aggregate reactivity; 2 years to test effectiveness of mitigation measures
C666/CRD-C 20	2 to 3 months

3-9 AVAILABILITY/CERTIFICATION OF CEMENTITIOUS MATERIALS.

3-9.1 Cementitious Materials.

Secure cement supplies to ensure supply during peak construction season. If the cement source is changed, conduct additional mix design and compatibility testing. Problematic combinations often include cements with relatively low sulfate contents or with sulfates available only in forms that are not readily soluble. While such cements may perform satisfactorily alone, they may be prone to early stiffening if used with water-reducing admixtures containing lignosulfonates or triethanolamine. In hot weather, these effects are more pronounced. Mixture designs should be pre-qualified using different cementitious materials in the event a substitution is necessary, alternate mix design data is available, and new materials can be accommodated without delay.

3-9.2 Portland Cement.

The various types and requirements of cement are given in ASTM C150/CRD-C 201. The cement types are presented in Table 3-4. ASTM C150/CRD-C 201 also specifies optional chemical requirements, such as limits on the maximum alkali content, and optional physical requirements, such as heat of hydration. Specify these requirements judiciously, if at all, since they often increase the cost or limit the available options. Frequently there are equally acceptable or even preferable alternatives. For example, deleterious expansions due to ASR may be controlled as well or better by a combination of cement with Class F fly ash or slag instead of low-alkali cement. Generally, do not specify a maximum limit on the alkali content of the cement. This may not be sufficient to control deleterious expansions. In some cases, higher alkali content may be desirable to increase the rate of hydration during cool weather or when supplementary cementitious materials are used. Sulfate resistance may be obtained with sufficient quantities of slag or an appropriate fly ash as well as (or better than) a Type II or Type V cement. Heat of hydration may be reduced using a combination of slag, Class F fly ash, and natural pozzolan with Portland cement. If the cement is used alone (that is, without supplementary cementitious materials), specify the optional requirement for false set; however, evaluate the setting characteristics for the concrete.

Table 3-4 Types and Uses of Portland Cements

Designation	Application
Type I	Most widely available; used when other special properties are not required.
Type II	For general use, especially when moderate sulfate resistance or heat of hydration is required. Some cements meeting requirements for both I and II are designated Type I/II.
Type III	Used for high early strength.
Type IV	Used when low heat of hydration is required.
Type V	Used when high sulfate resistance is required.

3-9.3 Blended Cement.

The types and requirements of blended cements are given in ASTM C595/CRD-C 203. The types of blended cements are listed in Table 3 5. All cements designated Type I under ASTM C595/CRD-C 203 have comparable strength requirements at early ages as do those specified by ASTM C150/CRD-C 201 for Type I cement. However, the actual strengths at early ages are generally lower because slag and pozzolans included in blended cements react more slowly than cement alone. Type IL (10) and IL (15) cements contain up to 10 or 15 percent limestone ground with the cement clinker. This material provides similar performance to Type I cement but can be slightly more porous. It also has a lower embodied carbon content than similarly produced Type I cement.

Table 3-5 Types of Blended Cements

Designation	Composition
Type IL (10) (15)	Contains 10 to 15 percent ground limestone
Type IS	Contains 25 to 70 percent blast furnace slag
Type P and Type IP	These contain 15 to 40 percent pozzolan (fly ash or natural pozzolan). Type P is used when higher early strengths are not needed.
Type I (PM)	Contains less than 15 percent pozzolan.
Type I (SM)	Contains less than 25 percent slag.
Type I (PM) and Type I (SM)	Should not be used when the special properties of pozzolan or slag are desired, as they don’t contain enough of these materials.
Type S	Contains at least 70 percent slag

3-9.4 Hydraulic Cement.

The various types of hydraulic cements are given in ASTM C1157/CRD-C 271. The types of hydraulic cements are given in Table 3-6.

Table 3-6 Types of Hydraulic Cements

Designation	Use
Type GU	For general use
Type HE	For high early strength
Type MS	For moderate sulfate resistance
Type HS	For high sulfate resistance
Type MH	For moderate heat of hydration
Type LH	For low heat of hydration

3-9.5 Supplementary Cementitious Materials.

Supplementary cementitious materials offer the potential for improved performance of concrete and reduced cost. They provide benefits more economically and sometimes more effectively than the appropriate choice of ASTM C150/CRD-C 201 cement. The benefits include:

- Control of expansions due to ASR
- Reduced permeability
- Sulfate resistance
- Reduced heat of hydration

3-9.5.1 Pozzolans.

ASTM C618/CRD-C 255 defines pozzolans as “siliceous or siliceous and aluminous materials which in themselves possess little or no cementitious value but will, in finely divided form, and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties.” Fly ashes and natural pozzolans must meet the requirements of ASTM C618/CRD-C 255. Class F fly ash with $SiO_2 + Al_2O_3 + Fe_2O_3 > 70$ percent, CaO content less than 8 percent, and loss of ignition not exceeding 3 percent is the preferred choice for controlling ASR and provides sulfate resistance. Class C fly ash is not permitted for concrete pavement.

3-9.5.2 Dosage.

Typical dosages for Class F fly ash are generally between 15 percent and 35 percent by mass of cementitious materials. Evaluate sources to determine actual chemical composition to establish typical usage rates. For treatments below 25 percent replacement, the SiO_2 + Al_2O_3 + Fe_2O_3 content must be greater than 70 percent. At 15 percent replacement, the SiO_2 + Al_2O_3 + Fe_2O_3 content must be greater than 90 percent.

3-9.5.3 Weather Effects.

In cool weather, concrete with Class F fly ash may not gain strength quickly enough to allow joint sawing before shrinkage cracks form.

3-9.5.4 Alkali-Silica Reactivity.

If fly ash is used to control expansions due to ASR, a lower CaO content is more effective. Ideally, the CaO content should be less than 8 percent. Test the fly ash to verify effectiveness and dosage requirements. Only use Class F fly ash with a total equivalent alkali content less than 4 percent when mitigating ASR potential in DoD airfield pavement. Only use Class F fly ash with a loss on ignition not exceeding 3 percent when mitigating ASR potential in concrete using air entraining admixtures in DoD airfield pavement.

3-9.5.5 Mixture Property Control.

Natural pozzolans are available either as components of Type IP cement or as additives. They can be effective in controlling expansions due to ASR and in reducing heat of hydration.

3-9.5.6 Slags.

Finely ground granulated blast furnace (GGBF) slag must meet the requirements of ASTM C989/CRD-C 205. Table 3-7 lists the three grades of GGBF slag. The three grades of GGBF slag are based on their activity index. Typical dosage of slag is between 25 percent and 50 percent of cementitious materials. For airfields, the minimum dose is 40 percent and the maximum is 50 percent. Note that concrete strength at early ages (up to 28 days) trends lower than slag-cement combinations, particularly at low temperatures or at high slag percentages. Establish the desired concrete properties while considering the importance of early strengths; the curing temperatures; and the properties of the slag, cement, and other concrete materials.

Table 3-7 Grades of GGBF Slag

Designation	Properties
Grade 80	Least reactive, not normally used for airfield pavements
Grade 100	Moderately reactive
Grade 120	Most reactive, through finer grinding. Difficult to obtain in some locations in U.S. and Canada

3-10 CERTIFICATION OF ADMIXTURES AND CURING COMPOUNDS.

3-10.1 Admixtures.

3-10.1.1 General.

Chemical admixtures are ingredients commonly used in paving concrete to obtain or enhance specific properties of concrete. For concrete with multiple admixtures, purchase the admixtures from the same manufacturer. The large manufacturers test their own admixtures for incompatibility and other interactions and can provide helpful advice for avoiding undesirable reactions. Not all admixtures work well in all applications. For example, the low slumps typical of paving concrete make certain air-entraining admixtures less effective. The contractor should seek the advice of the manufacturer on applying and using admixtures. Obtain batching requirements, mixing procedures, and recommended dosages from the manufacturer. Use trial batches to determine exact dosages for the particular concrete mixture design. Placement temperature affects the required dosages of chemical admixtures. Develop trial batches accordingly. Never use admixtures to compensate for marginal concrete mixtures. The specifier and the contractor must consider if adjustments to the concrete mixture design are preferable to admixtures. As an example, obtain the effects of accelerating and retarding admixtures by adjusting the quantity and composition of the cementitious materials in the mix. Blend admixtures separately into the concrete. Do not place admixtures directly on dry aggregate or on dry cement as they can be absorbed and are not available to readily mix with the concrete. Consult the manufacturer for information about potential interactions between admixtures. In higher dosages, some water reducers may retard setting or strength gain. Chemical admixtures must meet the requirements of ASTM C260/CRD-C 13 or ASTM C494/CRD-C 87.
ASTM C260/CRD-C 13 specifies the requirements for air-entraining admixtures. The types of admixtures specified by ASTM C494/CRD-C 87 are given in Table 3 8.

Table 3-8 Types of Admixtures

Designation	Use
Type A	Water-reducing admixtures
Type B	Retarding admixtures
Type C	Accelerating admixtures
Type D	Water-reducing and retarding admixtures
Type E	Water-reducing and accelerating admixtures
Type F	Water-reducing and high range admixtures
Type G	Water-reducing, high range, and retarding admixtures

3-10.1.2 Air-Entraining Admixtures.

Air-entraining admixtures entrain a system of finely divided air bubbles in the cement paste. They are an essential protection for concrete exposed to freezing as they provide outlets for freezing water to expand and not disrupt the internal structure of the concrete. Air-entraining admixtures can also improve the workability of fresh concrete. They reduce water demand, bleeding, and segregation. Select an admixture appropriate for pavement use; some admixtures are used only in concretes with higher slump allowances than typical for airfield pavements. Higher air content in concrete reduces its strength. If the air content of the production concrete is higher than specified in the approved mix design, it may reduce the strength of in-place concrete and strength samples. Typically, a 1 percent increase in air results in a 5 percent loss in compressive strength.

3-10.1.3 Accelerating Admixtures.

Accelerating admixtures are classified as Type C and Type E by ASTM C494/CRD-C 87. They accelerate the setting and early strength gain of concrete. Typically, they are used only in cold weather or in repairs when the reduction of an hour or two in the setting time is important. They are also used when some increase in the early-age strength is needed. If any of these properties are needed over the course of the job, it is preferable to design the concrete accordingly rather than rely on accelerating admixtures. Accelerating admixtures primarily affect the setting time, heat evolution, and strength development. The strength at later ages may decrease, and in aggressive environments the durability may be adversely affected. Alternate means of obtaining early strength development include:

- Use of Type III cement
- Higher cement contents
- Heating the water or aggregates
- Improving curing and protection
- Some combination of the above

3-10.1.4 Retarding Admixtures.

Retarding admixtures delay the initial and final setting times; however, they do not reduce the rate of slump loss. They affect the rate of strength gain for as little as one or two days, or as long as seven days, depending on the dosage. They may be used in hot weather when long haul times are unavoidable or to prevent the formation of cold joints. Changes in temperature may require adjustments in admixture dosage to maintain the desired setting time. In hot weather, the dosage may be increased to the point where excessive retardation occurs. In some cases, this results in cracking of the pavement because the concrete begins to crack due to drying before gaining sufficient strength to saw the joints.

3-10.1.5 Water-Reducing Admixtures.

Water-reducing admixtures, as defined in ASTM C494/CRD-C 87 as Types A, D, and E, are used in concrete pavement applications. Some Type A water-reducing admixtures act as Type D (water-reducing and retarding) admixtures at higher dosages. High amounts of water-reducing admixtures may lead to excessive retardation. The rate of slump loss is increased when using water-reducing admixtures. Some water-reducing admixtures enhance the effectiveness of air-entraining admixtures so a lower dosage achieves the required air content. High-range water reducers are typically not used in pavement concrete. Types A, D, and E can be used to:

- Reduce the water/cement ratio at a given workability.
- Increase the workability for a given water content.
- Reduce the water and cement contents for a given workability.

3-10.2 Curing Compounds.

Curing compounds (liquid membrane-forming compounds) need to conform to the requirements of ASTM C309/CRD-C 304 and CRD-C 300, as applicable. ASTM C156/CRD-C 306 specifies a method for determining the efficiency of curing compounds, waterproof paper, and plastic sheeting. Pigmented curing compounds are recommended because they make it easy to verify proper application. For concrete placement on sunny days and in hot weather, the selected curing compound should contain a white pigment to reflect the sun's heat. Properly applied curing compounds must have the following properties:

- Maintain the relative humidity of the concrete surface above 80 percent for seven days
- Be uniform and easily maintained in a thoroughly mixed solution
- Not sag, run off peaks, or collect in grooves
- Form a tough film to withstand early construction traffic

3-11 QUALITY CONTROL/QUALITY ASSURANCE REQUIREMENTS.

The development of specifications for contractor quality control/quality assurance (CQC/QA) is discussed in this section. The implementation of specific project CQC/QA requirements is discussed in Chapter 10.

3-11.1 Basic CQC/QA Definitions.

3-11.1.1 Contractor Quality Control (CQC).

CQC, also called process control, refers to the contractor's roles and responsibilities. The goal of the CQC program is to provide testing, monitoring, and reporting of information to adequately document that the contractor is meeting the project specifications and to allow the contractor to make timely adjustments to the construction process. The contractor needs to develop a written CQC plan that is available for review and approved by the Contracting Officer.

3-11.1.2 Quality Assurance (QA).

QA consists of all actions necessary to provide a reasonable level of confidence that the final product will meet the intent of the government from a serviceability and maintenance perspective. QA refers to the government's roles and responsibilities. The goal of the QA program is to verify that the results from the contractor's CQC plan are truly representative of the actual material being placed and that the contractor is "doing the right things." The government will develop a written QA plan and distribute it to all project personnel, including the contractor.

3-11.1.3 Acceptance Testing.

Acceptance testing describes the QA tests conducted to determine the degree of compliance with contract requirements and is linked to pay items. Acceptance testing can be part of the QA or CQC plan or both. For example, CQC may be responsible for fabricating and field curing concrete strength samples, but QA is responsible for transporting, laboratory curing, and testing. Clearly define all acceptance testing procedures and responsibilities prior to starting any work.

3-11.2 General Issues.

Important quality-related concrete pavement construction items include:

- Testing crew training/certification (typically ACI certification)
- Testing laboratory certification (as per ASTM C1077/CRD-C 553)
- Plant certification
- Plant operator certification
- Test equipment calibration: flexural strength test machine calibration and other laboratory testing equipment
- Role of QA/acceptance or verification/resolution of conflicts between QA and QC test results
- Use of control charts by contractors
- Development of a CQC plan
- Management of CQC data
- Timely review and processing of CQC data
- Ability of construction team to make decisions quickly with changing project conditions

3-11.3 CQC Plan.

One of the most important activities of a concrete pavement construction project is the contractor's development of a comprehensive CQC plan. The contractor must implement and adhere to the CQC plan throughout the course of the construction project. Meetings between the CQC and QA representatives prior to construction help resolve conflicts and identify gaps in the inspection process. The components of a good CQC plan include:

1. Introduction
    - Project description

- Key contact information (contractor, owner, and owner's representative)
- Contract plans and specifications highlights

2. Purpose of CQC
3. Organization chart (Clearly delineate the chain of responsibility from top management.)
    - CQC roles (testing laboratory, contractor)
    - Project personnel
4. Duties and responsibilities
    - QC manager
    - QA or acceptance testing administrator, as applicable
    - Project engineers
    - Technicians/inspectors
5. Inspections (paving related) (Include tests required and frequency and acceptance criteria.)
    - Material inspections
    - Excavation and embankment inspection
    - Concrete paving inspection
    - Demolition of existing pavement
6. QC test schedules/testing plans
    - Report submittals
7. Deficiencies reporting
8. Conflict resolution
9. Changes to the CQC/supplemental items
10. Placement agreement form
11. Appendices (as needed)

3-11.4 Review of CQC Plan.

Write the CQC plan clearly to minimize any misunderstanding. Review the plan for ambiguity with respect to sampling locations, number of tests, test procedures, special provisions, and acceptance limits. Make copies of all test procedures cited in the plan readily available at the project site or at the project test facility. The management of each organization must fully support the CQC process. Without management support, urgent deadlines and outside pressures can dominate project activities and CQC testing and inspection will suffer. An inspection and testing checklist is provided in Appendix B. The following are items to review in CQC plans:

- Are all required tests discussed?
- Are proper standards for each test referenced?
- Are testing requirements clearly defined and understood?
- Are all procedures clearly defined?
- What items are tested?
- What actions are taken when test results are unacceptable or outside of project action or suspension limits?
- What are the documentation procedures and timelines?
- How and to whom are the test results reported?
- How are nonconforming test results handled?
- Does the paving plan address hot and cold weather construction activities?
- If nighttime construction is anticipated, does the plan properly address the procedures for use and placement of portable light plants?
- Does the plan provide the chain of command for decision making?

3-11.5 CQC Versus QA Testing Responsibilities.

Contractors and inspectors must be aware of testing requirements and how test results are used. QA testing is used for acceptance and pay adjustments while the contractor's test results are used for process control. This can create conflicting situations. Minimize the potential for conflicts between QA and QC through timely communications. Once the CQC and QA plans are created, reviewed, and approved, the contractor and the inspection teams will meet to review and resolve any potential conflicts or gaps in the plans. For example, the CQC plan may assume that the owner is making flexural strength samples for opening to traffic while the QA plan assumes it is the responsibility of the contractor. Or the QC plan may call out storage of traffic samples at the paving location and the QA plan defines storage in the laboratory. An often-overlooked part of any construction project is CQC data management. Data management includes items necessary to document the construction process. These items include test results and procedures, consignment forms, laboratory control charts, and requests for information. Track any missing information and resolve as soon as possible. Missing items are difficult to locate if the project team waits until the end of the project. In addition to the types of documents submitted, the schedule for submission and the review process must be determined before construction begins.

3-12 TEST SECTION CONSTRUCTION.

Test sections are mandatory for all design-build paving projects, all airfield paving projects, and for other paving projects where the pavement thickness is 250 mm (10 in.) or greater and constructed using slipform paving. The designer and the using agency decide where the test section will be constructed. Use the test section to evaluate the concrete batching, transporting, placement, finishing, and curing processes. The specification clearly identifies the objectives for test section construction and establishes the construction monitoring and acceptance plan requirements. Develop the acceptance plan in accordance with project requirements. Clearly define test section dimensions and construction location. The designer and using agency must decide whether to place the test section near the project site or allow its use as part of the final pavement, provided it is placed at an outer edge location. Both the contractor and the government must have senior representatives present during the test section placement as this event establishes the acceptable and unacceptable procedures. The government must give the contractor timely notification of acceptance or a clear explanation of what is rejected.

3-12.1 Test Section Details.

Consider including the following construction details in the test section.

- Pave at the paving width anticipated for the project.
- Allow sufficient length (typically 122 m [400 ft]) for the contractor to demonstrate their paving operation.
- Place in conditions anticipated during pavement construction.
- Use the same equipment and concrete haulers as used during construction.
- Include blockouts to evaluate paving processes where light cans and embedded steel are located.
- Include at least one construction header to evaluate starting and ending.
- Include tie-down (mooring point) and ground point if the paving project includes them.
- For large projects, test strip construction should also include hand placement.

3-12.2 Test Evaluation Items.

Construct test sections using the same procedures as for production paving. The following paragraphs contain the items to evaluate during test section placement.

3-12.2.1 Pre-Paving Preparation and Inspection Activities.

Accomplish the following activities prior to starting paving operations.

- Base condition (grade and surface)
- Grade controls (stringline setup, paver track-line)
- Joint locations
- Dowel bar baskets, embedded steel, and tie bars, if used

- Blockouts
- Concrete aggregate (for gradation and moisture content)
- Equipment for transporting, placing, consolidating, finishing, texturing, and curing
- Vibrators on pavers (for frequency and amplitude).

3-12.2.2 Batch Plant Operations.

Evaluate the following batch plant charging and concrete mixing processes prior to the start of paving operations.

3-12.2.2.1 Plant Production Rate.

Batching through the plant at expected production rates will evaluate whether additional loaders are required and stockpile management plans are acceptable. Establish and approve mixing times based on plant uniformity testing.

3-12.2.2.2 Concrete Uniformity.

If difficulties in mixing or concrete uniformity are encountered, changes to the plant, changes in the mixing process, changes to the concrete mixture designs, or additional plant uniformity testing should be considered. Difficulties in concrete mixing at the design w/cm ratio, non-uniform concrete between the front and rear of the drum during discharge, and excessive loss in slump may indicate the following possible problems:

- Materials not sequenced properly into the drum
- Too large a batch size relative to drum capacity
- Inadequate mixing times
- Liquid admixture incompatibility with cement or supplementary cementitious materials
- Sensitivity to initial concrete temperature
- Sensitivity to stockpile moisture changes

3-12.2.3 Concrete Delivery.

Evaluate the following concrete delivery processes before starting paving operations.

a. The time between the addition of water and depositing concrete on grade must be checked to verify that the concrete can be batched, transported, and dumped on grade within specified time limits.

b. Additional concrete haulers are required if the paver stops and waits for concrete delivery.

c. Compare concrete material batch quantities with the approved mixture design quantities.

d. Deliver concrete using the same equipment as used in production (agitator, open-end dump trucks, as well as other material-handling vehicles and equipment).

3-12.2.4 Concrete Placement.

Evaluate the following concrete placement operations before starting paving operations.

a. Concrete dumped from trucks, chuted from agitator trucks, or spread using belt spreaders should not drop more than 1.5 m (5 ft).

b. Concrete dumped on grade or placed in front of the paver using belt placers or spreaders must be examined for aggregate segregation. If the concrete appears segregated, uniformity testing on coarse aggregate content must be conducted.

c. Significant differences in aggregate content between samples of concrete from the same truck indicate that concrete transport or dumping processes may need to be modified.

d. When concrete is dumped in front of the paver or spreader and dowel baskets are placed during slipforming, observe the alignment procedures to ensure the baskets are being properly located and installed.

3-12.2.5 Quality Assurance/Quality Control.

Evaluate the following concrete sampling and QA/QC operations before starting paving operations. Address deficiencies noted concerning acceptance, QA and QC, concrete sampling, transporting, beam fabrication, initial and final curing procedures, and subsequent testing, and implement corrective action.

a. Sample concrete in front of the paver and test for slump, air content, initial concrete temperature, and plastic unit weight in accordance with the project requirements. Check concrete air content behind the paver. Document ambient air temperatures.

b. Properly transport concrete samples for beam or cylinder if concrete beams are fabricated and initially cured at a central location. Fabricate extra samples for testing at different ages. Early-age strength tests can verify strength gain relative to the mixture design and establish relative opening times for construction equipment.

c. Fabricate beams and cylinders at intervals more frequently than the sublot limits. This provides a better indication of variability due to any minor changes in batch quantities and changes throughout the day.

3-12.2.6 Consolidation and Finishing.

Evaluate the following concrete consolidation and finishing operations before starting paving operations.

a. Difficulties in placing, consolidation, maintaining a smooth pavement, maintaining a tolerable edge slump, closing the surface and edges, and surface tearing indicate problems with concrete, concrete mixture design, or the paver operation.

b. Adjust the vibrator frequency, spacing, and elevation if problems with consolidation are encountered. Supplementary vibrators may be necessary at longitudinal construction joints if excessive entrapped air voids or honeycombing are observed along vertical edges.

c. If problems in consolidation are attributed to the concrete, conduct slump tests at the plant to establish slump loss. There may be an incompatibility problem between cement, liquid admixtures, and supplementary cementitious materials if concrete exhibits a high slump loss (generally considered greater than 25 mm [1 in.]). Verify aggregate moisture monitoring.

d. Dowel bar inserters are prohibited on DoD airfield projects.

e. Verify pavement thickness by probing or by stretching piano wire across string line pins and using a ruler.

f. Transfer transverse joint stations from the base or sides of forms to the pavement surface as references for joint sawcutting.

g. Observe paving at blockouts for movement of the blockout from the planned position. Check embedded steel behind the paver to ensure the steel is properly secured to the base and is not disturbed by paver vibrators.

h. Examine the surface directly behind the paver screed or the tube float to ensure the surface is not tearing. Surface tearing is associated with excessive concrete slump loss, excessive concrete slump, a poorly adjusted paving machine, or excessive paver speed. Closing tearing cracks during finishing operations may not prevent them from reflecting to the surface.

i. Examine the surface behind the paver screed or tube float to ensure it is closed. Difficulty in closing the surface is indicative of one or more of the following:

- Premature concrete stiffening (possible admixture incompatibility)
- Insufficient paste/mortar content
- Vibrator frequencies set too high
- Vibrator elevations set too low
- Paving speed too high
- Inadequate mortar quantities maintained in the grout box

j. Measure edge slump at frequent intervals. Increasing the coarse aggregate content, decreasing the water content, or decreasing the mortar content can reduce edge slump. Paver side form batter can sometimes be adjusted to compensate for edge slump. Reducing paver speed may also help reduce edge slump.

k. Examine the concrete, after finishing but prior to any texture operations, with a straight edge. The surface must be closed. Avoid adding water to aid in the finishing operation. If additional water is required during hot weather, a minimal amount of water addition is tolerable only if applied in a fine mist. An excess of surface laitance after finishing is indicative of excessive finishing or excessive water application. Finishing efforts need to be just enough to provide a smooth closed surface. An excessive amount of finishing leads to a non-durable concrete surface.

3-12.2.7 Texturing.

The method of texturing must be inspected for uniformity in appearance. If burlap is used, it must be wet enough to provide a rough surface texture without exposing or rolling any coarse aggregates. Ponding of laitance or the depositing of thick films of water is indicative of the burlap being excessively wet.

3-12.2.8 Curing.

Consider the following concrete curing operations before starting paving operations.

a. Establish curing compound coverage rates prior to test strip construction. The coverage rate depends on the surface texture applied.

b. The application of curing compound must be uniform along the pavement surface and vertical edges.

c. A non-uniform application is indicative of spray nozzles set too low, clogged nozzles, cure rig speed set too fast, insufficient mixing of curing compound, or an insufficient number of passes.

3-12.2.9 Sawcutting.

Consider the following concrete sawcutting operations before paving.

a. Periodically monitor the temperature of fresh concrete if maturity meters, infrared guns, or surface thermometers are used to establish sawcutting times. Sample temperatures approximately every 20 minutes until joints are ready.

b. If the maturity meter technique is used to establish sawcutting times, insert thermocouples into the plastic concrete as soon as possible after texturing. Thermocouples are inserted into the pavement per the manufacturer’s instructions. To obtain representative temperatures, the thermocouples should be positioned at least 0.6 m (2 ft) inward from pavement edges.

c. Allow sawcut operators to initiate cutting when concrete is slightly too green to calibrate temperature or maturity measurements.

d. Cut several meters (feet) to allow a visual rating or quantify joint raveling. Repeat this process until representatives for the owner, contractor, and inspector agree that sawcuts meet project requirements.

e. Document conditions of sawcuts and photograph to avoid future disputes over excessive raveling. Document the maturity and temperature when “acceptable” sawcuts can be made for production paving.

f. Check sawcut depths for each saw used on the test strip. Carry transverse sawcuts through the longitudinal free edges or as close to forms as possible.

3-12.2.10 Test Section Acceptance.

After test strip construction, perform a final inspection of the pavement. Items to inspect include:

- Condition of the surface and slipformed edges
- Texture and curing compound coverage
- Headers and sawcut joints
- Blockout areas (light can penetrations or other utilities)
- Edge slump and profile (straight edge or profile testing)
- Cores (for thickness and assessing consolidation and segregation).

See ASTM D6938, *Standard Test Method for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth).*

3-12.2.11 Adjustments to Quality Control/Quality Assurance Operations.

Document and discuss any deficiencies noted during test section construction or post-construction inspection and testing techniques. Hold meetings between the contracting officer and the contractor to review the test section results. Agree on actions to address and resolve deficiencies before commencing production pavement construction. Consider making any necessary changes in the CQC plan and operations.

CHAPTER 4 SUBGRADE PREPARATION

4-1 INTRODUCTION.

The subgrade provides the foundation for the entire pavement system. Uniformity and stability of the subgrade affect the long-term performance of the pavement and the construction process. Subgrade stability is needed to provide adequate support of the pavement section and to provide an acceptable construction platform. Pavement design begins with identification of the pavement foundation. Construction begins with foundation preparation. Important elements of subgrade preparation include evaluating subgrade stability, subgrade modification to improve stability, and evaluating surface tolerances. A geotechnical engineer experienced in subgrade preparation can address issues with:

- Variability of soil condition
- Soil with low bearing strength, ≤ 96 kPa (1 ton/square foot [tsf])
- Organic soil
- Swelling/expansive soil
- Frost-susceptible soil

Implement all measures within the limits of construction to control water pollution, soil erosion, and siltation as shown on the plans or required by applicable permit. Follow all pertinent local, state, and federal laws.

4-2 GRADING AND COMPACTING SUBGRADE.

4-2.1 Grading.

4-2.1.1 Pre-Grading Activities.

Mass grading is the first phase of subgrade preparation. It removes high points and fills low areas to achieve the desired finish elevation. The cut/fill items are typically addressed in the design phase of the project. Construction staking is the second phase of pre-grading. It is a good practice for the owner/engineer to perform an independent verification of the staking accuracy. Automated grading equipment using global positioning is commonly used to establish the grade. If these systems are employed, it is a good practice to periodically verify the results through the use of conventional surveying. Important items to consider include the following.

a. Fill material is usually obtained from cut operations. Use the geotechnical report to evaluate the potential of this material for engineered fill.

b. If the in-place material is not of sufficient quantity or has unacceptable material properties, identify alternate borrow areas to source fill material.

c. It is incumbent upon the contractor to inform themselves regarding local subgrade conditions related to pre-grading and other construction activities.

4-2.1.2 Removal of Unsuitable Subgrade.

When preparing the grade, unsuitable soil can be encountered. Materials such as peat, organic silt, silt, and soil with high organic content are classified as unsuitable. To deal with these materials consider the following actions:

- Remove and replace with soil similar to the surrounding subgrade.
- Remove and replace with granular material.
- Alter the properties through compaction or stabilization.

4-2.1.3 Protection of Grade.

During grading operations, protect the grade by performing two essential activities, as follows.

1. Provide temporary drainage: trenches, drains or ditches necessary to divert or intercept surface water. If water ponds on the subgrade, the material softens and is damaged by construction traffic. This results in delays and the need for repairs.
2. Implement procedures to manage site traffic over the grade. Do not use channelized traffic patterns over one portion of the grade. Make sure the traffic is distributed over the grade.

4-2.1.4 Grading Operations.

Grading operations for a concrete pavement may require an embankment.

a. The embankment is constructed by placing material in successive horizontal layers for the full width of the cross-section.

b. Most specifications include a maximum loose depth of fill placement. Using thicker fill layers requires a contractor to demonstrate to the engineer that the thicker fill layer can be compacted to the specified density.

c. During construction of the embankment, hauling equipment needs to travel evenly over the entire width of the embankment. If equipment travel is channelized, permanent deformation and shear failure can occur.

d. In the construction of embankments, begin layer placement at the deepest portion of the fill. As placement progresses, construct layers approximately parallel to the finished pavement grade line.

e. In areas where subgrade transitions occur, mix the subgrade materials by disc at the boundary of the transition zone. Perform subgrade mixing over a distance of about 30 m (100 ft) along the transition zone (15 m [50 ft] on either side of the transition). This practice reduces the potential for differential settlement or frost heave.

4-2.2 Compaction.

4-2.2.1 Compaction Requirements.

Subgrade compaction is essential to building a stable work platform. Due to the weight of construction equipment, it is good practice to compact all subgrade materials to 95 percent of the maximum density using the modified Proctor test (ASTM D1557/CRD-C 162); this helps provide a stable working platform. Field density control is a full-time function. This allows observation of the material as it is placed. If the material appears to change, one-point field Proctor tests are used to check the maximum density. Typical compaction requirements are as follows.

a. Use the modified Proctor test (ASTM D1557/CRD-C 162) to determine the maximum density for pavements trafficked by aircraft/vehicles greater than 27,215 kg (60,000 lb) in weight. Use the standard Proctor test (ASTM D698/CRD-C 653) for lighter aircraft/vehicles.

b. Cohesive soil use in fill sections: When a cohesive soil (plasticity index [PI] greater than 5 or a liquid limit [LL] greater than 25) is used, compact the entire fill to 90 percent maximum density.

c. Cohesive soils in cut sections: Compact the top 150 mm (6 in.) to 90 percent maximum density.

d. Cohesionless soil use in fill sections: When a cohesionless soil (PI equal to or less than 5 and a LL equal to or less than 25) is used, compact the top 150 mm (6 in.) of fill to 100 percent maximum density, with layers below compacted to 95 percent maximum density.

e. Cohesionless soil use in cut sections: Compact the top 150 mm (6 in.) to 100 percent maximum density and compact the next 450 mm (18 in.) to 95 percent maximum density.

f. If the natural subgrade exhibits densities equal to or greater than the specified densities, no compaction is required other than that required for a smooth surface, usually with only surface rolling.

4-2.2.2 Moisture Control.

Moisture control is essential to obtain a stable subgrade. Adhering to the following requirements promotes maximum soil density.

a. Specifications for compaction usually require the moisture content in the subgrade to be within ± 2 percent of optimum moisture content before rolling to obtain the prescribed compaction.

b. For expansive soils, moisture content must be 1 to 3 percent above optimum before compaction to reduce swell potential.

c. For fine-grained soils that do not exhibit swelling properties, keep the moisture content at 1 to 2 percent below optimum.

d. Cohesive soils compacted wet of optimum can become unstable under construction traffic even when the target density is achieved.

4-2.2.3 Moisture Compaction Relationships.

Moisture density curves of typical soils can provide insight into field performance. In Figure 4-1, the shape of the curve suggests that clayey sand soil is moisture sensitive. A small change in moisture content results in compaction difficulty. Additional compaction-related items to consider include the following.

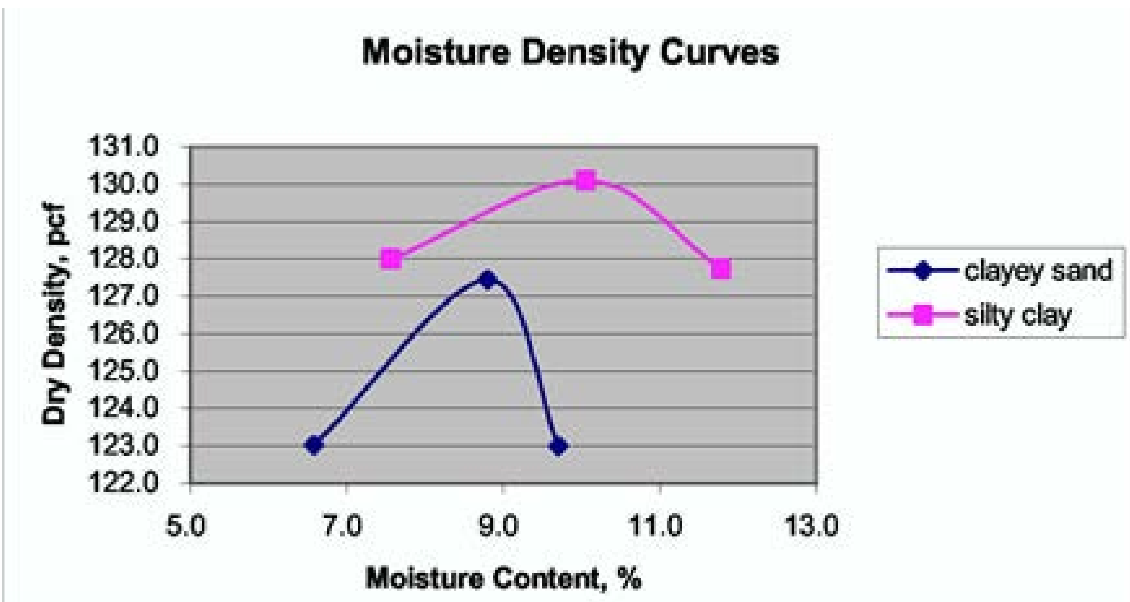
a. Use sheepsfoot rollers for cohesive soil. The pads must penetrate 70 percent of the lift thickness.

b. Discing of cohesive soil is necessary to control moisture.

c. Use static steel drum rollers to smooth the surface of the grade after compaction.

d. Use vibratory steel drum rollers for cohesionless soil. If the water table is close to the surface or if subgrade soils are saturated, use vibration with caution.

Figure 4-1 Typical Moisture-Density Curves.



4-2.2.4 Nuclear Density Gauge.

Nuclear density testing can check the density of the compacted soil. Calibrate gauges to local materials. If problems achieving density are encountered, use the following troubleshooting techniques:

- Perform additional moisture density testing to ensure the proper maximum density value is used to control field compaction.
- Use a sand cone or volume measure to perform the density tests.

- Use traditional methods to determine moisture content.
- Probe the subgrade to determine if soft layers are present below the problem area.

4-3 SUBGRADE STABILIZATION.

Subgrades are often stabilized for one of the following reasons: (a) to improve low strength soil, (b) reduce swelling potential, and (c) improve construction conditions. Unsuitable subgrade conditions can delay construction work due to the time required to implement appropriate measures. Having a stabilized subgrade facilitates staying on schedule. This is important on construction projects that require timely pavement opening to traffic. Find details on stabilization in UFC 3-250-11, *Soil Stabilization and Modification for Pavements*. If the site contains fine-grained soils, prepare a contingency plan for stabilization if unsuitable soils are encountered in localized pockets. Usually, fine-grained soils with unconfined compressive strengths of 190 kPa (2 tsf) or less present stability problems. For localized areas, consider the following procedures:

- Remove soft or disturbed material and replace with subgrade material from adjacent areas. This method works for surficial disturbance.
- Remove soft or disturbed material and replace with crushed stone. If the layer has a unconfined compressive strength less than or equal to 96 kPa [1 tsf]), use geotextile fabric to prevent intrusion of the subgrade into the stone layer.
- Place a geogrid over the soft area. Place and compact 250 mm (10 in.) of crushed stone on top of the geogrid to distribute the load to the subgrade.

4-4 ACCEPTANCE OF GRADE.

For unstabilized materials, consider scarifying, cutting, or filling areas to adjust the grade, if needed. With stabilized materials, filling in thin lifts is not possible. Therefore, with stabilized materials, construct the grade high and trim to final grade. For large projects, consider the use of an autograder or trimmer to minimize grade problems. Use the following criteria to accept a finished grade:

- Surface deviation: Maximum deviation of 10 mm (3/8 in.) (based on 3.6 m [12 ft] straightedge)
- Surface elevation: Maximum deviation of ±13 mm (0.5 in.)

4-4.1 Protection of Grade.

Once the grade is accepted, implement a traffic control plan. Heavy construction trucks traveling on the prepared surface can damage the grade. Enforce traffic management if logistics require use of the prepared grade by construction equipment. Smooth and re-compact all ruts or rough places that develop in a completed subgrade prior to placing the subbase.

4-5 ADVERSE WEATHER CONDITIONS

4-5.1 Drainage.

Implement provisions for drainage at each stage during the subgrade preparation. Maintain a positive slope to assure drainage. When the subgrade moisture content is above optimum, consider discing and drying to reduce the moisture content. If rain is expected after the subgrade is prepared for compaction, seal the subgrade surface using a rubber-tired or steel drum roller. If this is not done in time, serious problems can develop due to excess moisture in the subgrade.

4-5.2 Freezing Temperatures.

If a subgrade is subject to freezing, scarify the surface of the subgrade to a depth of at least 150 mm (6 in.) and re-compact. If the grade preparation was halted for winter, scarify the exposed subgrade surface to a depth of at least 150 mm (6 in.) and recompact prior to continuing grading the following spring.

4-5.3 Troubleshooting Guide.

Table 4-2 lists various subgrade problems, probable causes, and corrections.

Table 4-1 Troubleshooting Guide for Subgrades

Problem	Probable Cause	Corrective Action
Surface appears loose	• Low density	• Check moisture content and density • Re-condition to optimum moisture and re-compact area
Depressions or excessive movement under roller	• High moisture content • Weak layer under surface	• Check moisture content and re-condition to optimum moisture if high • Probe grade with DCP to find weak layer • Stabilize area
Surface varies from coarse to fine	• Segregation of imported material • Change of material	• Perform sieve analysis to check gradation • Mix surface and re-compact

CHAPTER 5 BASE AND SUBASE CONSTRUCTION

5-1 INTRODUCTION.

The layer immediately below the pavement surface is the base course. The term subbase designates layer(s) below the base and above the subgrade.

5-2 SUBGRADE PROTECTION.

Subbase and base course granular layers left exposed over a winter in a wet-freeze region can cause softening of the subgrade. Cover these layers with the pavement. If this is not possible, use caution when resuming construction. Construction traffic can make a subgrade unstable.

5-3 SUBBASE COURSE.

Subbase materials are generally granular materials that are natural material or crushed. Their stability in CBR values ranges from 20 to 100. These materials are generally used as subgrade protection layers (frost protection) or to provide drainage above the subgrade. In frost areas, limit the percent of the material less than 0.075 mm (passing the No. 200 sieve) to 3 percent. Important elements for subbase placement include the following.

a. Start placement along the centerline or high point to maintain drainage during construction.

b. Perform placement using automated equipment or a stone box on a bulldozer.

c. Develop moisture density relationships in the laboratory using the modified Proctor test (ASTM D1557/CRD-C 162) for aircraft/vehicle traffic greater than 27,215 kg (60,000 lb) in weight. Use the standard Proctor test (ASTM D698/CRD-C 653) for lighter aircraft/vehicles. Moisture control is critical to achieving compaction. It is the best practice to keep material within 1 percent of the optimum moisture. For free-draining subbase materials, consider a lower moisture content to avoid adding excess water to the subgrade during compaction of the subbase.

d. Layer thickness must be three to four times the largest aggregate size. A layer thickness close to the largest aggregate size adversely affects density, grading, and smoothness.

e. Prior to subbase placement, evaluate the subgrade for stability. Repair any soft areas.

f. Implement traffic management in front of placement to eliminate potential problems.

g. Nuclear gauges are permitted to monitor subbase density.

h. Verify density values using one-point tests at the delivered moisture content. Perform one-point tests twice a day.

i. The grade tolerance for subbase is 13 mm (0.5 in.) using a 4.8-m (16 ft) straightedge.

- Laser auto-graders or auto-trimmers are recommended on larger projects.
- For projects where automated equipment cannot be justified, it may be necessary to relax the surface tolerances.

j. Once the subbase layer is placed, protect the surface.

- Provide drainage so water does not pond on the surface.
- If dry conditions prevail, watering may be necessary.

k. Rolling can be accomplished with vibratory drum rollers. If compaction is difficult, use rubber tire rollers, as the kneading action of wheels aids in compaction.

5-4 BASE COURSE.

A good base course is important to avoid or minimize construction difficulties. Base course materials are similar to subbase materials, but are usually of higher quality in terms of crushed aggregate content, deleterious material, and gradation. The requirements for bases under rigid concrete pavement are less restrictive than for flexible pavements. Therefore, the designer must select the correct requirements and guide specifications for concrete pavements. The requirements for proof rolling of the completed base course are given in UFC 3-260-02. The critical elements for placement of a base course are the same as those described for subbase materials. In addition, consider the following items.

a. Check the underlying course (subgrade or subbase) before placing and spreading the base course. Correct and compact any ruts and soft or yielding areas (due to improper drainage conditions, hauling, or any other cause) to the required density before placing the base.

b. Do not place the base if the underlying course is wet, muddy, or frozen.

c. Suspend work on the base course during freezing temperatures or if the base material contains frozen material.

d. Use vibratory rollers, rubber tire rollers, and static wheel rollers for compaction of base material. With some material, the vibratory roller may be used alone to obtain compaction and a smooth, even surface.

e. Grade tolerance for base layers is 10 mm (3/8 in.) across a 4.8 m (16 ft) distance. Automated placement methods are usually required to attain the tight tolerances.

5-5 CHEMICALLY STABILIZED BASE COURSES.

DoD does not require stabilized base courses under concrete pavements. The need for stabilization is determined on a project-by-project basis. There are several types of stabilized bases. Cement stabilization is the most commonly used stabilizer, although asphalt cement, lime, or other materials are also used. The properties and qualities of a cement stabilized material depend upon the amount of cement added. The strength and stiffness of the stabilized layer will increase with increasing amounts of cement. The stiffness of stabilized base layers has an impact on the performance of concrete pavements. They affect the curling/warping behavior of a slab and they increase the restraint on the slab during the initial curing period. With higher amounts of cement, the stiffness of a lean concrete base can be extremely high. The result is an increased potential for random cracking, reflective cracking, or cracking due to unsupported edges of the pavement slabs. However, a well-designed and -constructed stabilized base increases the fatigue life and improves the constructability of a concrete pavement. Details are available in UFC 3-250-11.

5-5.1 Material Cautions.

Lean porous concretes such as cement treated base (CTB) courses are more susceptible to sulfate attack than pavement concretes. During the design phase of the project, consider investigating possible detrimental effects on the CTB caused by sulfates present in the soil, groundwater, or aggregates. Cover a CTB layer with the pavement layer before winter or a freezing event. If a CTB layer must remain exposed, it must first attain its design strength. Before construction resumes in the spring, check the grade.

5-5.2 Strength.

The primary issue with lean concrete is the strength of the mixture. If the compressive strength is greater than 10 MPa (1,500 psi), the flexural strength is greater than 2.5 MPa (350 psi), or the amount of material passing the 0.075 mm (No. 200) sieve is 15 percent or less, the material is a lean concrete rather than stabilized material. Restrict traffic on lean concrete until attaining a compressive strength of 2,400 kPa (350 psi).

5-5.3 Reflective Cracking.

As the maximum compressive strength achieved in the lean concrete increases, the potential for cracking, and therefore reflective cracking, increases. One method to counteract cracking is to design joints in the layer. The design of the jointing pattern in the lean concrete must match the joint pattern of the pavement or reflective cracking may occur. Take care to align the joints when placing the concrete pavement. Another method of preventing reflective cracking is by applying a double application of wax-based curing compound to the surface of the lean concrete. The double application reduces the potential for bonding between the lean concrete and the pavement and minimizes the potential for random cracking in the pavement.

5-6 DRAINAGE LAYERS.

By default, rigid pavement designs incorporate a drainage layer unless the existing subgrade is highly permeable. Normally, place the concrete pavement directly on the drainage layer. Drainage layers may be open-graded materials, either unstabilized or stabilized, with subgrade or asphalt cement, open-graded with a finer choke stone surface, or a rapid-graining material that limits fines but includes some sand-sized fraction to provide better stability under traffic. Construction on unstabilized open-graded materials may require special equipment and operations. Consequently, requirements for drainage layers must be clear in the project plans and specifications so the contractor can prepare a realistic bid. The common practice is to use cement or asphalt stabilized drainage layers. Match the porosity of the drainage layer to the anticipated needs for the quick evacuation of water. The design balances the need for stability against the need for porosity, with stability taking precedence. Drainage layers can increase restraint forces, resulting in early cracking. The use of unstabilized open-graded aggregate drainage layer is not recommended for pavements used by wide-body aircraft. These layers do not provide the necessary stability and construction-related problems (rutting due to construction traffic) are common. If an unstabilized open graded layer is necessary, place it deeper in the pavement structure to reduce stresses on the layer. The thickness of the drainage layer is typically 100 to 150 mm (4 to 6 in.) in thickness with no individual layer less than 75 mm (3 in.) in thickness.

5-7 CONSTRUCTION ISSUES.

Stabilized bases provide rigid paving platforms and uniform pavement support. However, they also have the potential to increase slab warping, curling, and frictional restraint forces on the concrete slab. This shortens the window of joint sawing opportunity and increases the potential for random cracking in the pavement. The designer must consider these issues in the joint layout and construction specifications of a concrete pavement on top of a stabilized base course. For cement stabilized materials, an application of a double coat of wax-based curing membrane or a geotextile will reduce restraint. If the surface is trimmed after curing, apply another coat of curing membrane. As the strength of a cement stabilized layer is increased, reduce the joint spacing of the pavement and saw cut joints as soon as possible.

5-8 TROUBLESHOOTING GUIDE.

Table 5-1 provides a list of various stabilized base problems, the probable causes, and suggested corrective actions.

Table 5-1 Troubleshooting Guide for Stabilized Base Courses

Problem	Probable Cause	Corrective Action
Granular base and subbase: surface appears loose	• Low density • Layer (lift) too thick for compaction • Insufficient rolling	• Check moisture content and density. • Re-condition to optimum moisture and re-compact area.
Granular base and subbase: depressions or excessive movement under roller	• High moisture content • Weak layer under base or subbase	• Check moisture content and re-condition to optimum moisture if high. • Probe grade with DCP to find weak layer. Stabilize area.
Bird baths on finished grade	• Improper grade control	• Perform grade survey and correct deficient areas

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CHAPTER 6 CONCRETE PAVING PREPARATION

6-1 INTRODUCTION.

This chapter discusses pre-paving construction items, including grade control and acceptance, concrete plant operation inspection, and paving equipment inspection. Addressing these items early on may help avoid problems associated with concrete quality, pavement thickness, and concrete placement and finishing operations. The following critical elements should be in place before production paving starts.

- Check all equipment in the paving train to assure it is operational.
- Verify that an acceptable length of grade is available for concrete paving.
- Check that approved test reports are available for all materials in storage at the job site and the plant site.
- Verify that backup testing equipment is available. Develop extra equipment backup plans.
- Verify that all necessary concrete placement tools are available, such as hand tools, straight edges, hand floats, edgers, and hand vibrators.
- Verify that extra vibrators and joint-sawing equipment are available in case the original equipment breaks down during construction.
- Verify that radio/telephone communication with the plant is operational.
- Verify that equipment is available to water the grade, if necessary.
- Monitor the string line regularly and re-tension as necessary.
- Verify that the day’s work header is in place (needed or just saw off excess).
- Develop an extreme weather management plan.
- Check the weather forecast for each day of paving.
- Make sure a sufficient length of plastic covering is available in case of sudden and unexpected rain.
- Verify positive drainage within the plant site.

6-2 GRADE ACCEPTANCE.

The grade is accepted after the base layer is placed, trimmed, leveled, and compacted. Proper base grade ensures that nominal pavement thickness is achieved and final profiles and elevations are consistent with contract documents. The following are grade issues to check.

a. Check elevation tolerances for each pavement layer. Elevations and tolerances are shown on plans for the compacted subgrade, stabilized and non-stabilized layers, and top of pavement.

b. Consider the following items prior to paving:

- Effect of grade on as-placed concrete volume; materials cost impact if final grade is low.
- Effect of grade on pavement thickness variability. If final grade is variable, it will affect thickness determined through core sampling. Minimize concrete thickness variability as it may affect payment for thickness.
- Remove loose debris on the base before paving.

c. Proper base grade control is critical, as it affects drainage during construction and the service life of the pavement.

6-3 CONCRETE PLANT OPERATION.

Concrete is a manufactured product, whose quality and uniformity are sensitive to quality control variation during manufacture. A plant must be in good condition, operate reliably, and produce acceptable concrete uniformly from batch to batch.

6-3.1 Quality and Uniformity.

Concrete quality and uniformity are greatly affected by aggregate segregation and varying moisture content of the aggregates. Batch plants and equipment must meet ASTM C94/CRD-C 31. Key items listed in ASTM C94/CRD-C 31 for batch plants are as follows.

- Separate aggregate bins for each size coarse aggregate with a capability of shutting off material with precision.
- Controls to monitor aggregate quantities during hopper charging.
- Scales accurate to ± 0.2 percent tested within each quarter of the total scale capacity. Adequate standard test weights for checking scale accuracy should be available.
- Cement and water added to an accuracy of ± 1 percent of the required total mass.
- Aggregate added to an accuracy of ± 2 percent of the required total mass.
- Admixture added to an accuracy of ± 3 percent of the required total mass.

6-3.2 Pre-production Inspection.

The engineer should inspect the concrete plant before the start of paving using the National Ready Mixed Concrete Association (NRMCA) checklist in *Certification of Ready Mixed Concrete Production Facilities*. Inspect plants before the start (or re-start) of each paving project and when uniformity or strength problems are encountered during production. The concrete plant inspection should include the following:

- Check foundations of stockpiles for proper separation and adequate drainage.
- Check bins for adequate partitions to prevent intermingling of aggregates.

- Check scales with test weights throughout range to be used.
- Check scales for seals by approved agency.
- Check water meter for accuracy.
- Check for leakage of lines.
- Check capacity of boilers and chillers if their use is anticipated.
- Check admixture dispensers for accuracy.
- Check mixers for hardened concrete around blades.
- Inspect concrete hauling units for cleanliness.
- Check to ensure all concrete-making materials have been certified and approved for use.
- Observe stockpiling operations; verify that segregation and contamination will not occur.
- Observe charging of the bins; verify that segregation and contamination will not occur
- Review aggregate moisture tests.
- Observe batching operations at start and periodically during production.
- Check scales for zeroing.
- Check to ensure proper batch weights are set on the scales

6-3.3 Traffic Flow.

Optimize the traffic flow at the plant. Consider the following:

- Delivery of raw materials.
- Delivery of concrete to the paver.
- CQC/QA-related traffic operations and testing personnel safety.
- Operation of equipment for managing the aggregate stockpiles.
- Plant safety requirements.

6-3.4 Managing the Aggregate Stockpile.

Develop and implement stockpile management procedures. Procedures must address construction of stockpile storage pads, keeping loader buckets off the floor, truck unloading, maximum stockpile heights, bin charging, quality control sampling, water sprinkling, aggregate washing, and aggregate moistures. The following are key items related to aggregate stockpile management.

a. Handle and store aggregates in a way that minimizes segregation and degradation and prevents contamination by deleterious substances.

b. Closely monitor and maintain aggregate stockpiles to keep moisture content at or above saturated surface dry condition. This is particularly important for absorptive aggregates used during hot weather.

c. If aggregate moisture varies throughout the day, increase the frequency for determining moisture content. Moisture content variability increases when loaders retrieve aggregates from one area of the stockpile or if water-sprinkling of stockpiles is not uniform.

d. The water added at the mixer must be adjusted for the moisture of the aggregate. In hot weather, use of chilled water may be considered.

e. Limit the aggregate drop height when building up a stockpile. Build stockpiles up in layers of uniform thickness. When removing aggregate from a pile (with a front-end loader), remove the material vertically from bottom to top so that each load contains a portion of each layer.

f. Stockpiles should be separated from one another. If there is not enough space between them to keep size fractions separate, use a wall.

g. Bulldozers should not be allowed on stockpiles because they break down the aggregate and segregate the particle sizes.

h. Proper stockpile management reduces the likelihood of aggregate contamination. Contamination generally occurs when clay and mud are tracked with trucks unloading aggregates. Aggregate contamination can also occur if aggregates are not unloaded onto belt placers but stockpiled by end loaders. Stabilize haul roads and dump area to minimize aggregate contamination from trucks. Aggregate contamination may also occur if loaders charging aggregate bins scrape the bottom of the pile.

i. Visually examine stockpiles for segregation. If apparent, perform gradation testing from representative areas of the stockpile to verify segregation. Reject segregated material.

6-3.5 Concrete Uniformity Testing.

Conduct concrete uniformity testing before the start of paving. Uniformity testing establishes minimum mixing times. Truck mixers must meet ASTM C94/CRD-C 31. Uniformity tests compare differences in concrete sampled at approximately 15 percent and 85 percent drum discharge. Differences between concrete discharged at 15 percent and 85 percent should be less than the maximum allowable differences stated in ASTM C94 for five of six tests. Test batch (stationary) plants in accordance with CRD-C 55. This test method differs from ASTM C94 in that it requires three samples from an individual batch. Minimum mixing times for production are established by the concrete uniformity tests. The six tests required for each method are:

1. Density (unit weight)
2. Air content
3. Slump

4. Coarse aggregate content
5. Air-free mortar unit weight
6. Seven-day concrete compressive strength

6-4 PAVING EQUIPMENT ISSUES.

Check the paving equipment for the following:

a. Check availability of required pieces of equipment. For example, the number of trucks hauling concrete will affect slipform production rates. In the event of mechanical breakdown, extra equipment (such as concrete saws) should be onsite.

b. Ensure equipment is in proper working order. The equipment requiring inspection include concrete haulers, concrete placers, concrete spreaders, slipform pavers, curing/texture rigs, and sawcutting equipment.

c. Inspect slipform pavers to ensure they achieve proper consolidation through vibration. Check vibrator frequency and amplitude prior to paving. Spud vibrators under no load must have a frequency of no less than 135 Hz (8000 vibrations per minute) and an amplitude of 0.75 mm (0.03 in.), as determined in CRD-C 521. Tube vibrators under no load must have a frequency of no less than 80 Hz (5000 vibrations per minute) and an amplitude of 0.75 mm (0.03 in.). Establish vibrator elevations that do not interfere with pre-placed dowel baskets.

d. Check curing application equipment to ensure a uniform and proper application of curing compound.

e. Blades for joint sawing must be suitable for the aggregate type used in the mix.

6-5 STRINGLINE ISSUES.

The accuracy of the elevations and offset distances for grade reference points is important to the final smoothness of the pavement surface. These elevations and offsets provide the basis for establishing the stringline. The stringline provides an accurate reference for elevation and alignment control of the grade trimming, subbase/base placement, and concrete paving train. The final product reflects any error in the stringline. Setting up the stringline takes careful planning. The interval between stakes is important, particularly on vertical curves. On tangent sections, a maximum staking interval of 7.6 m (25 ft) will usually result in a good product. A tighter interval is necessary to produce smooth pavements on vertical curves and is based on the rate of change of curvature.

6-5.1 Stringline Aids.

The following aid in establishing a proper stringline:

- Use rigid stakes

- Use quality line
- Avoid knots and splices
- Prevent perceptible sagging
- Eyeball for staking errors and irregularities
- Monitor, protect, and maintain line
- Adjust stake spacing to fit conditions

6-5.2 Stringline Type.

Stringline materials and their properties and behaviors are listed:

- Braided nylon (polyester, Kevlar, polyethylene) line
    - Typically, 3 mm (1/8 in.) diameter braided string
    - Lightweight, but good pull strength
    - Does not crimp like wire
    - Does not result in hand injury (cuts)
    - Develops a sag
    - Has a stretch over time
    - Requires frequent monitoring
- Aircraft cable
    - Typically, 2.5 mm (3/32 in.) galvanized cable
    - Splicing not as simple as nylon string
    - Less sag
    - Less affected by weather (humidity)
    - Less stretching over time

CHAPTER 7 CONCRETE MIXTURE

7-1 INTRODUCTION.

Concrete mixture design considerations are discussed in this chapter. The quality of concrete is usually defined in terms of workability, strength, and durability. Strength requirements are often mistakenly emphasized above quality requirements because concrete strength is an important component of the pay schedule. It is preferable to optimize all three aspects of concrete quality. Specific information on concrete mixture design is in TSPWG M 3-250-04.97-05, *Proportioning Concrete Mixtures with Graded Aggregates for Rigid Airfield Pavements*.

7-2 CONCRETE HIGHLIGHTS. `

Concrete is a two-component mixture: aggregates and paste. In this mixture, the aggregate particles are completely coated with the paste. The paste consists of cementitious materials and water and incorporates entrapped air or purposely entrained air. Aggregates make up about 60 percent to 75 percent of the total volume of concrete. The quality of the concrete depends on the quality of the aggregates and paste and the bond between the two. The quality of the paste is significantly influenced by the amount of water used. Typically, less water improves the quality of the concrete. A maximum w/cm ratio is typically specified to avoid excess water and ensure good quality paste is achieved. Cleanliness of the aggregates also influences paste/aggregate bond and the quality of the concrete. The properties of freshly mixed (plastic) concrete are changed by adding chemical admixtures to the concrete, usually in liquid form, during batching. Chemical admixtures are commonly used to improve or control the following attributes:

- Workability
- Entrained air
- Water demand
- Setting time
- Other properties

7-3 CONCRETE MIXTURE REQUIREMENTS.

A 90-day flexural strength is specified for airfield and heavy-duty pavement design purposes. However, this can be reduced to 28 days if required and approved by the Service-specific TSPDWG representative. A 28-day flexural strength may be specified for roads. Compressive strength testing can be used for field acceptance of strength provided correlations between compression and flexural tests have been developed. Project-specific correlations are developed during the concrete mix design phase. Seven-day compressive strength testing is performed for QC and 14-day testing is performed for QA. Requirements are established for aggregates (coarse and fine), cementitious materials, admixtures, concrete mixture design, and concrete acceptance. The following are a few of the required attributes for concrete used for airfield and heavy-duty pavement:

- Maximum design flexural strength cannot exceed 650 psi (4.5 MPa) at 90 days. Actual field measured strength may be higher.
- Minimum cement content of 280 kg/m^3 (470 lb/yd^3) and 310 kg/m^3 (517 lb/yd^3), if pozzolan is used.
- Maximum w/cm ratio of 0.45. For severe sulfate exposure areas, the practice is to limit the w/cm ratio to 0.40.
- Maximum slump for fixed-form concrete is 50 mm (2 in.). Adjust slump for slipform concrete as needed to meet tolerances for smoothness, joint face deformation, and edge slump.
- Air content is based on exposure condition and the maximum aggregate size.
- Fine aggregate fineness modulus between 2.5 and 3.4.

7-4 LABORATORY MIXTURE DESIGN PROCESS.

The following is a discussion of the procedure for proportioning concrete mixtures adapted from the Portland Cement Association (PCA) mixture design procedure.

a. Obtain required information (for example gradation, absorption, specific gravity) for the materials to be used.

b. Identify project requirements for maximum w/cm ratio, nominal air content, slump, sulfate resistance, and strength.

c. Choose slump. For slipform paving, it must be in the 13 to 38 mm (0.5 to 1.5 in.) range to minimize edge slump.

d. Choose maximum size of aggregate. Use the largest size of aggregate that is economically available and can be placed and consolidated.

e. Estimate mixing water and air content.

f. Select w/cm ratio. Determine the w/cm ratio needed to meet the requirements for strength and durability. It may need to be lower to resist sulfate attack.

g. Calculate cementitious materials content. Estimate the proportions of the various cementitious materials used according to the properties desired.

h. Estimate coarse and fine aggregate contents.

i. Adjust for aggregate moisture condition.

j. Conduct trial batches. These will determine the exact proportions of desired properties to obtain as well as the admixture dosages required. The admixture dosages may require adjustment to achieve the required air content and slump when the laboratory batch is scaled up to the sized field batch.

7-5 MIXTURE DESIGN ISSUES.

Mixture design procedures typically do not directly address concrete workability. They do, however, indirectly attempt to define workability in terms of the slump test. The slump test is not a true indicator of concrete workability, especially for slipform concrete. The contractor must recognize that in addition to designing the mixture to meet the requirements of strength, slump, and air, the mixture must be designed to ensure workability for the given mixture characteristics, the project paving equipment, and expected ambient conditions at time of paving. Mixture design requirements do not address the issue of aggregate gradation. There may be conflicting requirements related to allowable fine aggregate gradation in terms of material passing the 0.3 and 0.15 mm (No. 50 and No. 100) sieves and also with respect to the fineness modulus. The contractor must review these requirements at the time of the concrete mixture design phase. ASTM C33/CRD-C 133 provides guidance.

7-5.1 Mix Design Guides.

The following are general guidelines to use when developing a mix design.

a. Develop mixes with different w/cm ratios to establish sensitivity of flexural strength with a slight change in w/cm ratio (establish a 3-point curve).

b. Monitor slump loss during trial batching. Excessive slump loss (25 mm [1 in.] in 15 minutes) may indicate false setting or a material incompatibility problem.

c. Conduct early-age strength tests (at 3, 7, and 14 days) to evaluate potential problems for 28 days.

d. Monitor a well-insulated concrete cylinder temperature during the first 12 hours. A temperature increase of less than 10 °F (Δ5.5 °C) may indicate a retardation due to material incompatibility.

e. Concrete for hot weather placement should contain less cement and more supplementary cementitious materials, preferably Class F fly ash, calcined clay, or slag. Trial batches for hot-weather concreting also must include the use of retarders to verify the dosages and their effects on setting time.

f. Concrete for cold weather placement must contain more cement and less of the slow-reacting supplementary cementitious materials (Class F fly ash, slag). If these materials are required for other purposes, such as control of ASR, the early strength can be obtained by increasing the total cementitious materials content using Type III cement, using warm water, or reducing the w/cm ratio. Trial batches for cold-weather placement must include accelerating admixtures to verify the dosages and their effects on setting time.

g. Trial batches must be tested for the range of temperatures anticipated over the project duration.

7-6 CONCRETE MIXTURE DESIGN ISSUES.

The best concrete mixture design results in a concrete with the following characteristics:

- Easily mixed, placed, consolidated, and finished under the job conditions.
- Attains the required compressive or flexural strength at the desired time.
- Will be durable in the service environment. The durability concerns often outweigh the limitations imposed by the strength requirements.

7-6.1 Workability.

Workability is an essential characteristic of concrete. Workability is the ease of placing, consolidating, and finishing freshly placed concrete without segregation. Workability is also typically and erroneously specified in terms of slump measurement. However, because of the many factors that affect today's concrete, slump is not considered an adequate measure of workability and the contractor should not rely on the slump measurement alone to assess the workability of the project concrete.

7-6.1.1 Factors Affecting Workability.

The concrete mix design process should not focus solely on meeting the strength and slump requirements; achieving acceptable workability is equally critical. Workability-related factors include the following:

- Segregation during transport and placement
- Ease of consolidation that will result in a well-distributed concrete matrix
- Well-formed slipformed edges with little or no edge slump
- Minimum hand-finishing required behind the paver to manipulate the surface for tightness and smoothness

7-6.1.2 Mixture Components Affecting Workability.

Obtaining the desirable workability for a given mix requires consideration of the following items:

- Aggregate: size, grading, particle shape, water demand, variability
- Cement: cement content, water demand
- Fly ash (if used): effect on initial set, water demand, effect on finishing
- Slag cements and GGBF slag: effect on finishing and saw cutting
- Water: total water demand
- Admixtures: air-entrained concrete exhibits better workability; water reducers reduce water demand while improving workability

7-6.2 Strength.

The pavement designer establishes the strength requirement for the concrete that meets the intent of the design. The strength requirement may be in terms of flexural strength or compressive strength at ages of 14, 28, or 90 days. The standard deviation for the strength needs to be established to provide guidance on the target strength levels to be achieved during the mixture design phase. The concrete also needs to be produced uniformly from batch to batch to keep the lot standard deviation as small as possible. A higher standard deviation for a lot may result in a reduction in the strength-related pay factor. Mixture designs must also be developed for hand-placed (fixed-form) areas. These mixtures have workability requirements different from mechanically placed mixes. However, the strength and durability requirements must be the same as the production concrete.

7-6.2.1 Weather Conditions.

For hot or cold weather placements, the heat of hydration is a concern. Trial batches must verify that the proposed mixes will achieve the desired strengths for cold weather placements and not generate excessive heat in hot-weather placements. Refer to paragraphs 8-16 and 8-17, respectively, for details on the specific concerns that must be addressed for hot and cold weather job conditions.

7-6.2.2 Fast Track Concrete.

The following list contains considerations and requirements for placement and use of fast-track concrete.

a. Although fast track paving does not necessarily mean high early-strength concrete, there are many situations when fast track concrete or high early-strength concrete may be specified or is necessary.

b. Fast track concrete is best suited for bridging the areas incorporating cross taxiways or high traffic volume apron areas.

c. The production of high early-strength concrete can be achieved using normal locally available concrete-making ingredients and conventional construction methods.

d. Typically, a conventional high early-strength concrete mix incorporates higher cement factor, optimized w/cm ratio, uniform aggregate gradation, and admixtures as needed. A Type III cement may also be considered.

e. There are no specific or unique mix designs for achieving high early-strength concrete. A wide range of mixes can be designed to meet project needs.

f. High early-strength concrete can be produced using proprietary cements and admixtures.

g. When high early-strength concrete is specified, the early age strength requirement is typically defined in terms of compressive strength, as follows:

- About 5 to 7 MPa (750 to 1,000 psi) in about four to six hours.
- About 14 to 21 MPa (2,000 to 3,000 psi) in about 24 hours.

h. There may still be a requirement to meet a specified flexural strength at 14, 28, or 90 days.

7-6.3 Sulfate Resistance.

The potential for severe sulfate attack exists when concrete is exposed to water-soluble sulfate (SO_4) in soil or water (as determined by CRD-C 403 and ASTM D516/CRD-C 408) in excess of 0.20 percent or 1,500 parts per million. The potential for moderate sulfate attack exists for sulfate contents in excess of 0.10 percent or 150 parts per million. If the soils or groundwater contain sulfates, the cementitious material(s) must be appropriately resistant to sulfate attack and the w/cm ratio needs to be reduced appropriately. Also, as previously discussed, use of pozzolans or slags should be considered. For sulfate resistance, the main consideration is the tricalcium aluminate (C_3A) content of the cement. A supplementary cementitious material with high CaO and aluminum oxide (Al_2O_3) contents, however, may effectively add to the C_3A content of the system, making it more vulnerable to sulfate attack. For DoD construction, test for durability per ASTM C88. The maximum limit of sulfate soundness loss is 12 percent after five cycles, or for magnesium sulfate, 18 percent after five cycles

7-6.4 Air Entrainment.

Concrete subject to freezing must contain a well-distributed system of finely divided air voids to protect it from frost damage. While the specifications typically provide a required volume of air as measured by ASTM C231/CRD-C 41 (pressure method) or ASTM C173/CRD-C 8 (volumetric method), these methods do not distinguish between a good air void system and a poor one. Consider the following items.

a. Produce trial batches to determine the correct dosage of the admixture for the conditions, including temperature, expected on the job site.

b. Typical air content requirements for pavements range from 5 percent to 7 percent, depending on exposure.

c. The volume of air required for frost protection increases with decreasing aggregate size because of the corresponding increase in paste content.

d. All other factors being equal, an increase in air content results in a decrease in concrete strength.

e. Test the air-void system parameters on the hardened concrete according to ASTM C457/CRD-C 42.

- An air-void spacing factor of 0.20 mm (0.008 in.) or less is necessary
- For concretes containing supplementary cementitious materials, an air void spacing factor of 0.15 mm (0.006 in.) or less is necessary.

f. Allow the trial batch concrete to sit for a length of time representative of the haul time and then measure at the end of that period to ensure that testing accounts for loss of air. When concrete is delivered to the site in non-agitating trucks, the loss of air can range from 1 to 2 percentage points.

g. In a no-freeze environment, if air is entrained solely to facilitate workability, the minimum air contents required for frost damage protection do not apply.

h. Typical slipform paving operations reduce air content by 1 to 2 percent during consolidation.

7-7 BLENDED CEMENT/SUPPLEMENTARY CEMENTITIOUS MATERIAL.

The judicious use of supplementary cementitious materials, either as components of blended cements or added at the mixer, can greatly enhance the properties of the concrete. Key issues related to the use of cementitious materials and blended cements are summarized below.

a. Class C fly ash is not permitted for paving concrete.

b. Slags contain sufficient calcium to have some cementitious properties of their own. The potential for early stiffening in the presence of certain water reducers and in hot weather can be verified as follows:

- Test the concrete by making trial batches at the highest temperature anticipated.
- Verify that slump loss is not rapid for the conditions of the job and that setting times are acceptable.
- If the concrete loses slump rapidly, consider reducing the dosage of fly ash, using a different fly ash, using a different cement, or using a different water reducer.

c. Class F fly ash and natural pozzolans react with water and calcium hydroxide from the hydration of subgrade cement to form calcium silicate hydrate.

d. The reactivity of the cementitious materials and the rate of strength gain of concrete containing them can vary significantly, depending on their chemical and mineralogical composition and on their firmness.

e. Purely pozzolanic Class F fly ash and natural pozzolans tend to produce a lower heat of hydration and lower strengths at early ages than subgrade cement.

f. Slag generally lowers the heat of hydration and the early-age strength.

g. Most supplementary cementitious materials increase the strengths at later ages.

h. Appropriate supplementary cementitious materials, appropriately used, can provide the following benefits:

- Reduce the tendency for thermal cracking by reducing the heat of hydration.
- Increase the strength (particularly at later ages).
- Reduce concrete permeability and diffusivity.
- Control expansions due to ASR and increase resistance to sulfate attack.

i. For a particular application, some supplementary cementitious materials are better than others, and some may be completely inappropriate.

j. Natural pozzolans can provide excellent performance, somewhat like Class F fly ashes.

k. If the aggregate selected is susceptible to ASR, consider incorporating a Class F fly ash to control it. The CaO content of the Class F fly ash should be less than 8 percent. Test the combination of aggregate, cement, and fly ash to determine the quantity of fly ash required.

l. Class F fly ash is considered to the most effective supplementary cementitious material for control of heat of hydration, control of ASR, and resistance to sulfate attack.

m. Some supplementary cementitious materials make things worse. Therefore, test each combination of cementitious materials, aggregates, and admixture.

n. Blended cements containing Class F fly ash, slag, calcined clay, or silica fume may also be used for control of heat of hydration, control of ASR, and resistance to sulfate attack.

o. If the available blended cement does not meet the requirements for control of ASR or sulfate resistance, incorporate additional supplementary cementitious material of the same or different kind at the mixer as necessary.

p. Ternary mixtures that contain three cementitious materials may offer the best alternative in some applications. For example, a Type IS cement may not be sufficient on its own for the required sulfate resistance, but the addition of either slag or Class F fly ash at the mixer can improve its performance.

7-8 MATERIALS INCOMPATIBILITY.

Some concretes exhibit undesirable characteristics because of incompatibility among different concrete materials. These undesirable characteristics include: (a) early loss of workability (early stiffening), (b) delayed set (retardation), (c) early-age cracking due to excessive autogenous and drying shrinkage of concrete, and (d) lack of proper air-void system. These incompatibility-related problems affect construction productivity and long-term concrete performance. As concrete mixtures become more complex with the use of supplementary cementitious materials and combinations of chemical admixtures, the likelihood of incompatibility among components increases. The problem is compounded because:

- Factors that result in incompatibility among various cementitious materials and admixtures are not well known.
- Material incompatibility may be induced by temperature changes. Therefore, test trial batches at the extremes of temperature anticipated at the project site.

7-8.1 Early Stiffening.

Early stiffening occurs when there are insufficient sulfates in solution at the right time to control the hydration of the aluminates. The early stiffening leads to loss of workability, as indicated by loss of slump. Workability loss leads to difficulties in concrete placement and consolidation. The tendency to early stiffening may be attributed not only to the individual cementitious materials, but also to interactions among the various cementitious materials and the chemical admixtures and ambient temperatures.

7-8.2 Retarded Concrete.

Although retarded concrete is not a common phenomenon, from time to time some paving projects experience concrete setting problems. At these projects, setting may be delayed by a few hours to more than 12 hours. A consequence of this problem is the inability to perform joint sawing in a timely manner, leading to uncontrolled cracking.

7-8.3 Shrinkage.

Premature cracking in concrete can be caused by a host of factors. Shrinkage can occur in the fresh (plastic) or hardened concrete. Plastic shrinkage cracking results as water rapidly evaporates from the surface of the fresh concrete. Cracking may also occur somewhat later in the life of the pavement due to excessive autogenous and drying shrinkage.

7-8.4 Air Void System.

Problems related to the use of certain air-entraining agents include:

- Accumulations of air voids around the aggregate particles, leading to strength loss
- A poor-quality air void system in the hardened concrete that affects long-term freeze-thaw durability

7-8.5 Reducing Incompatibility.

It is advisable to have hot and cool weather mixture designs in locations where seasonal differences in temperature are usually significant. Other steps to minimize incompatibility problems include the following.

- All admixtures used on a project must be from the same manufacturer to ensure compatibility among them. Do not exceed the recommended dosages.
- Ensure all cementitious materials meet project specifications and the requirements of appropriate ASTM/CRD standards.

7-9 AGGREGATE REQUIREMENTS.

7-9.1 Aggregate Grading.

The grading of the aggregate can have a substantial effect on the properties of the concrete mixture. The grading of the fine aggregate fraction is also important; too little fines make the concrete difficult to extrude and finish as well as more prone to bleeding; excess fines increase the water demand of the concrete and the required dosage of air-entraining admixture.

7-9.1.1 Well-graded Aggregate.

Concrete mixtures produced with a well-graded aggregate combination tend to:

- Reduce the need for water
- Provide and maintain adequate workability
- Require minimal finishing
- Consolidate without segregation
- Enhance strength and long-term performance

7-9.1.2 Gap-graded Aggregate.

Concrete mixtures produced with a gap-graded aggregate combination tend to:

- Segregate easily
- Contain more fines
- Require more water
- Increase their susceptibility to shrinkage
- Limit long-term performance

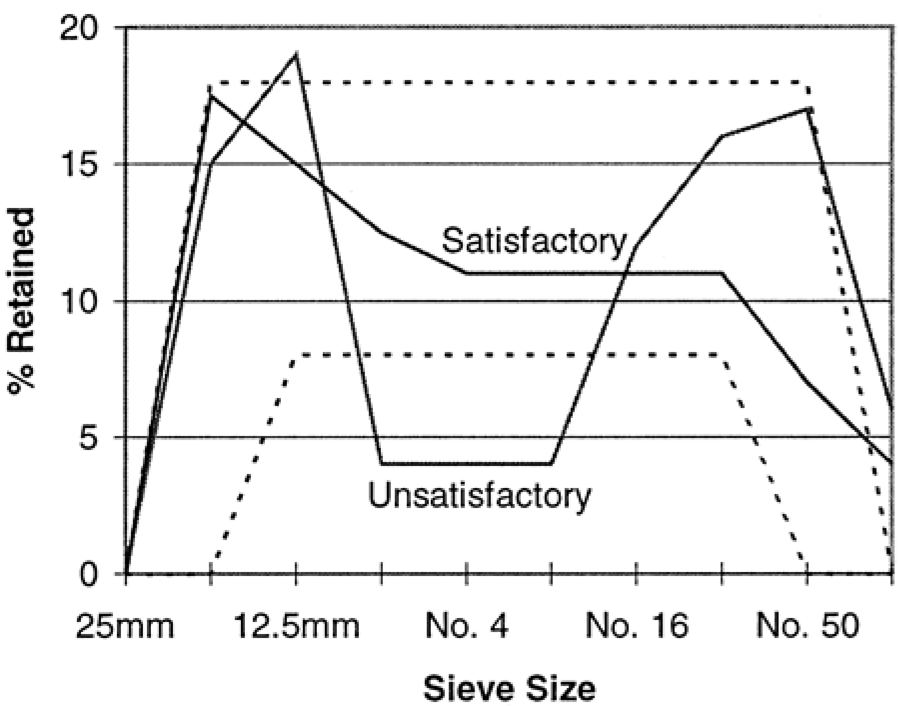
7-9.1.3 Combined Aggregate Grading.

Proportion the concrete mixture so the requirements for workability and finishability are met. Also, proportion the mixture as a well-graded combined aggregate such that the minimum requirements for air content and the water cementitious ratio are met.

7-9.1.4 Percent Combined Aggregate Retained Graph.

Grading reports should include the following sieve sizes: sieves used for the analysis include 50 mm, 37.5 mm, 25 mm, 19 mm, 12.5 mm, 9.5 mm, 4.75 mm, 2.36 mm, 1.18 mm, 0.6 mm, 0.3 mm, and 0.15 mm (2 in., 1 1/2 in., 1 in., 3/4 in., 1/2 in., 3/8 in., No. 4, No. 8, No. 16, No 30, No. 50, and No. 100, respectively). Plot the selected proportions for the combined gradation on a graph as the percentage retained for each reporting sieve size (y axis) versus the considered sieve size (x axis). The plot of the graph should be a line showing a relatively smooth transition between coarse and fine aggregate. The maximum and minimum percent retained limits, represented by the dotted lines in Figure 7 1, are a guide and the plot should not have no significant valleys or peaks between the 9.5 mm (3/8 in.) sieve size and the finest reporting sieve size. An example of the percent aggregate retained graph, including a satisfactory and unsatisfactory combined aggregate gradation plot, is shown in Figure 7-1.

Figure 7-1 Percent Combined Aggregate Retained



7-9.1.5 Coarseness Factor / Workability Factor.

Use the combined aggregate grading to calculate a coarseness factor and a workability factor. Determine the coarseness factor for a particular combined aggregate gradation by dividing the amount retained above the 9.5 mm (3/8 in.) sieve by the amount retained above the 2.36 mm (No. 8) sieve and multiplying the ratio by 100. The workability factor is the percentage of combined aggregate finer than the 2.36 mm (No. 8) sieve. Determine this factor by using the percentage passing the 2.36 mm (No. 8) sieve from the combined aggregate sieve analysis. Increase the workability factor by 2.5 percent for each 56 kg/m^3 (94 lb/yd^3) of cementitious material used in excess of the baseline amount of 335 kg/m^3 (564 lb/yd^3) of cementitious material. Only adjust the workability factor upwards, because 335 kg/m^3 (564 lb/yd^3) is the minimum amount of cementitious material permitted for rigid airfield pavement mix designs. The combined aggregate grading is used to calculate the coarseness factor and the workability factor as follows.

Equation 7-1. Coarseness Factor and Workability Factor

$$Coarseness\ Factor = 100\left(\frac{\%\ retained\ above\ 9.5\ mm\ \left(\frac{3}{8}\ in.\right)\ sieve}{\%\ retained\ above\ 2.36\ mm\ (\#8)\ sieve}\right)$$

$$Workability\ Factor = \%\ passing\ 2.36\ mm\ (\#8)\ sieve + 2.5\% *$$
$$each\ 56\frac{kg}{m3}\left(94\frac{lb}{yd3}\right) of\ cementitious\ material\ above\ 335\ kg/m^3\ \left(564\frac{lbs}{yd^3}\right)\ \ (7-9.1.5.)$$

The coarseness and workability factors are plotted on a chart similar to that shown in Figure 7-2. The coarseness factor should not be greater than 80 nor less than 30. The plot of the workability factor and the coarseness factor is a single point that is to be above the control line and within the workability box, as shown in Figure 7-2. Obtain the following information from an examination of where the aggregate mixture factors plot, as shown in Figure 7-2.

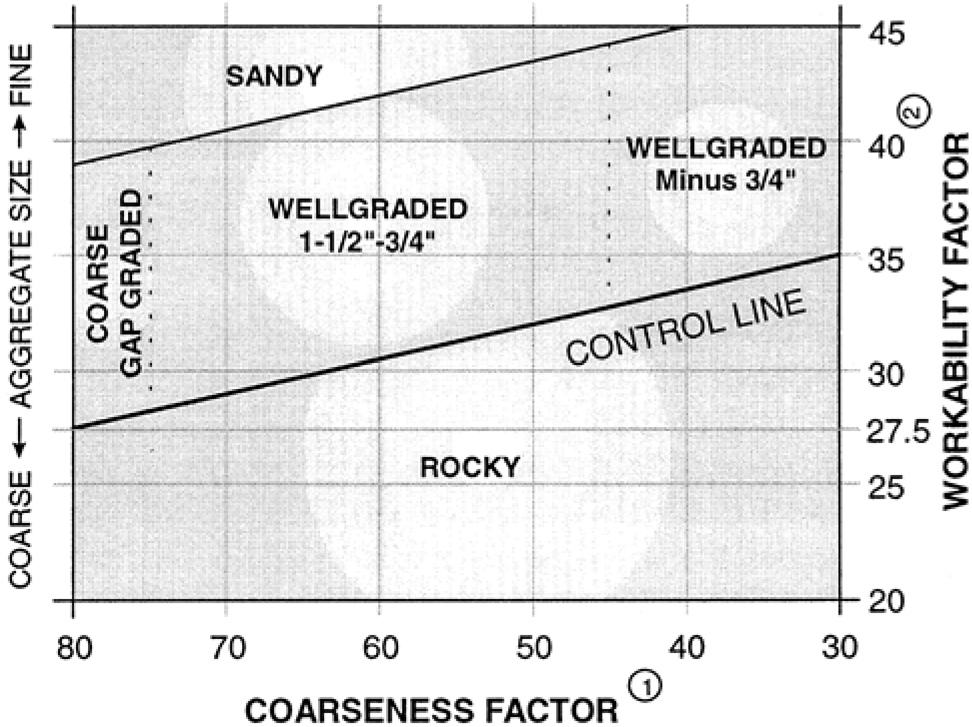
a. Aggregate blends that plot close to the bottom boundary line may tend to have too much coarse aggregate, producing rocky mixtures with inadequate mortar.

b. Aggregate blends above the top boundary line (Area D) will produce sandy mixtures with high amounts of fines requiring higher water content and potential for segregation.

c. Aggregate blends with coarseness factors higher than 75 (Area E) will produce gap-graded mixtures with inadequate workability and high potential for segregation.

d. For aggregate sizes less than 19 mm (0.75 in.), the areas will slide to the right within the given control lines.

Figure 7-2 Aggregate Proportioning Guide



7-9.1.6 Aggregate Proportioning Guide.

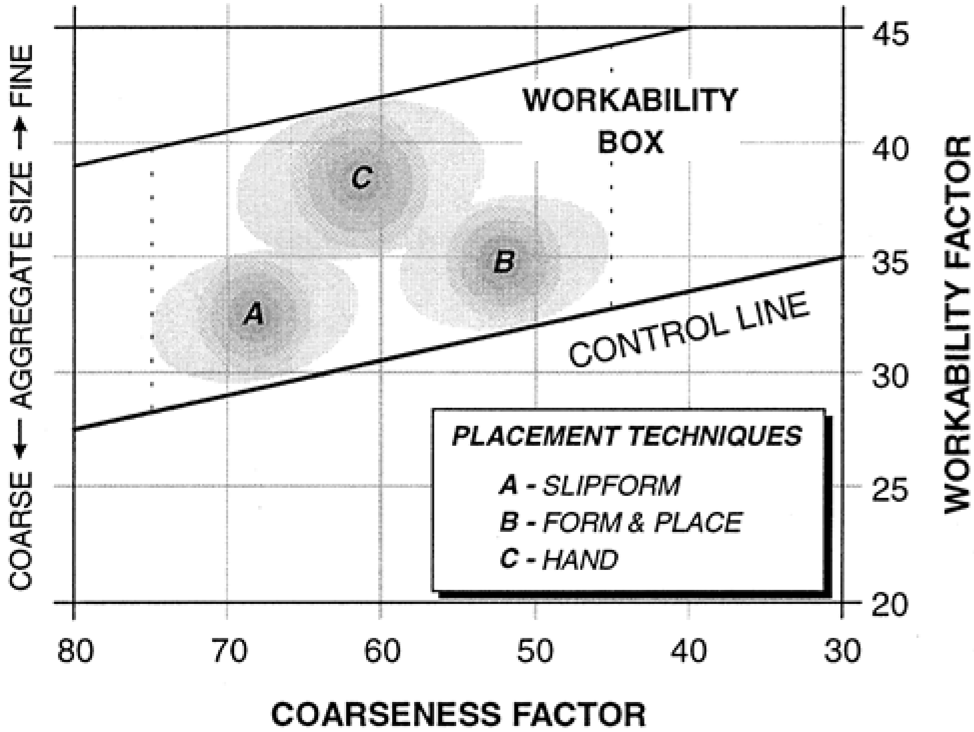
When a combined aggregate grading appears to meet the criteria of the percent retained graphic, then assess the location in the workability box that is best suited to the method of placement. Evaluate the workability factor and coarseness factor, as shown in Figure 7-3, as follows.

a. Aggregate blends that plot at the lower left of the box near the control line (Area A) produce mixtures suitable for slipform paving. However, based on texture and shape, aggregates falling in other regions of the chart can be acceptable for slipform paving.

b. Aggregate blends that fall at the lower right corner of the workability box (Area B) produce mixtures suitable for fixed form paving. This assumes that smaller aggregate sizes are needed to move the coarseness factor to a lower number and increase workability.

c. Aggregate blends that fall at the top of the box (Area C) produce mixtures suitable for hand-placed areas.

Figure 7-3 Workability Box within Aggregate Proportioning Guide



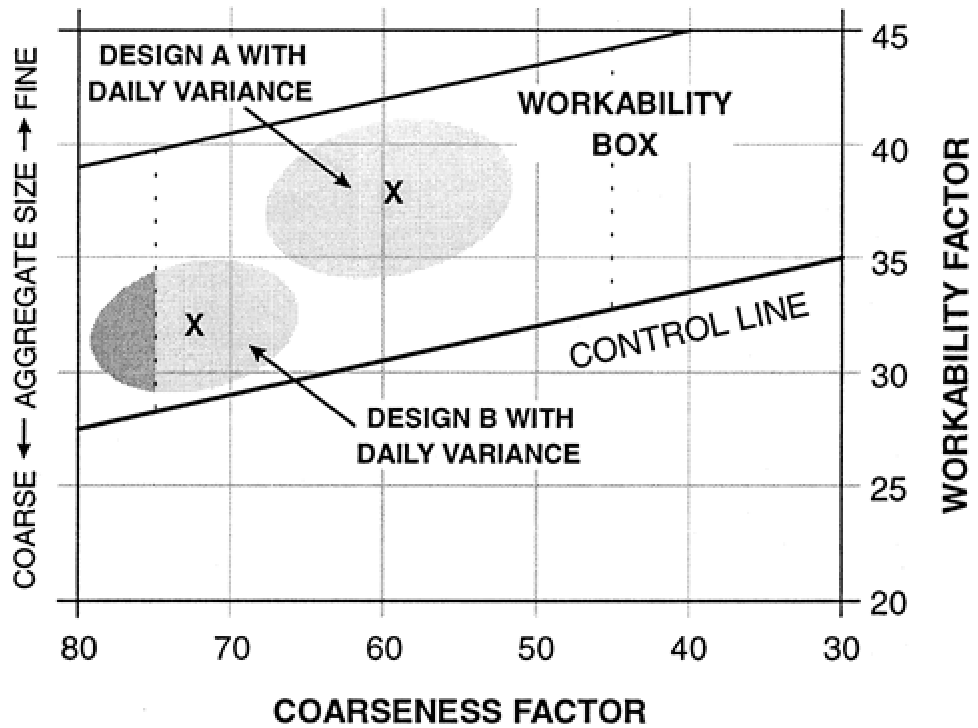
7-9.1.7 Controlling Factors.

The above criteria is not exact because the aggregate proportioning guide for grading does not take other “workability” factors into account. The shape of the fine aggregate particles will affect workability, but this is not reflected in the grading. When using the coarseness/workability chart it is assumed that particles are rounded or cubical shaped. Flat and elongated aggregates typically limit workability and finishing characteristics. Rounded or cubical shaped aggregates typically enhance workability and finishing characteristics. While the entrained air content directly affects workability, it is not considered in the aggregate proportioning guide. Chemical admixtures adjust the workability of the mixture and should not be neglected in the final selection of a concrete mixture for subgrade ability. Use the aggregate proportioning guide as a guide and not as a rule. It is necessary that the person doing the mixture proportioning be familiar with the method of placement and the characteristics of the mixture best suited to that method. In a similar fashion, the person evaluating the mixture proportioning study must balance the data presented and the results of previous paving projects. The final test, for both the contractor and the engineer, are the characteristics and the response of the mixture to the method of placement as observed at a test strip placement.

7-9.1.8 Gradation Variations.

An important consideration in selecting the final design aggregate grading, using the aggregate proportioning guide, is the location of the design grading relative to the expected daily variance of the concrete mixture materials. Changes in coarse, blend, and fine aggregate gradations could place the plot outside of the workability box, as illustrated in Figure 7-4. A normal variance of about 5 percent on the coarseness factor and about 3 percent on the workability factor should be considered in the final selection of an aggregate blend. Therefore, Design A would be a better choice than Design B, considering the daily variance.

Figure 7-4 Daily Variance within Workability Box for Aggregate Proportioning



7-9.1.9 Slag Aggregates.

Properly aged iron ore blast-furnace slag aggregates have a history of good performance. However, control of moisture content is important when slag aggregates are used. Potential problems include variations in workability and consolidation. If slag aggregate moisture is not managed well, the in-place concrete may exhibit honeycombing and poorly formed edges. **Note:** Never use slag from open hearth steel mills as concrete aggregate or for econocrete/lean concrete base because of the expansive nature of the steel slag aggregates.

7-9.1.10 Recycled Concrete Aggregates.

Recycled concrete, or crushed concrete, is a feasible source of aggregates if it meets the project-specific aggregate requirements. Recycled concrete generally has a higher absorption than virgin aggregates and may require more water to achieve the same workability and slump than concrete with virgin aggregates. Recycled aggregate may also require added cement to achieve desired workability. A potential problem with recycled aggregate is that the variability in the properties of the old concrete may affect the properties of the new concrete. Recommend evaluating recycled concrete aggregates by petrographic examination. Identify why the recycled concrete was removed. Do not incorporate problematic recycled concrete into new concrete mix. Recycled concrete cannot contain rebar.

7-10 FIELD ADJUSTMENTS OF CONCRETE MIXTURE DESIGN.

Shortages of cement or other concrete-making ingredients may occur during the construction season. If any changes in type, source, or brand of cementitious material, admixtures, or aggregate source need to be made, trial batches need to be carried out to verify the required properties are retained. Certain minor adjustments to the concrete mixture proportions may be necessary due to changes in the weather and to maintain the required workability and air content. However, if air content is increased or water is added above the design w/cm ratio, the concrete strength may decrease. Adjustments of admixture dosages are acceptable, provided the maximum dosages do not exceed the manufacturer’s maximum recommended dosage. The dosage of air-entraining admixture required to entrain a given volume of air will vary with the temperature of the concrete. If the required dosage was determined in the laboratory at 70 °F (20 °C), it can be decreased by approximately 30 percent for placement temperatures of 40 to 50 °F (4 to 10 °C) and increased by approximately 30 percent for placement temperatures of 100 to 110 °F (40 to 45 °C).

7-10.1 New Mixture Design Implementation.

If a new mixture design is developed because of changes in concrete materials, allow the contractor to proceed with paving once the early-age breaks indicate that the new mixture provides the specified strength at the specified age. It is advisable that the contractor use a higher strength mixture temporarily until all the new mixture strength results are available. Note that concrete strength is not the only criterion for the new mixture to satisfy. Required concrete characteristics include mixing, placing, consolidation, and finishing under the job site conditions. Verify setting times. If pavement construction spans more than one season, it is advisable to develop more than one mixture design.

7-10.2 Differences in Laboratory and Plant Mixing.

Note the following differences between laboratory and plant mixing.

a. Differences in the size of a batch and type of mixer produce different mixing efficiencies. It may be necessary to adjust chemical admixtures dosages to obtain the desired workability and air content.

b. Normal laboratory mixing procedures obscure any tendency of a concrete mixture to false set. A concrete mixture that behaves appropriately in the laboratory may false set when mixed in the batch plant. In the laboratory, test the slump after the initial three minutes of mixing and compare to the slump after final mixing to check the tendency to false set.

c. Temperature can significantly affect workability, water demand, slump loss, air content, and setting. Conduct laboratory mixture designs at the temperature(s) anticipated in the field.

d. Test the slump and air content every 10 to 15 minutes for a sufficient amount of time after initial mixing to simulate the longest anticipated haul time.

e. Long haul times may necessitate an initial air content higher than required at placement to compensate for the loss of air during transit.

f. Avoid mixture designs that are excessively sensitive to elevated placement temperatures, variations in aggregate moisture content, or slight variations in batching.

g. The manufacturer's maximum recommended dosage of water reducer should not be routinely required for acceptable workability in the laboratory, as there is no possibility of increasing the dosage in the field without affecting the setting time.

h. Closely monitor the concrete material properties as well as the fresh concrete properties during the early stages of a job to make quick adjustments if needed.

i. Perform 3-, 7-, and 14-day strength tests using field concrete. If results are not tracking the laboratory 3-, 7-, and 14-day results, then potential problems may exist. Stop the paving operation and redesign the concrete mixture. In this case, only a few days of concrete may potentially be of concern.

j. If plant mixture behavior differs from the laboratory mixture, causes may include:

- Ambient temperature
- Mixing time
- Material differences (laboratory materials are cleaner; different cement characteristics)
- Mixing process differences (drum vs. laboratory mixer)
- Aggregate moisture content
- Material charging differences

k. Hot (fresh from the mill) cement use during peak construction season may result in:

- Tendency to false set
- Admixture demand change; may need more in the field than in a laboratory

7-10.3 TROUBLESHOOTING GUIDE.

Observations and documentation are important tools to isolate and solve construction problems. Look for patterns that appear to connect cause and effect. For example, if everything works well until the weather becomes hot or a new shipment of cement arrives, the most recent change may be a clue to the root cause of the problem. Alternatively, if construction practices are marginal, the last change may simply tip the balance to unacceptable performance. In hot weather or cold weather, certain types of problems predominate. Paragraph 8-20 discusses common problems and possible remedies.

CHAPTER 8 CONCRETE PLACEMENT, FINISHING, TEXTURING, AND CURING

8-1 PAVING EQUIPMENT.

Paver-finishing machines accomplish concrete paving for mainline pavement and large fillets. Handwork areas are those areas too small to use a machine. Heavy and light pavers are used for machine paving. Slipform pavers are heavy machines. Only use light-weight machines, such as bridge deck finishers, clary screeds, truss screeds, or roller screeds if the contractor can show that they can produce satisfactory pavement with this type of equipment.

8-1.1 Slipform Pavers.

Slipform pavers can be used in side form applications by stretching the paver width beyond the forms. Slipform pavers can stretch to 14 or 15 m (45 to 50 ft), depending upon model and available attachments, but most are commonly used at 8 to 11 m (25 to 37.5 ft) width. Slipform pavers are usually used for airfield concrete pavement that is 200 mm (8 in.) or more in thickness. Slipform pavers provide the consolidation required for deep lift concrete pavement. Common elements of the slipform paver include:

- Self-propelled with four tracks
- Generally weigh at least 3,280 kg/m (2,200 Ib/ft) of paving lane width
- Variable-speed hydraulically controlled internal vibrators
- Ability to carry a head of concrete in front of the screed
- Continuous auger or hydraulic plow-pans to distribute concrete in front of the screed
- Finishing attachments

8-1.2 Manual Paving.

Labor-intensive manual paving is typically carried out only for small areas such as fillets.

8-1.3 Differences Between Slipform and Bridge Deck Paving Machines.

The differences between slipform and bridge deck paving machines are summarized below.

a. The bridge deck paver production capacity is significantly less than a slipform paver.

b. The bridge deck paver is most economical when paving lanes wider than 12 m (40 ft) and in geometrically constrained areas. Bridge deck pavers are capable of placing concrete up to 15 m (50 ft) wide.

c. A bridge deck paver is more mobile and maneuverable and may be used when paving constrained areas such as cross-taxiways or restricted aprons area.

d. A major difference between the pavers is the method of consolidation.

- The single vibrator of a bridge deck paver consolidates the concrete by plowing transversely across the truss.
- Combined with the forward travel of the paver, the concrete is plowed in a zigzag pattern.

e. For a constant radius of action with the vibrator, depending on forward speed, the amount of vibration energy and coarse aggregate distribution may not be as uniform as achieved using vibrators that are uniformly spaced and plowing in one direction as on slipform pavers.

- Vibrators on bridge deck pavers may have smaller offset weights that allow higher vibration frequencies than desired. Higher frequencies increase the potential for disrupting the air void system, increasing the potential for durability problems.
- Concrete mixtures are uniquely designed for fixed form paving. Slipform paver concrete mixtures do not work for fixed form paving and vice versa.

8-2 CRITICAL FACTORS FOR CONCRETE PAVING:

The following are critical factors affecting concrete paving.

- A good grade for paving; trimmed and compacted to specification
- Stringline management; monitor and maintain stringline at regular intervals
- Continuous supply of concrete to the paver
- Consistent concrete workability
- Well-maintained paving equipment
- Proper operation of paving equipment
- Controlled density of concrete; just the right level of vibration to consolidate concrete and provide enough fines at surface for a tight finish
- Most importantly, a skilled and dedicated crew

8-3 CONCRETE DELIVERY AT THE SITE.

Before and during concrete delivery, the following should be considered:

a. Inspect the grade for acceptance before depositing concrete. Remove loose debris and repair any base damage.

b. Verify string line elevations.

c. Concrete should be deposited on grade within reasonable time after the addition of mixing water. When placed, there should be time remaining for consolidation, strike-off, and finishing before initial set.

d. When pulling slipform pavers off headers, a slightly higher slump concrete should be used to facilitate hand consolidation and finishing operations.

e. Encourage the use of agitator trucks because they usually provide more uniform concrete placement and minimize concrete segregation.

f. The consistent delivery of concrete is necessary to minimize stopping and starting of the paver. If paving operations are stopped to wait for concrete from the batch plant, use additional trucks or reduce the paver speed.

8-4 CONCRETE PLACEMENT.

Acceptable concrete placement practices include the following.

a. Deposit concrete close to and uniformly in front of the paver or front spreader, taking care to minimize disturbance to the base, embedded steel, dowel bars, and side forms.

b. Place the concrete such that one side of the paving lane is not overloaded with concrete.

c. In formed areas, place the concrete as close as possible to its final position to minimize the potential for concrete segregation.

d. Concrete is either dumped on grade in front of the paver or onto belt placers and side-loading spreaders.

- If dumping on grade, control rate of dumping by controlling the tailgate opening.
- It is poor practice to spread concrete in front of a paver using an end loader.

e. The advantage of dumping directly in front of pavers or spreaders is that concrete head in front of the machine auger is easily maintained.

f. The disadvantages of directly unloading in front of the paver are the following.

- Trucks backing into the paver may disturb the compacted granular base.
- Dowel baskets must be placed just ahead of the paver. Placing dowel baskets just ahead of the paver may not allow time to verify dowel bar alignment or verify that baskets are securely fastened to the base. The safety of laborers fastening baskets in areas between the forward-moving paver and backward-moving dump trucks must be considered.
- When placing baskets just ahead of the paver, a full-time inspector may be required to check dowel bar placement and alignment.
- Stringlines may have to be broken on at least one side of the paver to allow trucks to back in and pull forward away from the paver.

g. When using a belt placer:

- Swing the belt back and forth to maintain a uniform head of concrete in front of the paver
- If the paver is low on concrete, back up placer to place more material where needed

h. When a spreader is used, do not advance more than 7.5 m (25 ft) ahead of the paver and thus allow timely adjustment if the head of concrete at the paver is too low or too high.

i. The paver operator must control the level of concrete in the grout box by raising or lowering the strike-off blade when required.

j. The following may reduce the potential for dowel bar misalignment associated with the forward-moving concrete head in front of the paver or spreader:

- Deposit small amounts of concrete carefully over pre-positioned baskets fastened to the base to minimize the weight associated with the forward-moving head of concrete in front of the paver or spreader.
- Do not dump concrete by trucks directly on basket assemblies.

8-4.1 Concrete Head.

Concrete head must be consistent and of proper height for the paver size and concrete mix. A heavier paver generally produces a smoother concrete pavement since it is less affected by surges of concrete coming into the paver.

8-4.2 Paver Speed.

a. Slow and constant speed of the paver results in smooth pavements.

b. The rate of placement (speed of the paver) should coincide with the capability of the batch plant and the rate of delivery of concrete to the paver.

c. The paver should not be stopped frequently during the paving operation.

d. Generally, the forward speed should be a minimum of 30 m (100 ft) per hour.

8-4.3 Filler Lane Placement.

If pilot lane joints are open wide at the time of filler lane placement, then mortar from the filler lane can seep into the joints and result in small comer breaks/spalls. If pilot lane joint widths are greater than 6 mm (0.25 in.), use backer rod, duct tape, or asphalt mastic to cover the joint openings. Although filler lanes may appear to be reasonably easy to place, the paving contractor must be aware of the potential for cracking within the filler lanes because of restraint from:

- Doweled longitudinal joints

- Friction from pilot lane joint faces
- Possible use of higher slump concrete (More shrinkage potential)
- Shorter window for sawing joints

8-5 EMBEDDED STEEL AND TIE-BAR PLACEMENT.

Use chairs to securely support embedded steel bars or mesh typically used in fillet areas and other odd-shaped panels. Space the chairs close enough to support the steel without sagging. Support tie bars used as embedded steel and positioned around penetrations on chairs within tolerances of the specified elevation. Welded wire fabric must be flat and meet specified elevations within tolerances after fastening to chairs. Supplementary consolidation with spud vibrators is commonly used around wire mesh; therefore, chairs must be strong enough to support the weight of laborers during concrete consolidation. Prior to concrete placement accepted by inspectors, verify the embedded steel bar diameter, length, presence of epoxy coatings, absence of breaks in epoxy, location, elevation, clearance of embedded steel (from other steel or dowel/tie bars at joints), and frequency of chairs.

8-5.1 Tie Bars.

Tie bars are not permitted on airfield pavements. Use tie bars only for road and street projects.

8-5.2 DOWEL BAR INSTALLATION.

During dowel bar installation, consider the following.

a. Dowel bars at transverse contraction joints are pre-positioned using dowel bar baskets secured to the base. Installing these dowels by dowel inserters attached to the paver or by any other means of inserting the dowels into the plastic concrete is not permitted.

b. Dowel bars at longitudinal sawed contraction joints can be pre-positioned using basket assemblies. Dowel bars at longitudinal sawed contraction joints cannot be injected using a dowel bar jammer on airfield or other heavy-duty pavement.

c. Dowel bar inserters are prohibited at longitudinal construction joints due to the high potential for misalignment and undesirable air pockets.

d. Dowel bars at longitudinal construction joints and transverse headers are installed using a drill and epoxy technique. Holes are drilled into vertical edges.

8-5.2.1 Dowel Bar Alignment.

Dowel bar alignment is a critical item and must be checked on a regular basis. Dowel misalignment has a significant effect on pavement performance. Table 8-1 lists the types of dowel bar misalignment and their impact on performance. Figure 8-1 illustrates these types of misalignments. Important dowel installation items are as follows.

8-5.2.1.1 Typical Alignment Specifications.

- 10 mm/m (1/8 in./ft) or less out of alignment in the vertical and horizontal plane
- 15 mm (5/8 in.) or less horizontal or longitudinal translation
- 13 mm (1/2 in.) or less vertical translation

8-5.2.1.2 Basket Assembly Stations.

Verify the assemblies to ensure they are centered at joint locations.

8-5.2.1.3 Dowel Bars at Longitudinal Joints.

Inspect bars to ensure the specified clearance from the ends of transverse joint dowel bars is maintained.

8-5.2.1.4 Reduce Restraint at Slab Corners.

To reduce restraint at slab corners, position dowel bars at longitudinal joints at least 150 mm (6 in.) and preferably 300 mm (12 in.) away from the ends of dowel bars in the transverse joints.

8-5.2.1.5 Dowel Baskets.

Securely fasten baskets to the base.

- Clips are generally adequate when fastening a basket to stabilized base.
- Long stakes are required to securely fasten baskets in granular and open graded bases.

8-5.2.1.6 Longitudinal Dowel Basket Wires.

Crimp wires instead of cutting. Crimping reduces cross-sectional area while maintaining basket stability.

8-5.2.1.7 Verify Dowel Bar Alignment.

Verify alignment by:

- Exposing dowels in plastic concrete
- Coring over dowel bar ends
- Using a magnetic rebar cover meter.
- Nondestructive testing such as GPR.

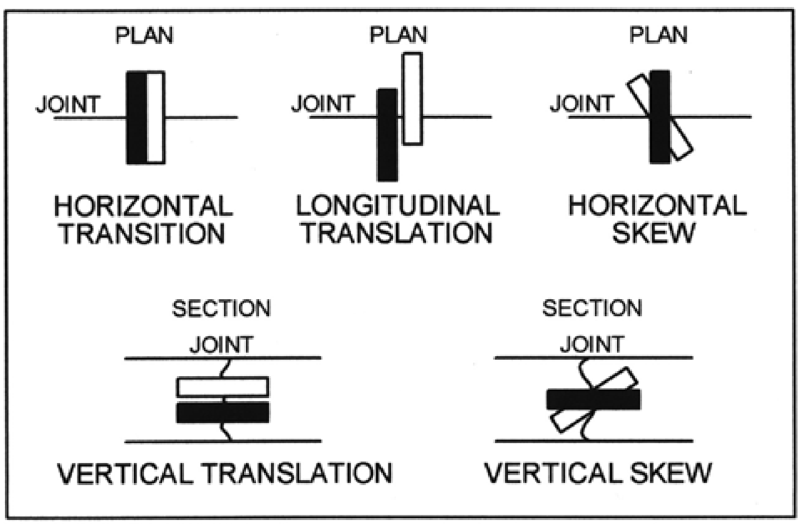
8-5.2.1.8 Prior to Paving.

Inspect dowel bars for breaks in the epoxy coating. Field kits are used to cover exposed dowel bar steel at basket welds and chips in the coating. If a light coat of form release oil or other de-bonding agent is specified, inspect the coverage before concrete placement.

Table 8-1 Types of Dowel Bar Misalignment and Impact on Performance

Type of Misalignment	Effect On		
	Spalling	Cracking	Load Transfer
Horizontal translation	---	---	Yes
Longitudinal translation	---	---	Yes
Vertical translation	Yes	---	Yes
Horizontal skew	Yes	Yes	Yes
Vertical skew	Yes	Yes	Yes

Figure 8-1 Dowel Bar Misalignment Categories



8-5.2.2 Basket Versus Inserted Dowels.

A method specification is typically used for dowel baskets.

- Positive tie-in to subbase is specified.
- Inspection of basket stability and dowel alignment is performed before concrete placement.
- Dowel placement (depth) for first few joints per day may be checked using a covermeter or GPR.

For inserted dowels, prior inspection is not possible.

- As a result, the contractor takes a risk because a check of dowel misalignment is only possible after concrete has hardened.
- The dowel placement (depth) for the first few joints of the day must be inspected using a covermeter.
- Also, there is typically not enough guidance in specifications for inspection of inserted dowels. The contractor should bring up this issue at the pre-bid meeting if the inserted dowel technique is to be used.

8-5.2.3 Dowel Bars at Construction Joints.

Install dowel bars at construction joints using the drill and epoxy grout procedure. Side injected dowel bars are prohibited on airfield pavements. Install dowel bars after the concrete has cured sufficiently to allow:

- The new pavement to support drilling equipment weight.
- Hole drilling without excessive chipping and spalling (> 12.5 mm [0.5 in.]) or beyond the diameter of the grout retention disc. Expect minor chipping.

Important items in the installation process include the following.

a. Use gang drills to simultaneously drill several holes.

b. Slightly over-size holes, about 3 to 6 mm (1/8 to 1/4 in.) larger than the dowel bar diameter.

c. Spot-check the depth of drilled holes to ensure the dowels are nominally inserted halfway into holes.

d. Inject epoxy at the back of the drilled holes and twist the dowel as it is pushed into the hole. Applying epoxy by hand to dowel bars before insertion is a prohibited technique.

e. Grout retention disks may be used to prevent epoxy from flowing out of the holes.

f. Inspect dowel bars to verify adequacy of the epoxy coverage. Proper epoxy grouting is important to ensure the dowels are bearing on a sound interface and voids do not exist. Otherwise, load transfer effectiveness is compromised.

g. Oil the exposed ends of the dowel bars before concrete placement. Do not use grease to coat the exposed ends of dowel bars.

8-6 CONCRETE CONSOLIDATION.

Proper use of internal vibrators is important to properly consolidate the concrete without adversely affecting the concrete strength and durability. Important items related to concrete consolidation are summarized below.

a. Slipform pavers consolidate concrete in the grout box using gang-mounted vibrators.

b. For larger pavers, vibrators are hydraulically driven. Electric or hydraulic vibrators may be used for small slipform pavers.

c. Inadequate consolidation results in lower concrete strength and honeycombing. Inadequate vibration can be due to:

- Poorly functioning or dead vibrator
- Paver speed too high
- A concrete mix with poor workability

d. Over-consolidation can lead to freeze-thaw durability problems if the air void system is adversely altered. Over-consolidation can be due to:

- Excessive vibrator frequency
- Reducing paver forward speed without an adjustment to vibrator frequency
- Concrete mix properties of poor workability

e. Vibrators are generally positioned no more than 100 mm (4 in.) below the finished pavement surface. Setting vibrators too low results in air being trapped under the grout box head, leading to delamination or blistering of the concrete surface.

f. Vibrators are generally positioned at an attitude of 5 to 10 degrees. As the paver moves forward, the angled vibrators plow the concrete.

g. Vibrator spacing is a function of the radius of the zone of influence. The zone of influence and vibration energy input into concrete is a function of paver speed, vibrator rotor force, and frequency (set by equipment operator).

h. Before each day of paving, vibratory frequencies and amplitudes must be checked under no load. Large deviations between vibrators are indicative of poorly functioning vibrators.

8-6.1 Verifying Consolidation.

Examine cores drilled in the test strip or initial stages of placement to ensure that for the paving variables (vibrator depth, attitude angle, frequency under load, spacing, grout box head, and travel speed), the consolidation is acceptable. Examine cores between and in vibrator paths for:

- Evidence of aggregate segregation in vibrator trails
- Excessive entrapped air
- Differences in hardened concrete density

8-6.2 Vibration for Consolidation.

Slipformed vertical edges should not exhibit excessive entrapped air voids. With slipform and fixed-form pavers, supplementary vibrators may need to be positioned close to vertical edges to ensure adequate consolidation. Evaluate the response of the concrete mixture to vibration on the first day of paving or after the test strip construction. Eliminate large pockets of entrapped air (honeycombing) and aggregate segregation by changing the following:

- Vibrator frequency
- Forward travel speed of paver
- Vibrator depth
- Vibrator spacing

Smart vibrator systems that continuously monitor individual vibrator frequencies during paving operations are available. Use of a smart vibrator system is recommended since this allows continuous verification of frequency uniformity. Vibrator frequency in the range of 6,000 to 8,000 vibrations per minute (under load) will usually result in acceptable consolidation for a properly designed mix.

8-7 CONCRETE FINISHING.

Concrete finishing is a critical step in the paving process. Concrete finishing is the hand finishing typically applied to obtain a smooth surface necessary to correct any unevenness behind the paver. Concrete finishing efforts are to be kept to a minimum. Ideally, the correct concrete mixture will result in an acceptable surface finish behind the paver. The concrete surface does not need to be very tight and every small blemish on the surface does not need to be corrected. The following can aid in obtaining a good finish:

- Minimize excessive handwork
- Do not apply water to help finish the surface
- Surface does not need to be excessively smooth or tight
- Too much paste at the surface results from:
    - Too much water applied to the surface
    - Over-vibration (high frequency)
    - Paver speed too slow for vibratory effort
    - Over-finishing
- Important items related to finishing are as follows.
    - The need for concrete finishing is minimized by:
        - Selecting a workable concrete mixture
        - Properly operating the paving equipment
    - Excessive hand finishing will work water to the surface and can affect surface smoothness and concrete durability.
    - Problems closing the surface behind the paver are indicative of:

        - Inadequate volume contained in the grout box or concrete setting up in the grout box
        - Fine to coarse aggregate volume or paste volume too low
        - The finishing pan angle needing adjustment
        - The paver speed being too high
        - Vibrators needing adjustment
    - If water is used to assist with finishing, it needs to be fogged, not sprayed, over the surface and should not be worked into the surface with floats.

8-7.1 Hand Finishing.

Excessive hand finishing or adding mortar and water to the surface of the pavement are indicators of mixtures with an undesirable combined gradation. Continuing these practices produces pavements that are FOD generators, such as scaling and spalling. Adjust mixture proportions and finishing techniques whenever necessary to minimize hand finishing.

8-8 CONCRETE TEXTURING.

Concrete pavements require a surface texture that provides the desired level of skid resistance. The primary functions of surface texture are to provide (a) paths for water to escape from beneath tires and (b) a degree of sharpness at the surface necessary for the tire to break through the residual film that remains after the bulk water leaves. Concrete texturing is the most common technique used to provide concrete with a high skid-resistant pavement surface. However, texturing will not prevent hydroplaning. Texturing is applied while the concrete is still in plastic condition. Texture methods include the following.

8-8.1 Brush or Broom Finish.

- Applied when the water sheen (bleed water) has just disappeared
- Applied transversely across the pavement
- Corrugations should be uniform in appearance and 1.5 mm (1/16 in.) deep
- The textured surface must not exhibit tears and be unduly rough
- Burlap or Astroturf drag finish

Macrotexture of the finished concrete surface should have a mean depth of 1 mm (0.04 in.) when measured by ASTM E965. Burlap drags are the most common texture techniques for airfield pavements.

- The burlap rating should be about 500 gm/m^2 (15 oz/yd^2).
- The trailing edge of burlap must have a heavy buildup of grout to produce the desired longitudinal striations on the surface.

- Operate the drag with the fabric moist and clean, or changed as required to keep clean.
- The corrugations produced by burlap drag must be uniform in appearance and about 1.5 mm (1/16 in.) deep.

8-8.2 Wire Combing (Rigid Steel Wires).

- Use wire combing to provide a deeper texture in the plastic concrete.
- Steel wires are about 100 mm (4 in.) long, 0.8 mm (0.03 in.) thick, and 2 mm (0.08 in.) wide.
- Continuous tracks are approximately 3 mm by 3 mm (1/8 in. by 1/8 in.) and spaced 13 mm (0.5 in.) center to center.
- Brush, broom, or burlap finish is not necessary before providing wire tining.
- Wire combing is not a substitute for grooving. It does not provide for improved surface drainage.

8-8.3 Wire Tining (Flexible Steel Bands).

- Use wire tining to provide a deep texture in the plastic concrete.
- Flexible steel bands are about 130 mm (5 in.) long, approximately 6 mm (0.25 in.) wide and spaced 13 mm (0.5 in.) apart.
- Brush, broom, or burlap finish is not necessary before providing wire combing.
- Wire tining is not a substitute for grooving. It does not provide for improved surface drainage.

8-9 GUIDANCE FOR TEXTURING AND GROOVING.

The designer must select the type of texturing desired. If no guidance is given, the usual default method is burlap drag. For airfield paving projects, do not specify artificial turf, wire comb, or surface grooving textures.

8-9.1 Grooving.

Spring tine grooving is limited to use on roads and streets only. Grooving of airfield pavement must be sawcut. Use either the FAA’s standard or trapezoidal grooving patterns. For the standard groove pattern, grooves are approximately 6 mm by 6 mm (0.25 in. by 0.25 in.) and spaced 37 mm (1.5 in.) center to center for airfield pavements and spaced 50 mm (2 in.) for roads. Trapezoidal grooves are spaced 57 mm (2.25 in.) center to center, 6 mm (0.25 in.) deep, 6 mm (0.25 in.) wide at the bottom, and 12 mm (0.5 in.) wide at the top.

Do not groove within 152 mm (±76 mm) (6 in. [±3 in.]) of the runway centerline, crown, Transverse joints, working cracks or light fixture. Do not groove within 6.1 m (20 ft) of the aircraft arresting system cable. Grooves are not required to cross joints. Do not groove through compression seals. Replace any compression seals cut or otherwise damaged by the grooving operations. Terminate grooves within 1.5 to 3 meters (5 to 10 feet) of the pavement edge to allow for operation of the grooving equipment.

8-10 CONCRETE CURING.

Curing is the maintenance of adequate moisture and temperature regimes in freshly placed concrete for a period of time immediately following finishing. Improper curing can have serious detrimental effects on near-term (plastic shrinkage cracking) and long-term properties of hardened concrete (less durable surface, excessive warping). Four important keys to proper application of a curing material are (a) proper mixing, (b) uniformity of application, (c) timing of application, and (d) yield check (rate of application). Important issues related to proper concrete curing are addressed below.

8-10.1 Timing of Curing Application.

Timing is critical, especially during hot weather. Apply curing compound as soon as free water disappears from the concrete surface after finishing and texturing. When using fly ash and slag, free water may not form.

8-10.2 Curing Compounds Spraying.

Uniform coverage and coverage rates are critical for sprayed curing compounds.

a. Apply spray curing using spray equipment mounted on a self-propelled frame that spans the paving lane.

b. Limit hand spray curing to hand-placed concrete areas.

c. Employ overlapping coverage that provides a two-coat application at a coverage.

d. Uniformity of white-pigmented curing compounds are subject to visual examination, but verify application rates by measuring the volume used for a given area and compare it to the specifications.

e. Apply curing to exposed concrete faces after slipforming or removing forms.

f. Apply curing to joint surfaces immediately after sawing and cleaning.

g. If using moist curing, maintain the entire concrete surface continuously wet for the entire curing period (typically seven days) or until a curing compound is applied.

See additional discussions related to curing for hot and cold weather concrete placement in paragraphs 8.16 and 8.17.

8-11 MINIMIZING EDGE SLUMP.

Detect excessive edge slump while concrete is in the plastic state. Edge slump is considered excessive if more than 15 percent of the joint length for a single slab exhibits edge slump greater than 6 mm (0.15 in.) or if any edge slump exceeds 10 mm (3/8 in.).

Minimize edge slump occurrences because it impacts joint efficiency and performance. The continual correction of excessive edge slump in fresh concrete can lead to unacceptable levels of joint spalling in the finished concrete. If such a problem develops, stop paving and implement measures to correct excessive edge slump. Factors that affect edge slump include:

- Concrete consistency
- Concrete mixture compatibility with placement techniques
- Paver adjustments and operation
- Excessive finishing

The correction of edge slump is discussed in Chapter 11.

8-12 FIXED FORM PAVING.

Fixed form paving is typically used to pave short lengths or isolated areas such as fillets or irregular pavements and employs machine pavers or manual placement. Important considerations include the following.

8-12.1 Steel Forms.

Position forms on the finished base and check top elevations.

8-12.1.1 Granular Base.

a. If grade along the forms is low, place and compact additional base material.

b. If grade along the forms is too high, rework the base to lower the grade.

c. Correcting high spots in granular material only near form edges is poor practice. High spots between the forms will result in a lower concrete thickness away from forms that result in variable thickness.

8-12.1.2 Stabilized Base.

a. If grade along forms is low, shim forms to maintain horizontal alignment during concrete placement. If more than 25 mm (1 in.) shimming is needed, remove and replace the base in low areas to achieve the required base elevation.

b. For high areas in cement treated base, cut down cement-treated open graded and open graded asphalt stabilized bases with a motor grader blade.

c. Grind high areas in lean concrete (econocrete) and asphalt concrete bases to elevation.

d. Lowering base elevations only in the vicinity of forms results in a thin concrete cross-section away from forms that produces variable thickness.

e. Consider a bond breaker layer of broadcast sand or double application of waxed-based curing compound in areas that are ground and thereby reduce the potential for bonding between the base and the concrete.

8-12.2 Set Forms.

Mechanically tamp forms and stake them securely into the base with stakes no more than 900 mm (36 in.) apart.

8-12.3 Check Transition Joints.

Ensure that no significant deviation affects the finished concrete smoothness between forms.

8-12.4 After Forms are Connected.

Check vertical and horizontal alignment.

8-12.5 Damage.

To minimize damage during form-removal operations, spray forms with form release oil not more than four hours before paving.

8-12.6 Spalling.

To prevent corner spalling and damage to concrete, forms are not normally removed earlier than 12 hours after concrete placement; however, remove forms no later than 24 hours. Removing forms later than 24 hours may affect concrete curing of vertical edges adjacent to forms.

8-12.7 Exposed Sides.

Spray exposed sides with curing compound within 30 minutes after form removal. Coat edges at coverage rates used for the pavement surface.

8-13 PAVING AND IN-PAVEMENT STRUCTURES.

8-13.1 Lighting Fixtures.

The most common in-place structures in airfield concrete paving are light cans. Layout in-pavement lighting systems to minimize interference with proposed pavement joints. For conflicts with pavement joints, make use of pavement blockouts to construct in-pavement lighting structures near a joint. Normally, a blockout is required when the centerline of the light base can is within 750 mm (2.5 ft) of a pavement joint. Light cans may be installed using one of the following techniques.

8-13.1.1 Blockouts.

a. Install blockouts at light can locations and place the pavement around the blockouts.

b. Check blockouts elevations for grout box clearance.

c. Place filler material used to stabilize blockouts within 75 mm (3 in.) or less of the finish elevation.

d. After construction, remove any filler material, position light cans, and backfill the blockout area with concrete.

e. Fixed blockouts can restrain slab movement and increase restraint stresses associated with moisture and thermal changes. Use deformed tie bars around diamond-shaped blockouts to hold any restraint cracks tight and reduce the potential for crack spalling. Position tie bars between the upper third and half depth of pavement. Securely tie bars to chairs fastened to the base.

8-13.1.2 Split Cans and Coring.

This technique allows the pavement to be slipformed with pre-placed light cans. Can elevation adjustments can be made after concrete placement. The steps involved are as follows.

1. Position partial can in the base.
2. Pre-place concrete at the base of the partial cans to anchor the cans.
3. Pave the lane.
4. Drill a 100 mm (4 in.) diameter core to determine the exact center of the can.
5. Drill a 360 to 460 mm (14 to 18 in.) hole for the can top section.
6. Complete light can installation.

8-13.1.3 Cookie Cutter.

This technique is similar to the coring method: light cans are anchored in place and paving is placed over them. The steps involved are as follows.

1. After the paving machine passes over a light base, a “cookie cutter” is pressed into the plastic concrete by a worker sitting on a bridge suspended over the pavement.
2. After the concrete sets (sufficiently rigid for the reservoir to retain its shape but plastic enough to allow surface finishing), the cookie cutter is removed, the concrete inside the impression is removed and discarded, and the surrounding surface is hand finished.

8-13.1.4 Implications of Improperly Installed Light Bases.

Benefits to the paving contractor include time and cost savings when light base installation deficiencies are detected before concrete paving. It is relatively cost free to check a light base before paving; it is an expensive proposition to remove a light base after the pavement is placed and finished. The height setting of a light base is the most common cause of a deficient installation. When the light base is set too high, there is no satisfactory mitigation other than to remove and replace. Therefore, checking the height before concrete paving is a critical step.

On some projects, the uniformity of the concrete surface surrounding the light base has been observed to distort to the extent that height tolerances become difficult to establish and high spots block the light beam. The specific cause or causes of this problem are not known and the condition is only detected during inspection after paving is complete. The surface of the concrete around light base locations must be carefully inspected immediately after pavement finishing and during the time that the concrete is plastic.

8-14 OTHER STRUCTURES.

Other in-place structures commonly encountered with airfield pavements include hydrant pits, utility manholes, and drainage structures (trenches). These are typically installed using the blockout method or pre-placed with concrete around the structure. In both cases, embedded steel must be used around the structure for crack control. Additional items to consider for the design and construction of in-place structures include the following.

a. Design details for in-place structures must account for expansion of concrete pavements adjacent to the structure and for moisture infiltration into the structure.

b. Larger in-place structures (such as utility manholes, hydrant pits, or drainage trenches) must be located at least 1.2 m (4 ft) from a transverse or a longitudinal joint to minimize potential for cracking. If it is not feasible to locate a larger structure outside of the 1.2 m (4 ft) dimension, place the structure at the pavement joint along with appropriate load transfer (thickened edge) and concrete slab expansion details.

c. Smaller slab penetrations, such as monitor wells and under-drain cleanouts, can be located closer to the pavement joints, in a similar manner to an in-pavement light fixture (no less than 750 mm [2.5 ft] from the pavement joint.

d. An isolation joint around an in-place structure must be used to accommodate concrete slab expansion. Load transfer between the concrete slab and the adjacent structure must also be accounted for.

e. Trench drain walls must be designed to be stiff enough to resist concrete pavement expansion. Struts in trench drains may be required if concrete expansion movement at the trench drain is anticipated to be high.

8-15 PAVING AT FLEXIBLE PAVEMENT INTERFACES.

Matching elevations is a common problem where concrete and flexible pavement sections abut one another.

8-15.1 Techniques for a Smooth Interface.

a. Sawcut flexible pavement vertically full depth where it abuts new concrete to minimize disturbance to the base layer under the asphalt layer.

b. If the flexible system is sawcut significantly ahead of paving, shore up the vertical face of the flexible pavement system to minimize loss of base associated with unsupported granular layers sloughing.

c. Alternatively, over cut the flexible pavement, pave along the planned flexible pavement interface, and replace the flexible pavement at the over cut. If possible, use a buried concrete slab tied to the concrete pavement along the over cut area.

d. To minimize the potential for faulting at the interface construction joint, compact the base adjacent to forms and along the cut flexible pavement edge using pole tampers and plate compactors.

e. To minimize the hand-finishing effort when matching elevations, start paving at the flexible pavement edge and move the paver away from the edge.

f. Do not allow slipform equipment to track on the unsupported flexible pavement edges.

g. When paving parallel to the flexible pavement, match elevations between the concrete and flexible pavements and manipulate the concrete during finishing. Depending on cross-slope drainage requirements, consider the following:

- Grind the flexible pavement down to the planned concrete elevation.
- Place concrete higher and thin mill or resurface the flexible pavement.
- During compaction of the surface layer of asphalt, do not allow the steel roller to run on the concrete edge.

8-16 HOT-WEATHER CONCRETE PLACEMENT.

ACI defines hot weather as a period longer than three consecutive days exhibiting the following conditions:

- The average daily air temperature is greater than 25 °C (77 °F). The average daily temperature is the mean of the highest and the lowest temperatures occurring during the period from midnight to midnight.
- The air temperature for more than one-half of any 24-hour period is not less than 30 °C (86 °F).

8-16.1 Concrete Mixture.

Only use a concrete mixture for hot weather previously verified as appropriate by using trial batches mixed and cast at temperatures representative of typical hot weather conditions for the site. During hot weather, problems that are likely to occur include:

- Rapid slump loss
- Reduced air contents
- Premature stiffening
- Plastic shrinkage cracking
- Thermal cracking

8-16.2 Hot Weather Concreting.

a. Do not exceed the maximum allowable w/cm ratio or the manufacturer's maximum recommended dosage of any admixture.

b. Retarding admixtures if their performance is verified during trial batches. High dosages of water reducers (even high-range water reducers) can retard setting.

c. Substitute slag, Class F fly ash, or natural pozzolans for part of the cement. These materials hydrate more slowly and generate lower heats of hydration than cement, thus reducing problems with slump loss, premature stiffening, and thermal cracking.

d. Correct air content by increasing the dosage of air-entraining admixture.

e. Early-age thermal cracking may be prevented by ensuring the temperature of the plastic concrete is as low as practical. It should not exceed 32 °C (90 °F).

   - Aggregates may be cooled by sprinkling with water. Corrections for the aggregate moisture are required.
   - Aggregates must be batched in a saturated surface dry condition to avoid absorbing mixture water.

f. Hot cement or fly ash provided by the supplier should not be used.

g. Mixing water may be chilled or chipped ice may be used to substitute for some of the water. Ensure all ice melts during mixing.

h. Mixing and transporting equipment may be painted white or a light color to minimize the heat absorbed from the sun.

i. Concrete placements can be scheduled for nighttime.

j. The base should be moistened before the concrete is placed to keep the temperature down and keep it from absorbing water from the concrete.

k. The concrete should be placed and finished as rapidly as possible and curing compound applied at the earliest possible time. The use of a white curing compound will reflect the sun's heat. If there is any delay in applying the curing compound, use a fog spray or evaporation retardant to keep the surface from drying out.

l. Steps should be taken during hot weather to reduce the rate of evaporation from the concrete. The likelihood of plastic shrinkage cracking increases with the rate of evaporation. Plastic shrinkage cracking results from the loss of moisture from the concrete before initial set. The rate of evaporation is a function of:

- Air temperature
- Concrete temperature
- Relative humidity
- Wind speed

m. Calculate the rate of evaporation using the American Concrete Pavement Association's (ACPA) Evaporation Rate Calculator (http://www.apps.acpa.org/apps/EvaporationCalculator.aspx) or the High PERformance Concrete PAVing (HIPERPAV) software. Current data from an on-site weather station should be used.

n. When the rate of evaporation is predicted to be above 1.0 kg/m^2/hr (0.2 lb/ft^2/hr), provide fog spraying or use an approved evaporation retardant, as appropriate.

o. If conditions of temperature, relative humidity, and wind are too severe to prevent plastic shrinkage cracking or corrective measures are not effective, paving operations must be stopped until weather conditions improve.

p. Refer to ACI 305, *Hot Weather Concreting*, for additional information.

8-17 COLD WEATHER CONCRETE PLACEMENT.

Cold weather is defined by ACI as a period when, for more than three consecutive days, the following conditions exist:

a. The average daily air temperature is less than 4 °C (40 °F). The average daily temperature is the mean of the highest and lowest temperatures occurring during the period from midnight to midnight.

b. The air temperature is not greater than 10 °C (50 °F) for more than one-half of any 24-hour period.

c. When concrete is to be placed in cold weather or at a time of year when cold weather is likely, plans to maintain the concrete at the appropriate temperature must be made well before the temperature is expected to drop below freezing. Consider the following for cold weather concreting.

- Concrete mixture designs developed for placement at cooler temperatures normally have higher cement content than those used in hot weather.

- The use of slag, fly ash, and pozzolans should be reduced or eliminated unless they are required to control ASR or provide some degree of resistance to sulfate attack. In the latter case, the total cementitious materials content may need to be increased or the cement changed to Type III instead of Type I/II.
- The required dosage of air-entraining admixture should be lower than the dose at normal temperatures.
- Because the concrete will take longer to set, there is also some danger of plastic shrinkage cracking, especially if the concrete is much warmer than the ambient air or if the wind is blowing.
- An accelerating admixture conforming to ASTM C494/CRD-C 87 Type C or E may be used, provided its performance has been previously verified by trial batches.
- Do not use admixtures containing added chlorides. Also, do not use calcium chloride.
- Aggregates must be free of ice, snow, and frozen lumps before being placed in the mixer.
- The temperature of the mixed concrete should equal or exceed 10 °C (50 °F).
  - o The mixture water and aggregates may be heated to less than 66 °C (150 °F).
  - o The material must be evenly heated.
- Concrete should not be placed when the temperature of the air at the site or the surfaces on which the concrete is to be placed is less than 4 °C (40 °F).
- Covering and other means of protecting the concrete from freezing must be available before starting placement.
- The concrete temperature should be maintained at 10 °C (50 °F) or above for at least 72 hours after placement and at a temperature above freezing for the remainder of the curing time (when the concrete attains a compressive strength of 20 MPa [3,000 psi]). Corners and edges are the most vulnerable to freezing.
- Completely remove and replace concrete damaged by freezing.
- Concrete placed in cold weather gains strength slowly. Concrete containing supplementary cementitious materials gains strength very slowly.
  - o Sawing of joints to opening to traffic may be delayed.
  - o Verify the in-place strength by a maturity method, temperature-matched curing, nondestructive testing, or tests

of cores from the pavement before opening the pavement to traffic.

- Refer to ACI 306, *Cold Weather Concreting*, for additional information.

8-18 PROTECTING CONCRETE AGAINST RAIN DAMAGE.

The paving team and the inspector must be knowledgeable of procedures to protect fresh concrete in the event of rain. Consider the following.

a. Protective coverings, such as polyethylene sheeting or tarpaulins, must be available onsite at all times.

b. When it starts to rain, batching and placing operations should stop. The fresh concrete must be covered so the rain does not indent the surface or wash away the cement paste.

c. There are two primary consequences of rain during pavement placement:

- Rain can damage the surface by leaving imprints or washing away paste at the surface. Damage is generally minimal once the concrete has achieved final set.
- Rain-induced rapid surface cooling after final set could lead to a more rapid development of thermal restraint stresses. Even if sawcutting is begun in a timely manner, an increase in the potential for early-age uncontrolled cracking exists. Joint sawing is discussed in Chapter 9.

d. Should a rainstorm occur before the curing membrane is effective, the damage is usually limited to the surface.

e. Stiff, low-slump, paving-quality concrete that has been consolidated, struck off, and finished may sustain only minor surface blemishes from light rain.

f. When the rain is light, water will not soak into the concrete and result in an increase in the w/cm ratio.

g. If the concrete was textured prior to the rainfall, the texture may be compromised. This surface blemishing and texture damage, if light, can generally be taken care of by diamond grinding the surface to a depth of about 3 mm (1/8 in.).

h. Any concrete exposed to significant rain while it is loose or unconsolidated must not be used in the pavement as it can absorb water.

i. Once the unprotected pavement surface is exposed to rain there should be no attempt to finish or texture the surface.

j. Removal of extra surface water prior to covering should not be attempted. Water removal operations often increase the erosion of paste at the surface.

k. Adding dry cement or floating dry cement into the surface should not be attempted. Adding cement extends the time the surface is exposed, increasing the potential for additional surface damage. Working dry cement into the surface can also alter the entrained air void system that is required for freezing and thawing protection.

l. As soon as the surface has dried, the curing membrane can be applied. Once the curing period is over, the surface exposed to rain should be diamond-ground to remove the surface blemishes and texture the surface.

m. Any attempt to finish or texture the surface during or after the rain event runs the risk of working water into the surface of the concrete. This will make a minor surface problem into a serious problem.

n. If unconsolidated concrete exposed to rain has been incorporated into the pavement, it must be removed.

o. Use of early entry saws or skip sawing (discussed in Chapter 9) to quickly install joints prior to incoming rain should be considered.

p. Installing joints as quickly as possible reduces the potential for early-age cracking attributed to restraint stresses generated with rapid surface cooling.

q. Once rain has ceased and surface coverings removed, needed joints are sawed as quickly as possible.

r. If a rainstorm catches an unprotected pavement, it is crucial that paving stop. The best precaution to avoid rain damage or random cracking is to quickly cease paving operations. On larger airfield projects, contractors may rely on weather stations at the airfield or subscribe to meteorological weather forecasting services to monitor current weather information.

8-18.1 Assessing Rain Effects.

Consider the following guidelines in assessing rain effects.

8-18.1.1 Mist.

An intermittent light mist may be beneficial, as long as no significant water is added to the unconsolidated concrete in front of the paver or to the concrete surface to be finished.

8-18.1.2 Accumulated Water.

If rain is sufficient to accumulate any water at all on the surface of freshly placed concrete prior to finishing, stop paving and take protective measures.

8-18.1.3 Hard Rain.

If rain is sufficiently hard to mark freshly placed concrete, it is past time to stop paving.

8-19 TESTING RAIN-EXPOSED SURFACE.

Evaluate any rain damage and establish the extent of damage. The rain-damaged concrete must be removed if the surface is determined to be not durable in terms of abrasion, skid resistance (surface texture), or freezing and thawing. Cores can be drilled for petrographic examination to determine if rain has altered the surface hardness or entrained air-void system. Cores should be recovered from the beginning and end of the damaged surfaces. Results from the petrographic examination can establish the limits of and disposition of damaged concrete. Generally, surfaces are not deemed durable for abrasion if damage extends down more than 3 mm (1/8 in.). For freeze-thaw durability, the air-void spacing factor should be less than 0.20 mm (0.008 in.). Other tests assess scaling and abrasion potential.

8-20 TROUBLESHOOTING GUIDE.

Common problems encountered at the job site and possible remedies are described in Table 8-2.

Table 8-2 Troubleshooting Placement, Finishing, Texturing, Curing

Problem	Probable Cause(s)	Action
Premature stiffening of concrete with little evolution of heat.	• False-setting cement.	• Do not add water. Plasticity can be restored with additional mixing. Notify cement supplier.
Premature stiffening of concrete with evolution of heat, lack of working time.	Any of the following could contribute to this problem: • Cement with too little or the wrong form of sulfates • High placement temperatures • Lignosulfonates in water-reducing admixture • Triethanolamine (TEA) in water-reducing admixture • Use of accelerator • Wrong mixture design for hot weather (high cement content, Type III cement, no supplementary cementitious materials) • Dry, absorptive aggregates absorbing water from the mix • Hot (fresh) cement	• If using an accelerator, stop using it or reduce the dosage. • Reduce the placement temperature of the concrete by any convenient method(s). See para. 8.17. • In hot weather, use the hot weather mixture design. • Make sure the aggregates are damp at the time of batching. Switch to a water reducer that does not contain lignosulfonates or triethanolamine (TEA). (Consult the admixture supplier for advice.)
Slump out of specifications or varying	• Change in water content or aggregate grading; concrete temperature too high.	• Check aggregate moisture contents and grading. • Stockpiles should be of consistent grading and aggregates must be moist. • Make sure batch water is adjusted for aggregate moisture content. • Check whether extra water was added at the site. • Perform mixer uniformity test. • Note the batch time on the concrete delivery ticket. Haul

Problem	Probable Cause(s)	Action
		times should not exceed allowable time.
Slump loss greater than 25 mm (1 in.) between the plant and the paver	• False setting tendency or material incompatibility	• Check cement composition • Check mixing time • Check admixture compatibility
Inconsistent air content	• Variations in pozzolan • Change in cement source, type, or brand • Change in sand grading • Inadequate or variable mixing due to worn mixer blades, an overloaded mixer, or varying mixing times • Concrete temperature effects	• Monitor air contents closely and adjust admixture dosages as necessary. • If the air contents drop between the cool morning and hot afternoon, it may be due to the change in concrete temperature. In that case, increase the dosage of air-entraining admixture as the temperature rises. • If a sudden change seems permanent, look for a change in the materials supplied. • Check the sand stockpile to see whether the grading has changed. • Examine the mixer (fins) and mixing procedures. • Contamination of one of the ingredients with organics can also effect a sudden change in the required dosage of the air-entraining admixture. Try to isolate the source.
Excessive concrete temperature	• Ingredients may be hot at batching: aggregates, cement, fly ash • Long haul times • Hot weather	• Follow hot weather concreting practice as appropriate. • Minimize haul times.

Problem	Probable Cause(s)	Action
Failure to set	• Organic contamination, excessive retarder, excessive water reducer, retarder not dispersed, and cold weather.	• Check for contamination of water, aggregates, and equipment. • Reduce dosage of retarder and water reducer. • Improve mixing to disperse retarder. • Follow cold weather concreting practices if appropriate.
Sticky mix	• Use of higher dosages (> 5 percent) of silica fume • Sand too fine • Using wood float on air-entrained concrete	• Change sand source. • Use magnesium or aluminum floats.
Honeycombing	• Hot weather may induce premature stiffening • Inadequate vibration • Changes in aggregate grading will affect workability • Dry aggregates • High paver speed	• Follow hot weather concreting practices, if appropriate. • Check that all vibrators are working properly and at the right frequency and amplitude. Paver speed should not be too high. • Check aggregate grading.
Edge slump	• Poor or nonuniform concrete • Improper operation of paving equipment	• Verify mixture design and batching procedures. • Check aggregate grading and moisture. • Check concrete placement procedures.
Smoothness problems	• Nonuniform concrete • “Stop and go” paver operation • Too much or too little concrete in front of paver • Frequent use of construction headers	• Check batching procedures. • Check aggregate grading. • Improve construction procedures. • Minimize delays in concrete delivery.

Problem	Probable Cause(s)	Action
	• Use of light paver	• Add extra haul trucks, if necessary, or slow paver. • Improve paver operation.
Popouts	• Unsound aggregates • Clay balls	• Check aggregates for soundness. • Check for inter-mixing of aggregate with soil.
Scaling, dusting	• Over-finishing • Premature finishing • Early freezing of concrete	• Improve finishing technique. • Protect concrete from freezing. Concrete damaged by freezing needs to be removed and replaced.
Plastic shrinkage cracking	• Excessive loss of moisture from fresh concrete	• Use an accelerator to make concrete set faster. • Protect concrete from loss of moisture both before and after placement: fog spray or immediate application of evaporation retardant or curing compound. • Make sure absorptive aggregates are kept moist. • Refer to hot weather concreting practices, if appropriate.
Random cracking	• Shallow sawcut/late sawing • Dowel misalignment • Bonding with stabilized base • Sudden cold front • Excessive joint spacing	• Saw sooner and check sawcut depth. • Check dowel alignment. • Take cores to check interface bond. • Review joint spacing.
Raveling of sawcut	• Sawing too soon	• Wait longer to saw. • Check blade compatibility. • Use early entry dry saw.

Problem	Probable Cause(s)	Action
Joint spalling	• Excessive hand finishing; trying to fix edge slump of low spots by hand-manipulated concrete; nonuniform concrete resulting in wavy longitudinal joint that spalls when sawed; and collateral damage from equipment, slipform paver tracks, and screeds	• Improve construction practice.
Low strength concrete samples	• Errors in batching or mixing of concrete • Incompatibility between cement and air-entraining admixture causing coalescence of air voids around aggregate particles • Improper sample preparation, curing, handling, or testing	• Verify entire process of making, curing, handling, and testing. Flexural specimens are particularly vulnerable to poor handling and testing procedures. • Verify entire batching and mixing process. • Trial batches can help eliminate the possibility of incompatibility. A quick visual examination of a cut specimen will identify any coalescence of air voids.

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CHAPTER 9 JOINT SAWING AND SEALING

9-1 INTRODUCTION.

Joint sawing and sealing require an experienced crew to correctly perform associated tasks. Although improved guidelines are available for estimating when sawing can begin, speed of sawing, blade condition, and operator care combine to influence the final product. Find additional information in UFC 3-250-08, *Standard Practice for Sealing Joints and Cracks in Rigid and Flexible Pavements*.

9-2 JOINT DESIGN.

There are three pavement categories: isolation, construction, and contraction (Figure 9-1). Find detailed guidance for jointing roads and parking areas in UFC 3-250-01. Refer to UFC 3-260-02 for guidance on airfield pavement jointing.

9-2.1 Isolation/Expansion Joints.

The purpose of an isolation/expansion joint is to separate intersecting pavements, isolate embedded fixtures within the pavement such as pavement drains, or when pavements abut buildings.

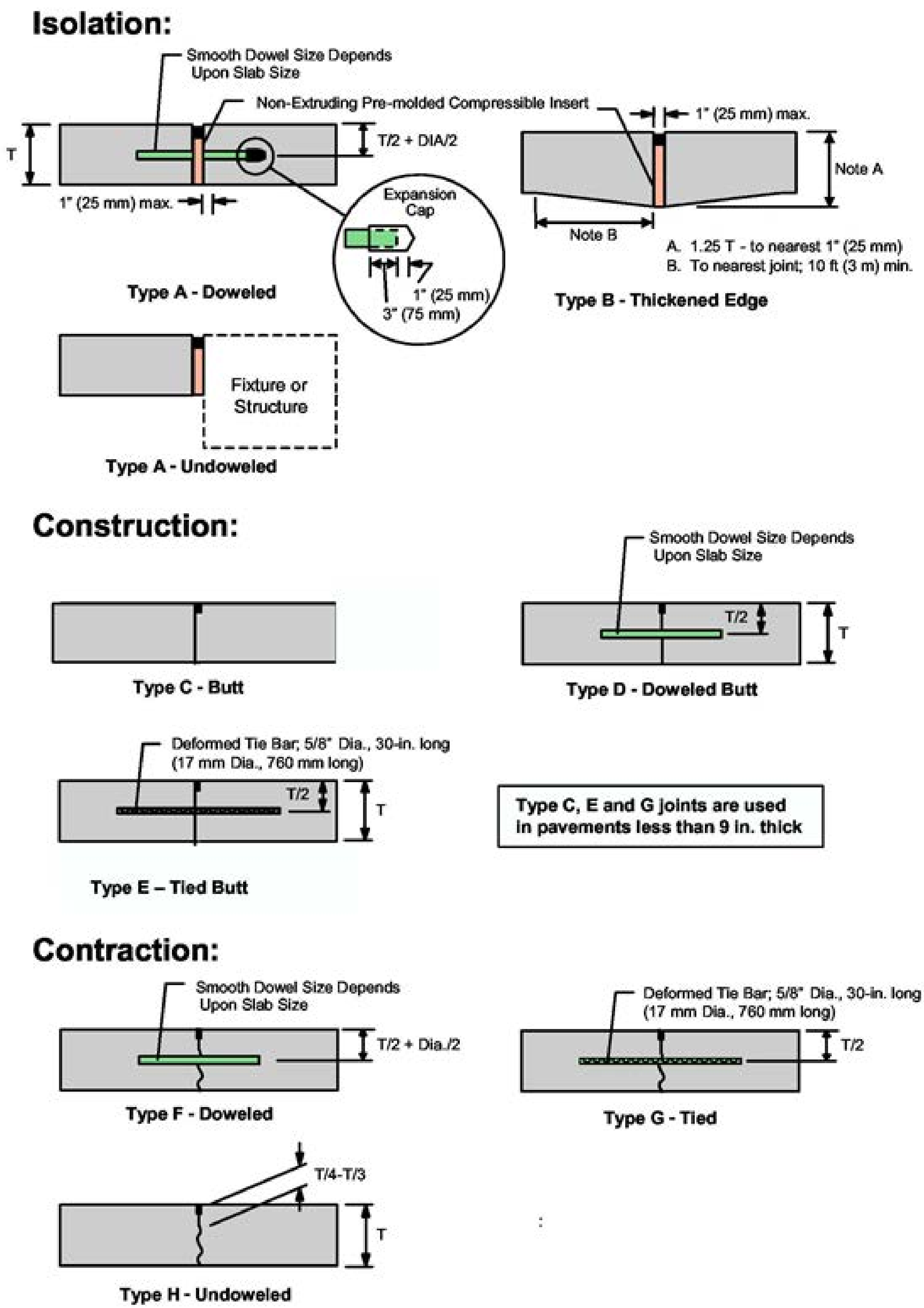
9-2.2 Construction Joints.

Construction joints separate abutting construction placed at different times, such as the end of a day’s placement or between paving lanes.

9-2.3 Contraction Joints.

Contraction joints control the location of pavement cracking caused by drying shrinkage or thermal contraction. Contraction joints also reduce stress caused by slab curling and warping.

Figure 9-1 Concrete Pavement Joint Types



9-3 JOINT LAYOUT PRACTICES.

Consider the following items when planning the joint layout.

- Check the plans for any conflicts with dowel bars and tie bars.
- Make sure joints line up across pilot lanes.
- Spot survey several locations to make sure joints will line up.
- Plan paving lanes such that only one longitudinal joint is sawcut.
- Plan blockouts and situate them more than 1.2 m (4 ft) from joints, when possible.

9-3.1 Joint Layout Considerations.

The following are necessary considerations.

9-3.1.1 Inspection.

Inspect the project drawings for the location of dowel bars and tie bars. If any problems are noted, discuss these elements with the engineer before paving.

9-3.1.2 Jointed Plain Concrete.

For jointed plain concrete pavements, do not exceed a slab length to width ratio of 1.25.

9-3.1.3 Odd-Shaped Panels.

Where rectangular-shaped slabs cannot be constructed (odd-shaped panels), embedded steel is placed in both directions at a ratio of at least 0.05 percent. The embedded steel will not prevent odd-shaped slabs from cracking but can minimize crack openings to reduce infiltration of debris and future spalling maintenance.

9-3.2 Factors Affecting Joint Spacing.

The primary function of all joints is crack control. Plain concrete pavement joints are spaced to reduce thermal and shrinkage restraint stresses such that no uncontrolled cracking occurs between joints due to these restraint stresses. The restraint stress magnitude influencing joint spacing depends on:

- Concrete temperature and moisture gradients (top and bottom of slab)
- Concrete temperature drop (relative to temperature at concrete final set)
- Concrete shrinkage
- Slab/base interface friction
- Modulus of base/subgrade reaction
- Pavement thickness

9-3.2.1 Concrete Properties Affecting Joint Spacing.

Concrete properties affect joint spacing. Concrete properties affecting restraint stress magnitudes are:

- Modulus of elasticity (generally 24,000 to 38,000 MPa (3.5 to 5.5 million psi); assumed as 27,000 MPa (4.0 million psi) for most design solutions)
- Coefficient of contraction (generally ranging from 9.0 to 11.8 x 10 ^{6} mm/mm/deg. C (5.0 to 6.5 x 10^{-6} in./in./deg. F)
- Shrinkage coefficient (generally ranging from 250 to 350 x 10 ^{6} in./in.)
- Density (generally 690 to 730 kg/m^2 (142 to 150 lb/ft^2) for air-entrained concrete)

Table 9-1 lists the maximum joint spacing.

Table 9-1 Maximum Joint Spacing

Slab Thickness, in.	Slab Thickness, mm	Joint Spacing, ft	Joint Spacing, m
< 9	230	12.5–15[1]	3.8–4.6
9–12	230–305	15–20	4.6–6
> 12	> 305	20	6

[1] 10–15 ft (3.0–4.6 m) for roads and parking lots

9-3.3 In-Pavement Structures.

9-3.3.1 Light Cans.

Pavements with light cans require special attention. Blockouts used to install light cans can restrain slab movement and increase restraint stresses associated with moisture and thermal changes. Design engineers typically add embedded steel to slabs containing light cans. While the embedded steel does not prevent restraint cracking around light can blockouts, the steel holds any cracks that develop tight and reduces the potential for crack spalling. Since most slab movements occur near longitudinal and transverse joints, establish jointing patterns such that light cans are located more than 1.2 m (4 ft) from planned joints. Cracks tend to emanate from light cans if the light cans are positioned closer than 1.2 m (4 ft) to joints.

9-3.3.2 Marking Joint Locations.

Mark joint locations on the base, edge of the slab, or on the forms. When paving a runway or wide taxiway, it is challenging to transfer joint locations across pilot lanes. Use surveying instruments to transfer joint locations across paving lanes. Small deviations in transferring joint locations across pavement can skew joint alignment. Carefully mark joint locations and construct joints at the proper locations.

9-4 TIMING OF JOINT SAWING.

Proper timing of sawcutting is critical to optimize joint performance. Consider the following factors.

9-4.1 Timing.

Commence sawing as soon as the concrete hardens sufficiently to permit cutting without chipping, spalling, or tearing.

9-4.2 Hardening.

Factors that influence the rate of concrete hardening:

- Air and concrete temperatures during placement
- Cement content of mixture
- Mixture characteristics

9-4.3 Readiness.

Regardless of the time of day or night, a contractor must be prepared to saw when concrete is ready.

9-4.4 Weather.

During warm weather, concrete is usually ready for sawing between 4 to 12 hours after placement. In cold weather, or when mixture water is below 10 °C (50 °F), sawing can be delayed as long as 24 hours.

9-4.5 Aggregate.

Generally, concrete mixtures with soft, coarse aggregate, like limestone, do not require as much strength development before sawing compared to mixtures with hard, coarse aggregates.

9-4.6 Delay.

If sawing is delayed, random cracking can occur.

9-4.7 Opportunity.

Several factors can reduce the length of the joint sawing window. If the sawing window becomes short, random cracking can develop.

9-4.8 Equipment.

When sawing, the concrete must support the equipment weight and associated personnel.

9-4.9 Hardness.

Spalling along a sawcut or aggregate tearing from the surface indicates inadequate concrete hardness.

9-5 EFFECTS FROM STABILIZED BASES.

Concrete pavement placed on a stabilized base is sensitive to sawcut timing. Inadequate precautions allow high slab/base interface friction to develop, producing uncontrolled cracking. A rapid overnight temperature drop causes shrinkage stresses in the concrete that can exceed the tensile strength of the concrete and lead to uncontrolled cracking. When adverse conditions are expected, saw as soon as possible and continue until complete. Conversely, the surface of a subbase can become hot during summer conditions. This increase in the temperature gradient through the slab significantly decreases sawing time. For asphalt treated bases, whitewash the surface of the material to increase reflectivity.

9-6 FACTORS THAT DECREASE SAWING TIME.

Factors that shorten the time frame available for joint sawing include:

- Sudden temperature drop
- High wind, low humidity
- High friction bases
- Bonding between base and slab
- Porous base
- Retarded set
- Paving fill in lanes
- Delay in curing application

9-6.1 Determining When to Saw.

It is difficult to determine when to saw. Sawing must occur before the concrete cracks on its own but after achieving sufficient strength to allow the saw to cut aggregate without dislodging.

9-6.1.1 Saw Equipment.

Determining the earliest time to cut joints is usually based on the equipment operator’s scratch test or observation of the raveling or spalling while making the initial saw cut.

9-6.1.2 Temperature.

As a rule of thumb, the limit of sawing is to cut before the surface concrete temperature significantly decreases.

a. Under most paving conditions, the top surface temperature starts to decrease while sub-surface concrete temperatures continue to increase. Once the concrete surface temperature decreases and a thermal gradient is generated, thermal curling restraint stresses start to develop. Concrete cracking results if the restraint stresses exceed the concrete tensile strength.

b. If saw cuts are installed before significant surface cooling, curling restraint stresses remain low and cracking develops only at planned joint locations.

c. Use surface thermometers or infrared guns to monitor concrete surface temperatures.

d. On larger projects, monitor slab surface temperature decreases to establish guidelines for allowable surface temperature changes.

- For example, assuming relatively constant paving conditions, if no slab cracking results in sections with a 5 degree drop in surface temperature, establish the last limit guideline for saw cuttings at a temperature drop of 5 degrees.
- Follow this guideline until weather condition changes or other data warrant establishment of new maximum allowable temperature decreases.
- The factor of safety is reduced as the maximum allowable temperature decrease increases.

9-6.1.3 Maturity Meter.

An improved method to establish the early limit window of opportunity uses a concrete maturity meter. The maturity method accounts for the combined effects of temperature and time on concrete strength development.

a. Concrete maturity meters use thermocouples installed in plastic concrete and automatically record temperatures at given time intervals.

b. Accounting for both curing temperature and time assumes that a given concrete mix has the same strength at equal maturities independent of curing time and temperature histories.

c. Thermocouples are typically inserted approximately 50 mm (2 in.) deep, as soon as possible after finishing operations. Set maturity meters to acquire temperatures at 15- to 30-minute intervals. The meters automatically calculate maturity. Early-age strength development is a function of ambient conditions, initial concrete temperatures, cement type, cement quantity, coarse aggregate type, and water-cementitious ratio. Maturity values can also establish early sawcutting times correlated with acceptable amounts of raveling or visual ratings.

9-7 JOINT SAWING OPERATION.

A two-step process is typical for sawing joints. In the first step, the initial cut relieves restraint stresses and allows cracking to develop at planned locations. A second cut forms the sealant reservoir after the hydration process is complete.

9-7.1 Initial Saw Cutting.

Items to be considered for the initial sawcut are as follows.

a. Make the first sawcut (early sawcut) with a single narrow blade (approximately 3 mm [1/8 in.] in width).

b. Perform early sawcuts made during rising concrete temperatures to the full design sawcut depth in one pass.

c. Early cuts made during falling concrete temperatures require special attention as concrete shrinkage occurs with falling temperatures.

d. Cuts to full design sawcut depth during falling concrete temperatures may cause random cracking (pop-off cracking) to occur ahead of the saw.

- It may be possible to avoid this problem by use of two sawcuts. Perform the first cut to one-half the design depth followed by a second pass to design depth.
- Discontinue sawing in any joint where a crack develops ahead of the sawcut.

e. Saw transverse joints consecutively in the same sequence as the concrete is placed in the lane.

- Sometimes a practice called skip sawing is used to control cracking. This practice involves cutting every other or every third joint.
- Skip sawing can result in variable joint width.
- Excessive sealant stresses may occur in those joints initially sawed.
- Before sawing each joint, examine the concrete closely for cracks. Do not saw planned joints if a crack appears near the planned joint.

9-7.2 Reservoir Cutting.

The following considerations are for the reservoir cut.

a. A second sawcut accommodates joint sealing material (reservoir cut).

b. A wide blade makes a second cut to the required depth.

c. Do not use gang blades to make the second cut. The gang blade system stability is insufficient to minimize spalling potential of the joint.

d. The second sawcut (in a single pass or two passes) is made at any time before sealant installation. However, the later in the concrete age the sealant reservoir is formed, the better the condition of the joint face.

e. Assure that the depth and width of the second sawcut meets the shape factor (width-to-depth ratio) requirements of the sealant. The satisfactory performance of the joint sealant depends on the shape factor of the sealant.

f. During both the early sawcut as well as during the second cut, periodically check the sawcut to verify proper depth.

- Saw blades tend to wear as well as ride up when hard aggregates are encountered.
- Periodically measure blade diameter to monitor blade wear.

9-7.3 Shape Factor.

The joint sealant shape factor is based on the width of the reservoir divided by the depth (W/D). The value of this factor is based primarily on the type of sealant, such as hot-poured, silicone and two-component cold pour, and preformed compression seals.

9-7.4 Cleaning the Saw Cuts.

Wet sawing leaves a slurry on the surface of the concrete and on the joint face. For the first cut, flush the slurry with low-pressure water followed by low-pressure air blasting. Once the slurry is removed, reapply the curing compound along the joint. For the reservoir cut, follow the same process except increase the air and water pressures since the concrete is hard and curing compound is not required if sufficient curing has occurred.

9-7.5 Sawcutting Equipment.

Sawcutting involves several types of equipment. Longitudinal contraction joints are installed with walk-behind saws or early age entry saws. Transverse contraction joints use one of the following:

- Spansaws
- Conventional walk-behind saws
- Early entry saws
    - o Do not use water.
    - o Are generally capable of sawing at earlier ages than spansaws or walk-behind saws.
    - o Depending on paving conditions and early-age concrete strength gain, early-age entry sawcutting is generally possible before any surface cooling and development of tensile restraint stresses.

- o Since sawcuts are performed earlier, the minimum depth requirements for the initial cut may be less. Current maximum depths for early entry saws are 100 mm (4 in.). This can limit their use to pavements less than 400 mm (16 in.) thick on aggregate base.

Other joint sawing items to consider include the following.

a. Both the longitudinal and transverse joints are cut at about the same time.

b. When concrete is slipformed, extend the transverse sawcuts completely through the longitudinal edge.

- If a sawcut is stopped short of the longitudinal edge, the transverse sawcut at the edge is not as deep and the potential for random cracks initiated at outside corners increases.
- When metal pavement forms are used, the saws must get as close to the forms as possible.

c. The risk of early-age restraint cracking before installing sawcuts increases if the concrete strength gain is retarded (slow strength gain) or the concrete surface temperatures rapidly decrease (surface cooling from rainfall).

d. If sawcuts cannot be installed quickly enough due to low strength gain or in relation to rapid generation of restraint stresses, consider concrete skip sawing.

- Installing every third or every other transverse joint may reduce the potential for random cracking. However, this can lead to variable crack widths at the planned transverse joints. Place roofing felt or a geotextile fabric over cracks that open significantly before placing an abutting lane.
- Only use skip sawing when there are no options.
- Consider adjusting the concrete mixture or paving procedure before using a skip saw technique.

e. Joint reservoir beveling (chamfering) at transverse joints increases angles at joint corners from 90 to about 120 degrees.

- Beveling reduces the potential of damage from snow removal equipment.
- A major disadvantage is the cost increase to install a beveled sealant reservoir.
- If beveling is used, calculate the shape factor based on the depth of sealant at the point where the joint face is vertical.

9-8 JOINT CLEANING BEFORE SEALING.

Joint reservoir cleaning before joint sealing ensures long-term service of the sealant. The following items are essential.

a. Immediately before sealing, thoroughly clean joints of all laitance, curing compound, and other foreign material.

b. Use sandblasting, wire brushing, water blasting, or some combination of these tools to clean the joint.

- Sandblasting or wire brushing is preferred.
- Prime joint faces immediately after cleaning.
- Perform sandblasting with great care because of the risk of sand particles filling the joint.
- The procedure for sandblasting applies it only to the joint face where the sealant will adhere.
- When sandblasting, hold the nozzle at an angle to prevent penetration of sand particles deeper into the joint.

c. Air blasting is the final cleaning step. The air stream must be free of oil. Many modem compressors automatically insert oil into the air lines to lubricate air-powered tools. For joint cleaning, disconnect this line and install an effective oil and moisture trap. In most cases, the inside of the hose of a lubricating air compressor is coated with oil. Use new hoses to clean joints. When air blasting, hold the nozzle no more than 50 mm (2 in.) from the pavement surface to blow debris at the front of the nozzle.

d. Once air blasting is complete, backer rod installation and sealant application can take place. Repeat air blasting at those joints remaining open overnight or for extended periods.

9-9 JOINT SEALING ISSUES.

Critical issues regarding joint sealing for pavement include timing of reservoir widening, beveling, joint cleaning, depth of sealant, and timing of sealing. Other joint sealing considerations include the following.

a. Joint sealants are used in concrete pavement joints to keep out damaging material and minimize infiltration of water.

b. To perform to expectations, sealant materials must be capable of withstanding repeated extension and compression as the pavement slabs expand and contract with temperature and moisture changes.

c. The size and shape of the sealant cross-section affects the sealant material performance.

d. In refueling locations and any airfield pavement area subject to fuel spillage, jet-fuel-resistant sealants are necessary.

e. Timing of sealing operations may vary from:

- As soon as possible
- Prior to placing the adjacent lane
- When the pavement achieves the minimum flexural strength for construction traffic
- Prior to grooving operations

f. Overall, it is better to wait as long as possible to seal the joints:

- Hard debris can infiltrate a green cut, causing spalling.
- The benefits of waiting to seal joints can outweigh the disadvantage of debris intrusion.
- Use a temporary filler such as backer rod or rope to prevent debris from infiltrating joints.
- Temporary filling of joints is a good practice to minimize infiltration by construction debris.

g. Clean joints are necessary for all sealant materials to perform properly.

9-9.1 Hot-Poured Joint Sealing Material.

Hot-poured sealants usually consist of some combination of asphalt, coal-tar, and rubber. Before sealing joints, the contractor must demonstrate that the equipment and procedures for preparing and placing the sealant will produce a satisfactory joint seal. The sealant must bond to the concrete surface of the joint walls, have no voids, and tack-free after a specified time period. The key to achieving good joint sealing include the following.

a. Install the closed-cell backer rod to the appropriate depth to achieve the right shape factor.

b. The backer rod should not bond to the concrete or sealant. If bonding occurs, it induces stress into the seal.

c. The backer road must be compressed about 25 percent if it is to maintain its position in the joint.

d. The heating kettle should be an indirect heating type. Direct heating elements can cause changes in materials properties. Kettles also need agitators to prevent localized overheating. Overheated material can lose plasticity. Discarded overheated material.

e. Fit the application wand with a re-circulation line. Otherwise, sealant in the hose can drop below application temperature.

f. Fill the reservoir from bottom to top. Take care to apply the sealer so the material is solid, with no entrapped air.

g. Conduct a trial installation to verify the sealant can achieve a good bond.

h. The sealant must recess from the surface to provide protection from early traffic.

9-9.2 Cold-Poured Joint Sealing Material.

Cold-poured sealants are usually polysulfides, polyurethanes, or silicones. The material is a single component ready to use or a two-component material requiring onsite mixing. Before sealing joints, the contractor should demonstrate that the equipment and procedures for preparing, mixing, and placing the sealant will produce a satisfactory installation. The sealant must bond to the concrete surface of the joint walls, have no voids, and must be tack-free after a specified time period. The following are key items to consider.

a. Depending on the material and the recommendation of the manufacturer, the cold poured materials may be mixed in a paddle wheel or other mixer or fed from separate containers to a mixing nozzle that injects the material into the joint.

b. Silicone is either self-leveling or non-self-leveling. These materials cure by chemical reaction, transforming from a liquid state to a solid state.

c. Check the potential for incompatibility between silicone seals and the concrete aggregates. A silicone sealant that does not develop proper bond with aggregates is going to fail.

d. Aggregate surface moisture at the time of sealing can affect the bond between silicone and concrete. Consider the use of a joint primer provided by the manufacturer to ensure the silicone seal develops a satisfactory bond.

e. Cold-poured materials are generally more sensitive to moisture in the reservoir; therefore, it is essential to ensure reservoirs are dry when installing sealant.

f. Cold-applied joint sealing compounds are applied by pressure equipment that forces the sealing material to the bottom of the joint and completely fills the joint without spilling material on the pavement surface.

g. Non-self-leveling sealants require additional tooling to maintain the required depth of sealant. Employ tooling on non-self-leveling sealants before the material cures.

9-9.3 Preformed Joint Sealer.

Most preformed seals are made of extruded neoprene rubber. These sealants are also called compression seals. The neoprene material is compressed and inserted into the joint reservoir. The pre-compression amount is based on the anticipated movement of the joint over the service life of the sealant. The key aspects of achieving a good preformed sealant application include the following.

a. For the sealant to be effective during its service life, the sealant material must be maintained in the sealant reservoir at a minimum amount of compression (it is always in compression).

b. Follow the sealant manufacturer’s recommendations for sealant sizing and installation.

c. Insert the sealant using a device that uniformly compresses the sealant with nominal stretch.

d. The sealant must be lubricated, straight, vertical, and not damaged.

e. The installation device should not stretch the sealant. Stretching reduces the allowable sealant compression and sealant failure can occur. The maximum stretch is 2 percent.

f. There are two ways to check for stretching.

   1. First, insert the sealant in a known length of joint and then remove the material and measure the extracted length.

   2. The second method is to pre-measure a length of sealant. A permanent mark is placed on the roll. After installation, the length of the installed sealant is measured.

9-10 TROUBLESHOOTING GUIDE.

Early age cracking problems are discussed in Appendix D. These problems may be due to a single cause or a combination of causes. The troubleshooting guide in Table 9-2 discusses the non-cracking problems associated with joint sawing and sealing.

Table 9-2 Troubleshooting Guide for Joint Sawing and Sealing

Problem	Probable Cause	Corrective Action
Poured joint sealant adhesion failure	• Joint face not clean • Joint shape factor not correct	• Check joint face for cleanliness • Check joint shape factor • Replace sealant
Poured joint sealant cohesive failure	• Sealant properties poor due to overheating or underheating	• Reduce heat • Apply proper heat • Use insulated hoses • Replace sealant
Loose preformed sealant	• Sealant not sized properly • Joint width too large • Sealant stretched	• Use properly sized sealant • Check joint width • Check sealant quality • Review installation procedure
Raveling or spalling of joint face.	• Sawcutting performed early • Poor sawcutting operation • Joint area not cured properly	• Apply curing compound after first cut • Delay the reservoir cut • Review sawcutting operation • Review joint face curing process

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CHAPTER 10 IMPLEMENTING CQC REQUIREMENTS

10-1 INTRODUCTION.

The implementation of CQC programs in this chapter is limited to the framework of the project CQC plans in Chapter 3. Operational issues are presented instead of actual test performance.

10-2 CQC TESTING AND PRODUCTION PLANS.

The CQC plan should be specific and contain enough detail to implement during construction. For example, basic requirements of a QC plan for slump testing in fresh concrete may include the following:

- Specification item: PCC paving
- Item description: Process control testing
- Type of field or laboratory test: Slump of fresh concrete
- Test standard: ASTM C143/CRD-C 5
- Test frequency:
  - First three trucks each day
  - One test per 50 yd^3 (40 m^3)
- Responsibility: QC paving technician
- Specified tolerance: 40 mm ±25 mm (1.5 in. ±1.0 in.) (action limits) and ±38 mm (±1.5 in.) (suspension limits)
- Corrective action:

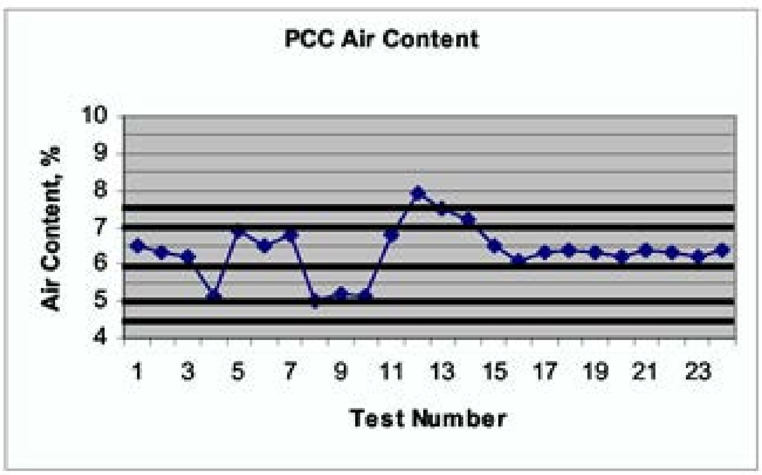
  If one individual slump test is outside the action limits, test the next three trucks. If those tests are within the action limits, then resume the normal testing frequency. If at any time one individual slump test is outside the suspension limits or two consecutive slump tests are outside the action limits, halt production and test each truck enroute. If the slump of any of the remaining trucks is outside the action limits, reject the loads. If the slump tests for the remaining trucks are acceptable, place the material. Production paving should not be resumed until the contractor has identified the problem and implemented corrective action. After concrete placement resumes, test the first three trucks for slump. If those tests are within the action limits, resume the normal testing frequency.

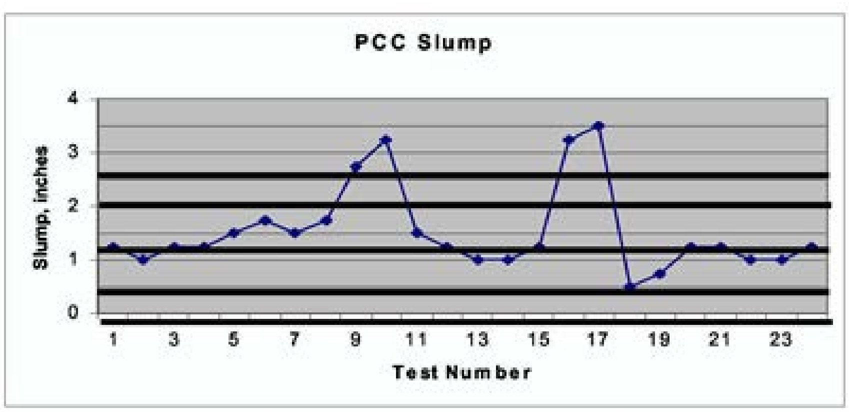
  Although it is impossible to account for all scenarios in the CQC plans, it is important to outline the procedures for known or possible recurring problems. CQC plans fail when there is no clear corrective action plan for each tested item.

10-3 CONTROL CHARTS.

Control charts (Figure 10-1) provide the inspection and testing team and senior management a summary of the construction process. Control charts are excellent tools to track trends and anticipate problems. The benefits of using control charts include the early detection of problems, monitoring variability, and establishing the process capabilities. Similar to other documentation on a construction project, control charts are only useful when updated and adjustments implemented on a timely basis. The CQC plan must contain a detailed procedure identifying which items require control charts, the information presented on each control chart, the required posting time, and distribution. Control charts should include individual test results, the average of all test results, and action limits at 3 standard deviations (3s). Action limits should not be based on specification requirements. Each contractor's process has a unique variability that dictates where to place the 3s limits.

Figure 10-1 Example Control Charts





10-4 TESTING PROCESS.

Field laboratories follow the same standards as permanent facilities for each test conducted (for example ASTM C1077/CRD-C 553 requirements). Items to address for a field laboratory include:

- Sufficient capacity for properly curing beams and cylinders. If curing tanks are used, identify the method that controls the water temperature, water level, and lime content of the water.
- Sufficient area for properly separating or quartering aggregates for testing.
- Calibration of testing and monitoring equipment, including test machine scales, sieves, and laboratory thermometers, by certified/qualified source. When practical, separate agencies perform calibration for QA and QC.
- Calibration of all field testing equipment, including air meters, slump cones, and field thermometers.

10-4.1 Definitions.

When test methods are specified and the variability in a test method affects the pay factor, it is important that the engineer and contractor understand the limitations inherent in the test methods as stated in their precision and bias statements. The following definitions are derived from ASTM E177.

10-4.1.1 Accuracy.

Accuracy refers to how close a test result is to a reference value and incorporates both the imprecision of the measurement and the bias of the test method.

10-4.1.2 Precision.

Precision refers to closeness of agreement between test results obtained under like conditions. The greater the scatter in test results, the poorer the precision.

10-4.1.3 Bias.

Bias is the consistent difference between a set of test results and an accepted reference value of a property being measured. When an accepted reference value is not available, bias cannot be determined.

10-4.1.4 Components of Variability.

Variability in a measured construction attribute may be due to:

- Natural (material) variability
- Variability introduced by the construction process
- Testing variability is introduced through the precision (or lack of precision) and bias of the test method

10-4.2 Achieving Quality.

Three conditions must be consistently met to achieve high levels of quality.

1. The process is stable (only common cause variability is present).
2. The process is capable (common cause variability must be small enough to permit consistent results within the specified tolerances).
3. The process is on target (the process is consistently performing near the specified target).

10-4.3 Subgrade, Subbase, and Base Testing.

Major testing items for subgrades, subbases, and bases include material characteristics such as gradation and appropriate density and moisture values, thickness, and grade control. A smooth, uniform pavement starts at the subgrade. The uniformity of these layers affects the overall performance of the pavement. If failed material is placed on the grade, typical remediation blends in loads of good material. However, to maximize quality, remove the failed material to reduce material variability. Items to address in CQC plans include:

- Density requirements for each material lift
- Density requirement for each different subgrade type
- Maximum and minimum placement thickness
- How to determine the target density for each material type
- Gradation requirements for each material
- Testing frequency and location for all tests
- Mix design requirements for stabilized layers
- Process for documenting, reporting, and distributing all test results, including schedule
- Action list for handling failed test results

10-4.4 Fresh Concrete Testing.

Take representative samples of concrete placed for paving. Collect from several different discharge areas. Remix the sample before performing any tests and keep the sample covered with a plastic sheet to prevent evaporation. Testing of fresh concrete typically includes assessing the air content, slump, temperature, and the unit weight. Consider the following items for concrete testing.

a. Properly calibrate meters for air content testing (ASTM C231/CRD-C 41, *Pressure Method*, and ASTM C173/CRD-C 8, *Volumetric Method*). Pressure meter accuracy depends on the altitude at which it is calibrated. Repeat tests before considering concrete out of specification.

b. The slump test (ASTM C143/CRD-C 5) determines consistency, but not necessarily the workability of concrete. Clean and pre-wet the cone for each test. Repeat test using another sample before deciding concrete is off specification.

c. Record the temperature of the fresh concrete (ASTM C1064/CRD-C 3) every time strength specimens are made and whenever concrete temperatures are suspected of nearing specification limits.

d. The density of the fresh concrete (ASTM C138/CRD-C 7) can indicate a possible change in air content and determines yield. Properly calibrate the container.

e. Although these tests are widely used and understood, often the details of the testing requirements are not. It is important for the contractor and inspectors to review testing standards and agree on testing procedures. Describe these details and logistics in detail in the CQC plans. Items to address in the CQC plans include:

- Testing frequency
- Testing location (**Note:** Testing is conducted at the plant or onsite to determine the effect transporting the concrete has on basic concrete material properties.)
- The process for updating and distributing control charts
- Clearly defined action items for test results that do not conform to the specifications or standards

Obtaining a representative sample of fresh concrete is very important to ensure reliable test results. Take the fresh concrete sample from the center one-third of the batch. The CQC plans need to address the location of sampling within each batch for each type of concrete delivery vehicle. Control charts are useful for evaluating fresh concrete test results. Create action and suspension limits for each test and in the CQC plans address the specific actions to take when test results are outside the action or suspension limits.

10-4.5 Thickness Testing.

Pavement thickness is tested in several ways. It is checked by using paving stringline as a guide, performing destructive testing by excavating non-stabilized material or taking cores from stabilized material and concrete layers, or surveying elevations before and after placement. Coring is the preferred method. Preferably, label and store cores (typically 100 mm [4 in.] in diameter) onsite until the end of the project. Items to address in CQC plans include:

- Testing frequency and location
- Clearly defined procedures for locating, measuring, and reporting the test results
- For projects with stabilized open-graded drainable bases, agree on the procedure to determine the bottom of the core

- Avoiding thickened edges and transition areas for test locations

10-4.6 Aggregate Tests (Gradation and Moisture Content).

Aggregate gradation testing varies based on the specifications for bases, stabilized bases, trench backfill, and concrete. Since projects use large quantities of aggregate, testing the gradations can become overwhelming. Items to address in the CQC plans include:

- Testing frequency
- Requirements for stabilized bases and concrete mixture verifications
- Sampling location (stockpiles or individual trucks)
- Aggregate moisture content tests - frequency (ASTM C70/CRD-C 111, ASTM C566/CRD-C 113)
- Gradation in fresh concrete, washed gradations
- Clearly defining action items when the aggregate fails the gradation tests
- How to determine the limits of unacceptable material
- Developing a clear reporting process to ensure timely distribution of test results
- Verifying bulk specific gravity of each aggregate at designated times throughout the project. This is not practical on a smaller project (less than 42,000 m^2 [50,000 yd^2])

10-4.7 Strength Testing.

Strength testing may include flexural and compressive testing.

10-4.7.1 Flexural Strength Testing.

Due to the importance of strength in the design and acceptance of pavements, flexural strength testing requires attention to detail. Test results are affected by minor changes in procedures that can lead to increased variability and, in some cases, suspect results. The test machine must be calibrated and operators must understand the testing requirements. Check the beam tester for the correct load and rate of loading and check for uniformity of loading (load distribution) between the two supports and across the width of the beam. Field supervisors must monitor the handling of the test specimens at the job site, during transportation, and at the laboratory. Beams are vulnerable to damage in handling and transport. Damaged beams will yield low strength results. Items to address in the CQC plans include:

- Location of material sampling, such as at the plant or delivery truck, or on-grade in front of the paver
- Sample fabrication location
    - Near the material sampling point

  - o Onsite laboratory

- Ensuring that requirements concerning the time allowed between material sampling and beam fabrication are met
- Dimensions of beam samples. Typically, 150 by 150 by 530 mm (6 by 6 by 21 in.) specimens are used
- Type of beam molds allowed: plastic or steel
- Fabrication procedures
- Field curing, transportation, and laboratory procedures
- Frequency of testing
- Number of beams per sample location
- Determination of sample locations
- Curing requirements for additional beams to be made for other reasons, such as opening to traffic (field cured or laboratory cured)
- Use of a consignment form that tracks each concrete sample from fabrication, field curing, transportation to laboratory, laboratory curing, and testing
- Procedure for disposition of possibly damaged beams and results of known bad tests

10-4.7.2 Compressive Strength Testing.

Compressive testing may be required in addition to flexural strength testing. Even if not required, it may be preferable to make companion sets of cylinders along with beams. The cylinders may help resolve future disputes over the in-place strength of the concrete pavement if flexural strength testing is found to be questionable. Items to address in the CQC plans include most of the flexural strength testing items previously discussed. Cylinder specimens are less vulnerable to damage in handling and transport than beam specimens. Coring, core conditioning, and core testing are conducted in accordance with ASTM C42/ CRD-C 26 and the use of the splitting tensile strength test is conducted in accordance with ASTM C496/CRD-C 77.

10-4.7.3 Core Strength Testing.

When beam or cylinder strength tests are not performed adequately or if test results are suspect, consider core strength testing to determine the strength quality of the in-place concrete. If core testing is used, consider the following items.

a. Test cores for compressive or splitting tensile strength.

b. Use core strength test results in accordance with established procedures, as defined in the specifications. These procedures typically involve use of project-specific correlations between the core strength and the beam or cylinder strength.

c. Initiate core testing at a test age close enough to the specified test age for the flexural or compressive strength testing.

d. Core conditioning before testing is important.

- Air-dry conditioning typically results in higher compressive or split tensile strengths.
- However, condition cores as defined in the project specifications.

10-5 EDGE SLUMP/JOINT FACE DEFORMATION/PROFILE TESTING.

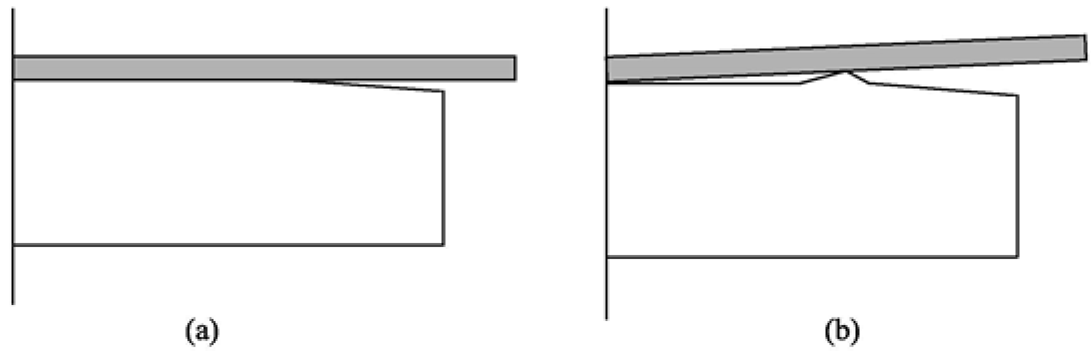
Excessive edge slump and joint face deformations under slipform paving are indications of improper concrete mixture proportioning, improper concrete placement, or improper equipment operation.

10-5.1 Edge Slump Testing.

Typical specifications require that edge slump not exceed 6 mm (0.25 in.) over 15 percent of the joint length and that edge slump be no greater than 10 mm (3/8 in.). Checking for edge slump requires a straight edge and level adjusted for the cross-slope, as shown in Figure 10-1. Edge slump can be measured on either fresh or hardened concrete. The straight edge must be of sufficient length, typically 3.1 to 3.7 m (10 to 12 ft), to support itself on the central portion of the slab and away from the area of edge slump, 300 to 600 mm (12 to 24 in.). Inspectors must be aware that small bumps or deviations, exaggerated in Figure 10-1 (b), might yield incorrect results. Items to address in the CQC plans include:

- How soon to begin edge slump testing
- Frequency of edge slump testing
- Detailed procedure, agreed upon by QA and QC, for measuring the edge slump
- Agreed upon corrective action for edge slump that occurs in the fresh concrete and the hardened concrete
- Is the contractor allowed to correct excessive edge slump in fresh concrete?
- Are temporary forms allowed in areas where edge slump is excessive?
- Is sawing of the edges of the hardened concrete an acceptable solution for edge slump? The distance back from the edge depends on the amount of edge slump.

Figure 10-2 Measurement of Edge Slump



10-5.2 Joint Face Deformation.

Items to address in the CQC plans include:

- Are the joint face tolerances the same for transverse and longitudinal joints?
- How are headers handled? Are they part of the testing or are they excluded?
- Can vertical deviations be corrected with concrete saws? If yes, do the cuts have to be full-depth?

10-5.3 Surface Smoothness Testing.

Conduct surface smoothness testing, per the project specifications, that may use a straight edge or a profilograph.

Items to address in the CQC plans include:

- Type of equipment allowed
- Method of evaluation used
- Are the criteria different for different facilities?
- Are any areas excluded?
- Are headers included in the smoothness evaluation?
- How soon after paving is profile testing conducted?
- If a straightedge is used, will the testing be continuous, random, or subjective?
- If using a rolling straightedge, where will the testing occur? In the center of the slab, near the longitudinal paving lane joint, or at the third points of the slab?
- If multiple passes are required, are these per lane or per paving width (which may incorporate two or more lanes)?

10-6 DOWEL BAR ALIGNMENT AND INSPECTION.

Specifications for dowel bar misalignment limit the skew misalignment and horizontal and vertical displacements. Items related to dowel bar placement to address in the CQC plans include:

- Dowel bar material transmittals and bond-breaker coatings
- Detailed procedures for transporting, storing, inspecting, installing, and securing dowel bars
- Detailed procedures for dowel bar inserters (roadways only) that include random checks to ensure equipment is operating properly
- Checking dowel bar assembly for trueness to eliminate skewed bars
- Allowable dowel bar misalignment and how to measure
- Joint saw cut line deviation: How much is acceptable with regards to dowel bar embedment?
- Permissible number of misaligned dowel bars per joint per panel

Note that dowel bar alignment is measured only for pre-placed baskets before concrete placement and for drill and grouted dowels along the longitudinal construction joints. The inspector must ensure that pre-placed baskets are properly positioned and fastened and that the paver operation does not indicate any potential for moving or dragging the dowel basket assemblies. For drill and grouted dowel bars, check the alignment after the epoxy grout sets. Cut and install new dowels for any dowel bars that are misaligned beyond the allowable limits. For machine-inserted dowel bars, as well as the pre-placed dowel bars, ground penetrating radar (GPR) can check the alignment after the concrete is about one day old. However, GPR testing can only determine vertical dowel bar alignment to an accuracy of 3 to 6 mm (1/8 to 0.25 in.); therefore, coring may be required for complete verification of dowel bar placement.

CHAPTER 11 EARLY DISTRESS REPAIR

11-1 INTRODUCTION.

Concrete pavements can exhibit early distress. This occurs while the concrete is in plastic state or soon after hardening. When early distress is observed, identify the cause of the failure and take appropriate corrective measures to reduce the potential for reoccurrence. It is good practice to discuss the disposition of slabs that exhibit early distress at the pre-construction meetings. Commonly encountered early distress are:

- Plastic shrinkage cracking
- Edge slump
- Joint spalling
- Full-depth cracking

11-2 PLASTIC SHRINKAGE CRACKING.

Plastic shrinkage cracking is surface cracking that may develop if the rate of evaporation at the surface is high. Plastic shrinkage cracking typically manifests as shallow 25 to 75 mm (1 to 3 in.) deep, closely spaced parallel cracks. In some cases, the cracking may extend deeper than 75 mm (3 in.) but it is unusual for the cracks to be full depth. It is recommended to take 100-mm (4 in.) -diameter cores over a few cracks to determine the depth of cracking. Repair plastic shrinkage cracking by injecting low-viscosity epoxy or high molecular weight methacrylate in each crack after concrete has hardened. Follow epoxy injection procedures in accordance with the epoxy manufacturer's instructions. The gravity-fed epoxy technique is not recommended, as the crack penetration is not fully effective. Cracking deeper than 75 mm (3 in.) or extensive cracking requires slab removal and replacement (paragraph 11-5).

11-3 EDGE SLUMP.

When a slipform paver pulls forward, there is a tendency for the unsupported edge to slump down at the edge, with depression extending inwards on the slab. If excessive edge slump occurs, adjust the concrete mixture, the paving equipment, or the paving operation. Edge slump is a serious defect because it creates an area for ponding of water and can affect joint performance.

11-3.1 Plastic Repair.

If the edge slump is detected before initial set of the concrete, a plastic repair can be attempted. The repair of edge slump must be carried out correctly to ensure durability of the repaired area. Important items to consider are as follows.

a. The edge must be formed along the repair area.

b. If additional material has to be added to repair the edge slump, the added material must contain a mixture of aggregate particles. Plain mortar addition is not allowed.

c. The repair area material must be vibrated into the existing material.

d. Repair should not be attempted after the curing compound has been applied as the repair area concrete can become contaminated with the curing compound.

e. If initial set has occurred, vibration is ineffective; it is too late to make a plastic edge slump repair.

f. Use of plain mortar or addition of material to hardened concrete may lead to spalling.

g. After vibrating the repaired concrete, screed and finish as uniformly as possible with the surrounding concrete.

h. Texture and cure the repaired area using the same processes as the surrounding concrete.

i. Plastic repairs should be the exception.

Note: Edge slump repairs should be isolated problems and not routine occurrences. If excessive edge slump is occurring, stop the paving until the problem is corrected.

11-3.2 Hardened Pavement.

If edge slump repair cannot be done in a timely manner, it may be necessary to allow the affected slab panels to harden and repair by:

- Sawing the slumped edge and performing a partial-depth repair at the surface depression
- Removing and replacing the slab with excessive edge slump

11-4 JOINT SPALLING.

Joint spalling or excessive joint raveling may develop as a result of the joint sawing operation—typically due to early joint sawing, use of wrong blade type, or poor operation of the sawing equipment. Minor or localized joint spalling is typically repaired using a partial-depth repair technique with the concrete mixture used for paving. If the spalling is severe and excessive in length, consider replacing the affected slab.

11-5 FULL-DEPTH CRACKING.

Localized full-depth cracking may result from the following causes:

- Late transverse joint sawing or insufficient depth of sawing
- Misaligned dowel bars
- Excessive curling or warping
- Rapid surface cooling
- Early-age loading by construction equipment
- Excessive drying shrinkage

- Excessive base frictional restraint

Full-depth cracking that appears within 30 days is usually the result of poor construction practices, poor design, or both. Important items to consider for repair of full-depth cracking include the following.

a. Replace panels in critical pavement areas with full-depth cracking that extends the full width or length of the slab panels. Critical pavement areas are those areas subject to aircraft landing gear loading.

b. Full-depth cracking in non-critical pavement areas (most exterior lanes of a runway or taxiway) may be left in place at the option of the owner. Rout and seal the crack.

c. Treat full-depth cracking in critical pavement areas that extends less than one-third the width or length of the slab as full-width cracking.

d. Repair full-depth corner cracking in critical pavement areas by full panel replacement.

e. Avoid using partial panel replacement in critical pavement areas on new pavement.

f. Follow proper procedures for slab removal and replacement. The procedures must include the following.

  - Remove slabs without damaging adjacent sound slabs or the base.
    - Use double saw cutting along slab perimeter.
    - No heavy impact loading to break slab into small pieces.
    - Sawcut panel into smaller segments and lift out.
  - Inspect the base for damage and correct before concrete placement.
  - Restore load transfer along all joints with dowel bars using the drill and epoxy grouting technique.
  - Use approved concrete mixtures for hand placement operations.
  - Use vibration to consolidate the concrete.
  - Use proper techniques to finish, texture, and cure the replacement slab.

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APPENDIX A PRECONSTRUCTION REVIEW CHECKLIST

A-1 GENERAL ITEMS.

- Identify the chain of command in the decision-making process.
- Identify roles and responsibilities of key staff for all involved parties.
- Review all design and construction changes issued since bid.
- Certification of materials sources.
- Mix design submittals.
- CQC laboratory and personnel certifications.
- Batch plant certification and mixer efficiency tests.
- Construction schedule.
- Sub-contractor activities.
- Haul roads and access points.
- Conduct a joint half-day construction workshop.

A-2 BATCHING ACTIVITIES.

- Stockpile management.
- Aggregate moistures and added mixture water.

A-3 SUBGRADE.

- Review soil testing reports.
- Cut and fill plans.
- Borrow and waste areas.
- Acceptable fill.
- Removal of organic material or unacceptable soil.
- Procedures when cut depths exceeds engineer's estimate.
- Review of compaction requirements and acceptance testing (moisture and density).
- Proof rolling requirements and acceptance criteria.
- Expected production rates and tentative schedule.

A-4 SOIL STABILIZATION (IF APPLICABLE).

- Review soil stabilization QC plan.
- Review soil data regarding stabilization requirements.
- Mix design submittals (per soil type).

- Field testing requirements and frequency (soil gradation, minus No. 200, plasticity, density, strength, lime/cement/fly ash content, depth, grade elevation).
- Tentative division of project into various areas based on soil stabilization requirements.
- Identification in field as to soil type and stabilization requirements (visual or plasticity testing).
- Who is responsible in field for approving soil stabilization requirements and acceptance?
- Plasticity testing frequency or procedures to further subdivide area based on soil type.
- Trimming procedures and equipment.
- Disposal of trimmed material.
- Initial mixing and production requirements (calendar day restrictions).
- Lime spread rates.
- Minimum passes with mixing equipment.
- Mellowing and curing periods.
- Moisture control and limits during compaction.
- Ambient temperature requirements prior to covering.
- Moisture density, soil classification, pH, lime content, liquid and plastic limit, soluble sulfate, density, strength, and thickness acceptance testing frequency and procedures.
- Allowances for unprotected soil stabilization (protection requirements for various time periods and paving season).
- Allowances for finishing high then re-trimming if stabilized soil is not protected.
- Expected production rates and tentative schedule.

A-5 STABILIZED BASE.

- Review base stabilization in QC plan.
- Mix design submittal.
- Specifications and lot areas.
- Mixing procedures and quantity verification.
- Water content, strength, thickness verification, and grade testing and acceptance procedures.
- Weather (temperature) limitations for mixing and placement on-conformance procedures (under thick, under strength, and over strength).

- Placement procedures and cold joints.
- Rough grading and finish rolling procedures.
- Jointing procedures.
- Moist curing and curing membrane (coverage, time, and material) requirements.
- Aggregate durability, soundness, abrasion, and gradation test data and requirements.
- Grade survey issues (who decides action to be taken if grade is a concern).

A-6 CONCRETE PAVING/PLACING/FINISHING/TEXTURING/CURING.

- Placement and filler lane scheduling.
- Base conditioning.
- Equipment breakdown procedures.
- Maximum concrete haul times.
- Placement procedures.
- Thickness verification during placement.
- Hot/cold weather specifications and precautions.
- Vibrator testing/consolidation issues.
- Curing and texturing procedures.
- Drill and epoxy grouting of dowel bars.
- Tie bar/dowel alignment, spacing, offset verification.
- Straight edge and edge slump tolerances.
- Plastic shrinkage cracking, edge slump, joint spalling, and full-depth cracking treatments.

A-7 JOINT SAWCUTTING.

- Review of sawcutting QC plan.
- Use of early entrant saws.
- Backup saws.
- Rain conditions and skip sawing procedures.
- Reservoir and sealing installation and acceptance procedures.
- Sawcutting sequence and acceptable degree of sawcut raveling.
- Initial and reservoir cut dimension tolerances and dimensions.
- Joint sealant and backer rod material submittals.

- Removal and flushing of joint sawing residue.
- Joint beveling procedures.
- Sealant and concrete curing time.
- Sand blasting, reservoir cleanliness, and moisture condition requirements before sealing.
- Sealant depth tolerances.
- Reservoir priming material requirements.
- Sealant pump, water truck, and sawcutting equipment.
- Allowable ambient temperatures during sealing operations and compression seal reservoir requirements.
- Joint inspection procedures.

A-8 CQC ACTIVITIES.

- Review contractor's QC plan.
- Aggregate durability, soundness, abrasion, and gradation test data and requirements.
- Reinforcing steel and dowel bar submittals.
- Materials sampling and testing procedures.
- Using control charts.
- Concrete mixture designs and w/cm ratio effects on strength.
- Concrete beam sampling, fabrication, curing, and testing procedures.
- Sampling and pay factor computation overview.
- Effects of strength/thickness variability on pay factor.
- Determining locations for thickness tests.
- Partial lots consideration.
- Treatment of premature cracking and spalling.
- Edge slump and smoothness testing and timing.
- Actions to be taken if specification requirements are not met.
- Documentation of test results and deviations.
- Verification of failing acceptance tests, retesting, and referee testing.

APPENDIX B INSPECTION AND TESTING CHECKLIST

B-1 INSPECTION.

B-1.1 Materials.

- Cement and fly ash tickets conforming to accepted and approved sources.
- Approved liquid admixture type and manufacturer conforming to submitted mixture designs.
- Water testing requirements (suitable for concrete).
- Approved curing compound type and source.
- Approved joint sealant and type.
- Approved backer rod material.
- Approved expansion joint filler and dimensions.
- Certifications for embedded steel and dowel bars.
- Approved epoxy for dowel bar grouting.

B-1.2 Equipment.

- Batch plant inspection completed.
- Certification of scales (load cells/belts), water meters, liquid admixture dispensers.
- Batch plant and agitator truck mixer uniformity tests.
- Concrete haulers clean and free of debris and oil.
- Daily verification of slipform vibrator frequency and amplitude.
- Verification of spud vibrator and pan/surface vibrating screed frequency and amplitude.
- Sufficient number of saws to minimize potential for random cracking.
- Curing compound coverage and uniformity tests approved.
- Saw blades suitable for coarse aggregate type.

B-1.3 Base Condition.

- Grade acceptance.
- No equipment damage from loose debris.
- Moisture conditioning of base (granular).
- Application of bond breaker (stabilized base).
- No standing water or frost.
- Transverse grade checks off of string lines or forms.

B-1.4 Embedded Steel and Dowel Bars.

- Tie bar length, diameter, and epoxy coatings.
- Dowel bar length, diameter, and coatings meeting project/plan requirements.
- Dowel basket location, elevation, orientation, and alignment.
- Dowel baskets secured to base.

B-1.5 Concrete Batching.

- Use of stabilized pads for aggregate stockpiles (if required).
- Procedures to mitigate aggregate contamination.
- Uniform stockpile loading.
- Sprinkling for consistent aggregate moistures.
- Utilization of actual aggregate moisture contents.
- Computer printouts of date, time, mixing time, dry batch weights, water, and liquid admixtures.
- Procedures to document added water after batching.
- Minimum mixing times meeting mixer uniformity testing requirements.

B-1.6 Concrete Placement Conditions.

- Concrete placed within specified time after batching.
- Cold weather requirements (air temperatures, no ice in aggregates, initial concrete temperatures).
- Hot weather conditions (air temperatures, initial concrete temperatures).
- Plastic shrinkage potential (air temperatures, initial concrete temperatures, relative humidity, and wind speed).
- Foggers, windbreaks, and evaporative retardants (hot weather) are available.
- Polyethylene sheeting (or other approved covering) available in the event of rain.

B-1.7 Concrete Placement.

- Uniform placement in front of paver.
- No large pockets of entrapped air or voids at vertical slipformed edge.
- Transferring of accurate location for sawed transverse joints.
- Control chart action/suspension limits.

B-1.8 Concrete Consolidation and Finishing.

- Closed surface and adequate consolidation at inserted dowel bars.
- Minimizing concrete floating/finishing after striking off and consolidation.
- Minimizing application of water to surface during final finishing.

B-1.9 Concrete Placement Tolerances.

- Verify interior thickness and at slipformed edges regularly.
- Check final elevation of wire stretched transversely across pavement.
- Edge slump checks.
- Edge shoring needs and procedures.
- Straightedge testing.

B-1.10 Concrete Curing.

- Application of curing compound within 60 minutes of final finishing.
- Curing compound coverage rates and uniformity.
- Vertical longitudinal edges covered with curing compound.
- Minimum concrete curing temperature requirements.

B-1.11 Joint Sawcutting.

- Sawcut depth (initial and reservoir cuts).
- Alignment in relation to transverse joint dowel baskets.
- Acceptable amounts of spalling/raveling.
- Sawcut carried through vertical edge.
- Water/slurry containment.

B-1.12 Opening to Construction Traffic.

- Minimum strength and time requirements.

B-1.13 Joint Dowel Bar Installation (Construction Joint).

- Dowel bar elevation, spacing, alignment, and minimum clearance from transverse joints.
- Dowel bar diameter.
- Drilled hole dimensions meeting specification/plan requirements.
- Epoxy injection procedure.
- Use of epoxy retainer disks.

B-1.14 Joint Sealing.

- Sealant reservoir dimensions.
- Reservoir cleanliness.
- Backer rod placement.
- Sealant curing temperatures meet manufacturer's recommendations.
- Recessed sealant depths.

B-1.15 Grooving.

- Groove depth and spacing requirements.
- Clearance requirements at joints.

B-1.16 Cracking, Spalling, and Acceptance.

- Unacceptable cracking and spalling criteria.
- Repair of cracking and spalling.

B-2 TESTING.

B-2.1 Aggregate Testing.

- Gradation and durability test requirements.
- Sampling for gradations at daily frequencies off belt or representative samples from stockpiles.
- Control chart action/suspension limits.
- Representative sampling for aggregate moistures.
- Determination of aggregate moistures at specified frequencies.
- Frequency for flat and elongated aggregate requirements.

B-2.2 Concrete Sampling, Fabrication, and Curing.

- Sampling location on grade, frequency, and randomness requirements.
- Fresh sample transport requirements; preventing loss of moisture.
- Air content and slump frequency and control chart action/suspension limits.
- Beam mold water tightness, warping requirements.
- Vibration and consolidation sequence.
- Vibrator equipment inspection.
- Initial curing moisture loss control and temperature criteria.
- Transporting molded strength specimens to laboratory for final curing.

- Final curing temperatures and conditioning.

B-2.3 Concrete Flexural Strength Testing.

- Machine calibration and setup.
- Loading rate requirements.
- Sample preparation.
- Leather shims or grinding for beam testing.
- Moisture control during testing.
- Loading rate.
- Measuring beam dimensions.
- Strength calculation.
- Documentation of sample deficiencies.

B-2.4 Core Length (Thickness) Testing.

- Random locations.
- Number of measurements.
- Average core length determination.

B-2.5 Smoothness Testing.

- Straightedge and profile equipment.
- Recommended timing.
- Grinding limits.

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APPENDIX C JOINT SAWING CHECKLIST

C-1 EQUIPMENT.

- Number of saws.
- Early-age entry saws.
- Saw blade type; compatible with concrete aggregate type.

C-2 INSPECTION ITEMS.

- Test strip sawing.
- Planned versus actual sawcut locations.
- Acceptable raveling and spalling.
- Sawcut depth (initial and reservoir).
- Timing of longitudinal joint sawing.
- Sawcut carried through vertical edge.
- Odd-shaped slabs at radii.
- High tie bar situations.

C-3 COLD WEATHER, RAIN, AND SLOW CONCRETE SETTING TIMES.

- Use of insulation or geotextile fabric.
- Check fly ash usage requirements.
- Consider early-age entry sawing.
- Consider skip sawing.

C-4 POST-CUTTING ISSUES.

- Flushing joints.
- Re-application of curing compound.
- Timing of backer rod placement.
- Early-age cracking inspection.

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APPENDIX D DECISION TREE FOR EARLY-AGE CRACKING

D-1 INVESTIGATION.

Determine cause(s) of early age-cracking immediately and action items to minimize/eliminate causes or their effects implemented before proceeding further with paving. Early-age cracking is typically classified as any cracking within the first seven days after concrete placement. However, some cracking may initiate at the slab bottom that is not visible for days or weeks. Table D-1 contains the types of cracks and possible causes and investigative techniques for each type of crack. The following are types of early-age cracking.

- Plastic shrinkage cracking
- Random cracking (no orientation)
- Longitudinal cracking
- Transverse cracking
- Corner cracking
- Cracks just ahead of sawing (pop-off cracks)
- Later age cracking (early age slab bottom cracking propagating to surface)
- Sympathy cracks
- Settlement cracks over dowel bars or tie bars
- Re-entrant cracks

Note the following when early age cracking develops:

a. Some cracking has an obvious cause and requires immediate corrective actions.

b. Marginal conditions can cause cracking.

   - Correcting one marginal condition may resolve an immediate problem but may not reduce the cracking potential for subsequent paving.
   - It is important to identify as many marginal conditions as possible and rectify as many that are under the control of the design engineer or the contractor as possible.

The process of investigating early-age distress, for which the obvious cause is not readily apparent, involves the following steps:

1. Gather relevant information.
2. Identify if the distress manifests as isolated or systematic (widespread) occurrences. If the distress is systematic, undertake a thorough review of the design features as well as all key construction procedures.

3. Work through an iteration of logical steps to pinpoint one or more causes. This involves a process of elimination, starting with obvious factors verified by field and laboratory personnel. As causes are eliminated, additional steps may require more rigorous evaluation of data, coring, and laboratory testing.

D-2 GATHER RELEVANT INFORMATION.

D-2.1 Design Information.

- Pavement thickness as designed.
- Pavement thickness as constructed.
- Joint spacing.
    - Transverse
    - Longitudinal
- Base type.

D-2.2 Concrete Mix Information.

- Cement type and source.
- Cement grind history: fresh grind / not fresh grind.
- Supplementary cementitious materials.
    - Type F fly ash source
    - Slag source
- Cement content.
- Supplementary cementitious content.
    - Type F fly ash
    - Slag
- Aggregate data.
    - Gradation: uniform / gap graded / other
    - Gradation description
    - Coarse aggregate type, source and amount
    - Fine aggregate type, source and amount
    - Coarse aggregate coefficient of thermal expansion
- Admixture manufacturer, type and dosage.
    - Air entraining
    - Water reducer
    - Other admixture

D-2.3 Environmental Data.

- Weather condition for three (3) days before paving to 14 days after or present, whichever is earlier.
- Hot/cold weather precautions taken.
- Temperature readings for three (3) days prior to paving to 14 days after or present, whichever is earlier (attach table).
- Rainfall history during and up to three (3) days after concrete paving or present, whichever is earlier.

D-2.4 Construction Data.

- Paving history.
  - Start time
  - Finish time
  - Curing time
- Method used for minimizing bond for stabilized base.
- Base surface condition.
- Concrete curing method.
  - Curing compound type and rate of application (if used)
  - Number of days of moisture curing, if applicable
- Timing of sawcut.
  - Transverse joints
  - Longitudinal joint
- Depth of sawcut.
  - Transverse joint - As specified: Actual range:
  - Longitudinal joint - As specified: Actual range:
- Dowel alignment verification results.
- Early-age loading history.
  - Construction equipment loadings
  - Drill rig loading
  - Other

D-2.5 Other Relevant Data.

- Develop distress maps. Estimate or measure crack widths. Note ambient temperature at time of distress survey.
- Update maps regularly (every day or every few days) to determine if the distress is progressive and if cracks are getting wider.

Table D-1 Early Age Cracking Types/Possible Causes/Investigation

Cracking Type	Plastic Shrinkage	Random Cracking (No Orientation)	Longitudinal Cracking	Transverse Cracking (Partial or Full Width)	Corner Cracking	Cracks Just Ahead of Sawing (Pop-off Cracks)	Late Cracking (After About 7 Days to About 60 Days or Before Aircraft Loading)	Sympathy Cracks	Settlement Cracks over Dowel or Tie Bars (not allowed on airfields)	Re-entrant Cracks
Possible Causes	High rate of evaporation - Warm temp. - Low humidity - Windy	Slab to base bonding	Late sawing for prevailing conditions	Late sawing for prevailing conditions	Early loading	Late sawing for prevailing conditions	Early-age slab bottom cracking finally becoming visible	Joints in paved lane do not match joints in adjacent lanes	Higher slump concrete	Use of odd-shaped slab panels
	Dry concrete mix	Concrete slab friction against rough base or concrete penetration into open graded base	Shallow sawing of longitudinal contraction joint in relation to actual slab thickness	Shallow sawing of transverse contraction joints in relation to actual slab thickness	Excessive curling and warping due to temperature changes or moisture loss	Sawing against high wind	Frost heave	Different joint cracking patterns in adjacent lanes	Shallow dowel bars or tie bars (not allowed on airfields)	Rigid penetrations (in-place structures)
	Dry aggregates	Reflection cracking (from base cracking)	Slabs too wide in relation to thickness and length	Slabs too long in relation to thickness and width	Dowel bars too close to each other at transverse and longitudinal joints		Foundation settlement	Joints match in location but not in type	Delay in setting time	
	Late or inadequate curing	Late or inadequate curing	Temperature drop due to sudden cold front or rain	Temperature drop due to sudden cold front or rain	Late or inadequate curing					
	Delay in finishing	Late sawing for prevailing conditions	Misaligned or bonded dowels in adjacent longitudinal joints preventing cracked joints to function	Misaligned or bonded dowels in adjacent transverse joints preventing cracked joints to function	Misaligned or bonded dowels in adjacent transverse joints preventing cracked joints to function					
	Temperature drop due to sudden cold front or rain	Shallow sawing of contraction joints in relation to actual slab thickness	Excessive curling/ warping	Excessive curling/warping						
	Material incompatibility leading to higher concrete shrinkage and delay in setting time	Poor aggregate gradation (sand too fine; gap gradation)	Poor aggregate gradation (sand too fine; gap gradation)	Retarded concrete						
	Poor aggregate gradation (sand too fine; gap gradation)		Early loading	Poor aggregate gradation (sand too fine; gap gradation)						

Cracking Type	Plastic Shrinkage	Random Cracking (No Orientation)	Longitudinal Cracking	Transverse Cracking (Partial or Full Width)	Corner Cracking	Cracks Just Ahead of Sawing (Pop-off Cracks)	Late Cracking (After About 7 Days to About 60 Days or Before Aircraft Loading)	Sympathy Cracks	Settlement Cracks over Dowel or Tie Bars (not allowed on airfields)	Re-entrant Cracks
			Infill lane restraints	High shrinkage concrete						
			Late or inadequate curing	Early loading						
			High-shrinkage concrete							
			Slab to base bonding							

APPENDIX E ROLLER-COMPACTED CONCRETE PAVEMENTS

E-1 APPLICATION.

Procedures and criteria described in this appendix are applicable to the design and construction of roller-compacted concrete (RCC) pavement (RCCP). RCCP is prohibited for airfield pavement use unless approved by the USACE TSC or appropriate TSPDWG Service representative.

E-2 GENERAL.

RCCP is a concrete paving process that involves laydown and compaction of a no-slump PCC mixture using techniques similar to that used for hot-mix asphalt (HMA) pavement. RCC combines existing HMA paving and cement treated base construction procedures with the final product of a PCC pavement. This construction technique can place a large amount of concrete quickly with no forms, dowels, or reinforcing steel. Construction cost savings of 10 to 30 percent, or even more, of the cost of slipformed or fixed formed concrete pavements have been realized. The surface smoothness and surface texture of RCC pavement is somewhat rougher and coarser than conventional concrete pavement and this tends to limit RCC pavement applications to areas where low-speed, heavy-load traffic is the primary user of the pavement. Non-pavement applications that employ a similar construction method include slope protection of embankment or dams, providing an impermeable lining for sludge drying basins or wastewater lagoons, platforms for handling containerized freight, for recycling yards, for composting yards, for log sorting yards, and for mine storage areas.

E-3 CONSTRUCTION PROCESS.

RCC is typically mixed in a continuously mixing pugmill plant located near the paving site. In the plant, the aggregates, cement, and fly ash are weighed with belt scales or volumetrically proportioned on a continuous conveyer belt, which dumps the dry materials in the pugmill, where the water is added. The pugmill provides the vigorous mixing action necessary to evenly distribute the relatively small amount of water throughout the relatively stiff, no slump concrete mixture. The freshly mixed RCC is discharged into dump trucks equipped with protective covers for hauling to the paving site. At the paving site, the base course material is graded and compacted to form a smooth, firm working platform for the RCC pavement. The surface of the base course is moistened with water just before placing the RCC and setting up stringlines along the paving lanes to guide the height of the paving screed during placement. The RCC is placed with a paving machine to a uniform density and smoothness. Immediately after placement, the fresh RCC is compacted with several passes of a dual-drum vibratory roller to the specified final densities. After the compaction, make several passes of a rubber-tired roller to tighten the surface texture of the pavement. In some instances, finish rolling with steel-drum rollers to remove roller marks. When the rubber-tire rolling is complete, keep the surface of the RCC moist using water trucks equipped with fogger spray bars until an irrigation sprinkler system is set up by the end of the day. The sprinkler system keeps the surface of the RCC pavement continuously moist for the duration of the curing period, usually seven days (although 14 days is better).

Membrane-forming curing compounds and asphalt emulsions are also successful. Cold joints are construction joints formed between paving lanes placed more than one hour apart and always between two separate days of paving. Perpendicular cold joints are formed between lanes placed perpendicular to each other, longitudinal cold joints are oriented in the direction of paving, and transverse cold joints are located perpendicular to the direction of paving, between lanes oriented in the same direction. Transverse cold joints are constructed by sawing across the ends of the paving lanes, which have been rounded off from rolling, and removing the excess material. Finally, transverse contraction joints may be cut with a concrete saw within four to 20 hours after the RCC is placed and compacted. Historically, the standard practice has been to allow the RCC pavement to crack; however, current practice is to sawcut contraction joints to improve pavement aesthetics and ease the application and maintenance of joint sealants.

E-4 SUBGRADE AND BASE COURSE PREPARATION.

The subgrade and base course should conform to the requirements outlined in UFC 3-250-01 and UFC 3-260-02. The freeze-thaw durability of RCC is not fully understood, but the long-term performance of non-air-entrained RCCP is generally satisfactory, despite marginal laboratory performance. For this reason, in areas where the pavement or base course might be subject to seasonal frost action, give particular attention to providing a base course that adequately drains any water infiltrating through the pavement or subgrade. The base course should provide sufficient support to permit full consolidation of the RCCP through its entire thickness upon compaction.

E-5 SELECTION OF MATERIALS.

E-5.1 General.

One of the most important factors in determining the quality and economy of concrete is the selection of a suitable aggregate source. The recommended RCC gradation is shown in Table E-1. This gradation is similar to gradations used for asphalt concrete. This gradation should produce an RCCP surface with relatively few surface voids. Conventional PCC mixtures are generally obtained by combining coarse and fine aggregates. The well-graded blend of aggregates given in Table E-1 may be difficult to produce from two groups due to segregation of the different-sized aggregate particles. When possible, using more than two aggregate groups (coarse and fine) at the plant provides more flexibility in blending aggregates to control the gradation of the RCC.

Table E-1 Recommended Combined RCC Gradation

Sieve Size, mm (in.)	Cumulative Percent Passing, by Weight
25 (1)	100
19 (3/4)	85–100
12.5 (1/2)	70–95
9.5 (3/8)	55–85
4.75 (No. 4)	40–65
2.36 (No. 8)	30–55
1.18 (No. 16)	20–45
0.60 (No. 30)	15–35
0.30 (No. 50)	10–25
0.15 (No. 100)	5–15
0.075 (No.200)	2–10

E-5.2 Coarse Aggregate.

The coarse aggregate may consist of crushed or uncrushed gravel, recycled concrete, crushed stone, or a combination thereof. The quality of coarse aggregate used by the Corps of Engineers to date in RCCP generally complies with ASTM C33, although satisfactory RCC is possible with coarse aggregate not meeting these requirements. Local state highway department coarse aggregate grading limits, for example, are generally acceptable. Primarily, regardless of the grading limits imposed, the grading of aggregate delivered to a project must be relatively consistent throughout the production of RCC. This is an important factor to maintain control of the concrete mixture's workability. The nominal maximum aggregate size normally should not exceed 19 mm (0.25 in.), particularly if pavement surface texture is a consideration. Using aggregate larger than 19 mm (0.75 in.) results in segregation and rock pockets are likely.

E-5.3 Fine Aggregate.

Fine aggregate may consist of natural sand, manufactured sand, or a combination of the two, and should be composed of hard, durable particles. Base fine aggregate quality on the limits given in ASTM C33 except give consideration to relaxing the maximum 5.0 percent limit of material finer than the 0.075 mm (No. 200) sieve. Canada has increased the amount of material passing the 0.075 mm (No. 200) sieve to 8 percent of the total weight of aggregates with acceptable results. Sands with higher quantities of nonplastic silt particles may be beneficial as mineral filler and may allow some reduction in the amount of cement required. However, mixtures made with fine aggregates having an excessive amount of clay may have a high water demand, with attendant shrinkage, cracking, and reduced strength. Determine the specific gravity and absorption of these sands with high quantities of fines according to Note 3 in ASTM C128. Expedient construction with RCC can utilize minimally processed aggregates such as pit- or quarry-run aggregates to produce an RCC pavement. This RCC pavement may require greater water content, be less durable, and have a lower flexible strength.

E-5.4 Other Aggregates.

Recent experience with RCC shows that aggregate produced for uses other than PCC are successful as aggregate for RCC. Material produced for asphalt paving and base courses are effective as RCC aggregate. These materials typically have a higher percentage of fines passing the 0.075 mm (No. 200) sieve than conventional concrete aggregates and, as a result, may produce a “tighter” pavement surface texture. Because these aggregates range in size from 19 mm (0.75 in.) to the 0.075 mm (No. 200) sieve, control of the grading may be more difficult due to segregation. Therefore, direct due attention toward stockpile formation and subsequent handling of a single size group aggregate.

E-5.5 Cement.

The Portland cement for use in RCC must meet the requirements of ASTM C595, Type I or II.

E-5.6 Admixtures.

A proper air void system prevents frost damage in concrete that freezes when critically saturated. Research indicates that air-entrained RCC pavement mixtures can be successfully produced in the laboratory; however, field production and placement have only been tried on a very limited basis. The most widely used method to minimize freezing and thawing damage to RCC pavement is to combine a low w/cm ratio with a highly compacted RCC. The low w/cm ratio and good compaction ensure the concrete has a minimum amount of freezable water in the capillaries and has low permeability. This makes it difficult for sufficient water to enter the RCC and reach critical saturation. A free-draining base under the RCC pavement will further prevent water from saturating the RCC pavement. As long as the RCC pavement is not critically saturated, freezing and thawing will cause no damage. Laboratory studies show that water-reducing or -retarding admixtures are successful with RCC but not as effective as in conventional concrete because they affect the paste content of the mixture. RCC contains less paste than conventional PCC mixtures. If these admixtures are proposed, base such use on investigations demonstrating that the benefits outweigh the cost.

E-6 MIXTURE PROPORTIONING.

E-6.1 General.

The basic mixture proportioning procedures and properties of conventional concrete and RCC are essentially the same; however, conventional concrete cannot be reproportioned for use as RCC by any single action such as (1) altering proportions of the mortar and concrete aggregates, (2) reducing the water content, (3) changing the w/cm ratio, or (4) increasing the fine aggregate content. Differences in mixture proportioning procedures and properties are mainly due to the relatively dry consistency of the fresh RCC and the selected use of nonconventionally graded aggregates. The primary differences in the properties of RCC are (1) RCC generally is not air entrained, (2) RCC has a lower water content, (3) RCC has a lower paste content, and (4) RCC generally requires a higher fine aggregate content to limit segregation. Several methods are available to proportion RCC pavement mixtures, including those found in CRD-C 161, ASTM D 558, EM 1110-2-2006, ACI 211.3, and ACI 207.5R. The first two of these methods treat the material as cement stabilized soils rather than concrete and establishes a relationship between moisture and the density obtained from a particular compactive effort. The latter three methods follow an approach similar to that used in proportioning conventional concrete. Currently, CRD-C 161 is the method recommended for RCC pavement mix design. The procedures for RCC pavement mixture proportioning are not as well defined as for conventional concrete. The key to successfully selecting an RCC trial batch that performs well in the field is the experience of the laboratory personnel conducting the proportioning study.

E-6.2 CRD-C 161 Method.

This method covers the procedures for proportioning RCC mixtures with 19 mm (0.75 in.) nominal maximum size aggregates and having a workability suitable for placement with the vibratory screed of an asphalt paving machine. Select RCCP mixture proportions based on test data or experience with the materials actually used. Where such data or experience is limited or not available, estimates given in this standard practice provide a first approximation for air-entrained or non-air-entrained RCCP mixture proportions. Check these proportions by trial batches in the laboratory or field and adjust, as necessary, to achieve the desired RCC characteristics.

E-6.3 ASTM D558 Method.

A proportioning based on ASTM D558 has produced satisfactory RCC mixtures. The method produces the optimum moisture content necessary to obtain maximum density for a particular set of materials and compaction procedures. Previous tests indicate that the optimum moisture content obtained by CRD-C 653 may produce a mixture too wet to allow efficient operation of a vibratory roller.

E-6.4 ACI 207.5R Method.

The method in ACI 207.5R, with some modifications, is used on many RCC mixtures. The primary consideration for this method is proper selection of the ratio (Pv) of the air-free volume of paste (Vp) to the air-free volume of mortar (Vm). This selection is based primarily upon the grading and particle shape of the fine aggregate. The Pv affects both the compactability of the mixture and the resulting surface texture of the pavement. Ratios of 0.36 to 0.41 are satisfactory for mixtures having a nominal maximum size aggregate of 19 or 38 mm (0.75 or 1.5 in.). Include the fraction of fine aggregate finer than the 0.075 mm (No. 200) sieve in Vp when calculations use Pv.

E-7 MIXTURE PROPERTIES.

E-7.1 Handling Characteristics.

The workability of RCC determines its capacity for successful mixing, placement, and compaction. It embodies the concepts of compatibility and to some degree moldability and cohesiveness. The same factors that affect the workability of conventional concrete affect RCC: the grading, particle shape, and proportion of the aggregate; the cementitious material content; and the presence of chemical and mineral admixtures in the mixture. However, the effect of each factor is not necessarily of the same magnitude for RCC as for conventional concrete. When placing RCC or conventional concrete, the consistency of the mixture is important. The slump test measures the consistency of conventional concrete. The slump test is not meaningful for RCC since it has no slump. Make a preliminary judgment of the workability, placeability, and compatibility of RCC pavement mixtures during mixture proportioning studies by determining the optimum moisture content using soil compaction concepts. Use the soil compaction procedures described in CRD-C 161, paragraphs 7.1 through 7.6, to determine the optimum moisture content. Experience indicates that the actual optimum RCC water content necessary may need to be slightly greater than the lab-determined optimum moisture content. This is probably due to the loss of water from the mixture due to evaporation during transport and placement operations or to different compaction in the field. Ambient conditions determine the water content variation of a mixture. Typically, moisture increases are 0.1 to 0.5 percent above optimum. Construct a test section for each RCC project to adjust the mixture proportions as necessary to achieve the required workability.

E-7.2 Sample Fabrication.

Primarily, the w/cm ratio and the degree of compaction attained control the strength of an RCC mixture. All RCC pavement mixtures placed by the Corps of Engineers to date had w/cm ratios ranging from 0.30 to 0.40. Fabricate cylindrical laboratory test specimens for strength determinations per ASTM C1176 or CRD-C 160. There is no standardized procedure for fabricating RCC beam specimens to determine concrete flexural strength. However, as described in CRD-C 161, some success has been achieved by filling beam molds in two layers. Consolidate by vibrating each layer on a vibrating table having a frequency of 3,600 vibrations per minute under a surcharge of 57 kg (125 lb). Uniformly distribute the surcharge over the entire specimen area during molding and vibrate until a ring of mortar forms around the complete periphery of the mold. Cure all specimens fabricated in the laboratory according to ASTM C192.

E-7.3 Strength Results.

Test specimens fabricated and cured in the laboratory generally exhibit higher strengths than those cored or sawn from an RCCP. This is probably due to the higher unit weights typically obtained with the fabricated specimens and the more efficient laboratory moist curing. Laboratory test specimens generally have unit weights that are 98 to 99 percent of the theoretical maximum (air-free) weight of the mixture, while core samples taken from RCCP typically have unit weights ranging from 95 to 98 percent of the theoretical weight. Therefore, during the laboratory mixture proportioning studies, consider fabricating a companion set of test specimens having the lowest relative density allowed by the contract specifications.

E-8 THICKNESS DESIGN.

E-8.1 General.

The thickness design procedure for RCC pavement is outlined in UFC 3-250-01 and UFC 3-260-02. The primary difference in the approaches to RCC pavement and plain concrete pavement thickness design is the assumption of no load transfer at any joint or crack in the RCC pavement. Limited load transfer tests conducted at Fort Hood, Texas and Fort Stewart, Georgia revealed average load transfer at transverse contraction cracks of 16 to 19 percent. The load transfer at longitudinal and construction joints will be lower and all were less than the 25 percent used for plain concrete pavement design for parking areas, open storage areas, and airfields. Placement of RCC pavement immediately adjacent to existing structures is not practical. Conventional formed concrete should be used between the structure and the RCC pavement. The RCC pavement can be placed first and cut back to the desired line or the RCC can be placed against the previously placed formed concrete. Beams sawn from various RCCP at various locations have shown that the actual flexural strength of the pavement was 20 to 50 percent higher than the typical strength assumed in the design for those pavements. This suggests that the thickness design for compacted RCCP could be modified based upon the 28-day strength of beams sawn from a test section constructed using the same aggregate, cement, and construction procedure as planned for the entire work. However, until additional performance records and testing procedures are developed for RCCP, conventional pavement thickness design will be used.

E-8.2 Lift Thickness.

The maximum thickness of a lift of RCCP is governed by the ability of the pavers to place the RCCP in a smooth and continuous fashion. This maximum uncompacted thickness is usually 250 to 300 mm (10 to 12 in.). The maximum uncompacted thickness can be approximated by multiplying the design thickness by 1.25, thus accounting for the reduction in thickness due to compaction. The minimum thickness of any lift should be 100 mm (4 in.).

E-8.3 Two-Lift Construction.

If the total uncompacted thickness exceeds the capacity of the paver, the RCCP should be placed in two or more lifts, thus creating a horizontal joint (or horizontal plane between the layers) in the RCCP. Sufficient bond develops at a fresh horizontal joint in RCCP (top lift placed within one hour of bottom lift) to allow the use of a monolithic thickness design. If the top lift is not placed within one hour of the bottom lift, the thickness should be designed as a rigid overlay of a rigid base pavement. The surface of the lower lift should be kept moist and clean until the upper lift is placed, and the upper lift should be placed and compacted within one hour of compacting the lower lift to ensure a bond between lifts is formed. In two-lift construction, the uncompacted thickness of the first lift should be two-thirds the total uncompacted height of the RCCP (or the maximum lift thickness the paver can handle, whichever is smaller). The thinner section in the upper lift aids in creating a smoother final surface, and because of the smaller volume of material, allows the paver placing the second lift to move quicker than and follow closer behind the paver placing the first lift. Multiple lifts will be necessary if the total uncompacted thickness of the RCCP is greater than twice the maximum lift capacity of the paver.

E-9 TEST SECTION.

E-9.1 General.

A test section must be constructed to determine the ability of the contractor to mix, haul, place, compact, and cure RCC pavement. The test section must be constructed of the same material using the same equipment intended to be used in production placement. The test section must be constructed at a location near the jobsite at least 10 days before construction of the RCC pavement. The test section should be large enough to establish the rolling pattern for the vibratory and finish rollers, the correlation between laboratory and nuclear gauge densities, and the correlation between the number of passes and relative density. The density tests should be obtained with a nuclear gauge in accordance with ASTM C1040. The test section should contain both longitudinal and transverse cold joints and a fresh joint. A suggested minimum size is two 3.7- to 4.3-m (12 to 14 ft) -wide lanes, with each joint type a minimum of 38 m (125 ft) long, with one and one-half lanes placed the first day and the rest placed the next day.

E-9.2 Optimum Number of Rolling Passes.

During the test strip construction, use a nuclear gauge operated in the direct transmission mode and standardized with a calibration block to determine the optimum number of passes with the vibratory roller to reach maximum density. The density should be measured by inserting the nuclear gauge probe into the same hole after each pass of the vibratory roller. The hole should be made with an instrument specifically designed for the purpose, and should be formed using the same method throughout the test section and main construction. This rolling and measuring procedure should be continued until there is less than a 1 percent change in successive readings. These data may be used in conjunction with correlation between the nuclear gauge and the laboratory density to determine the minimum number of passes needed to achieve or slightly exceed the specified density in the RCCP construction. However, a minimum of four vibratory passes should be used, and this minimum will probably prevail in most cases.

E-9.3 Nuclear Density Gauge/Lab Density Correlation Calibration Block.

Use a calibration block each day before paving begins to calibrate the full-depth readings of the nuclear density gauges. The block should be fabricated from the RCC mixture to be used in the project before the test section construction begins. The block size should be 460 mm by 460 mm (18 in. by 18 in.) by the maximum thickness of one lift, plus 25 mm (1 in.). The block should be compacted to between 98 and 100 percent of the maximum wet density determined in accordance with ASTM D1557. The block should be measured and weighed to determine the actual density (unit weight) and used to check the calibration of the nuclear density gauge. After drilling a hole in the block to accommodate the nuclear density gauge probe, three full-depth nuclear density gauge tests should be performed in the direct transmission mode and the results averaged. This average nuclear density gauge reading should then be compared with the measured unit weight of the block and the difference used as a correction factor for all readings taken that day. If the adjusted nuclear gauge density is less than the specified density, additional passes with the vibratory roller should be made on the fresh RCC until the specified density is reached. Two nuclear density gauges should be calibrated (using the same holes) during the test section construction, so that an extra one is available during construction.

E-9.4 Strength Tests.

Pavement strength is determined from samples obtained from the test section. The testing should determine the flexural and splitting tensile strength of the RCC pavement. If the design strength requirements are not met, adjust the mix proportions (or the compaction procedure or curing altered, and another test section built) until the strength results meet specifications.

E-10 BATCHING, MIXING, AND TRANSPORTING.

RCC requires a vigorous mixing action to disperse the relatively small amount of water evenly throughout the matrix. This action has been best achieved by using a twin shaft pugmill mixer as commonly used in asphalt concrete mixing. RCC may be produced successfully in either a continuous mixing plant or batch-type plant. The continuous mixing plant is recommended for mixing RCC because it is easier to transport to the site, takes less time to set up, and has a greater output (or production) capacity than the batch-type plant. The batch-type plant allows more accurate control over the proportions of material in each batch, but generally does not have enough output capacity for larger paving jobs. The most widely used and recommended equipment is a continuous plant with weight controls (belt scales) for the materials. The output of the plant should be such that the smooth, continuous operation of the paver(s) is not interrupted. Generally, for all but the smaller jobs (840 m^2 [1,000 yd^2] or smaller), the capacity of the plant should be no less than 225 metric tons (250 tons) per hour. The output of the plant should match the laydown capacity of the paver(s) and the rollers. The plant should be located as close as possible to the paving site, but in no case should the haul time between the batch plant and the paver(s) exceed 15 minutes. The RCC should be hauled from the mixer to the paver(s) in dump trucks. These trucks should be equipped with protective covers to guard against adverse environmental effects on the RCC, such as rain or extreme cold or heat. The truck should dump the concrete directly into the paver hopper.

E-11 PLACING.

For most pavement applications, RCC should be placed with a paving machine. The paver should be equipped with automatic grade control devices such as a traveling ski or electronic stringline grade control device. Pavers should have at least two tamping bars. These machines provide a satisfactory surface texture and some initial compaction when the RCC is placed. Necessary adjustments on the paver to handle the RCC include enlarging the feeding gates between the feed hopper and the screed to accommodate the large volume of stiff material moving through the paver, and adjusting the spreading screws in front of the screed to ensure the RCC is spread uniformly across the width of the paving lane. Care should be taken to keep the paver hopper from becoming empty to prevent any gaps or other discontinuities from forming in the pavement. The concrete should be placed and compacted within 45 minutes after water has been added to the batch. When paving adjacent lanes, the new concrete should be placed within 60 minutes of placing the first lane to form a fresh joint. This time may have to be reduced, depending on ambient conditions. If these time restraints cannot be met then a cold joint is formed. The height of the screed should be set even with the uncompacted height of the adjacent lane, thus allowing simultaneous compaction of the edges of the adjacent lanes into a fresh joint. Two or more pavers operating in echelon may reduce the number of cold joints by one-half or greater, and are especially recommended in road construction where the entire width of the road can be placed at the same time.

E-12 COMPACTION.

E-12.1 General.

RCCP has usually been compacted with a dual-drum (9 metric ton [10 ton] static weight) vibratory roller making four or more passes over the surface to achieve the design density (one back-and-forth motion is two passes). To achieve a higher quality pavement, the primary compaction should be followed with two or more passes of an 18 metric ton (20 ton) pneumatic-tired roller (620 kPa [90 psi] minimum tire pressure) to close up any surface voids or cracks. The use of a dual-drum static (non-vibratory) roller may be required to remove any roller marks left by the vibratory or pneumatic-tired roller. A single-drum (9 metric ton [10 ton]) vibratory roller has been successfully used to compact RCCP, but may require the use of a pneumatic-tired or dual-drum static roller to remove tire marks.

E-12.2 Proper Time for Rolling.

The consistency of the RCC when placed should be such that it may be compacted immediately behind the paver without undue displacement of the RCC pavement surface. If rolling has to be delayed, the cause should be investigated and the problem corrected. In no case should more than 10 minutes pass between placement and the beginning of the rolling procedure. The rolling should be completed within 45 minutes of the time the water was added at the mixing plant. A good indication that the RCC is ready for compaction is obtained by observing the displacement of the surface after two static passes with the 9 metric ton (10 ton) vibratory roller. A mixture that is too wet may appear "rubbery" under the roller, or even spread to form a deep rut after two passes. A mixture that is too dry will hardly consolidate at all under the first passes. In either case, only minor changes in the design water content should be made at the plant to correct the problem; otherwise, a new mix design may be needed. With practice, the roller operator should be able to tell whether the consistency of the RCC is satisfactory for compaction.

E-12.3 Rolling Pattern.

After making the static passes, the vibratory roller should make four vibratory passes on the RCCP using the following pattern: two passes on the exterior edge of the first paving lane (the perimeter of the parking area or the edge of a road) so that the rolling wheel extends over the edge of the pavement 25 to 50 mm (1 to 2 in.) (done to “confine” the RCCP to help prevent excessive lateral displacement of the lane upon further rolling), followed by two passes within 300 to 450 mm (12 to 18 in.) of the interior edge. This will leave an uncompacted edge to set the height of the screed for an adjacent lane, and allows both lanes of the fresh joint to be compacted simultaneously. Any remaining uncompacted material in the center of the lane should be compacted with two passes of the roller. This pattern should be repeated once to make a total of four passes on the lane (or more if the specified density is not achieved). If the interior edge will be used to form a cold joint, it should be rolled exactly as the exterior edge was rolled, taking care to maintain a level surface at the joint and not round the edge. When the adjacent lane is placed, two passes should be made about 300 to 450 mm (12 to 18 in.) from the outer edge of the lane (again, to confine the concrete) followed by two passes on the fresh joint. The first two passes should extend 25 to 50 mm (1 to 2 in.) over the outer edge of this adjacent lane if the lane will form an outer edge of the completed pavement. Any remaining uncompacted material in the lane should be rolled with two passes of the roller. This pattern should be repeated to make a total of four passes over the RCCP. Additional passes may be necessary along the fresh joint to ensure smoothness and density across the joint.

E-12.4 Compacting the End of a Lane.

When the end of a lane is reached, the roller should roll off the end of the lane, creating a rounded ramp. The recommended procedure is to cut the ramp with a power saw full depth to form a vertical face. This will eliminate hand work and lessen the possibility of damage to the in-place RCC pavement. Another method is to saw the concrete to at least one-half the depth of the pavement, then trim the lower portion of the joint by hand to form a nearly vertical face, clean from debris and loose particles.

E-12.5 Proper Roller Operation.

During vibratory compaction, the roller should never stop on the pavement with the vibrator on. Instead, the vibrator should be turned on only after the roller is in motion and should be turned off several feet before the roller stops moving. The stopping points of successive rolling passes should be staggered to avoid forming depressions in the fresh pavement surface. The roller should be operated at the proper speed, amplitude, and frequency to achieve optimum compaction. Experience has shown that the best compaction will probably occur at high amplitude and low frequency (because of the thick lifts) and a speed not exceeding 2 km (1.5 mi.) per hour. A low amplitude/high frequency combination may be necessary if the surface is disturbed during the high amplitude rolling.

E-12.6 Finish Rolling.

The vibratory compaction should be immediately followed with two or more passes of the pneumatic-tired roller so the surface voids and fissures close to form a tight surface texture. This rolling may be followed by a light dual-drum roller to remove any roller marks on the surface, but this will probably not be necessary. It is very important that all exposed surfaces of the RCCP be kept moist with a light water spray after the rolling process until the curing procedure is implemented.

E-13 COLD JOINTS.

E-13.1 General.

A cold joint in RCC pavement is somewhat analogous to a construction joint in conventional concrete pavement. It is formed between two adjacent lanes of RCC when the first lane has hardened to such an extent that the uncompacted edge cannot be consolidated with the fresher second lane. This happens when there is some time delay between placement of adjacent lanes such as at the end of the day’s construction. This hardening typically takes approximately one hour, depending on properties of the concrete and environmental conditions. The adjacent lane should be placed against the first lane and compacted within this time frame. Otherwise, the joint between the two lanes should be considered a cold joint.

E-13.2 Cold Joint Construction.

Before placing fresh concrete against hardened in-place pavement to form a longitudinal cold joint, the edge of the in-place pavement should be cut with a power concrete saw. As discussed in paragraph E-16.8, the recommended procedure is to saw full depth with a power concrete saw to form a vertical face. This will eliminate hand work and lessen the possibility of damage to the in-place pavement. Another method is to saw to at least one-half the depth of the pavement, then the lower unsawed portion of the joint should be trimmed by hand to form a nearly vertical face, clean of debris and loose particles. Care should be taken to avoid undercutting the pavement edge. This vertical face should be dampened before the placement of the fresh lane begins. The height of the screed should be set to a sufficient elevation to compensate for the reduction in thickness due to compaction. The screed should overlap the edge of the hardened concrete surface 25 to 75 mm (1 to 3 in.). The excess fresh concrete should be pushed back to the edge of the fresh concrete with rakes or lutes and rounded off so no fresh material is left on the surface of the hardened concrete before compacting the joint. The loose material should not be broadcast over the area to be compacted; this may leave a rough surface texture after rolling. The edge of the fresh lane adjacent to the hardened concrete should be rolled first in the static mode, with about 300 mm (1 ft) of the roller on the fresh concrete, to form a smooth longitudinal joint. Transverse cold joints are constructed in a similar manner. After cutting back the rounded-off edge and wetting the vertical face, the paver is backed into place and the screed set to the proper elevation using shims sitting on top of the hardened concrete. The excess material should be pushed back (as mentioned before) and a static pass made in the transverse direction across the first 300 mm (1 ft) of the freshly placed lane. The joint should be carefully rolled to ensure a smooth surface transition across the joint.

E-13.3 Sawing of Contraction Joints.

RCC pavement has been allowed to crack naturally in many previous projects to save the cost of sawing joints. However, this has probably resulted in larger crack openings, increased raveling, and higher maintenance costs than if cracking was controlled. Contraction joints may be sawn in RCC pavement to induce controlled crack formation. The weakened plane should be sawn at least one-fourth the slab depth using a 3 mm (1/8 in.) blade. Sawing of joints can commence when the concrete strength is sufficient to enable the saw to cut through the concrete with a minimum of spalling, tearing, or aggregate pullouts. The use of special green-cut saws that penetrate the pavement surface to only a depth of about 1 in. have been shown to be effective on at least one RCC paving project. The time of sawing is very important and usually ranges from 4 to 20 hours after compaction, depending on weather conditions and other factors. To date, sawn transverse contraction joints in RCC pavement have typically been spaced from 9 to 18 m (30 to 60 ft). These spacings may vary with different materials and thicker pavements, so optimum contraction joint spacing should be determined during test section construction. Local service records may also be helpful to establish a joint spacing that will effectively control transverse cracking. Joint spacing greater than 12 m (40 ft) should never be used without backup data.

E-13.4 Sealing Joints and Cracks.

Rigid pavements that do not receive adequate joint and crack seal maintenance will rapidly deteriorate due to the intrusion of water and incompressible materials that migrate through and into the pavement joints and cracks. Incompressible materials lodge between the individual pavement slabs and parts of slabs, restricting movement that allows for expansion and contraction. This restriction of movement causes spalling and cracking along the edges of the joints and cracks and can result in breakage and blowup of entire slabs. Water in the subgrade material causes a migration of fines that eventually results in loss of support under the edge of the pavement slab.

E-13.5 Load-Transfer Devices.

The stiff consistency of RCCP does not lend itself to application of load-transfer devices such as dowels or keyed joints. Until an efficient method is developed to insert and align dowels properly in RCCP, the use of dowels should be limited.

E-13.6 Vertical Joints in Two-Lift Construction.

In two-lift construction, care should be taken to align the cold transverse and longitudinal joints in the upper and lower lifts to form a uniform, vertical face through the depth of the pavement along the joint. If the edge of the upper lift is not even with the edge of the lower lift, the lower lift should be cut back even with the edge of the upper lift.

E-14 CURING.

E-14.1 General.

The relatively rough or open surface texture of the compacted RCC pavement will tend to dry very quickly. To prevent this, moist curing has been commonly recommended to prevent drying and scaling of the RCC pavement surface. For moist curing, the pavement surface should be kept continuously moist after final rolling for at least seven days by means of a water spray truck, sprinkler (fog spray) system, wet burlap, or cotton mat covering. If burlap mats are used, they should be thoroughly wetted, placed on the RCC pavement so the entire surface and exposed edges are covered, and kept continuously wet. An irrigation sprinkler system has been used to cure RCC pavement on some projects, but caution should be exercised so that the fines in the surface of the RCC pavement are not washed away by excessive pressure, particularly in the first few hours. Curing RCC pavement with water can generate considerable runoff and, if not properly handled, cause erosion or saturation of exposed subgrade. Curing with membrane-forming curing compound and asphalt emulsion applied at double the rates used on conventional concrete have been used successfully.

E-14.2 Effect of Moist Curing on Frost Resistance.

Preliminary results of laboratory freezing and thawing tests indicate that RCC having a sufficiently low w/cm ratio and moist cured for an extended period is more frost resistant. The improved frost resistance may be due to more complete hydration reducing the fractional volume of freezable water at saturation or by reducing the permeability of the RCC, making it more difficult to saturate under wet conditions.

E-14.3 Early Loading.

All vehicular traffic should be kept off the RCCP until the end of the curing period. If it is absolutely necessary, a water-spraying truck may be driven onto the pavement before that age but any turns must be kept to a minimum. Water-spraying trucks or any other traffic should be kept to a minimum.

E-15 QUALITY CONTROL/ASSURANCE.

E-15.1 General.

The UFGSs provide requirements on the construction method and outline expected QC and QA measures and limits for density, smoothness, thickness, and surface texture.

E-15.2 Quality Control Operations.

QC operations for DoD RCC pavement projects are the responsibility of the contractor. QC consists of sampling, gradation, quality, and moisture testing of aggregates going into the concrete; checking the plant calibration regularly; conducting moisture-density relationship tests (ASTM D1557) on the fresh RCC; measuring the in-place density and moisture content of the RCC by using a nuclear gauge; checking the smoothness of the finished RCC with a straightedge; taking core samples from the RCC for measurement of density, strength, and thickness; and, if desired, fabricating RCC cylinders and beams.

E-15.3 Quality Assurance Operations.

QA consists of providing the RCC mixture proportions, testing cementitious materials and aggregates for quality, and testing in-place density, smoothness, surface texture, and thickness for acceptance. QA testing by the government may also consist of randomly duplicating any QC test to determine if consistent results are being obtained. Payment is based on the results of the QA tests (density, smoothness, surface texture, and thickness) for each lot, which represents a day's placement of pavement. If the QA test results show deficiencies in any of these four areas, the payment for the lot is reduced, and the lot is rejected if the deficiency is too great.

E-15.4 Tests at Plant.

Moisture contents of the fine and coarse aggregates should be determined daily, as necessary, and appropriate changes made in the amount of mixing water. Washed gradation tests should normally be performed on the combined aggregates three times per day: in the morning, at midday, and in the afternoon. The samples should be taken from the conveyor before the cement or fly ash is added to the combined aggregates. The amount of materials passing the 0.150 mm (No. 100) sieve should be determined during this analysis. Whenever the characteristics of the mixture change or a check on the ingredients is required, a proportioning check can be performed on the combined dry ingredients on samples taken from the conveyor belt between the cement and fly ash hoppers and the pugmill using a washout test according to procedures in ASTM C685 (paragraph 6.5). By washing the dry ingredients over the 4.75 and 0.150 mm (No. 4 and No. 100) sieves and weighing the material in each size category, the approximate proportions of coarse aggregate, fine aggregate, and cement and fly ash combined may be determined and checked against predetermined limits.

E-15.5 Field Density Tests.

Field density tests should be performed on the RCC pavement using a nuclear density gauge operated in the direct transmission mode according to ASTM D6938, with the full-depth reading being used for control and acceptance. At least one field reading should be taken for every 30 m (100 ft) of each paving lane. The readings should be taken as closely behind the rolling operation as possible. The reading should be adjusted using the correlation determined in the test section construction and checked against a specified density. Areas that indicate a deficient density should be rolled again with the vibratory roller until the specified density is achieved.

E-15.6 Obtaining Core Samples.

The acceptance criteria for the thickness of the RCC pavement are based on appropriate tests conducted on cores taken from the pavement. Take cores from the pavement when it is no less than five days old. Take one core at a random location selected within each sublot, which is one-fourth the size of a lot, and measure the thickness. Take additional cores as determined by the government for density and splitting tensile strength.

E-15.7 Smoothness.

Do not finish the surface of the RCCP outside the tolerances given in the specifications. Check the smoothness as closely behind the finish roller as possible. Correct excessive variations in the surface with the finish roller. Pay particular attention to the smoothness across fresh and cold joints because this is typically a critical area for surface variations. A skilled vibratory roller operator is essential to minimize smoothness problems.

E-15.8 Surface Texture.

The final surface texture of an RCC pavement resembles that of an asphalt concrete pavement surface: a coarse surface texture with regularly spaced voids and interconnected fissures. The final surface texture should be devoid of surface tears, check cracking, segregation, rock pockets, surface patches, pumped areas, aggregate drag marks, loose aggregate, or exposed aggregate from washed fines.

E-15.9 Cylinder and Beam Fabrication.

The fabrication of cylinders and beams during RCCP construction may be specified and is encouraged if not specified. These beams and cylinders complement the coring operation to check RCCP strength and density. When fabricated cylinders and beams are used as a QC aid during construction, determine and report a correlation between their strength and density and those obtained from cores and sawed beams obtained from the test section.

E-15.10 Method of Cylinder and Beam Fabrication.

Fabricate cylinders in the field by filling cylinder molds in three equal layers. Each layer is consolidated by vibrating each layer on a vibrating table having a frequency of 3,600 vibrations per minute, under a surcharge of 9.1 kg (20 lb). Vibrate each layer until a mortar ring is visible around the entire periphery of the surcharge. Fabricate eight cylinders for every 225 m^3 (300 yd^3) of RCC placed. Test two cylinders each at 7, 14, 28, and 90 days. Test the cylinders for splitting tensile strength according to ASTM C496. No procedure has been standardized for fabricating RCC beam specimens such as those used to determine concrete flexural strength. However, CDR-C 161 details a procedure that fills beam molds in two layers. Each layer is consolidated by vibrating each layer on a vibrating table having a frequency of 3,600 vibrations per minute, under a surcharge of 57 kg (125 lb). The surcharge is uniformly distributed over the entire specimen area during molding and vibration is continued until a ring of mortar forms around the complete periphery of the mold. Fabricate four beams during each shift of construction: two to be tested at 14 days and two at 28 days. Test the beams for flexural strength according to ASTM C78.

E-15.11 Inspectors.

Inspections are vital in QC operations. Station at least one inspector at the mixing plant and at the jobsite to ensure a quality pavement is being built. At the mixing plant, check mixing times and spot-check the consistency and appearance of the mix coming out of the plant. The inspector coordinates the aggregate moisture content tests, the gradation tests, calibration of the plant, and washout tests to see that they are performed properly and at the right frequency. At the jobsite, the inspector ensures the base course and cold joints are moistened before the RCC is placed against them and that the RCC is placed and compacted within the proper time limitations. The inspector checks the paver operation to ensure proper grade control is continuously maintained and ensures no gaps or discontinuities are left in the pavement before rolling. The inspector ensures the roller begins compaction at the proper time and that the proper rolling pattern and number of passes are used. The inspector ensures adequate smoothness across joints is achieved and that the surface texture is tight after final rolling. The inspector spot-checks the final compacted thickness of the RCCP and corrects when out of tolerance. The inspector ensures the curing procedures are implemented as specified. The inspector also ensures all exposed surfaces of the RCCP are kept moist at all times and that the curing compound, if used, is applied properly and in a continuous fashion. The inspector coordinates the nuclear gauge density test, the coring procedures, cylinder and beam fabrication, and the surface smoothness test to ensure they are performed properly and at the required frequency.

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APPENDIX F GLOSSARY

F-1 ACRONYMS.

ACI	American Concrete Institute
Al_2O_3	Aluminum Oxide
ASR	Alkali-Silica Reaction
ASTM	American Society for Testing and Materials
CaO	Calcium Oxide
CONUS	Continental United States
CQC	Contractor Quality Control
DCP	Dynamic Cone Penetrator
DoD	Department of Defense
Fe_2O_3	Iron(III) Oxide or Ferric Oxide
FOD	Foreign Object Damage
ft	Foot
GGBFS	Ground-Granulated Blast Furnace Slag
gm/m^2	Gram per Square Meter
GPR	Ground-Penetrating Radar
HMA	Hot Mix Asphalt
Hz	Hertz
in.	Inch
in./ft	Inch per Foot
IPRF	Innovative Pavement Research Foundation Report
kg/m	Kilogram per Meter
kg/m^2	Kilogram per Square Meter
kg/m^2/hr	Kilogram per Square Meter per Hour
kg/m^3	Kilogram per Cubic Meter

kPa	Kilopascal
lb/ft	Pound per Foot
lb/ft^2	Pound per Square Foot
$lb/ft^2/hr$	Pound per Square Foot per Hour
lb/yd^2	Pound per Cubic Yard
LL	Liquid Limit
m	Meter
m^2	Square Meter
mg/m^3	Milligram per Cubic Meter
mm	Millimeter
mm/m	Millimeter per Meter
MPa	Megapascal
oz/yd^2	Ounce per Square Yard
PCC	Portland Cement Concrete
PI	Plasticity Index
psi	Pound per Square Inch
QA	Quality Assurance
QC	Quality Control
RCC	Roller-Compacted Concrete
RCCP	Roller-Compacted Concrete Pavement
SiO_2	Silicon Dioxide (Silica)
SG	Specific Gravity
TEA	Triethanolamine
TSC	Transportation Systems Center
tsf	Ton per Square Foot
TSPDWG	Tri-Service Pavement Discipline Working Group

UFC	Unified Facilities Criteria
UFGS	Unified Facilities Guide Specification
USACE	United States Army Corps of Engineers
w/cm	Water/Cementitious Material Ratio
yd^2	Square Yard

F-2 DEFINITION OF TERMS.

Alkali-Silica Reaction (ASR): A chemical reaction between alkalis in cement and certain reactive silica minerals with aggregate that forms a gel. The gel absorbs water and expands, thereby damaging the concrete.

Compaction: The process of reducing the void volume by applying mechanical energy.

Compressive Strength: The maximum resistance of a concrete specimen to axial compressive loading.

Curing: Maintaining moisture and temperature conditions in a freshly placed cementitious mixture to allow cement hydration to occur.

Dowels: A round steel bar that extends into adjoining slabs at an expansion or contraction joint to transfer shear loads.

D-Cracking: Pattern of cracks formed parallel to a joint or linear crack due to the inability of the concrete to withstand environmental factors such as freeze-thaw cycles.

Durability: Ability of concrete to resist weathering action, chemical attack, and abrasion.

Flexural Strength: Maximum resistance of a concrete specimen to flexural loading.

Fly Ash: Fine powder that is a byproduct of burning pulverized coal in electric power generating plants. Used as a supplementary cementitious material.

Gap-Graded Aggregate: An aggregate graded so one or more intermediate-size fractions are absent.

Ground Granulated Blast Furnace Slag (GGBFS): A granular byproduct of the iron- and steel-making process, which is dried and ground into a fine powder. GGBFS is highly cementitious and high in calcium silicate hydrates.

Pozzolan: A siliceous or siliceous and aluminous material that in itself possesses little or no cementitious value, but in finely divided form and in the presence of moisture, chemically reacts with calcium hydroxide to form compounds having cementitious properties.

Silica Fume: A byproduct of producing silicon metal or ferrosilicon alloys and a very reactive pozzolan.

Slump: Measure of consistency of freshly mixed concrete equal to the subsidence of a molded specimen immediately after removal of the slump cone.

Slipform Paver: A paver that does not use fixed forms but has forms that are pulled or raised as concrete is placed.

Tie-Bar: Deformed steel bars or connectors used to hold the faces of abutting slabs in contact. Typically used at longitudinal joints.

APPENDIX G REFERENCES

UNIFIED FACILITIES CRITERIA

https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc

UFC 1-200-01, *DoD Building Code*

UFC 3-250-01, *Pavement Design for Roads and Parking Areas*

UFC 3-250-08, *Standard Practice for Sealing Joints and Cracks in Rigid and Flexible Pavements*

UFC 3-250-11, *Soil Stabilization and Modification for Pavements*

UFC 3-260-02, *Pavement Design for Airfields*

UNIFIED FACILITIES GUIDE SPECIFICATIONS (UFGS)

https://www.wbdg.org/ffc/dod/unified-facilities-guide-specifications-ufgs

JOINT SERVICE

TSPWG M 3-250-04.97.05, *Proportioning Concrete Mixtures with Graded Aggregates for Rigid Airfield Pavements*, https://www.wbdg.org/ffc/dod/supplemental-technical-documents

ARMY

EM 1110-2-2006, *Roller-Compacted Concrete*, https://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-2-2006.pdf

ER 1110-34-1, *Transportation Systems Mandatory Center of Expertise*, https://www.publications.usace.army.mil/USACE-Publications/Engineer-Regulations/udt_43546_param_orderby/Title/udt_43546_param_direction/ascending/?udt_43546_param_page=5

CRD-C Standards: https://mtc.erdc.dren.mil/standards.aspx

CRD-C 3, *Standard Test Method for Temperature of Freshly Mixed Portland Cement Concrete (C1064)*

CRD-C 5, *Standard Test Method for Slump of Hydraulic Cement Concrete (C143)*

CRD-C 7, *Standard Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Concrete* (C138)

CRD-C 8, *Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method (C173)*

CRD-C 11, *Standard Practice for Making and Curing Concrete Test Specimens in the Field (C31)*

CRD-C 13, *Standard Specification for Air-Entraining Admixtures for Concrete (C260)*

CRD-C 16, *Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading) (C78)*

CRD-C 20, *Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing (C666)*

CRD-C 26, *Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete (C42)*

CRD-C 31, *Standard Specification for Ready-Mixed Concrete (C94)*

CRD-C 41, *Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method (C231)*

CRD-C 42, *Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete (C457)*

CRD-C 55, *Test Method for Within-Batch Uniformity of Freshly Mixed Concrete*

CRD-C 77, *Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens (C496)*

CRD-C 87, *Standard Specification for Chemical Admixtures for Concrete (C494)*

CRD-C 111, *Standard Test Method for Surface Moisture in Fine Aggregate (C70)*

CRD-C 113, *Standard Test Method for Total Evaporable Moisture Content of Aggregate by Drying (C566)*

CRD-C 127, *Standard Guide for Petrographic Examination of Aggregates for Concrete (C295)*

CRD-C 130, *Standard Recommended Practice for Estimating Scratch Hardness of Coarse Aggregate Particles (C851)*

CRD-C 133, *Standard Specification for Concrete Aggregates (C33)*

CRD-C 160, *Standard Practice for Making Roller-Compacted Concrete Specimens in Cylinder Molds Using a Vibrating Table*

CRD-C 161, *Standard Practice for Selecting Proportions for Roller-Compacted Concrete Specimens in Cylinder Molds Using a Vibrating Table*

CRD-C 162, *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3)) (D1557)*

CRD-C 174, *Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method) (C1260)*

CRD-C 175, *Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction (C1293)*

CRD-C 201, *Standard Test Method for Water Retention by Concrete Curing Materials (C150)*

CRD-C 203, *Standard Specification for Blended Hydraulic Cements (C595)*

CRD-C 205, *Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars (C989)*

CRD-C 255, *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete (C618)*

CRD-C 271*, Standard Performance Specification for Hydraulic Cement (C1157)*

CRD-C 300, *Specifications for Membrane-Forming Compounds for Curing Concrete*

CRD-C 304, *Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete (C309)*

CRD-C 306, *Standard Test Method for Water Retention by Concrete Curing Materials (C156)*

CRD-C 403, *Method of Test for Determination of Sulfate Ion in Soils and Water*

CRD-C 408, *Standard Test Method for Sulfate Ion in Water (D516)*

CRD-C 521, *Standard Test Method for Frequency and Amplitude of Vibrators for Concrete*

CRD-C 553 (C1077)

CRD-C 653, *Standard Test Method for Determination of Moisture-Density Relation of Soils*

CRD-C 662, *Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials, Lithium Nitrate Admixture and Aggregate (Accelerated Mortar-Bar Method)*

AMERICAN CONCRETE INSTITUTE (ACI)

https://www.concrete.org/

ACI 207.5, *Roller Compacted Mass Concrete*

ACI 211.3, *Standard Practice for Selecting Proportions for No-Slump Concrete*

ACI 305, *Hot Weather Concreting*

ACI 306, *Cold Weather Concreting*

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM C31, *Standard Practice for Making and Curing Concrete Test Specimens in the Field*

ASTM C33, *Standard Specification for Concrete Aggregates*

ASTM C42, *Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete*

ASTM C70, *Standard Test Method for Surface Moisture in Fine Aggregate*

ASTM C78, *Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)*

ASTM C88, *Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate*

ASTM C94, *Standard Specification for Ready-Mixed Concrete*

ASTM C117, *Standard Test Method for Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing*

ASTM C123, *Standard Test Method for Lightweight Particles in Aggregate*

ASTM C128, *Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate*

ASTM C138, *Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete*

ASTM C142, *Standard Test Method for Clay Lumps and Friable Particles in Aggreg*ates

ASTM C143, *Standard Test Method for Slump of Hydraulic Cement Concrete*

ASTM C150, *Standard Specification for Portland Cement*

ASTM C156, *Standard Test Method for Water Loss [from a Mortar Specimen] Through Liquid Membrane-Forming Curing Compounds for Concrete*

ASTM C173, *Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method*

ASTM C192, *Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory*

ASTM C231, *Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method*

ASTM C260, *Standard Specification for Air-Entraining Admixtures for Concrete*

ASTM C295, *Standard Guide for Petrographic Examination of Aggregates for Concrete*

ASTM C309, *Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete*

ASTM C457, *Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete*

ASTM C494, *Standard Specification for Chemical Admixtures for Concrete*

ASTM C496, *Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens*

ASTM C566, *Standard Test Method for Total Evaporable Moisture Content of Aggregate by Drying*

ASTM C595, *Standard Specification for Blended Hydraulic Cements*

ASTM C618, *Standard Specification for Coal Ash and Raw or Calcined Natural Pozzolan for Use in Concrete*

ASTM C666, *Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing*

ASTM C685, *Standard Specification for Concrete Made by Volumetric Batching and Continuous Mixing*

ASTM C989, *Standard Specification for Slag Cement for Use in Concrete and Mortars*

ASTM C1040, *Standard Test Methods for In-Place Density of Unhardened and Hardened Concrete, Including Roller Compacted Concrete, By Nuclear Methods*

ASTM C1064, *Standard Test Method for Temperature of Freshly Mixed Portland Cement Concrete*

ASTM C1077, *Standard Practice for Agencies Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Testing Agency Evaluation*

ASTM C1157, *Standard Performance Specification for Hydraulic Cement*

ASTM C1176, *Standard Practice for Making Roller-Compacted Concrete in Cylinder Molds Using a Vibrating Table*

ASTM C1260, *Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)*

ASTM C1293, *Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction*

ASTM C1557, *Standard Test Method for Tensile Strength and Young's Modulus of Fibers*

ASTM C1567, *Standard Test Method for Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method)*

ASTM D516, *Standard Test Method for Sulfate Ion in Water*

ASTM D558, *Standard Test Methods for Moisture-Density Relations of Soil-Cement Mixtures*

ASTM D698, *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3))*

ASTM D1557, *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))*

ASTM D2487, *Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)*

ASTM D6938, *Standard Test Method for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)*

ASTM E177, *Standard Practice for Use of the Terms Precision and Bias in ASTM Test Methods*

ASTM E965, *Standard Test Method for Measuring Pavement Macrotexture Depth Using a Volumetric Technique*

INNOVATIVE PAVEMENT RESEARCH FOUNDATION

IPRF-01-G-002-1, *Best Practices for Airport Portland Cement Concrete Construction (Rigid Airport Pavement)*, http://www.iprf.org/products/jp007p%20-%20airport%20best%20practices%20manual.pdf

NATIONAL READY MIXED CONCRETE ASSOCIATION (NRMCA)

Certification of Ready Mixed Concrete Production Facilities

PORTLAND CEMENT ASSOCIATION (PCA)

Guide Specifications for Concrete Subject to Alkali-Silica Reactions, https://www.cement.org/

UFC 3-250-07
7 December 2021

UNIFIED FACILITIES CRITERIA (UFC)

STANDARD PRACTICE FOR PAVEMENT RECYCLING

UNIFIED FACILITIES CRITERIA (UFC)

STANDARD PRACTICE FOR PAVEMENT RECYCLING

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER CENTER (Preparing Activity)

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

Change No.	**Date**	**Location**

This UFC supersedes UFC 3-250-07, dated 16 January 2004.

FOREWORD

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

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of a UFC is the responsibility of the cognizant DoD working group. Send recommended changes with supporting rationale to the respective service proponent office by the following electronic form: Criteria Change Request. The form is also accessible from the Internet sites listed below.

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

- Whole Building Design Guide web site http://DoD.wbdg.org/.

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

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UNIFIED FACILITIES CRITERIA (UFC)
REVISION SUMMARY SHEET

Document: UFC 3-250-07, *Standard Practice for Pavement Recycling*

Superseding: This UFC supersedes UFC 3-250-07, *Standard Practice for Pavement Recycling*, dated 16 January 2004.

Description: This UFC documents and explains standard operating practices for recycling pavement materials and using the material in pavement structures. These practices apply to roads, airfields, and construction platforms having a stabilized surface layer.

Reasons for Document: This update brings the document in compliance with UFC 1-300-01, *Criteria Format Standard*. Editorial changes were to improve readability, correct typographical errors, update outdated references, and clarify standard practices.

Impact: Cost impact is negligible; improved guidance typically results in improved performance and reduced lifecycle cost.

Unification Issues: None

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FIGURES

TABLES

CHAPTER 1 INTRODUCTION

1-1 PURPOSE AND SCOPE.

This UFC documents the standard practices for recycling pavement materials and using recycled materials in the Department of Defense (DoD) and the National Aeronautics and Space Administration (NASA) pavement structures. It covers recycling methods permitted on DoD and NASA pavements. It provides requirements for the selection of recycling methods as well as the design of pavement cross sections using the recycled materials and recycling methods.

1-2 APPLICABILITY.

These standard practices apply to DoD and NASA pavements. These practices apply to roads, airfields, and construction platforms having a stabilized surface layer. Do not use, plan to use, or bid on a project while planning to use any materials or methods on or in DoD or NASA pavements that are not outlined in this or any other applicable UFC or UFGS without prior approval of the Pavements Discipline Working Group (DWG) and contracting officer and Designer of Record (DOR).

1-3 GENERAL BUILDING REQUIREMENTS.

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

1-4 BEST PRACTICES AND OTHER CONTENT.

Appendix A is reserved for future use.

1-5 SUPPLEMENTAL RESOURCES.

Appendix B contains a list of supplemental resources and references not used herein.

1-6 GLOSSARY.

Appendix C contains a list of acronyms, abbreviations, and definitions

1-7 REFERENCES.

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

1-8 BACKGROUND.

Pavement recycling reuses pavement materials from existing pavement. Pavement recycling may remove and reprocess existing pavement materials at a central plant and then incorporate them into a new pavement structure, or it may involve reprocessing or modification of existing material in-place and making them part of a new pavement. Recycling is an economical and feasible alternative to using all virgin materials for pavement rehabilitation, reconstruction, and new construction. This is especially true at remote sites. The primary advantages are in reduced cost and time savings, reduced environmental impact, conservation and protection of natural resources, and ability to maintain existing pavement lines and grade.

Recycling presents many advantages for the rehabilitation of fatigued and deteriorated airfield and roadway pavements. Technical advances (since the adoption of early recycling concepts in the 1970s) in terms of materials and mixes, construction methods, and equipment, make recycling a viable solution for rehabilitation or reconstruction. Recycling of pavement materials plays a significant role in sustainable development and reuse of materials.

This UFC contains guidance from a variety of documents, to include:

- Asphalt Recycling and Reclaiming Association (ARRA) *Basic Asphalt Recycling Manual*, 2015.
- Federal Highway Administration (FHWA) *Pavement Recycling Guidelines for State and Local Government,* 1997.
- FHWA National Highway Institute (NHI) *4R Participant's Manual* (Course 131008), *HMA Pavement Evaluation and Rehabilitation Reference Manual* (Course 131063), *PCC Pavement Evaluation and Rehabilitation Reference Manual* (Course 131062), and *Asphalt Pavement Recycling Technologies Manual* (Course 131050).
- Permanent International Association of Road Congresses (PIARC) *Pavement Recycling Guidelines,* 2003.
- Airfield Asphalt Pavement Technology Program (AAPTP) *Use of Reclaimed Asphalt Pavements* and *Development of Guidelines for Rubblization July 2008*.
- Innovative Pavement Research Foundation (IPRF) *Evaluation, Design, and Construction Techniques for Airfield Concrete Pavement Used as Recycled Material for Base,* 2006.
- Federal Aviation Administration (FAA) Advisory Circulars and Engineering Briefs.
- Transportation Research Board (TRB) Recycling Reports.

Key DoD documents used in preparing this manual are:

- UFC 3-250-01, *Pavement Design for Roads and Parking Areas*
- UFC 3-250-04, *Standard Practice for Concrete Pavements*
- UFC 3-260-02, *Pavement Design for Airfields*
- UFC 3-260-03, *Airfield Pavement Evaluation*
- UFC 3-260-16, *O&M Manual: Standard Practice for Airfield Pavement Condition Surveys*
- UFC 3-270-08, *Pavement Maintenance Management*
- UFGS 32 01 16.70, *Cold-Mix Reused Asphalt Paving*
- UFGS 32 01 16.71, *Cold Milling Asphalt Paving*
- UFGS 32 01 16.74, *In-Place Hot Reused Asphalt Paving*
- UFGS 32 01 16.75, *Heater Scarifying of Asphalt Paving*
- UFGS 32 11 16.16, *[Base Course for Rigid] and [Subbase Course for Flexible][Subbase Course for Pervious] Paving*
- UFGS 32 11 23, *Aggregate Base Course*
- UFGS 32 11 36.13, *Lean Concrete Base Course*
- UFGS 32 12 15.13, *Asphalt Paving for Airfields*
- UFGS 32 12 16.16, *Road-Mix Asphalt Paving*
- UFGS 32 13 13.06, *Portland Cement Concrete Pavement for Roads and Site Facilities*
- UFGS 32 13 14.13, *Concrete Paving for Airfields and Other Heavy-Duty Pavements*
- TSPWG 3-260-03.02-19, *Airfield Pavement Evaluation Standards and Procedures*
- TSPWG M 3-250-04.06-2 *Alkali-Aggregate Reaction in Portland Cement Concrete (PCC) Airfield Pavements*
- TSPWG 3-250-07.07-6, *Risk Assessment Procedure for Recycling PCC Suffering from Alkali-Aggregate Reaction in Airfield Pavement Structures*

Always consider recycling materials when repairing or rehabilitating existing pavements. The remaining sections of this chapter provide guidance for industry-wide recycling practices. To determine the latest restrictions/limitations on using recycled materials on DoD projects consult the following UFGS documents:

32 01 13 64
32 01 16.70
32 01 16.71

32 01 16.74
32 01 16.75
32 12 15.13 and 32 12 16.16 for asphalt recycling applications
32 13 14.13 and 32 13 13.06 for concrete recycling applications

Do not alter or waive UFGS requirements without prior approval of the Pavements DWG Representative. Chapters 4 through 5 detail the current restrictions/limitations.

1-9 JUSTIFICATION FOR RECYCLING.

Recycling pavement materials is a feasible approach to rehabilitate distressed pavements. Reclaimed materials can reduce the cost of rehabilitation or reconstruction and provide other benefits. Therefore, consider using recycled materials when repairing, rehabilitating, or reconstructing existing pavements. The following are reasons for using reclaimed pavement materials:

- *Environment.* Prior to the inception of recycling techniques, reconstructing old pavements consisted of removing, stockpiling, or disposing of old pavement materials. Recycling can reuse these pavement materials and often offers a cost reduction compared to purchasing virgin materials. Recycling eliminates the disposal problem and conserves natural resources. Some recycling methods reduce greenhouse gases and save energy (Mueller, 2008).
- *Material availability and cost.* The supply of natural material is limited. Even though there is presently an abundant supply of aggregates in the US, the distribution of these sources does not always coincide with the project location. The amount of asphalt and high-quality aggregate available for construction is limited. The high cost of aggregates and asphalt binder increase the unit cost of pavement and encourages the use of recycled materials. The rising cost of fuel and equipment operations encourages recycling, especially for longer haul distances.
- *Technology and equipment.* The increased interest in recycling pavements drives technology and equipment development for recycling that improve performance and reduce cost when utilizing recycled materials. While there are problems peculiar to recycling, the number and complexity of these problems has declined significantly in recent years.
- *Performance*. Studies show that properly designed recycled mixes perform as well as virgin mixes. Experience of different states in the U.S. indicates that, in most cases, the performance of the recycled asphalt pavements is comparable to asphalt pavements constructed with virgin materials. Successfully incorporating recycled asphalt requires; good project selection criteria, proper mix design and good quality control and acceptance (QC/QA) criteria as is with asphalt mixtures using virgin materials.

- *Recycling of non-pavement materials.* Several materials in recycled pavements come from non-pavement sources including reclaimed asphalt shingles, crumb rubber, plastics, and many other products. While widely used elsewhere, this manual does not cover their use.
- *Improved structural capacity*. Except for asphalt surface recycling, all other recycling methods can improve the structural capacity of pavements through the improvement of material properties, increased layer thickness, and/or the addition of a structural layer.
- *Maintain geometry of pavement surface.* Recycling can help maintain pavement surface geometry. This is important in relation to existing curbs and gutters, maintaining clearances underneath bridges or other structures, and in other areas where the design requirements require matching the elevation of adjacent structures.
- *Construction at remote sites.* In some instances, recycling is a necessity such as for pavements at remote sites and/or island bases, where local aggregate materials are not available or are extremely expensive to crush, screen, and mine.

1-10 RECYCLING METHODS AND MATERIALS.

The processes, technologies, and equipment for pavement recycling have greatly improved since the early adoption of recycling techniques in the 1980s. The following sections describe basic recycling methods used in the United States (ARRA, 2001; Kandhal and Mallick, 1997; Bozkurt et al., 2002; Buncher and Jones, 2006; ARRA and FHWA, 2015) along with the applicable UFGS and other documents covering the construction requirements for DoD airfield and roadway pavements.

1-10.1 Asphalt Pavement Recycling.

1-10.1.1 Cold milling (CM).

Cold milling is the controlled removal of an existing pavement to some desired depth. CM is used to correct the surface profile and/or cross-slope or to remove a pavement surface exhibiting distresses such as raveling, top down cracking, rutting, bleeding, and polished aggregate. Overlay the milled surface with hot mix asphalt (HMA), apply a surface treatment, or use as a temporary surface for immediate correction of friction problems (UFGS 32 01 16.71). Construction contracts often state that the milled pavement material is the property of the contractor, who may stockpile and process the material as reclaimed asphalt pavement (RAP) for a future project.

1-10.1.2 Hot recycling (HR).

Hot recycling is the process in which RAP is combined with virgin aggregate, asphalt binder, and/or recycling agents in a central plant blending and mixing operation to produce HMA paving mixtures. The primary benefit of HR is to offset the high cost of virgin asphalt binder. Allow the use of HR on all DoD pavements except the surface course for airfields. Other DoD airfield mixtures may contain RAP such that the amount of asphalt binder from RAP does not exceed 20 percent of the total asphalt content in the recycled asphalt mixture. DoD roadway mixtures may contain RAP such that the amount of asphalt binder from RAP does not exceed 30 percent of the total asphalt content in the recycled asphalt mixture. (UFGS 32 12 15.13 *and UFGS 32 12 16.16*).

1-10.1.3 Hot in-place recycling (HIR).

Hot in-place recycling is the process of heating and softening the existing pavement to allow it to be scarified/milled to a specified depth and combined in-place with virgin aggregate, asphalt binder, and/or HMA. HIR is then re-laid to serve as a base or intermediate course under a new HMA overlay. In some cases, HIR is used as the final wearing surface. HIR is comprised of three specific types:

1-10.1.3.1 HIR-I, Surface Recycling.

In HIR-I, Surface Recycling, the top 0.75 to 2.0 inches (19 to 50 mm) of the existing pavement surface is heated, scarified, combined with new asphalt binder, and re-laid for the purpose of minor mix improvement/modification. Surface recycling can be single-pass or double-pass. In single-pass, the recycled mix is re-laid and serves as the final wearing surface (mix heated-scarified material with new asphalt binder or recycling agent to produce in-place hot recycled mixture). HIR-I is typically used on roadways with low traffic volume (UFGS 32 01 16.75 and UFGS 32 01 16.74).

1-10.1.3.2 HIR-II, Remixing.

In HIR-II, Remixing, the existing pavement is heated, loosened, combined with virgin aggregate and new asphalt binder or new HMA, and re-laid for significant mix improvement and modest pavement strengthening. Remixing can be single stage or multiple stage. In single stage remixing, heat and scarify the pavement to a specified depth in one pass, mix with additional virgin aggregate and asphalt binder, relay mix, and compact. In the double pass method of remixing, the first pass of remixed material is covered with a layer of HMA prior to compaction (UFGS 32 01 16.75 and UFGS 32 01 16.74).

1-10.1.3.3 HIR-III, Repaving.

In HIR-III, Repaving, heat, loosen and combine the pavement surface with virgin asphalt binder and re-lay in tandem with an HMA overlay to strengthen and restore the surface profile and/or friction characteristics. Repaving is surface recycling with an integrally applied thermally bonded overlay (Kandhal and Mallick, 1997). Repaving is single-pass or double-pass. The single-pass method uses one unit equipped with two screeds. In-place material is recycled and repaved with the first screed. New HMA is dumped into the front of the unit, conveyed past the first screed, placed atop the recycled mix, and paved with the second screed. The double-pass method uses two separate units. The first unit recycles and repaves using its own screed. The second unit is a conventional asphalt paver that places and spreads new HMA on top of recycled layer (UFGS 32 01 16.75 and UFGS 32 01 16.74).

1-10.1.4 Cold Recycling.

1-10.1.4.1 Cold in-place recycling (CIR).

Cold in-place recycling is the process of milling and sizing RAP, in-place mixing of RAP with recycling additive and new aggregate (either in the milling machine cutting chamber or in a mix paver) to produce a recycled cold mix, and then placing and compacting the recycled cold mix, typically in a single pass. Use CIR to restore the profile or cross-slope of the existing surface or to mitigate surface and base layer distresses. HMA overlays are required for airfields and higher volume roads (UFGS 32 01 16.71; UFGS 32 01 16.70).

1-10.1.4.2 Cold central-plant recycling (CCPR).

Cold central-plant recycling combines stockpiled RAP with virgin aggregate, recycling additives, and water at a central plant to produce recycled cold mix for use as a new base course. Like CIR, use CCPR to restore the profile or cross-slope of the existing surface or to mitigate surface and base layer distresses. CCPR is generally a viable alternative when stockpiles of high-quality RAP are available or when it is not possible to recycle the pavement in-place (ARRA, 2015). An HMA overlay is required for airfields and higher volume roads (UFGS 32 01 16.70).

1-10.1.4.3 Full-depth reclamation (FDR).

Full-depth reclamation is a process in which all of the asphalt pavement section and a predetermined amount of underlying base material is integrally mixed, treated, and re-laid in-place using a reclaiming machine to produce a stabilized base course. Add asphalt emulsion or portland cement as part of the process. Type C fly ash and lime-fly ash are also used to as chemical stabilization agents in FDR. FDR eliminates existing distresses and restores structural capacity by creating a stronger, higher load-carrying base and is recommended for pavements having a base or subgrade problem. FDR is generally used on low volume roads (Kandhal and Mallick, 1997, UFGS 32 01 16.70*).*

1-10.2 Portland Cement Concrete (PCC) Pavement Recycling.

1-10.2.1 Slab Fracturing (SF).

The process consists of in-place recycling involving breaking or cracking of the existing PCC pavement to prevent reflection cracking in an HMA overlay. SF comprises the following three specific types:

1-10.2.2 Crack and Seat.

Slabs of a jointed plain concrete pavement (JPCP) are fractured into small segments 2 to 6 feet (0.6 to 1.8 m) in length, which are then seated firmly into place in preparation for an HMA overlay.

1-10.2.2.1 Break and Seat.

Fracture slabs of a jointed reinforced concrete pavement (JRCP) into small segments 1.5 to 4 feet (0.5 to 1.2 m) long, with reinforcing steel adequately ruptured/sheared to ensure discontinuity among the fracture pieces. Seat the pieces firmly into place in preparation for an HMA overlay.

1-10.2.2.2 Rubblization.

The rubblization process breaks and pulverizes slabs of JPCP, JRCP, and continuously reinforced concrete pavement (CRCP) into small, discontinuous pieces which no longer act as slabs, but rather function as a high quality granular base. At the slab surface, sizes range from sand-sized particles to 6 inches (150 mm). At the slab bottom sizes are 6 to 15 inches (150 to 375 mm). The rubblized PCC is compacted prior to receiving an HMA overlay. Rubblization is the most widely used slab fracturing process since it best prevents reflective cracking.

1-10.2.3 Recycled Concrete Aggregate.

Recycled concrete aggregate is the product of PCC demolition and removal and off-site processing (i.e., crushing, sizing, and steel removal) of broken concrete into aggregate for use in unbound layers, lean concrete base, or PCC surfacing. (UFGS 32 11 23; UFGS 32 11 20, *[Base Course for Rigid] [and] [Subbases for Flexible] Paving*; UFGS 32 11 36.13; UFGS 32 13 14.13.

There are a number of variations of each method using various additives and different equipment. Moreover, a wide array of construction techniques is possible in terms of the depth of existing pavement removal, the thickness of the recycled material layer, and the type and thickness of cover layer (e.g., chip seal, HMA surface course), if used.

Table 1-1 provides a summary of the basic recycling methods used on asphalt-surfaced pavements while Table 1-2 provides a summary of PCC pavement recycling methods.

1-11 DESIGN CONSIDERATIONS IN RECYCLING.

To achieve satisfactory results by recycling requires an evaluation of the available materials and proper mix design. Additionally, determine the structural adequacy of the existing pavement and design calculations to ensure that the recycled pavement section suffices for the anticipated traffic levels.

Consider the functional aspects of pavement performance in the selection of recycling treatments. In cases where the recycled mix serves as the wearing course, the mix must be capable of (a) placement to the required level of smoothness, (b) providing adequate long-term friction, and (c) providing long-term durability to environmental and traffic effects. The sections below provide brief discussions of these critical aspects of recycling and present relevant DoD specifications and guidance documents corresponding to pavement recycling methods.

Table 1-1 Summary of Asphalt Pavement Recycling Applications

Type	Treatment Equipment	Product	Central Plant or In-Place	Placement and Compaction Equipment	Use
Cold Planing/ Milling (CM)	Milling machine[1]	RAP for Hot or Cold recycling (HR/CR)	N/A	N/A	Controlled removal of the existing pavement to the desired depth
Hot Recycling (HR)	Milling machine[1] or ripper crusher to produce RAP[2]	HMA with RAP	Central plant	Conventional paver and rollers	Some RAP can generally be used in all HMA pavements, except as a surface course on airfields
Hot In-Place Recycling, Type I—Surface Recycling (HIR-I)	Heater-scarifier or hot rotary milling machine	Recycled HMA	In-place	Screed attached to recycling equipment and conventional rollers	Surface course or base course. HMA overlay required on airfields
Hot In-Place Recycling Type II—Remixing (HIR-II)	Heater-scarifier or hot rotary milling machine	Recycled HMA	In-place	Screed attached to recycling equipment and conventional rollers	Typically used as surface course but can serve as base course. HMA overlay required on airfields
Hot In-Place Recycling Type III—Repaving (HIR-III)	Heater-scarifier or hot rotary milling machine	Recycled HMA integrally laid with new HMA overlay	In-place	Screed attached to mixer and conventional rollers	Surface course, except on airfields and high volume roads.
Cold In-Place Recycling (CIR)	Milling machine	Recycled asphalt mixture	In-place	Screed or auger/screed system, or conventional asphalt paver, rollers	Base course
Cold Central Plant Recycling (CCPR)	Milling machine[1] or ripper/ crusher equipment[2]	Recycled asphalt mixture	Central plant	Conventional HMA paver, motor grader, or Jersey spreader, conventional rollers	Base course

Type	Treatment Equipment	Product	Central Plant or In-Place	Placement and Compaction Equipment	Use
Full-Depth Reclamation (FDR)	Reclaiming machine	Recycled mix of asphalt, base and subgrade soil	In-place	Motor grader, vibratory pad-foot roller, steel drum roller, pneumatic rollers	Base course

N/A: Not applicable.
[1] Cold planing/milling machine cut/pulverize W/grinding heads, e.g. conventional or micro milling machine.
[2] Ripping/crushing machine, earthmovers (dozer, excavator, backhoe) W/ripper teeth, scarifiers, grid rollers

Table 1-2 Summary of Concrete Pavement Recycling Applications

Recycle Method	Demolition and/or Removal Equipment	Recycle Material	Use
Slab Fracturing, Crack and Seat	Cracking equipment[1], pneumatic roller	PCC slabs resized through cracking operation	Converts JPCP into base layer to support new HMA overlay
Slab Fracturing, Break and Seat	Cracking equipment[1], pneumatic roller	PCC slabs resized through cracking operation	Converts JRCP and CRCP into base layer to support new HMA overlay
Slab Fracturing, Rubblization	Rubblizing equipment[2], vibratory roller	PCC material resized by rubblizing operation	Converts JPCP, JRCP and CRCP into high quality granular base layer to support new HMA overlay
Recycled Concrete Aggregate (RCA)	Demolition equipment[3], backhoe or front-end loaders (with Rhino horn), crushing plant	RCA	In PCC, lean concrete base, asphalt treated base mixes. As unbound base or subbase. Small sizes of RCA used as aggregates for HMA and PCC mixtures

[1]Cracking equipment includes pile drivers, guillotine hammers, whip hammers, and impact hammers.
[2]Rubblizing equipment includes resonant pavement breakers and multi-head breakers.
[3]Demolition equipment includes drop balls, gravity-drop hammers, hydraulic or pneumatic hammers, trailer-mounted diesel hammers, spring-arm whiphammers, and vibrating-beam breakers.

CHAPTER 2 EVALUATION AND SELECTION OF REHABILITATION STRATEGY

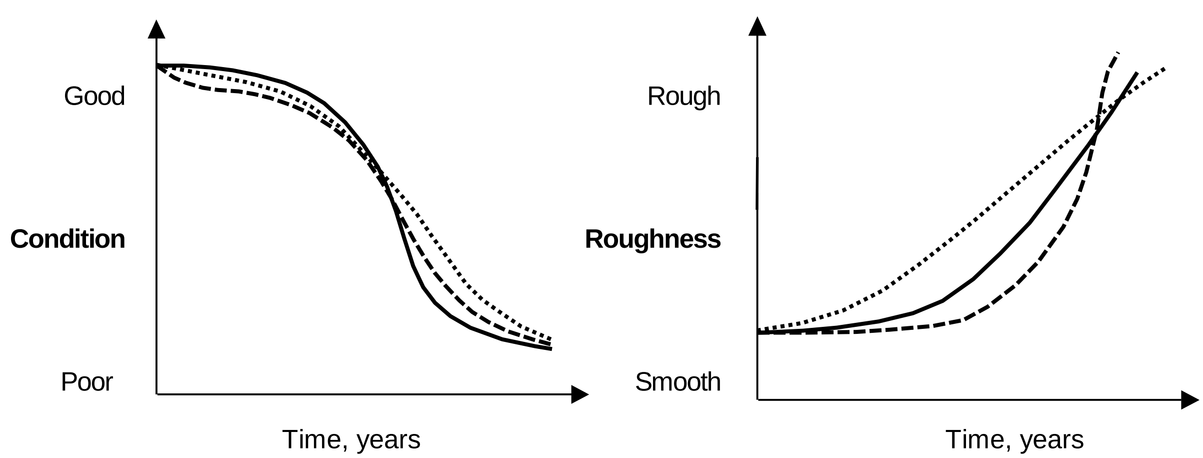
2-1 INTRODUCTION.

The detrimental effects of traffic loading and environmental factors degrade all pavements. The deterioration manifests in a variety of ways (such as cracking, rutting, raveling, spalling), that reduce the structural integrity and functional quality of the pavement. Loss of structural integrity translates into a loss of load-carrying capacity. Loss of functional quality (increased roughness, decreased friction and surface drainage, foreign object damage (FOD) potential) compromises safety and reduces comfort of operation.

Although the manner and speed with which pavements deteriorate differs, the overall trend is one in which the pavement condition changes from good to poor and the pavement surface condition progresses from smooth to rough, as illustrated in Figure 2-1. Factors governing changes in pavement condition include (ARRA, 2015):

- Pavement type
- Quality of project design
- Quality of original construction, including mixes and materials
- Type, thickness, and properties (strength, stiffness, durability, etc.) of individual pavement layers
- Subgrade soil type, bearing properties, and moisture content
- Traffic composition and loading characteristics
- Environmental conditions
- Types, levels, and effectiveness of maintenance activities

Figure 2-1 Pavement Deterioration Trends



(a) Condition deterioration
(b) Roughness progression

2-1.1 Pavement maintenance and rehabilitation (M&R) slows deterioration, extends pavement life and addresses the following (Zimmerman):

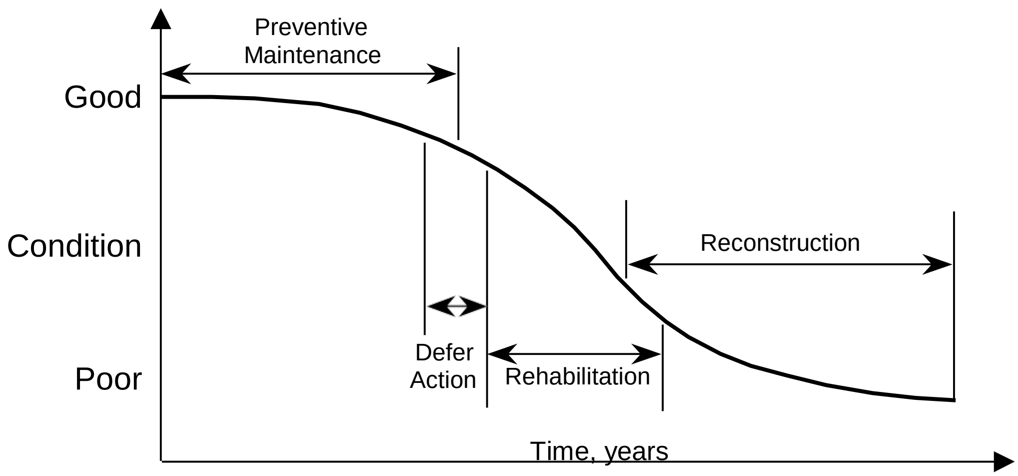
- Inadequate smoothness.
- Excessive pavement distress.
- FOD potential (generally airfields only).
- Reduced surface friction.
- Excessive maintenance requirement.
- Unacceptable user costs.
- Inadequate structural capacity for planned use or projected traffic.

2-1.1.1 Many types of M&R treatments are available for these purposes. They range from localized corrective maintenance (e.g., surface patching, full-depth repairs, rut patching and filling) to preventive maintenance (e.g., crack and joint sealing, surface treatments, thin overlays) to minor rehabilitation (e.g., grooving, functional overlays, limited restoration) to major rehabilitation (e.g., structural overlays, extensive restoration, rubblize-and-overlay).

2-1.1.2 The selection of M&R treatment and timing is a critical component in the economical operation of a pavement network. In the pavement life cycle shown in Figure 2-2, localized corrective maintenance is required at any point on the deterioration curve except at the highest condition levels. However, as the condition level significantly decreases, the costs of corrective maintenance become excessive in the absence of rehabilitation or reconstruction.

2-1.2 Preventive maintenance is a cost-effective treatment that preserves the pavement, retards future deterioration, and maintains or improves functional condition. It is most appropriate when the pavement is in relatively good condition (Zimmerman). As seen in Figure 2-2, the window of opportunity for cost-effectiveness is during the early stages of pavement life.

Figure 2-2 Timing of Pavement Activities*



*Source: Zimmerman.

Rehabilitation, defined as the structural or functional enhancement of a pavement that produces substantial extension in service life (Hall et al., 2001), is most appropriate when preventive maintenance is no longer cost-effective, yet the structure has not deteriorated so badly to warrant reconstruction. During this period, structural capacity remains such that one or several rehabilitation techniques are economically justified over reconstruction.

2-1.3 Although recycling techniques generally fall under the category of rehabilitation, certain forms of recycling, such as CM and HIR-I, constitute corrective maintenance. While HIR-I with an overlay is preventive maintenance. FDR is characterized as reconstruction.

2-2 SELECTION OF PREFERRED REHABILITATION ALTERNATIVE.

2-2.1 Introduction.

2-2.1.1 This chapter provides an overview of the rehabilitation selection process, as it pertains to asphalt and concrete pavement recycling methods. It is a general familiarization tool and a lead-in for the detailed, project-level applications presented in Chapter 3.

2-2.1.2 The selection process favors those recycling techniques that fall under the rehabilitation and reconstruction categories. Such treatments transform an existing deteriorated pavement into a new pavement with significant future performance expectations that necessitate an economic analysis. UFC 3-270-08 provides useful background guidance in the determination of feasible M&R alternatives, including many of the recycling techniques discussed in this manual.

2-2.1.3 Determining the most appropriate rehabilitation strategy for a given pavement at a given time is not a simple process, especially if cost-effectiveness is a consideration. The process requires information about the existing pavement as well as the needs and constraints of the rehabilitation proposed. In addition, there are usually several solutions to consider, each with unique advantages and disadvantages.

2-2.1.4 When identifying a pavement for possible rehabilitation, perform a sequential approach to evaluate strategies and identify possible solutions. First survey the existing pavement to identify and quantify the various types of distress and the rate(s) at which they are developing. Prepare a list of feasible rehabilitation techniques based on the distresses identified. Next, collect historical information, and perform a detailed evaluation to identify the mechanisms causing the distress and to determine the structural and functional capacities of the pavement. Formulate rehabilitation strategies (i.e., a specific treatment or a combination of treatments) that adequately address the cause of the distress. These strategies may or may not include recycling materials and techniques.

2-2.1.5 Then further develop the strategies to satisfy the needs and constraints of the project. After identifying a final set of feasible rehabilitation strategies, perform a cost analysis and evaluate the results in conjunction with non-monetary factors to select the preferred alternative.

2-2.2 Identification of Feasible Recycling Techniques.

2-2.1.1 As discussed in Chapter 1, there are several basic recycling methods for rehabilitating existing asphalt-surfaced pavements and rehabilitating existing concrete-surfaced pavements. Perform the basic asphalt recycling methods individually or in combination with other methods and supplement with HMA overlays or surface treatments to satisfy design life requirements. A summary of asphalt recycling methods covered in this document follows below. (*Asphalt Pavement Recycling* (ARRA and FHWA, 2001; Kandhal and Mallick, 1997) and *Basic Asphalt Recycling Manual*, Second Edition (FHWA/ARRA, 2015)).

- Cold Milling/Planing (CM)
- Hot Recycling (HR)
- HIR Type I—Surface Recycling (HIR-I)
- HIR Type II—Remixing (HIR-II)
- HIR Type III—Repaving (HIR-III)
- Cold In-Place Recycling (CIR)
- Cold Central Plant Recycling (CCPR)
- Full Depth Reclamation (FDR)

2-2.1.2 Concrete recycling methods:

- Slab Fracturing—Crack and Seat
- Slab Fracturing—Break and Seat
- Slab Fracturing—Rubblization
- Recycled concrete aggregate (RCA)

2-2.1.3 Consider many factors to determine the feasibility of each application. Obtain a preliminary indication by examining the current condition of the pavement, as reflected by pavement condition index (PCI) survey data and identify the types of pavement distress. Complete descriptions of the PCI procedure, including the distresses evaluated and distress deduct values, are provided in UFC 3-260-16, American Society for Testing and Materials (ASTM) D5340, *Standard Test Method for Airport Pavement Condition Index Surveys*, and ASTM D6433 *Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys*.

2-2.1.4 Currently, airfield pavement PCI surveys are required on a regular basis for DoD pavements. Conducting PCI surveys on DoD roadway pavements helps determine the appropriate pavement maintenance, repair, or rehabilitation technique.

2-2.1.5 DoD agencies use the MicroPAVER™ pavement management system (PMS) to enter and store PCI survey data and track pavement conditions over time. The MicroPAVER™ system computes the structural condition index (SCI) of a pavement from the distress data collected in PCI surveys. The SCI represents the structural component of the PCI and considers only load-related distresses. Hence, deduct values are applied for distresses, such as, fatigue cracking, potholes, rutting, and shoving in asphalt pavements and corner breaks, longitudinal, transverse, and diagonal cracking, corner spalling, and divided/shattered slabs in concrete pavements.

2-2.1.6 A PCI trigger is more difficult to establish because of the inclusion of non-load-related distresses, but values of 65 to 70 are typical. Trigger levels for reconstruction on major facilities generally span the PCI range of 45 to 50.

2-2.1.7 The PCI is a good measure for determining the timing of an M&R activity; however, selection of an appropriate recycling method is best determined by considering the distresses exhibited. Table 2-1 illustrates typical pavement distresses along with recommended recycling techniques for repair. Repair techniques other than those presented in Table 2-1 may be appropriate, but Table 2-1 presents only recycling techniques. From functional treatments like CM with an HMA overlay to reconstruction using FDR with an HMA overlay, asphalt recycling provides a host of options.

2-2.1.8 Concrete pavements include two approaches for recycling: fractured slab technologies (crack and seat, break and seat, and rubblization) and recycled concrete aggregate.

2-2.1.9 Each recycling technique features advantages and disadvantages in terms of the specific pavement distresses treated and the ability to meet project objectives (e.g., design, construction, and environmental). Table 2-3 provides guidance in identifying feasible recycling techniques for deteriorated asphalt and concrete pavements. The table lists the appropriateness of each recycling technique in terms of how well it mitigates a particular distress.

Table 2-1 Suitability of Asphalt Recycling Techniques Based on Distresses

Pavement Distress	Suitable Asphalt Recycling Techniques					
	CM[2]	HIR[1]	HR[3]	CIR[4]	CCPR[4]	FDR[4]
Alligator Cracking	Green	Red	Green	Green	Green	Green
Jet Blast Erosion	Green	Yellow	Green	Red	Red	Red
Reflection Cracking	Red	Red	Yellow	Yellow	Yellow	Yellow
L&T Cracking	Red	Yellow	Red	Red	Red	Yellow
POL Spillage	Green	Yellow	Green	Red	Red	Red
Raveling	Yellow	Green	Green	Red	Red	Red
Rutting	Green	Yellow	Yellow	Yellow	Yellow	Yellow
Loss of Friction	Green	Green	Green	Red	Red	Red
Slippage Cracking	Green	Red	Green	Red	Red	Red

Key: Green—Likely applicable
Yellow—Maybe applicable
Red—Highly unlikely to be applicable

Notes:
[1] Do not use HIR on airfields without HMA overlay.
[2] CM generates FOD. Do not open milled surface to aircraft traffic under normal operations. Apply HMA overlay prior to opening to traffic. Milled roadway surfaces may be temporarily open to traffic with appropriate traffic control and warning measures. Due to safety concerns, noise and the rough surface associated with milled surfaces, do not allow traffic for extended periods.
[3] HR is suitable in all HMA mixes, except for airfield surface courses. Most HMA contains some RAP, so use HR where HMA is used. See specification requirements for limits on the amount of RAP allowed.
[4] Adhere to the minimum surface thickness requirements for flexible pavements above these recycled mixtures.

Table 2-2 Ideal Candidates for Asphalt and Concrete Recycling Techniques

Recycling Technique	Ideal Candidate Pavement Based on Existing Distresses
CM Only	Expedient repair technique to correct a friction-related and other surface problems, such as roughness, POL spillage, jet blast, etc. This technique is not allowed on airfields since it significantly increases FOD.
CM with HMA Overlay	Milling followed by HMA overlay is the most common approach for repairing existing asphalt pavements. This process works well for raveling, bleeding, cross-slope adjustment, rutting, and roughness.

Recycling Technique	**Ideal Candidate Pavement Based on Existing Distresses**
Hot Recycling (HR)	RAP is not allowed in HMA mixtures used as surface courses on DoD airfields. RAP is allowed in HMA mixtures used as base course or shoulder pavements on airfields. For DoD airfield pavements, the amount of RAP is limited such that the asphalt binder contributed by the RAP does not exceed 20 percent of the total asphalt content of the mixture, by weight. For DoD roadway and parking lot pavements, the amount of RAP is limited such that the asphalt binder contributed by the RAP does not exceed 30 percent of the total asphalt content of the mixture, by weight.
Hot In-Place Recycling (HIR)	HIR can solve surface problems such as raveling, surface cracking, minor rutting, and friction. Along with HMA overlays, HIR can solve more severe cases of rutting and cracking and add additional structure to the pavement. Do not use HIR on airfields without an HMA overlay.
HIR-I, Surface Recycling	HIR-I typically treats the uppermost pavement surface by heating, scarifying, adding virgin asphalt binder, and placing and compacting for minor HMA mix improvement and modification. Use HIR-I to rejuvenate surfaces that have experienced oxidation and to solve minor surface deficiencies. HIR-I is not allowed on airfields or on high volume roadway pavements.
HIR-II, Remixing	HIR-II is a remixing process that heats and loosens the existing asphalt pavement, combines with virgin aggregate and asphalt binder (or new HMA mix), and places and compacts for significant mix improvement, mix modification, or minor pavement strengthening. This process addresses pavement distresses such as rutting, raveling, loss of friction when confined to the pavement surface. HIR-II is not allowed on airfields or high volume roadway pavements.
HIR-III, Repaving	HIR-III is a more complex process in which the uppermost pavement surface is heated, loosened, combined with virgin asphalt binder, and placed integrally with an HMA overlay for the purpose of pavement strengthening or surface restoration.
Cold In-Place Recycling (CIR)	CIR is used for pavements with significant surface problems such as smoothness, rutting, and cracking. Works well to provide additional structural capacity when coupled with an HMA overlay. When used on an airfield or on high volume roadways, an HMA overlay is required.
Cold Central Plant Recycling (CCPR)	Same as for CIR.

Recycling Technique	Ideal Candidate Pavement Based on Existing Distresses
Full Depth Reclamation (FDR)	Use FDR to correct significant performance problems in an existing pavement, including fatigue cracking, rutting and other distresses that reduce the ability of the pavement to support traffic. Use FDR to significantly strengthen pavements. Rarely used on airfields or high volume roadways. Best used for low volume roads.
Crack and Seat	Crack and seat is a fractured slab technology appropriate for JPCP to reduce to delay, minimize or prevent the onset of reflective cracking in an HMA overlay. Crack and seat technology reduces the length of the existing PCC slabs to approximately 2 to 6 ft (0.6 to 1.8 m) to reduce the inducement of tensile strains at the interface with the new HMA overlay.
Break and Seat	Break and seat is similar to crack and seat, except that it is applied to JRCP and CRCP. In addition to reducing the base PCC slab size to approximately 1.5 to 4 ft (0.45 to 1.2 m), this method breaks the bond of reinforcing steel in the base slab prior to the application of the new HMA overlay.
Rubblization	As the name implies, rubblization is a fractured slab technology that breaks the base PCC slab apart into individual concrete particles ranging from dust to 15 inches (375 mm) diameter, depending on the thickness of the base slab, drainage and subgrade support. Rubblization is appropriate for JPCP, JRCP and CRCP and is effective in minimizing or preventing the onset of reflective cracking in an HMA overlay.
Recycled Concrete Aggregate (RCA)	RCA is appropriate for deteriorated concrete pavements where removal and replacement is the best rehabilitation alternative. Crush old concrete to acceptable particle sizes to produce unbound structural layers for use as base or subbase, and for blending into HMA or PCC mixtures. If used to produce concrete, RCA cannot contain particles that result in alkali silica reaction (ASR). For airfield pavements, only use RCA for aggregate base or lean concrete base.

2-2.3 Formulation of Feasible Rehabilitation Strategies.

Each pavement project comprises a unique set of conditions and circumstances beyond the types, severities, and extents of distresses present. These conditions and circumstances pose constraints on or limits to the effectiveness of individual recycling techniques, as well as the other forms of rehabilitation. A detailed project evaluation is crucial in determining the root cause(s) of pavement distress(es)—design inadequacies, applied loads, water, temperature, materials/construction shortcomings—and formulating a set of feasible rehabilitation strategies that adequately address the cause(s). Such an evaluation requires collecting key information about the existing pavement, establishing rehabilitation performance requirements/expectations, and identifying all factors affecting the suitability of alternative rehabilitation strategies.

Listed below are several specific informational items needed or desirable to formulating feasible recycling strategies. For some of these items, the airfield pavement structural evaluations and runway friction tests are valuable, especially if conducted recently. Pavement Information to collect includes the following:

- Pavement Cross Section—Define the existing pavement structure in terms of material layer types and thicknesses based on design information, as-built construction records, and maintenance data.
- Construction and Materials Quality—QC/QA data provides important information regarding the types of aggregates, binders, and additives used in HMA and PCC mixtures, as well as the mix properties (gradation, binder content, laboratory air voids, in-place density).
- Maintenance—Maintenance records may indicate the presence of chip seals, surface treatments, crack or joint sealant, machine patches, and other material applications that may factor into decisions about recycling and other rehabilitation strategies.

2-2.3.1 Detailed Evaluation of Existing Pavement Properties.

- Layer thicknesses—If historical data cannot characterize the pavement cross section or to obtain additional insight regarding the thickness and uniformity of material layers, then perform coring or ground penetrating radar (GPR) testing.
- Roughness and Friction—A detailed assessment of the pavement profile will quantify the overall roughness of the existing pavement and identify any significant differences in roughness throughout the limits of the project. Similarly, a detailed assessment of pavement friction using the Grip Tester or Mu-Meter will quantify the level of friction on the existing pavement and could identify differences in friction throughout the limits of the project. Texture depth testing via the sand patch method or laser systems (e.g., circular texture meter) can help assess the micro-texture and macro-texture components of pavement friction.
- Drainage—If needed, conduct a drainage survey to further assess the drainage characteristics of the existing pavement structure and determine the appropriateness of individual recycling alternatives. Moisture-related distresses identified in the PCI survey are a key part of this evaluation, as are cross-sectional design information and information about the design and condition of ditches, daylighted bases, and edge drains.
- Strength/Deflection—Nondestructive deflection testing (NDT) using impulse loading devices like the falling-weight deflectometer (FWD) and the heavy-weight deflectometer (HWD) can provide important information about the strength and structural capacity of the existing pavement.

- Strength/Bearing Capacity—The dynamic cone penetrometer (DCP) can evaluate the strength of unbound materials contained in the existing pavement structure. DCP readings can be directly correlated to the California Bearing Ratio (CBR). Like NDT data, CBR data may indicate a deficient unbound layer.
- Material properties—Examine and test pavement cores and other samples taken from throughout the project to gain additional information about the composition and condition of the pavement structure and the physical properties of the material layers.

2-2.3.2 Project Physical Characteristics.

- Project Size and Location—Although available funding may dictate project size, projects are typically defined as those pavement sections of an airfield or roadway pavement facility experiencing similar distresses. Develop a general idea of the project size and the proximity of the project to local aggregate sources and determine material production plants to understand mobilization and hauling considerations.
- Project Geometrics—Project geometrics include the need to maintain vertical alignment (adjacent pavements, in-pavement lighting, manholes, shoulders, curb-and-gutter, etc.), observe overhead clearances (bridges, power lines) or subsurface clearances (electrical circuitry, drainage structures), and address the impacts of lateral structures (e.g., buildings, hangars, lighting, barrier walls) on construction operations.

2-2.3.3 Design Characteristics/Performance Requirements.

- Design Life—Establish the required or desired design life of the rehabilitated or reconstructed pavement. Consider short and long term solutions and balance with budget considerations. Consider staged construction when appropriate.
- Traffic Projections—Determine the current composition of aircraft or vehicles using the pavement facility and their current levels of operation or volume, along with the projected growth rates of individual aircraft or vehicle types over the expected performance period.
- Climate—Climatic variables, such as temperature, precipitation, and freeze-thaw cycles can significantly impact the performance of recycled materials and must considered in the formulation of pavement rehabilitation strategies.

2-2.3.4 Construction Considerations.

- Construction Time Requirements—The available time for construction is often limited due to the scope of the project, the availability of alternate routes or facilities, regular traffic volume and the need to minimize disruptions due to mission requirements or safety concerns.

- Availability of Local Experience and Resources—Determine the knowledge and experience base of local contractors to perform rehabilitation or reconstruction activities, along with the availability of necessary equipment and local aggregates to fulfill the work requirements.
- Support of Construction Equipment—Consider how the removal or alteration of portions of a pavement structure may affect the ability to provide an adequate platform to support construction equipment and compaction of the constructed layers. Special consideration must be given to support of construction equipment when subgrade soils are saturated.

2-2.4 Selection of the Preferred Rehabilitation Strategy.

Selecting the preferred rehabilitation strategy requires evaluating economic and non-economic factors. The sections below briefly describe these factors.

2-2.4.1 Evaluation of Economic Factors.

Chapter 5 of UFC 3-270-08 outlines a procedure for conducting life cycle cost analysis (LCCA) for DoD pavement facilities. This procedure uses the net present worth (NPW) economic formula, an analysis period long enough to capture at least one major rehabilitation activity for each alternative, and a discount rate based on Army policies. An analyst estimates performance lives of the initial rehabilitation treatment and the sequence of M&R treatments expected over the analysis period, along with treatment costs. For each alternative, compute the NPW by summing the initial rehabilitation cost and each of the discounted future M&R costs. Compare the NPW of all feasible alternatives to identify the lowest life cycle cost alternative.

Use other economic factors in addition to life cycle costs for evaluation to include the following:

- Initial costs—Ensure that a project level alternative does not compromise the needs of the entire network (i.e., overall pavement management).
- Indirect/user costs—Costs incurred due to closures for construction and/or M&R work. These are a concern if the expected initial construction and/or future M&R operations generate a high degree of user dissatisfaction.
- Future maintenance costs—Alternatives requiring a disproportionate amount of future maintenance to sustain an adequate level of service, may exceed the personnel and/or equipment available.

2-2.4.2 Evaluation of Non-Economic Factors.

Evaluate numerous non-economic factors when selecting the preferred rehabilitation technique to include: Airfield class/type and traffic area type, roadway traffic level/composition, geometrics (lane widths affecting shoulder dimensions, drainage features, and horizontal and vertical alignment influence on traffic speed, drainage features), continuity of adjacent pavements and/or lanes, peripheral features, and future rehabilitation options and needs. Construction/materials considerations include availability of local materials and contractor capabilities, traffic control during construction (safety and congestion), duration of facility closure, recycling, conservation of materials and energy, roughness, and environmental implications. Consider the following maintenance issues: future maintenance operations, performance of treatment elsewhere under similar conditions, and maintenance capability. Design issues include noise issues (pavement-tire noise), subgrade soils, climate, DoD component or Base preference, safety considerations (friction/texture characteristics, pavement/shoulder contrast, and reflectivity).

CHAPTER 3 PROJECT PROCESS SELECTION AND STRUCTURAL DESIGN

3-1 INTRODUCTION.

This chapter describes a process of analyzing a pavement project to identify acceptable rehabilitation strategies and techniques. It also provides information on the structural design of recycled pavements and life cycle costs.

Airfield pavement conditions at individual military Bases are monitored through PCI surveys and structural evaluations utilizing an FWD. The collected condition data are entered and stored in the MicroPAVER™ pavement management system database. Some installations perform PCI surveys of roadway pavements. Airfield pavement PCI data and other available information determine maintenance and rehabilitation needs and identify those pavements that need detailed pavement structural evaluation or runway pavement friction testing. Base roadway pavements do not typically receive detailed structural evaluations.

Data used to determine the best treatment method includes PCI, FWD, construction and maintenance history, pavement coring and analysis, dynamic cone penetrometer (DCP), and other information. Since PCI and FWD data may have been collected over a considerable length of time, it may not be representative of current conditions. For that reason, a visual inspection may be needed to verify the overall condition and assess the need for additional testing.

3-2 PAVEMENT INFORMATION TO COLLECT.

3-2.1 Layer Thicknesses.

Coring, GPR, FWD, other tests and layered elastic analysis provide the layer information to validate recycling alternatives. The data also indicates the depth of pavement issues. The layer thicknesses and existing pavement issues influence the pavement design and help identify acceptable recycling alternatives.

3-2.2 Friction.

Friction test results and texture depth data provide information about the friction characteristics of the pavement surface. Steps to improve friction will require modifications to the pavement surface. Since friction is a surface problem, treatment for low friction are typically limited to surface repairs. Treatments include HIR, HR, or an HMA overlay. Surface milling can temporarily solve friction problems by improving the surface texture. Utilizing a milled surface is not ideal since the surface tends to have loose aggregate, is noisy under traffic, and can more quickly wear and damage tires of the vehicles and aircraft. FOD is a significant problem for milled pavement surfaces, so it is generally not acceptable to operate aircraft on this type of surface.

3-2.3 Roughness.

If available, roughness measurements, along with distress data from PCI surveys, can help determine specific performance problems causing increased roughness. Some roughness is attributable to design and construction, but most pavement roughness is the result of traffic operations and environmental effects. Performance problems causing roughness in the surface layer including segregation, raveling, and rutting favor recycling strategies such as HIR, HR, and HMA overlays. Conversely, roughness caused by problems in subsurface layers suggests the need for deeper, more extensive forms of recycling such as CM with HMA overlay, CIR, CCPR, FDR.

3-2.4 Drainage.

A drainage survey can identify excessive moisture, the sources of moisture, and the affected pavement layers and materials (Grogg et al., 2001). Surface drainage issues causing performance issues in the upper pavement structure are suitable for treatment using recycling strategies that address the upper layers.. However, if damage extends more deeply into the structure, consider more extensive recycling and/or drainage retrofitting. Subsurface drainage improvement may involve the installation or replacement of longitudinal edge drains and lateral outlets, or daylighting a base layer by replacing base material under shoulders with better-draining material (Hall et al., 2001).

3-2.5 Material Properties.

Pavement cores and other samples provide additional information concerning the cause of pavement distress. Evidence of asphalt binder stripping, bare and uncoated aggregate, friable or disintegrating mix, retention of excessive moisture, bleeding, and a tendency for layer debonding are examples of material deficiencies (ARRA, 2001) that aid in selecting feasible asphalt recycling alternatives. HMA mix properties (binder content and binder properties, aggregate gradation and quality, and voids in the mixture, etc.) and unbound material and subgrade properties influence the effectiveness of techniques that improve the existing materials. PCC pavement with ASR issues precludes the use of RCA materials on most airfield pavements as well as break/crack-and-seat and rubblization techniques.

3-3 RECYCLING METHODS TO ADDRESS PAVEMENT DISTRESSES.

3-3.1 Pavement Performance Problems.

Figures 3-1 through 3-12 illustrate pavement conditions suitable for recycling techniques. Other forms of rehabilitation, such as conventional overlays, with or without RAP, or pavement preservation activities, are also viable options. Use a combination of these techniques to compare their life cycle costs to select the final approach.

3-3.1.1 Alligator Cracking (Figure 3-1).

Alligator cracking often occurs in asphalt pavements and is an indicator of structural weakness. It can occur locally due to localized moisture problems or contamination in the underlying materials. Localized alligator cracking may be repaired by cutting out and patching the affected areas, but more widespread cracking throughout an entire section of pavement indicates pavement failure and likely requires rehabilitation. Alligator cracking is a structural problem that may be related to weakness in the underlying base or subgrade layer or may be related to a drainage problem. For these reasons, treatment of alligator cracking may require significant effort to address.

Figure 3-1 Alligator Cracking

3-3.1.1.1 Alligator cracking requires a detailed inspection and evaluation to determine potential causes. Identify whether drainage is a factor. Cutting a trench across the traffic lane allows inspection, sampling and testing of all layers including subsurface materials. Review available design and construction data. Nondestructive pavement evaluation provides insight into the pavement structure. If cracking is substantial, it may be difficult to conduct FWD testing since the cracking affects the pavement response making it difficult to obtain a good nondestructive evaluation.

3-3.1.1.2 Repair alligator cracking by cutting out and patching or by applying an HMA overlay to the surface. It is often difficult to obtain funding for a pavement just beginning to show distresses, hence, some justification for early repair is needed.

3-3.1.1.3 Rehabilitating alligator cracking often requires removing extra material to eliminate all unsatisfactory material. This is an ideal situation for cold recycling processes (CIR, CCPR, and FDR). For example, remove unsatisfactory material including the base course and pull it to the side for reuse. Stabilize the underlying material before reapplying the base course and a new HMA layer. Perform adjustments to the base materials prior to placement. Adjustments to the base course may include additional aggregate or water.

3-3.1.1.4 Remove the HMA mixture by milling. Treat the milled material with a small percentage of asphalt emulsion before replacing. Place one or more lifts of HMA as an overlay to the milled material. This process is acceptable for low volume roads and airfields. For high volume roads and airfields, HMA over the CIR are required to meet the minimum thickness requirements for HMA over crushed aggregate base course.

3-3.1.1.5 Some low volume roads are suitable for mixing the top several inches of existing structurally deficient pavement with a pulvimixer to produce homogenous underlying materials (FDR). Use this process to mix up to 15 to 20 inches of materials. Move the material to the side of the pavement under repair to rebuild the structure in layers having adequate density and smoothness. Add water or asphalt emulsion to aid in handling and compaction and provide some cohesion. Once the materials are thoroughly mixed, placed, and compacted, cover with an asphalt surface treatment or the minimum required thickness of HMA pavement.

3-3.1.2 Jet Blast Erosion (Figure 3-2).

Jet blast erosion occurs on asphalt pavements in areas where jets operate in slow moving or stopped conditions. The jet blast heats the pavement surface turning the area of direct heat impact black and in some cases actually blasting aggregate particles from the surface and burning the asphalt binder. In extreme cases, the blast removes the entire top layer. This generally only happens when there is delamination between the asphalt surface course and the underlying layer or when the total thickness of asphalt mixture is thin allowing removal of the entire thickness of asphalt.

Figure 3-2 Jet Blast Damage

3-3.1.2.1 Jet blast erosion is a surface problem that does not typically cause significant damage to underlying pavement layers. The normal procedure mills down approximately 2 inches or deeper as needed followed by a patch. On larger projects, recycle the milled material into the project. This is especially beneficial in remote areas. Clearly define in the statement of work whether the millings are contractor property or are retained in a government stockpile.

3-3.1.2.2 Do not use the HIR processes to repair the areas damaged by jet blast erosion. HIR on airfields require the placement of an HMA overlay, hence, HIR is not a good option for correcting areas of blast effect. It is also very difficult to modify the in-place asphalt binder due to the jet blast damage.

3-3.1.2.3 While surface recycling methods can potentially treat jet blast areas, these methods are not normally the best approach. A more straightforward approach is CM with an HMA overlay, which generally provides more satisfactory performance compared to HIR.

3-3.1.3 Reflective Cracking (Figure 3-3).

Applying an HMA overlay directly on an old concrete pavement frequently results in reflective cracking in the new HMA overlay. Applying an HMA overlay to a cracked HMA pavement can result in reflective cracking, but it seldom occurs and is typically not as distinctive the reflective cracking that develops in HMA over PCC. Reflective cracking is caused by the opening and closing of joints and cracks in the underlying layer due to temperature fluctuations. Seal reflective cracks as soon as they occur. If reflective cracks continue to propagate and deteriorate, additional work may be required, such as CM with an HMA overlay. Placement of a fabric or stress absorbing membrane interlayer (SAMI) prior to the HMA overlay may delay the onset or minimize reflective cracking in the HMA overlay, especially over cracked HMA pavements. If the pavement is in poor condition, consider using CIR or CCPR procedures to recycle an HMA pavement exhibiting reflective cracking. CIR or CCPR must incorporate an HMA overlay on DoD airfields and high volume roads.

Figure 3-3 Reflective Cracking

HIR may be effective to address reflective cracking on roadways. For moderate to high volume roadway pavements, apply an HMA overlay or asphalt surface treatment to the HIR surface. HIR may serve as the wearing course on low volume roadways.

3-3.1.4 Longitudinal and Transverse Cracking (Figures 3-4 and 3-5).

Longitudinal and transverse cracking is a common distress on HMA roadway and airfield pavements. Much of the longitudinal cracking is deterioration of the longitudinal paving joints (Figure 3-4). Low density at the longitudinal joint results in cracks forming over time. Longitudinal cracks can develop in the middle of the paving lane at the paver gear box. This phenomenon occurs when the auger flights fail to adequately maintain a uniform head of material in front of the screed. Identify and correct this problem during construction to promote long term performance. Longitudinal cracking can develop into fatigue cracking. In this case, the initial crack occurs longitudinally followed over time by additional cracking parallel and transverse to the intial crack, forming a system of interconnected cracks.

Low ambient temperatures and frequent and significant temperature changes cause cracking in the transverse direction (Figure 3-5) at some spacing along the roadway/airfield. As the pavement ages and becomes embrittled, transverse cracks develop between the earlier cracks, resulting in more closely spaced transverse cracking.

The first maintenance procedure for longitudinal and transverse cracks to seal the cracks to prevent water from entering into the joint and weakening the underlying layers. When cracks widen and become more closely spaced, more aggressive repairs are required. Consider CM with an HMA overlay or HIR with an HMA overlay.

Figure 3-4 Longitudinal Cracking

Figure 3-5 Transverse Cracking

3-3.1.5 Petroleum, Oil or Lubricants (POL) Spillage (Figure 3-6).

Petroleum, oil or lubricant spillage generally occurs under aircraft or vehicles during maintenance or refueling operations. This spillage can soften HMA pavements and can result in the loss of asphalt binder and fine aggregate particles. On roads, this type of damage usually arises from accidents or equipment malfunction. On airfields, POL spillage typically occurs in areas where refueling or minor maintenance is performed. Fuel-resistant HMA mixes should be specified for the surface of airfield pavements where there is risk of POL spillage.

Repair POL spills (Figure 3-6) to prevent raveling and subsequent loss of aggregate particles. Treat by milling the damaged areas and overlaying with HMA.

In many cases, blotting the POL spill on a roadway with sand or sawdust minimizes the damage and quickly allows the road to be opened to traffic. Large spills that are not promptly cleaned up will penetrate the pavement and lead to rapid failure. Remove the damaged material and patch with HMA. Collect the damaged material for treatment and off-site recycling. Further recycling is not cost effective for small areas.

Figure 3-6 Fuel or Oil Spillage

3-3.1.6 Raveling (Figure 3-7).

Raveling (Figure 3-7) typically occurs in areas having segregation or low density, such as longitudinal joints. Areas of segregation or low density observed on the surface may exist through the full depth of the layer. Localized problem areas may ravel enough to require some type of repair. The most common repair is to mill the problem area and patch with HMA. Bituminous surface treatment or an HMA overlay may also be suitable treatments.

When raveling is more widespread, rehabilitate the entire surface by mill and overlay with HMA. For large projects, remove the material from the project site for use as RAP.

Use the HIR process to treat raveled areas followed by application of an HMA overlay on airfields and high volume roads. The HIR process may eliminate the need for milling and may be more cost effective than traditional CM and HMA overlay. On low volume roads, the HIR process without an HMA overlay can be used to treat raveled pavement. HIR may reduce the initial cost and overall life cycle cost.

Figure 3-7 Raveling.

3-3.1.7 Rutting (Figures 3-8 and 3-9).

Rutting can occur in HMA pavements when subjected to slow moving traffic. Rutting can be related to structural weakness (Figure 3-8) in the underlying base, subbase, or subgrade layers or relatively high tire contact pressure that affects the surface layer (Figure 3-9). Rutting, when caused by underlying structural problems, is typically wider and deeper than rutting in the HMA layer caused by high tire pressures. The recycling techniques shown in Table 2-1, except HIR, may be considered for repair of rutted pavement. Rutting due to structural weakness requires excavating and replacing deficient material with satisfactory material. Repair rutting of the HMA layer by removing the top 2-4 inches (25 to 50 mm) of surface and replacing with acceptable HMA.

Prior to repairing a pavement experiencing rutting, investigate the extent of the rutting by cutting trenches across a rutted pavement. If the rutting extends into the base and underlying layers this is an indication that the underlying materials may require improvement or removal and replacement.

Consider recycling processes such as CIR and CCPR to rehabilitate rutted pavement caused by weakness of the underlying layers. For example, the investigation may indicate that there is a problem in the subgrade. In this case, excavate to the subgrade and repair by stabilization. Place the recovered materials back in their appropriate layer in the pavement. It may be necessary to modify or stabilize some of the materials prior to putting back in place.

Repair rutting confined to the existing HMA surface by CM followed by HMA overlay. Use the milled material as RAP in the recycled mixture.

Figure 3-8 Rutting of the Pavement Structure

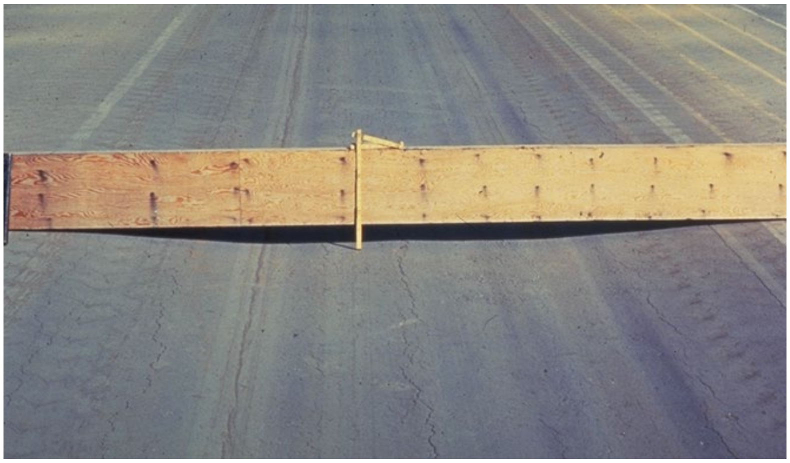


Figure 3-9 Rutting in the HMA Layers

3-3.1.8 Loss of Friction.

Loss of friction often occurs due to polishing of aggregate or asphalt binder bleeding to the pavement surface. Loss of friction can generate significant safety issues and requires prompt repair. Pavement surface issues cause friction problems and are corrected by modifying the surface.

As an expedient repair, mill the surface to improve friction. A milled surface has a rough surface texture that significantly improves friction. The milled surface may deteriorate with time when exposed to environmental conditions and traffic. Therefore, the milled surface is a temporary method. Be aware, using a milled surface to improve surface friction is a significant problem on airfields due to the potential for FOD as aggregates may ravel from the milled surface. Permanently correct the surface with an HMA overlay as soon as practical.

Friction test results and, if available, texture depth data, provide information about the friction characteristics of the pavement surface. Steps to improve friction require modifications to the pavement surface. Friction is a surface issue and the repair for low friction does not require significant modifications below the pavement surface. Repairs for friction problems include HIR, HR, or an HMA overlay.

3-3.1.9 Slippage (Figure 3-10).

Slippage occurs when delamination occurs between two layers of asphalt mixture (typically the top two layers). This is due to a number of factors including the type of tack coat used, application procedures for tack coat, and the cleanliness of underlying surface. Moisture problems can also cause delamination and loss of bond. If slippage occurs, remove the top layer by milling below the depth of delamination and applying an HMA overlay. The overlay can consist of HR.

Figure 3-10 Slippage due to Loss of Bond

3-3.1.10 Alkali Silica Reaction (ASR) (Figure 3-11).

ASR results in scaling or map cracking around joints or other areas subject to moisture. The ASR generates swelling in the concrete resulting in internal stresses. In time this leads to deterioration of the concrete surface. Typically, concrete pavements with ASR continue deteriorating, eventually requiring repairs. There is a risk of expansion and breakdown of this material if left in place, even if cracked and seated or rubblized, This risk increases in the presence of soils or ground water that contain Alkalis and/or Sulfates. ASR or sulfate reactions may generate additional swelling of the mixture, cause breakdown of the material or generate additional performance problems. Remove and crush this material to aggregate size and use as base course or similar use for roadways. Do not design, place or use this material under airfield pavement without prior approval of the DoD’s Pavements Discipline Working Group (DWG). Requests to the Pavements DWG for use of ASR infected recycled concrete under airfield pavements must include a detailed risk assessment, the type of cement in the concrete or the type of cement used in concrete supplied by local ready mix plants for building foundations, field measurements of sulfate concentrations in the soil and ground water, the pH of the soil and ground water, a list and drawing showing the location of any utility, drain, gutter, foundation, or arresting system component within 20 feet (6 meters) of the material placement and a detailed list of design and operational means and methods that will be employed to monitor and mitigate any expansion of the material that may develop. Only submit such requests as value engineering proposal requests in Design-build or construction contracts of designs not including the reuse of the ASR recycled material on airfields. Do not bid a design-build contract assuming or accepting or calculating the use of ASR infected recycled concrete is or will be allowed in any airfield pavement.

Figure 3-11 ASR Distress (Scaling/Map Cracking) on Concrete Pavement

3-3.1.11 Shattered Slabs (Figure 3-12).

Shattered slabs occur when the pavement has exceeded its design life or the pavement is overloaded. Fractured slab technologies, such as crack and seat, break and seat, or rubblization, coupled with HMA overlay, work well to address concrete with shattered slab distress. Account for the loss of strength in the fractured concrete in the structural design of the HMA overlay. Alternately, remove and crush the concrete for use in HMA or PCC mixes or as base course.

Figure 3-12 Shattered Slabs on Concrete Pavement

3-4 PAVEMENT CONDITION AND PERFORMANCE TRENDS.

Finally, assess the feasibility of recycling based on pavement condition/performance trends. Historical PCI or SCI trends, or even trends of key distresses, indicate the rate of deterioration. Knowing the PCI or SCI deterioration rate allows a more accurate selection of techniques to address future conditions. As a general note, UFC 3-270-08 provides illustrations of low, normal, and high long-term rates of deterioration for four pavement types: asphalt concrete (AC) pavements, AC overlays of AC pavements, PCC pavements, and AC overlays of PCC pavements. Measure the long-term rate from the time of construction or last overall M&R activity. It also categorizes short-term deterioration rates, i.e. a drop in the pavement condition index (PCI) during the last year, as low (≤3 PCI points), normal (4 to 6 points), and high (≥7 points).

3-4.1 Evaluating Existing Pavement.

If available, detailed pavement structural and/or functional information may shed light on the causes of pavement distress, leading to a more viable set of candidate recycling strategies. PCI results are useful. Inspecting the project is essential. The following paragraphs discuss the indicators that pavement properties provide to identify appropriate repair strategies.

3-4.2 Design Considerations.

Following are aspects of CIR design.

3-4.2.1 Existing Pavement Structure and Conditions Analysis (ARRA, 2001).

Carry out a detailed review of written and/or verbal historical information. While much of this information may not exist, collect as much data as possible. If sufficient data is lacking, collect it through the site inspection and additional testing.

Past project design documents and construction records such as QC data and inspection reports are helpful. Other useful information includes data collected since the construction of the road/airfield such as the types of maintenance performed and documentation of observed performance problems. Surface treatments are particularly important as they have a high asphalt binder content to account for in the new mix design.

The following is information and techniques useful in evaluating the composition and condition of a pavement structure.

a. General information.

- Thickness of HMA layers
- Moisture problems such as delamination, poor bond, and stripped aggregates
- Asphalt binder properties in HMA layers
- Maximum aggregate size
- Presence of paving fabric
- Presence of special mixes such as porous friction course (PFC), open graded, or stone matrix asphalt (SMA).
- Patch location and age
- Patch materials (e.g., HMA, cold mix asphalt, injection spray patching)
- Crack seal material type and ages
- QC/QA information, including:
    - Asphalt binder content
    - Aggregate gradation, angularity, flat/elongated particles and/or petrographic analysis
    - Voids total mix (VTM), voids in mineral aggregates (VMA), voids filled with asphalt (VFA)
    - Field compaction
    - Recovered asphalt binder properties

b. Pavement performance curves or data that indicates the rate of pavement deterioration

c. Visual inspection of the pavement conducted by an experienced person. Verify the following information:

- Type and severity of the surface and structural distresses (localized or generalized problems)
- Segments with similar problems
- Identification of localized problems that may need special treatment
- Segments that need correction of the surface profiles
- Presence of manholes or similar structures
- Characteristics of the shoulders
- Adequate area to stage construction equipment

d. Non-destructive deflection testing (NDT) evaluation to identify limits of sections with relatively uniform support. It is important to know if the pavement has structural capacity to support the CIR construction equipment and to verify the design for repair. Conduct destructive evaluation on pavement having special problems or to obtain samples for laboratory testing.

e. Obtain representative RAP samples using random sampling techniques for adequate CIR mixture design. Take sufficient cores to provide material for the testing described in the mix design section.

f. Core samples are typically 6 inches (150 mm) in diameter. The number of samples depends upon the size of the project. Large projects, greater than 4 miles (6.4 km) long, require at least two samples per lane-mile (1.6 lane-km) with a minimum of six samples per project. Additional cores may be required to provide enough material for mix design. Small projects require at least eight samples per mile (1.6 km) or one per block if the pavement is not homogeneous (ARRA, 2001; FHWA, 1997).

3-4.2.2 Identifying Distress Causes.

Identifying distresses and their likely causes during the visual inspection is mandatory to identify all root causes to consider in the decision-making process. For example, rutting on the pavement surface may be caused by a number of factors including but not limited to weak subgrade or an unstable mixture. The repair for rutting in asphalt layers is much different from repairing rutting in the underlying layers.

3-4.2.3 Analysis of Road/Airfield Profile/Geometric Assessment.

Analysis of the road or airfield pavement profile and a geometric assessment is of paramount importance to determine project requirements, including the following:

- Major realignment, widening or drainage corrections
- Special consideration for underground utilities and drainage structures

- Attention to bridges and overpasses. Evaluate structural capacity to determine if they provide adequate support of construction equipment
- Longitudinal grade corrections
- Corrections for cross slope and fall

These analyses assist in evaluating whether the project is a good candidate for recycling or other alternatives.

In urban areas, check whether construction equipment can maneuver onto or exit the construction site.

In general, correct small problems with longitudinal/transverse profiles during the paving process. If these defects are serious, consider the following alternatives:

- Use CM to correct profile deficiencies if the road or airfield HMA pavement has adequate thickness
- Use additional granular material or RAP to correct profile
- Correct during CIR and add a leveling course or HMA overlay

3-4.2.4 Selection of Best Materials and Methods.

It is essential to know the properties of the existing in-place materials before selecting the best new materials to add. The mix design topic discusses how to evaluate material properties.

3-4.2.5 Traffic Assessment.

For an existing pavement, historical traffic data can be used to assess remaining structural life as well as the effect of construction quality on the adequacy of the original design. For new pavements, the designer develops a forecast of future traffic to support the selection of layer materials and compute individual layer thicknesses within the optimized design solution.

3-4.2.6 Layer thicknesses.

Results of coring and other tests such as GPR and NDT can provide the layer information needed to verify the appropriateness of recycling alternatives and indicate the depth of any pavement problems that must be addressed. This information, in turn, may determine acceptable recycling alternatives.

3-4.2.7 Friction.

Friction test results and texture depth data provide information about the friction characteristics of the pavement surface. Steps to improve friction require modifications to the pavement surface. Friction is a surface issue and the repair for low friction does not require significant modification below the pavement surface. Techniques used to address friction problems include HIR, HR, or an HMA overlay. Temporarily solve friction problems using CM to improve the surface texture. Do not allow aircraft to operate on milled pavement surface due to potential FOD damage to aircraft engines and tires. If it cannot be avoided, vehicular traffic may be allowed on milled roadway pavements for a short duration, with adequate traffic control to reduce safety concerns due to loose aggregate, vehicle damage, and noise.

3-4.2.8 Roughness.

Evaluate roughness from test results and from PCI survey distress data. Correct roughness in the surface layer caused by segregation, raveling and rutting using recycling strategies such as HIR, HR, and CM with an HMA overlay. Roughness from subsurface layers will require more extensive forms of recycling including CM with HMA overlay, HR, CIR, cold central plant recycling (CCPR), and FDR.

3-4.2.9 Drainage.

A drainage survey and evaluation can identify excessive moisture, the sources of moisture, and the affected pavement layers and materials (Grogg et al., 2001). Surface drainage issues are suitable for treatment by recycling strategies that target the surface layer. However, if the effects are deeper in the structure, more extensive recycling or drainage retrofitting may be necessary. Subdrainage improvement may involve installing or replacing longitudinal edge drains and lateral outlets or daylighting a base layer by replacing base material under shoulders with better draining material (Hall et al., 2001).

3-5 STRUCTURAL DESIGN.

Structural design of airfield and roadway pavements is accomplished by engineering analysis of test results and material properties to develop pavement rehabilitation alternatives to support intended traffic over an established design period. Design of flexible and rigid pavements can be accomplished using layered elastic or mechanistic design methods. NDT is conducted to estimate pavement layer and subgrade elastic properties. DCP testing can be used to estimate mechanistic properties such as CBR or k-value. Load transfer efficiency across joints and cracks and the presence of voids under slab corners and edges may assist the designer in developing rigid pavement design alternatives.

Structural pavement design for pavement rehabilitation alternatives using recycling technologies is the same as those for ordinary pavements.

3-5.1 Structural Design for Roads.

The primary structural design tool for DoD roadway pavements is the Pavement-Transportation Computer Assisted Structural Engineering (PCASE) computer program. PCASE performs flexible and rigid pavement design for roads using mechanistic or layered elastic methods. The equivalency factors for use in designing pavements using recycling technologies are provided below.

3-5.2 Structural Design for Airfields.

PCASE is also the primary structural design tool used for DoD airfield pavements. PCASE performs flexible and rigid pavement design for airfields using mechanistic or layered elastic methods. The equivalency factors for use in designing pavements using recycling technologies are provided below.

PCASE Web Site - http://www.pcase.com

PCASE Computer Based Training – http://www.pcase.com/cbt/

Tri-Service Transportation Web Site – http://www.triservicetransportation.com

3-5.3 CBR Design Method.

The CBR design method is detailed in UFC 3-260-02 and UFC 3-250-01. The CBR design method is automated within PCASE. In the CBR method, the thickness and strength of each layer must protect the layers below. PCASE estimates layer thicknesses for conventional flexible pavements. In the case of stabilized layers, modify the layer thickness by using equivalency factors, such as those shown in Table 3-1, which have been developed based on research and field experience.

Design the pavement structure using the equivalency factors shown in Table 3-1 for recycled layers. If the aggregates to be recycled are angular, according to appropriate specifications, then the recycled material can be used for base course. Otherwise, the material can only be used for subbase. Typically, the recycling techniques shown in Table 3-1 are for base material and require a minimum thickness of HMA as a surface course. Low volume roads may use bituminous surface treatment as the wearing surface.

3-5.4 Layered Elastic Design of Airfield Pavements.

The layered elastic design method can be used for the structural design of DoD airfield pavements and is detailed in UFC 3-260-02. The layered elastic design method is automated within PCASE. In this method, failure is defined as excessive tensile strain at the bottom of the HMA layer or excessive compressive strain at the top of the subgrade. Stresses, strains and deflections are computed assuming elastic properties in each pavement layer. The following assumptions apply:

- The pavement is a multilayered structure.
- Each layer is described by its thickness, modulus of elasticity and Poison's ratio.
- The interface between layers is continuous. In other words, the friction resistance between layers is greater than the developed shear force.
- The subgrade is modeled as a homogeneous, isotropic, elastic half-space.
- All loads are static, circular and uniform over the contact area.

Table 3-1 Granular Base Equivalent Factors

Recycling Technique	Equivalency Factor	
	Base	Subbase
HMA (including HR and HIR)	1.15	2.30
Crushed aggregate base	1.00	2.00
Uncrushed aggregate subbase	---	1.00
Pulverized/crushed RAP blended granular base	1.00	2.00
CIR, CCPR, and FDR (asphalt/cement stabilized)	1.00	2.00
Rubblized portland cement concrete	1.00	2.00

3-5.5 Recommendations for Pavement Design.

The following recommendations are for the CBR method of design when using PCASE:

- Use the appropriate equivalency factors shown in Table 3-1.
- Only use uncrushed aggregate as subbase.

3-6 DETAILED DESIGN OF RECYCLING STRATEGIES.

Evaluate feasible recycling strategies by establishing the specific details for each strategy in terms of the pavement cross-section and the engineering properties of the recycled and new surface layers. These details dictate the quantity of material required, the scheduling of work tasks, and the future M&R requirements.

Formulating a detailed design requires considering the needs and constraints of the project. The needs define the service life of the recycled pavement, including the potential levels of future M&R. The constraints pertain to the available funds for the recycling work and to a variety of construction considerations. A discussion of how these items affect the recycling design strategies follows.

3-6.1 Performance Requirements.

Available funding often controls the selected technique and the expected life of a recycling project. The condition of the existing pavement also affects the expected life.

Selecting and designing the recycling strategies to achieve the desired design life follows one of two approaches. In the first, if sufficient performance data exists for a particular recycling strategy and the data are representative of projects with similar conditions (traffic, climatic, etc.), use the data to formulate a design that achieves the design life requirement. In the second approach, make certain assumptions about the strength and durability of the recycled layer and any surface layer. Then, coupled with an understanding of the strength of the underlying subgrade, subbase, and base layers, determine the thickness of the recycled layer and surface layer in relation to climatic properties and the projected design traffic. Utilize as much confirmed engineering data regarding the subgrade and underlying layers as possible.

Although substantial performance data exist for recycled materials on specific projects, predominantly for highway pavements, nationwide performance data is not available.

Recognizing that actual performance largely depends on project conditions, facility type, projected traffic, climate, recycling design details, and the quality of materials and workmanship, the ranges of expected mean service life are as follows (Sullivan, 1996; ARRA, 2001; Grogg et al., 2001; FHWA, 2005):

- HR: 9 to 16 years (HR mix generally accepted as having the same performance as new HMA)
- HIR-I only: 3 to 5 years
- HIR-I with surface layer: 6 to 10 years
- HIR-II only: 7 to 14 years
- HIR-II with surface layer: 7 to 15 years
- HIR-III: 6 to 15 years
- CIR with surface layer: 5 to 15 years
- CCPR with surface layer: 7 to 15 years
- Break/crack-and-seat with HMA overlay: 8 to 12 years
- Rubblization and HMA overlay: 15 to 20+ years
- Recycled concrete aggregate (RCA) PCC: 15 to 20+ years

Mean service life differs from design life. Mean service life represents the timeframe over which a pavement has a 50-percent probability of providing acceptable service under the conditions (traffic, environment) in which it must function. Acceptable service is generally defined as PCI>70 for Primary pavements and PCI>65 for Secondary pavements. Design life represents the timeframe over which a pavement is structurally designed to serve based on a specified degree of reliability (typically, between 80 and 95 percent probability of providing acceptable service). Hence, a 10-year design life using 90-percent reliability will likely yield a mean service life of 12 or more years.

3-6.2 Future M&R Requirements.

Pavement facilities requiring minimal disruption to traffic and thus minimal numbers and durations of M&R require enhanced designs for some recycling strategies. For instance, the addition of chemical additives such as cement, lime, or fly ash and increasing proportions of virgin HMA or aggregate will achieve stronger and more durable recycled asphalt material. Increasing the thickness of surface layers will generally extend the life of the recycling technology.

3-6.3 Pavement Cross-Section.

For HMA pavements, the presence of a concrete layer, stress absorbing membrane interlayer (SAMI), paving fabric, rubber modifier, and other distinct paving layers can dictate the maximum depth of recycling. Likewise, the total thickness of asphalt bound layers and the depth to which distortions such as rutting, depressions, or swells exist in the pavement profile also influences recycling depth. A limited recycling depth may require thick recycled base and surface layers or greater proportions of virgin materials to achieve the intended design life.

For concrete pavements, rubblization requires a thicker HMA overlay compared to crack/break-and-seat. This is due to the fact that rubblization destroys any capability of the PCC to function as a slab and effectively converts the PCC layer into a high-quality aggregate base. Crack/break-and-seat, on the other hand, reduces the length of the slab, but still allows the remaining pieces of PCC to provide structural support to the pavement system.

3-6.4 Construction and Materials Quality.

Variability in the mix properties of recycled HMA may preclude the use of certain recycling techniques such as in-place recycling on high-quality pavements. Variability of recycled HMA may also require thicker base and surface layers or greater proportions of virgin materials to create a durable pavement that will meet the intended design life. For concrete pavements, the extent and severity of D-cracking or ASR may preclude the use of any recycling technique or may require a thick HMA overlay over fractured PCC. Any ASR will preclude the use of RCA techniques on most airfield pavements.

3-6.5 Maintenance.

The presence of previous M&R treatments including chip seal, surface seal, crack/joint sealant, machine patches, or other materials may influence the detailed design of a recycling strategy. Some technologies may require additional work to remove a previously applied surface treatment prior to recycling. In other cases, special design measures may be used to accommodate the mix properties of these treatments.

3-6.6 Project Size and Location.

Occasionally, the size and location of a project provides a cost advantage to one recycling techniques over others. For example, on a significantly large project, the mobilization of in-place recycling equipment or on-site recycling plants may be more cost-effective than a central-plant setup. Do not discard more expensive recycling strategies too quickly; rather, develop detailed designs and perform LCCA to evaluate and compare alternatives.

3-6.7 Project Geometrics.

If vertical alignment is constrained to the existing surface grade, some recycling strategies are not practical. The same is true if overhead clearances severely restrict building up the cross-section and/or if subsurface clearances limit recycling depths. Recycling strategies must account for these types of constraints and satisfy the performance goals.

Slab fracturing techniques, including cracking or breaking and seating, are a cause for concern in situations where buried utilities, like sewer and water lines, are near the surface. The concentrated impact force induced by the drop hammer poses a much greater threat of damage to utilities compared to the distributed impact forces associated with rubblization.

Another consideration for overhead clearances is the ability of recycling equipment and haul trucks to pass under such features and the ability of recycling equipment to effectively operate next to lateral constraints (e.g., buildings, hangars, barrier walls, straight-faced curbs) and around sharp curves or in tight settings (e.g., short perpendicular taxiways, roadway intersections).

3-6.8 Construction Time Requirements.

Pavement facilities with high-type functional uses and/or high levels of traffic often limit the duration of construction activities. Such limitations may preclude certain recycling strategies and influence the adoption of other strategies and their associated operations (e.g., in-place recycling, on-site plants, multiple recycling trains, night work). For instance, because the depth of the recycled layer and the type of asphalt emulsion influences the length of time required for the asphalt emulsion to break, CIR may not be feasible or may require thin recycled layers to meet a compressed schedule. Proprietary “engineered emulsions” offer reduced break/cure time and can be compacted immediately following mixing.

3-6.9 Availability of Local Resources.

The equipment and technology base for most recycling techniques is common throughout the U.S. However, in less populated areas, locally experienced and properly equipped contractors may be limited. Further, the availability of local good-quality aggregates for use in recycled mixes and/or surfacing mixes may also be limited. For projects facing these limitations, eliminate the affected recycling strategies from consideration or properly account for them in the detailed design process.

3-6.10 Structural Capacity.

Recycling often involves removing or reprocessing an existing HMA layer, which may reduce the structural capacity of the pavement system to a low enough level where the remaining layers are no longer able to support construction equipment. Similarly, the remaining layers must provide sufficient platform stiffness during construction to allow the recycled layer to be compacted. The most critical elements in determining the maximum recycling depth and formulating a detailed design are:

(a) Thickness and condition of the non-recycled portion of asphalt bound layers.

(b) Thickness and strength of underlying unbound base and subbase layers.

(c) Subgrade strength.

(d) Anticipated loading characteristics of the construction equipment.

3-6.11 Traffic Accommodation.

In some cases, the project layout is more conducive to certain recycling techniques in terms of accommodating traffic during construction and providing better overall safety.

3-7 SELECTING THE PREFERRED REHABILITATION STRATEGY.

The LCCA procedure described in UFC 3-270-08 represents a traditional approach to life cycle costing. The procedure makes use of the NPW economic formula, an analysis period of between 10 and 30 years, a set discount rate, and a deterministic computational approach. To ensure that alternative pavements are of equal value at the end of the analysis period, compute the cost to rehabilitate the pavement for each alternative. A more commonly used approach to account for value differences in the competing pavement alternatives at the end of the analysis period computes salvage value in terms of the remaining service life of the final pavement structure.

CHAPTER 4 COLD RECYCLING FOR ASPHALT SURFACED PAVEMENTS

4-1 INTRODUCTION.

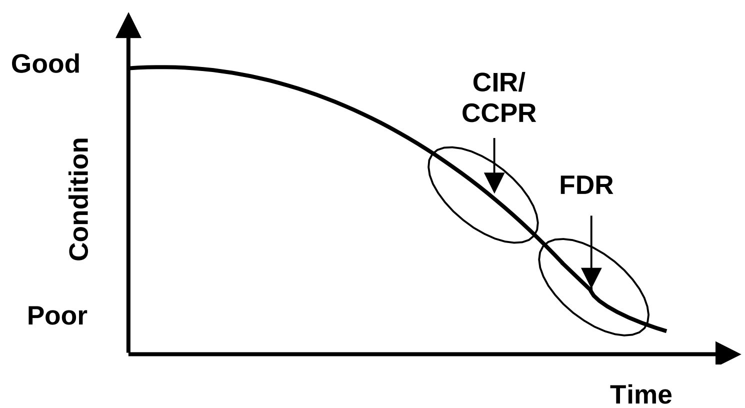
Cold mix recycling involves reusing existing pavement by reprocessing and adding asphalt binder at ambient temperatures. This chapter discusses the application of the three types of recycled cold mix: CIR, CCPR and FDR.

Cold mix recycling takes advantage of chemical additives such as cement, lime or fly ash to increase the early strength and resistance to moisture of the new mixture. Alternative additives include cutback asphalt, foamed asphalt, asphalt emulsion, and a combination of emulsion with cement, fly ash, or lime.

CIR and CCPR are generally used to correct pavements with functional distresses and provide minor strengthening. FDR is appropriate when major structural rehabilitation is required.

Figure 4-1 shows when it is advisable to use CIR/CCPR or FDR in the typical pavement life cycle.

Figure 4-1 Indication of CIR/CCPR or FDR as a Function of Pavement Life



4-2 COLD IN-PLACE RECYCLING.

4-2.1 Introduction.

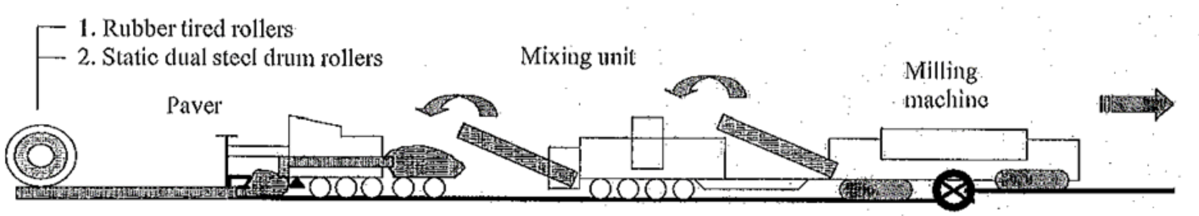
CIR is a partial-depth pavement recycling process. Remove some HMA pavement by milling 2 to 4 inches (50 to 100 mm). CIR creates a layer of material to serve as base course, but it sometimes serves as the surface course on highways with low to medium traffic volume. For example, CIR can be used as the surface for secondary roads if a surface treatment is applied.

CIR is a good technique to rehabilitate thick HMA pavements exhibiting cracks, rutting, shoving, raveling, potholes, bleeding, poor skid resistance, corrugations, fatigue, block cracking, slippage, longitudinal and transverse cracking, reflection cracking, and poor ride quality. However, it requires underlying layers and the drainage system to be in good condition.

CIR can increase pavement strength when placed with an HMA overlay on the recycled material for additional pavement thickness and to provide a higher quality surface.

CIR transforms a distressed pavement into one similar to a new pavement. The CIR process uses special equipment similar to that depicted in Figure 4-2. Ensure the equipment can mill deteriorated pavement and convey the RAP into a unit that crushes the RAP, sizes the RAP, and blends the material into a homogenous mixture. The mixing unit adds asphalt binder and water to the RAP and blends before feeding the mix into the paver hopper. The paver places the recycled mixture at the desired thickness and grade. Vibratory and rubber-tired rollers compact the mix. Cover the CIR with an HMA overlay or surface treatment to provide a smooth riding surface and protect the mixture from water and traffic. When used on airfields, ensure the thickness of the HMA over the CIR meets the minimum HMA thickness required over a crushed granular base course.

Figure 4-2 CIR Recycling Train*



*Source: Hajek et al, 2005.

4-2.2 Past and Current Use.

Mixtures similar to CIR have been used for over 50 years (Bardesi, 2000). Cold recycling has become more common since the 1990s due to technological advances in pavement and material engineering.

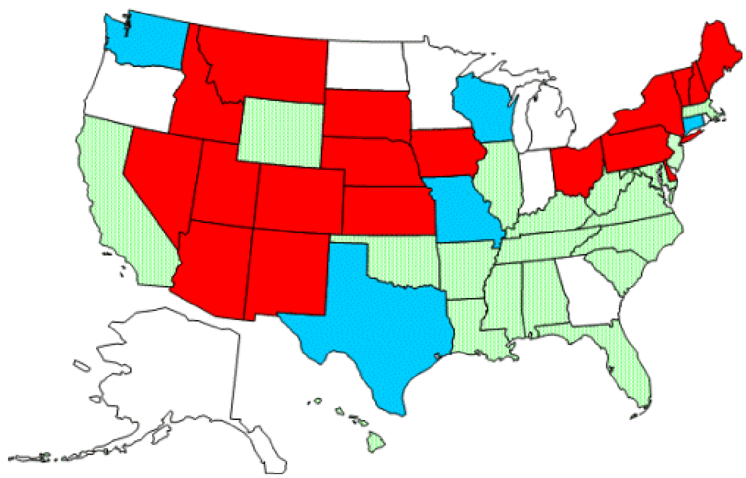
In the past, CIR was used on roads with low to medium traffic volume. Currently, there is no limit to using CIR on high traffic volume roads or as base course material for airfields when properly designed and constructed.

State DOTs have placed millions of square yards of CIR since the 1970s. The main reasons to use of CIR are to correct premature full depth thermal cracking that causes poor ride quality or to address fatigue cracking, rutting, and asphalt stripping problems. A surface treatment or an HMA overlay is used as a surface on most CIR projects.

Asphalt recycling grew rapidly after the early 2000s as highway agencies looked for significant cost savings in highway rehabilitation as well as methods that reduce emissions during construction.

Figure 4-3 shows Federal Highway Administration research on CIR use in the United States (FHWA, 2007). Eighteen states (red) extensively used CIR, five states (blue) reported low use, nineteen states (green) had no use and six states (white) did not respond.

Figure 4-3 Use of CIR in the United States*



*Source: FHWA, 2007.

4-2.3 Guidelines for Use of CIR.

4-2.3.1 Primary Purpose.

CIR is a technology that transforms HMA surfaces into asphalt base material, restores a profile or cross-slope and mitigates surface distresses prior to receiving an HMA overlay or surface treatment. In general, potential projects for CIR are pavements with fatigue cracking, permanent deformation, and surface roughness.

Corrective actions may be necessary for rough or distorted pavement or for flushed pavement. When the pavement is rough, the CIR process may require cold milling (CM) before the CIR operation. When the pavement surface is flushed or is bleeding, adding virgin aggregates may reduce the propensity of the flushing to exist in the CIR mixture.

4-2.3.2 Advantages and Disadvantages.

The main advantages of CIR are as follows:

- Reduced environmental impact due to reduced demand for virgin asphalt binder and aggregates.

- Energy savings compared to other construction techniques.
- Fewer vehicles transporting material at the site. Reduced traffic damage to the pavement when compared to conventional rehabilitation techniques.
- Significant savings compared with conventional rehabilitation techniques.
- Capability to correct surface roughness and reducing cracking.
- Capability to correct surface characteristics such as rutting, potholes, shoving, bleeding and raveling.
- No interference or disturbance of base, subbase and subgrade materials.
- Capability to adjust the mixture by adding virgin aggregates or recycling agent.
- Improved surface ride quality.

The main disadvantages of CIR are as follows:

- Not all materials are economically recycled.
- CIR cannot solve problems associated with layers other than the surface.
- CIR requires a curing period to gain strength and it cannot open immediately to traffic after construction.
- This technology does not apply to projects that require nighttime work in some regions due to temperature limitations and moisture conditions.
- The presence of paving fabric in the existing pavement presents some limitations on the use of CIR.
- CIR is not applicable to pavements with poor drainage or weak base support.

4-2.3.3 Mix Design.

Before starting a mix design, ensure all samples are broken into small particle sizes to simulate RAP during milling operations. Use a small laboratory crusher to crush the RAP in the laboratory to produce a gradation similar to that during actual construction.

There is no nationally accepted cold mix recycling design method. An adaptation of the Marshall Design method (Modified Marshall, Method A) is the method used by most agencies (ARRA, 2001; FHWA, 1997; Asphalt Institute, 2002). Determine the amount of virgin asphalt binder needed in the recycled cold mix by conducting a conventional HMA mix design on the RAP obtained during sampling prior to start of construction.

4-2.3.3.1 Trial Mixes, Curing Time and Job Mix Formula (JMF).

Prior to starting the mix design process, crush the recovered asphalt mix to produce a gradation similar to that expected with the milling machine. Compact the sample at 50 blows per face for low-pressure tires or 75 blows per face for high-pressure tires such as airfields and heavy-duty roads. Equivalent gyratory compaction is permissible.

The main parameters sought are density, stability, flow, voids in the total mixture, and voids filled with asphalt. Plotting these parameters versus asphalt content assists the designer in identifying the optimum asphalt content for the mixture. The optimum additional asphalt is often between 0 and 3%. Do not add additional asphalt if the optimum value is 0% or lower. In this case, only add water to lubricate the mixture so that the expected maximum dry density is achievable in the field. In fact, if the laboratory air voids are too low (below approximately 3 percent), add virgin aggregate to increase the air voids in the mixture to an acceptable level.

In summary, the mix design method consists of:

- Obtain samples of the HMA pavement. Remove samples equal to the depth of milling expected during construction. Crush RAP in the lab to approach the expected gradation of RAP during the milling operation.
- If new aggregate is added, determine the percentage of virgin aggregate to add.
- To determine the percentage of asphalt that provides 3.5 to 4% air voids, design as a hot mix, adding the RAP, virgin aggregate and varying the asphalt emulsion content. The heating process removes the moisture in the mix since this is designed using HMA procedures.
- Once the optimum emulsion content is determined, add the emulsion to the RAP then vary the moisture content in 0.5 percent increments from 0 percent to 2.5 percent. Determine the optimum moisture content by adding moisture in 0.5 percent increments to the cold mix and compacting using 50 blows with the Marshall hammer to determine the optimum additional moisture content to provide maximum dry density. Determine optimum moisture content at room temperature.
- Cure the compacted mixture for 96 hours at 140 ºF (60 ºC).
- Remove the samples from the oven and cool to room temperature. Test the specimens for bulk specific gravity. Then reheat to 140 ºF (60 ºC) and determine Marshall stability and flow.

Table 4-1 shows the mix design parameters recommended by UFGS 32 01 16.70.

Table 4-1 Recommended CIR Mix Parameters[1]

Parameter	**Requirement 50 Blows**
Voids in total mix (%)	3-5
Voids filled with asphalt (%)	75-85

[1]UFGS 32 01 16.70.

4-2.3.3.2 Evaluation of Existing Salvage Material through Lab Analysis of Field Samples.

- RAP Properties: Determine RAP gradation using ASTM C136 *Standard Test Method for Sieve Analysis of Fine and Coarse Aggregate.*
- Extracted Aggregate: Obtain the extracted aggregate after removing the asphalt binder from the mixture using one of the asphalt extraction tests (ASTM D6307 or ASTM D2172).

4-2.3.3.3 Determining Amount of Virgin Aggregate.

Evaluation studies of existing material are very important for determining the adequate amount of virgin aggregate. The gradation of the aggregate recovered from the RAP may be unsatisfactory or the recovered aggregate quality may not be acceptable. This may require adding virgin coarse or fine aggregate. The majority of CIR projects do not add virgin aggregate.

There are two primary cases that require the addition of virgin aggregates: 1) excess asphalt binder content in the RAP or 2) poor aggregate quality of the RAP. In both cases, the addition of virgin aggregate allows minor adjustments to the RAP mixture to address these deficiencies.

4-2.3.3.4 Asphalt Emulsion.

Most projects use asphalt emulsion to introduce additional asphalt binder to a CIR mixture. In this case, the small amount of additional asphalt binder does not significantly modify the properties of the existing asphalt binder, but serves as additional asphalt to fill voids and improve cohesion. On the other hand, a recycling agent tends to mix and soften the oxidized binder to improve the overall binder properties. A potential problem with adding a recycling agent is incomplete mixing with the other components, which results in uneven distribution of the recycling agent in the mix. The result is that one portion of the mix may become too soft and another portion too brittle. Thoroughly blend all mixture components.

Important specifications for asphalt emulsions for cold-mix recycling are ASTM D5297 for anionic asphalt and ASTM D2396 for cationic asphalt emulsions. Most cold mixes use anionic emulsions. Use cationic asphalt emulsions if past experience with cationic emulsions has been successful.

The grades of asphalt emulsion most commonly used are MS, HFMS, and SS.

- Medium-Setting (MS): designed for mixing with open or coarse-graded aggregate. Because they do not break immediately, mixes with medium-setting emulsions keep their workability for a significant amount of time.
- High Float Medium-Setting (HFMS): designed for mixes that work at high temperatures, which allows better aggregate coating and asphalt retention.

- Slow-Setting (SS): these emulsions are generally more stable. Asphalt droplets in a slow-setting asphalt emulsion stay in suspension in the water for a longer period of time and over a wider range of temperatures, which results in fewer construction problems.

4-2.3.3.5 Recycling Agent.

Recycling agents are used in CIR mixes to improve the properties of the asphalt binder. The oxidized asphalt binder in old HMA mixtures benefits from the use of recycling agents. The recycling agent tends to soften the asphalt binder, resulting in improved properties. If experience shows success with the recycling agents, use it in place of asphalt emulsion. Specify asphalt recycling agents using ASTM D5505.

4-2.3.3.6 Moisture in Mix.

Moisture is necessary to facilitate mixing, handling, and the compaction process. RAP may contain enough free moisture so that adding water is unnecessary. Add water before adding recycling additives to lubricate and promote cooling of the cutting head. If using a pugmill, add water simultaneously with the recycling additive. Slow-setting asphalt emulsions and the anionic grades of medium-setting asphalt emulsions require moisture to promote adequate coating during mixing process. High float emulsions and cationic medium-setting asphalt emulsions may contain petroleum distillates and require less moisture to provide good workability and compaction.

Conduct coating tests for any type of asphalt binder additive used to verify if the mixing water is adequate to disperse the additive. It is a very simple test that requires 2.2 pounds (1000 g) of RAP with the estimated initial amount of recycling additive. Test different samples with 0.5% increments of water. Add water and mix briefly (maximum of 30 seconds) to humidify the RAP. Incorporate the recycling additive and blend the mixture for 2 additional minutes. Perform this test manually, because it is easier to observe mix workability and coating. Visually evaluate and select the dispersion and the lowest moisture content that results in no additional increase in coating. The total liquid content (sum of the mix water content + recycling additive + moisture of the RAP) is different for each project and is determined during the mix design.

4-2.3.4 Structural Design.

Chapter 3 provides a general overview of structural design and its application to pavement recycling. One concern in the structural design of a pavement using CIR mixtures is the difficulty in characterizing the mixture sufficiently for use in the CBR method or layered elastic design method. Information required for design includes the equivalency factor for CIR and the modulus and thickness of the CIR layers. Chapter 3 provides this information.

4-2.3.5 Construction.

4-2.3.5.1 Types of Equipment.

The CIR train consists of a cold milling machine capable of reclaiming old asphalt pavement to depths of 2 to 6 inches (50 to 150 mm). The equipment for CIR is available in different configurations: single machine (single-unit train), two-unit train and multi-unit train. Use the same compaction equipment as used for HMA.

4-2.3.5.2 Single Machine (Single-Unit Train).

The milling machine of the single-unit train cuts the old pavement to a specified depth, providing the desired profile grade and transverse slope. The equipment separates the RAP into sizes and mixes the RAP with asphalt emulsion or recycling agent. Figure 4-4 shows one example of these machines.

Figure 4-4 Single Machine*

*Source: Roadtec, https://www.roadtec.com/

- Simple operation.
- High production capacity.
- Good for operation in urban areas and roads with small turning radius.

One disadvantage of the single machine is its lack of control of oversize RAP aggregate. The operator is unable to control the exact amount of material and is unable to control minimal mix times. Since the single-unit train lacks screening and crushing units, the operator likely will have difficulty controlling the maximum particle size. Old pavement with serious fatigue cracking exacerbates this limitation. Do not use the single unit train for pavements that present edge drop-off and severe distortion caused by rut depth because the application rate of recycling additive cannot be controlled. Base the amount of additive on the volume of material considered and it depends on the cutting depths and widths as well as the previously estimated speed for the machine operation.

If the mix design recommends incorporating aggregates or dry additives, such as lime or cement, spread the additives on the pavement prior to milling.

4-2.3.5.3 Two-Unit Train.

The two-unit train has an advantage when compared to the single machine, namely, it allows precise control of liquid additives in the RAP. Control of liquid additives is based on weight rather than the volume of material or speed.

The two-unit train incorporates pugmill mix pavers in the system and is able to mill a full lane wide. An example of this machine is in Figure 4-5.

Like the single-unit train, the two-unit train is able to work in urban areas and on roads with short turning radii. The primary disadvantage is its lack of crushing and screening units which means this type of equipment is not able to control aggregate oversize. Simple operation and high production capacity are the main advantages when compared with the multi-unit train.

The two-unit train removes the RAP with the milling machine and deposits the mix into the pugmill of the mix paver. The pugmill has a feeder belt with a scale and a computer system estimates the weight of the liquid recycling additive to incorporate into the mix.

CIR is a process of milling a portion of existing pavement to a specified depth, screening and crushing the reclaimed material to comply with specifications, incorporating aggregates, mixing additives and water, spreading and compacting the mixture. Typically, the maximum particle size ranges from 1 to 1.5 inches (25 to 37.5 mm) (Hajek et al, 2005).

Do not operate during rainfall. In addition, ensure the ambient temperature is at least 50 ºF (10 ºC) and freezing temperatures are not expected for at least 5 days. In general, the warmer the weather, the better the final properties of the CIR mixture.

Figure 4-5 Two-Unit Train*

*Source: Lee and Kim, 2007.

4-2.3.5.4 Multiple-Unit Train.

The multiple-unit train, as indicated in Figure 4-6, has the highest degree of quality control and productivity of CIR. The multi-unit train produces as much as 2 lane miles/day (3.2 lane km/day). The sequence of the multi-unit train operation is as follows (ARRA, 2015):

- Mill the pavement to the design depth and slope with a milling machine.
- The milling machine can work with the “down cutting mode”, which produces finer RAP aggregates or with the “up cutting mode”, which allows higher working capacity. The down cutting mode should reduce the chance for scabbing during the milling operation.
- The RAP is screened and oversized material is sent to a crushing unit.
- The crushed material is sent back to the screening unit.
- An aperture below the screens controls the maximum RAP size.
- After passing through the screening and crushing unit the RAP goes to the pugmill mixer.
- The belt that transports the RAP has a scale that controls the weight of the RAP that goes into the pugmill.
- A computerized system controls the amount of liquid recycling additive, based on the weight of the material estimated by the belt scale.
- A pump equipped with a meter device indicates the flow rate and the amount of liquid recycling additive incorporated in the pugmill
- The pugmill thoroughly mixes the RAP with liquid recycling additive or asphalt emulsion.
- The mixture is conveyed to a windrow or paver hopper.
- A windrow elevator takes the mix from the windrow and feeds it to a conventional HMA paving machine.

Figure 4-6 Multiple-Unit Train*

*Source: Ken, 2008.

The main advantages of the multi-unit train are:

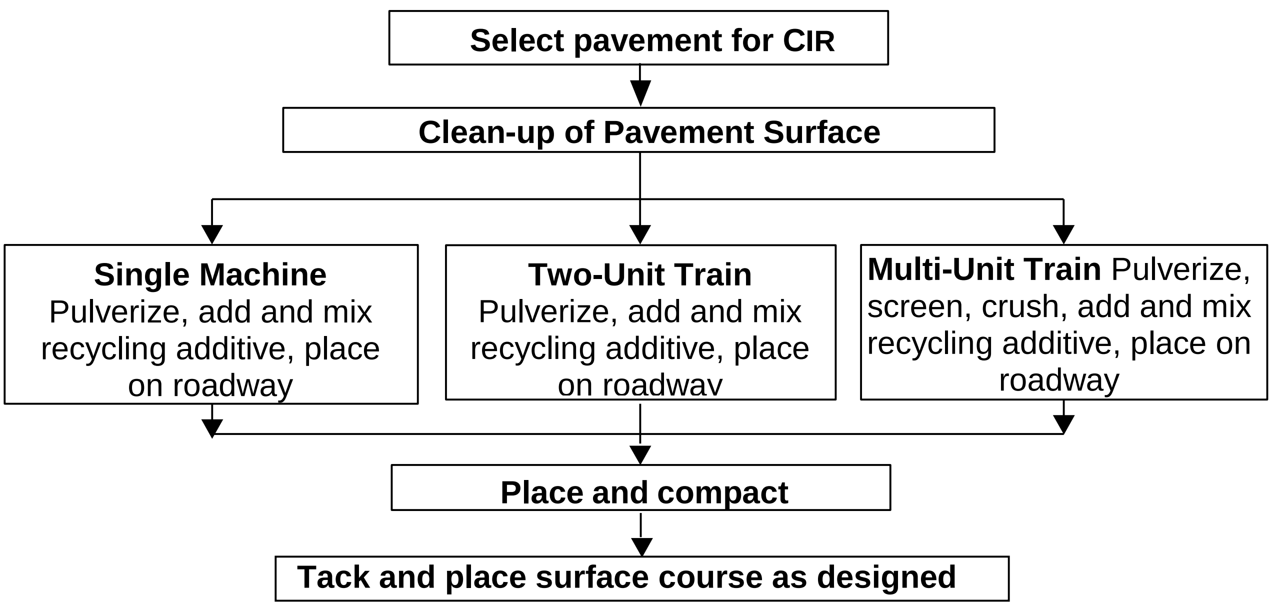
- high productivity.
- high quality control process.

The main disadvantages are:

- length of the train.
- It is not suited for urban areas or roads that have no room for maneuvering.

Figure 4-7 presents an abbreviated summary of the CIR construction process for the three types of equipment configurations.

Figure 4-7 CIR Construction Process*



*Source: ARRA, 2001.

4-2.3.5.5 Technical Aspects on CIR Construction.

Some additional technical aspects are necessary during CIR construction.

a. Clean-Up of Pavement Surface. Inspect the pavement surface before recycling operations begin to clear vegetation and debris across the pavement and shoulders.

b. Cold Milling Process. Mill existing pavement to a pre-defined depth and width in one pass. The cold-milling machine removes a portion of the existing HMA layer, typically between 2 and 6 inches (50 and 150 mm) deep, always leaving at least 1 inch (25 mm) of HMA in place.

Generally, the particle size of the removed material is satisfactory for recycling and no further crushing is necessary.

c. Placement of the Recycled Material. Place and finish recycled material in one continuous pass, without segregation. Compact material in minimum 2 inches (50 mm) thick and no more than 4 inches (100 mm) thick. Increase the upper limit to 6 inches (150 mm) when required to place more than 4 inches in one pass, but only if the contractor has suitable equipment to place and compact this thicker layer.

Begin by spreading the material along the centerline of areas paved on a crowned section or on the high side of areas with one-way slope, always in the primary direction of traffic flow. Pavements surrounding curbs, manholes and other structures may need special attention.

d. Field Adjustments of the Mix. Adjust the job mix formula (JMF)in the field to take into consideration the gradation of the RAP. Modification of the percentage of additives and water may improve the aggregate coating and mix workability. Determine the optimum amount of water. Excessive water content may flush the asphalt to the surface during the placement and compaction process. Lack of adequate water may cause mix segregation, loss of workability, raveling and poor density.

Excess asphalt emulsion or rejuvenating agent may lead to an unstable mix. On the other hand, an insufficient asphalt emulsion may cause mix raveling due to low asphalt content. A practical rule is to adjust the asphalt content by 0.2% increments. However, only an experienced technician should make adjustments to the mixture.

e. Curing. Cold mix recycled mixtures gain strength and stability with time as they cure. Factors that affect the cure time are:

- Type of emulsified asphalt
- Mix water content
- Gradation
- Layer thickness
- Ambient and mixture temperatures
- Wind velocity
- Humidity

When multiple lifts are required, allow 2 to 5 days cure time between them depending on the amount of moisture and porosity of the mixture. Ensure the water content of the recycled mixture is less than 1.5% prior to placing additional layers.

The final curing time is typically between 7 and 14 days. In general, depending on the climatic conditions, the cure period is about 2 days for each 1 inch (25 mm) of lift thickness.

f. Compaction. The objective of compaction is to achieve the desired mat density. Start compaction as soon as the emulsified asphalt breaks or when the mixture is adequately aerated. Usually the mixture starts to break between 30 minutes to 2 hours depending on ambient conditions such as temperature, wind speed, and humidity. However, if portland cement, lime or fly ash are used as recycling additives, begin rolling immediately after placement. Ensure the minimum layer thickness is no less than twice the size of the maximum aggregate particle of the RAP or aggregate. The compaction process encompasses three phases:

- Carry out breakdown rolling with vibratory roller(s). If the mix is tender and moves excessively underneath the vibratory roller, use a pneumatic tire roller. This phase of rolling continues until obtaining a tight, smooth, stable surface.
- Conduct intermediate rolling with at least 12-ton double drum vibratory steel-wheeled or pneumatic rollers preferably weighing approximately 20 tons. Achieve adequate density before completing intermediate rolling.
- Carry out finish rolling with steel-wheeled static or double-drum vibrating rollers operating in static mode to eliminate roller marks.

Use the theoretical maximum density in accordance with ASTM D2041 to establish field density and control compaction. Theoretical maximum density is the density which corresponds to zero air voids in the mixture.

Construct a test section to evaluate various combinations of rollers and monitor the process step-by-step with a density gauge to determine the relative increase in density with roller passes. Set the number of passes required to provide a density equal to or exceeding the minimum density requirements.

g. Field Density Measurements. It is very difficult to cut and remove undamaged cores from completed CIR mixtures. The longer the mixture has cured, the easier it will be to obtain good cores without damage. Alternatives to obtain samples of in-place pavement within 24 hours include:

- Ice placed on the sample locations for 1 to 2 hours before coring samples will cool the material during the coring operation, reducing the damage caused by the heat developed during this process.
- Use a concrete saw to cut small cubes from the pavement.
- Use density gages as an indication of the densities. This device does not eliminate the need to take actual pavement cores for testing later, but it will provide a reasonably good first estimate of the in-place density.

Modify rolling procedures to improve the compaction and meet the specified density requirements.

4-2.3.5.6 Surface Course.

Since CIR contains high voids in the total mix, do not use it as a wearing course. For low volume roads, use single or double bituminous surface treatment to cover the CIR. For roads with high volume traffic and for airfields, cover the CIR with an HMA overlay having thickness equal to or exceeding the minimum thickness required for HMA placed over granular base course.

4-2.4 Specifications, Quality Control, Inspection and Acceptance.

4-2.4.1 Specifications.

The specification for cold mix recycling is UFGS 32 01 16.70. This specification includes the in-place mixture and compaction requirements as well as the plant mixed cold recycling processes. It includes requirements for using asphalt emulsions as well as requirements for using asphalt recycling agents.

4-2.4.2 Quality Control/Quality Assurance.

A good QC/QA plan is a key factor for the success of a cold in-place recycling project.

Old pavement sections present great variability in aggregate gradation, asphalt content, and areas subjected to different maintenance types, etc. As a result, during the CIR process, small changes may be necessary in the rolling patterns, aggregate gradations, moisture and recycling agent content to improve performance of the resurfaced pavement. QC personnel should prepare a QC plan that accommodates changes without needing to redesign the mixture.

Follow testing requirements identified in UFGS 32 01 16.70 for the contractor QC plan. Inspect work continuously and identify any deviations from the specifications or from good standard construction practices.

4-2.4.3 Inspection and Acceptance.

4-2.4.3.1 Inspection is one of the most important steps for CIR construction. Inspection must identify problems early so that the construction process can change to correct the problem before too much CIR is constructed. Identifying problems early allows prompt resolution of construction deficiencies with less effort. However, missed problems are a bigger problem to correct later in the paving process.

4-2.4.3.2 Conduct both inspection and acceptance in accordance with specification requirements. While the specifications identify many items related to inspection, many other important items that may not be in the specifications are presented and discussed in the following paragraphs.

4-2.4.3.3 Regular meetings during construction ensure compliance with all aspects of the specifications and ensure timely implementation of necessary adjustments. Identify problems early and take steps to correct these problems before performing a large quantity of unacceptable work. Meetings are a good place to identify problems and the necessary steps to correct them.

4-2.4.3.4 On some projects, traffic flow is a concern. Develop plans to control traffic flow and inspections to minimize traffic problems. At times the completed layer may temporarily serve as a riding surface for traffic. Temporary pavement markings are a part of the project.

4-2.4.3.5 Control the materials used for the project to ensure acceptable quality and that the quantity of material is sufficient. Control aggregate quality at delivery and perform aggregate handling in a manner that avoids segregation. Supply the specified asphalt emulsion or recycling agent and provide test certificates.

4-2.4.3.6 Specific equipment requirements are minimal. Ensure that the contractor has the flexibility to select equipment necessary to produce the mixture according to the specifications and to ensure compaction requirements are met. However, maintain all equipment in good working condition.

4-2.4.3.7 Remove isolated locations of unsuitable material as part of the project. Identify and discard this material and ensure that no discarded material is used in the project.

4-2.4.3.8 The mix design identifies the materials and proportions used in the project. Only an authorized government official can approve changes to the mix design. Supply issues or changes in quality may require a change in the mix design.

4-3 COLD CENTRAL-PLANT RECYCLING.

4-3.1 Introduction.

CCPR recycles RAP in a central plant to produce recycled mixes. Two conditions make CCPR a feasible technique: (a) availability of stockpiles of high quality and uniform RAP and (b) inability to use CIR process.

The general process is that the RAP is hauled to a plant site or stockpiled. The plant crushes, screens, and mixes in additives prior to the mix being transported to a job site. The mix is then placed and compacted in accordance with specifications. In some circumstances, it is also possible to use a portable unit to process the RAP at the stockpile area.

Use CCPR as stabilized base course with an HMA overlay for roads with higher traffic volume as well as for airfields. For low traffic roads, it can be used along with a single or double bituminous seal coat to seal and protect the surface.

4-3.2 Past and Current Use.

The U.S. does not use a large amount of CCPR; however, its use is significant in several other countries. The use of CCPR has decreased in the U.S. due to improvements in CIR and FDR and the cost effectiveness of these processes. CIR methods are less expensive and less likely to cause traffic problems when transporting materials from the plant to the project site.

4-3.3 Guidelines for Use of CCPR.

The guidelines established to use CIR and FDR are applicable to CCPR. When better control is required, use CCPR over a CIR approach.

4-3.3.1 Primary Purpose.

CCPR is an adequate technique when a pavement cannot be in-place recycled and the HMA layer must be removed to allow for treatment of underlying layers. In other words, CCPR is a good solution for pavements that present problems in underlying layers such as lower HMA lifts or aggregate base layers. Successful CCPR projects should only be used in areas having no major problems with realignment, drainage, or frost heave.

The ability to control aggregate gradation, percentage of water, recycling additives and stabilizers makes CCPR an attractive alternative for some special cases. Use the CCPR process when additional aggregate is required to correct pavement cross slope and when there are restrictions for CIR equipment in the work area.

4-3.3.2 Advantages and Disadvantages.

The main advantages of using CCPR are similar to those advantages for CIR and FDR. Other complementary advantages are: 1) stockpiled RAP is cleaner than in-place recycled material, 2) crushing RAP allows gradation requirements to be met, 3) RAP is mixed with asphalt emulsion in a central plant allowing better control, and 4) multiple feed bins provide an opportunity for better control of aggregate gradations.

The primary disadvantages of using CCPR are higher cost and increased material handling required to move materials from the job site to the plant, feed materials into the plant, and haul the completed mixture back to the job site.

4-3.3.3 Performance and Costs.

Similar to CIR and FDR, the performance of CCPR depends on several aspects such as local conditions, climate, traffic, types of material, quality of construction, specifications, and QC/QA. The estimated life of a CCPR mix with surface treatment is between 6 and 8 years and with HMA overlay is between 12 and 15 years (ARRA, 2015).

4-3.3.4 Mix Design.

The discussion carried out for mix design of CIR applies to CCPR. Removing materials from the project site prior to producing CCPR mixture provides time to take samples of materials and conduct mix design. Take core samples prior to starting work. However, the mix design based on these samples is not as reliable as samples taken from the milled material.

4-3.3.5 Structural Design.

All the considerations for structural design for CIR apply to CCPR.

4-3.4 Construction.

As pointed out before, transport the RAP to a special location for crushing, screening and blending with recycling aggregates. Process in a central mixing plant. Another option is to process the RAP at the project location using a mobile mixing plant located at or near the job site. In both situations, use a pugmill mixer.

Store RAP as any other aggregate. Be aware of the variability inherent in different sources of RAP. Contractors typically have sources of RAP to produce the CCPR or the specifications may require that only RAP from the existing project be used. If using RAP from other sources, evaluate this RAP to ensure it is satisfactory for the existing project. The most common problem that may occur is the RAP source may contain aggregates with unsatisfactory aggregate properties. In any case, manage the stockpiles to minimize segregation of materials.

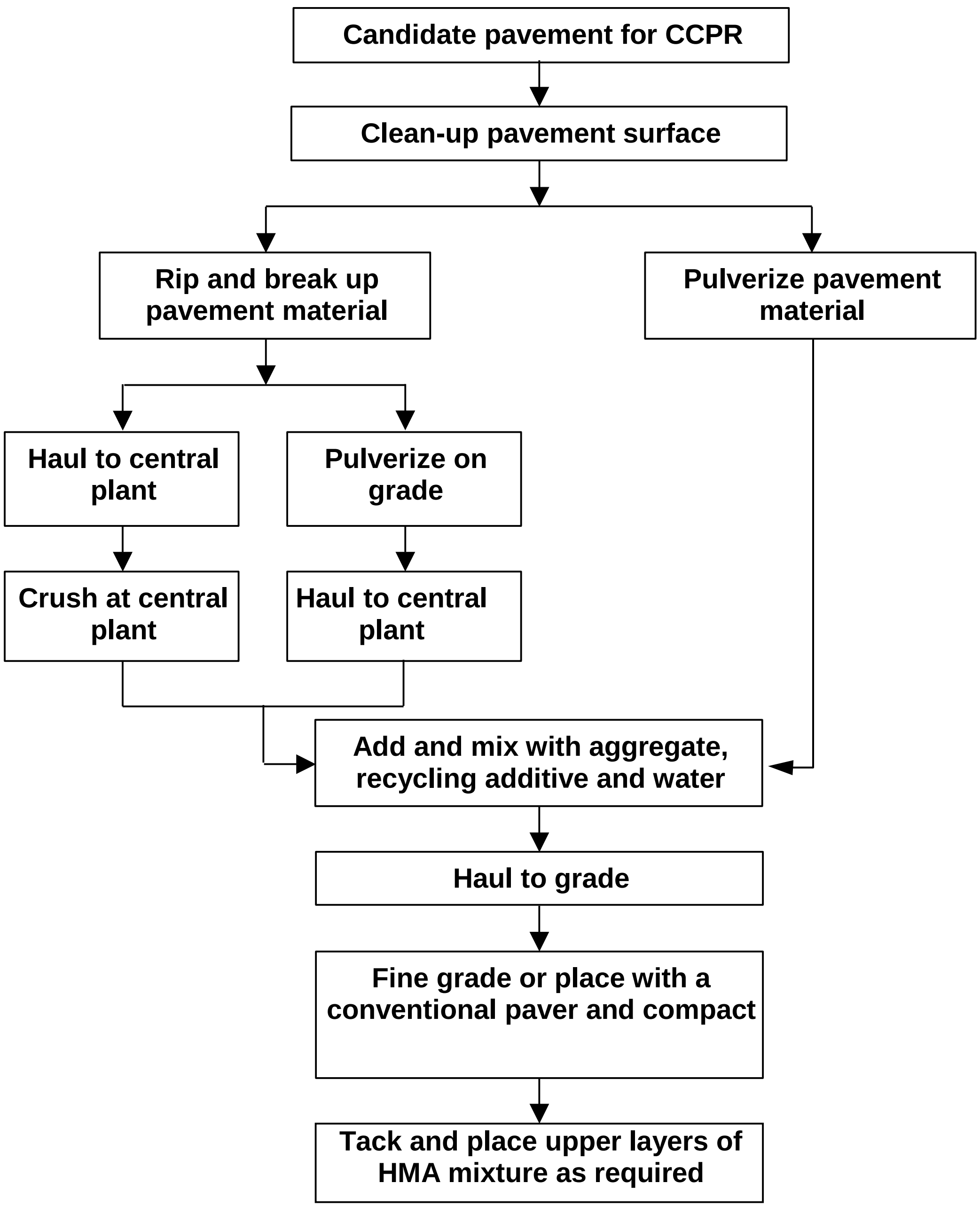
4-3.4.1 Types of Equipment.

Process equipment produces RAP by milling, ripping, breaking, crushing or pulverizing old HMA layers. Other equipment transports the RAP to the plant and handles the RAP at the plant. The central plant is similar to an HMA plant and should have the following parts:

- Screening and crushing units to keep the maximum size of the RAP under control. Alternatively, it can use a scalping screen to remove oversize particles in the RAP.
- RAP feed hopper.
- Conveyor belts with a belt scale.
- A computerized system, connected to the belt scale, controls the amount of liquid recycling additive and water added to the pugmill, based on the weight of the RAP estimated by the belt scale.

Figure 4-8 shows the steps in the CCPR process.

Figure 4-8 CCPR Construction Process*



*Source: ARRA, 2015.

4-3.4.2 Technical Aspects on CCPR Construction.

Additional technical aspects to consider during work at the central plant:

- Complete coarse aggregate coating is not required during the mixing process. Additional coating will occur during the hauling, spreading, and rolling of the mix.
- Ensure the mixing time is sufficient to obtain good mixing of all materials. Excessive mixing causes excessive breakdown of the material and may adversely affect the coating. Under-mixing results in lack of good coating of materials.

4-3.4.2.2 Clean Up Pavement Surface.

It is a good practice to inspect the pavement surface before the recycling operation to clear vegetation and debris across the pavement and shoulders.

4-3.4.2.3 Cold Milling Process.

Conduct cold milling and pulverization of asphalt pavement layers according to the required depth and maximum RAP size specified for the project.

4-3.4.2.4 Placement of the Recycled Material.

Haul the mixed material to the project site and laydown the recycled material with an asphalt paver. A paver works better than other equipment to place the recycled mixture in a uniform manner to the desired grade. The paver provides some initial compaction.

Aeration may be necessary to decrease water and/or volatile content before the compaction process. Perform placement in several lifts as required by the project. Maximum lift thickness is limited to 4 inches (100 mm) when compacted.

Inspect the placement of the CCPR to minimize segregation. When segregation occurs, stop the project until the causes of segregation are identified and corrected.

4-3.4.2.5 Field Adjustments of the Mix.

Perform field adjustments of the mix during construction of the test section as discussed in UFGS 32 01 16.70. Consider using a variety of roller combinations during construction of the test section. Monitor changes step-by-step with a density meter to understand the relative increase in density with roller passes. Ensure the test section has a minimum length of 150 ft (15 m) and is the width of two pavers. Place the test section and compact to the thickness required for the project. All CCPR projects require compliance with performance specifications.

4-3.4.2.6 Curing, Compaction, and Field Density.

See the discussion for CIR.

4-3.4.3 Surface Course.

Since CCPR contains high voids in the total mix, do not use as a wearing course. For low volume roads, use single or double bituminous surface treatment to cover the CCPR. For roads with high volume traffic and for airfields, keep the thickness of HMA equal to or greater than the minimum requirements for thickness of HMA placed over a granular base course.

4-3.5 Specifications, Quality Control, Inspection and Acceptance.

4-3.5.1 Specifications.

The specification used for CCPR are UFGS 32 01 16.70. In addition to the specifications for CIR, define the spreading depth because it only applies to CCPR. Monitor this feature to avoid inadequate thickness and to assure compliance with the design requirements.

4-3.5.2 Quality Control/Quality Assurance and Inspection and Acceptance.

See comments for CIR.

4-4 FULL-DEPTH RECLAMATION.

4-4.1 Introduction.

Full-depth reclamation rehabilitates flexible pavements with significant deterioration. For example, a pavement with base failure is an excellent candidate for FDR. The process can involve modification to the HMA layers and possibly underlying granular layers. The technique consists of uniformly breaking up the material to a specified depth between 4 and 12 inches (100 and 300 mm), pulverization, incorporation of a stabilizing agent, blending, shaping and compaction of the reclaimed mixture as a base layer. Mechanically stabilize the material if the pavement is for low and medium traffic. For pavements with higher traffic or higher load capacity, including high volume roads and airfields, chemically stabilize the FDR material by introducing and blending additives such as cement, fly ash, lime, foamed asphalt, and asphalt emulsions.

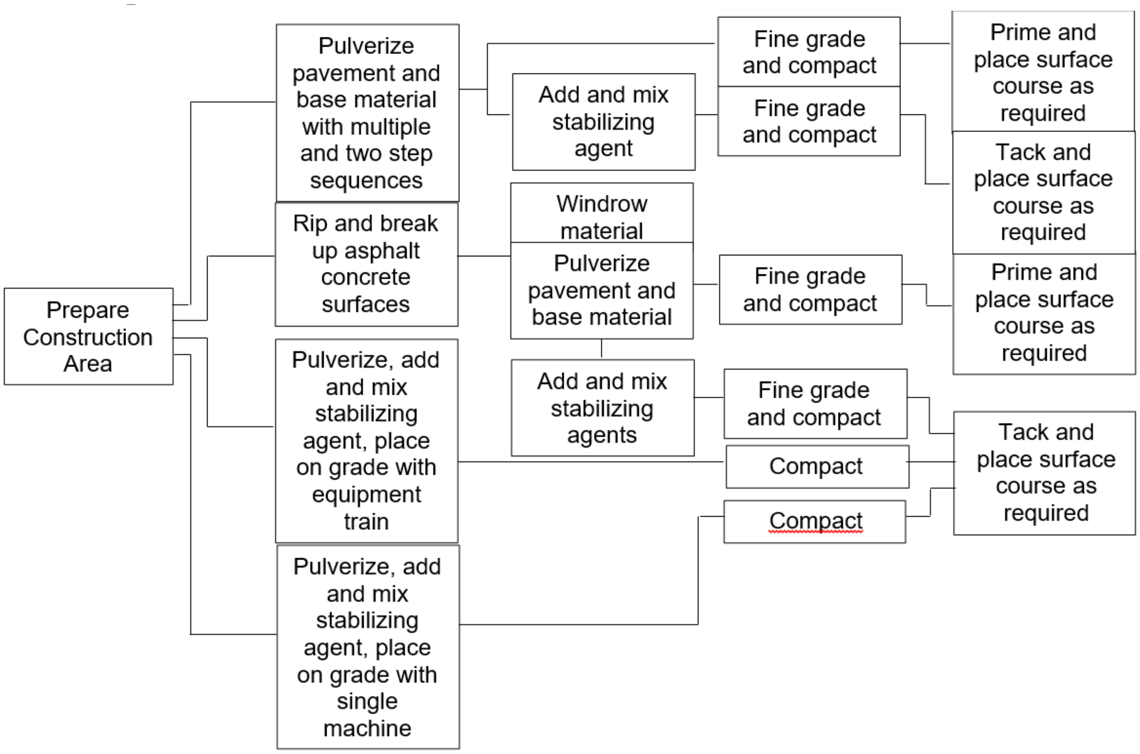
Pavements that do not have structural capacity to support CIR equipment are also good candidates for treatment with FDR. This is usually a pavement with less than 3.5 inches (90 mm) of HMA and a weak subgrade with a resilient modulus less than 5000 psi (34.5 MPa) (PIARC, 2003).

Figures 4-9 and 4-10 show examples of recycled material and a schematic of the FDR process, respectively.

Figure 4-9 Recycled Material*

*Source: https://cdn.ymaws.com/arra.site-ym.com/resource/resmgr/files/ARRA_Full_Depth_Reclamation_.pdf

Figure 4-10 Full Depth Reclamation*



*Source: Kandhal and Mallick, 1997; https://cdn.ymaws.com/arra.site-ym.com/resource/resmgr/files/ARRA_Full_Depth_Reclamation_.pdf

4-4.2 Past and Current Use.

Full-depth recycling is not new and was first competed in the early 1900s (Kandhal and Mallick, 1997; Sullivan, 1996). Several state DOTs have experience with FDR.

FDR technology applies to airfields. One example is an airport that used FDR with cement stabilization to rebuild a runway pavement. The construction period was only 30 days and they estimated that they saved approximately $1 million by using FDR compared with other paving options (Arroyo, 2007).

Since the 2000s one state DOT implemented a large FDR program with stabilized base. One project saved $200,000 on a $3 million project to reconstruct a 6-mile section of roadway. This state DOT stabilized projects with cement and fly ash (Terra, 2008).

One city in Canada began to use FDR with foamed asphalt in 2000. Since then, they have successfully constructed more than 30 million sq yd (25 million sq m) of FDR, much of which was stabilized with foamed asphalt.

4-4.3 Guidelines for Use of FDR.

Most of the guidelines suggested for CIR are applicable to FDR. There is no UFGS specification for FDR. Hence, DoD projects must use local state DOT specifications for FDR. The following sections discuss some aspects unique to FDR.

4-4.3.1 Primary Purpose.

FDR is suitable for pavements with structural problems such as deteriorated HMA and base layers. Figure 4-11 shows good candidates for FDR where there are significant problems with the HMA mixture and likely with underlying granular layers and subgrade.

Under the correct conditions, FDR allows:

- Adjustment of the profile and cross slope of the pavement
- Accommodation of pavement widening, if necessary
- Ability to improve quality of underlying pavement layers

4-4.3.2 Advantages and Disadvantages.

4-4.3.2.1 Advantages.

FDR has advantages similar to CIR to include:

- Crown and cross-slope are easily restored.
- Reflective cracks are eliminated or reduced.
- FDR is cost effective in the long-term since FDR can eliminate problems with an inadequate base course.

- FDR offers a low environmental impact, because materials are not transported back and forth.
- Reduction in future maintenance costs due to the long-term correction of structural and other problems.
- The typical FDR depth is between 6 and 9 inches (150 and 225 mm). However, the literature indicates the possibility of depths over 12 inches (300 mm).
- With good quality control during construction, pulverizing base and HMA layers and mixing with stabilizing additives increases the structural capacity of the pavement.

Figure 4-11 Good Pavement Candidates for FDR*

*Source: ARRA, "Full Depth Reclamation."

4-4.3.2.2 Disadvantages.

The main disadvantages of using FDR are:

- The mixing and uniformity of mixture are not as well controlled for FDR compared to CCPR or CIR.
- Any construction problem at the longitudinal joints in between adjacent strips may cause longitudinal cracks.
- Usually FDR requires more time than required to construct an HMA overlay.

4-4.3.3 Performance and Cost.

The performance of FDR depends on several aspects such as local conditions, climate, traffic, type of material, quality of construction, specifications, and QC/QA. Several states in the US have good experience with FDR and excellent results.

Shuler and Schmidt (2008) evaluated the performance of a number of recycling methods. The research concluded that it generally took 6 to 8 years for the recycled pavement to reach the condition of the original pavement prior to application of the recycling technologies. This was true for every distress except roughness. It took an average of 14 years to reach the same level of roughness.

4-4.3.4 Mix Design.

The CIR mix design concepts apply to the mix design of FDR. The following sections discuss other details concerning FDR mix design.

4-4.3.4.1 Trial Mixes, Curing Time, and Job Mix Formula.

Most of the information concerning CIR mix design applies to FDR. Additional aspects to consider due to the variability of stabilization methods available for FDR are:

- Mechanical Stabilization - use one or more of the following options:
  - crushed virgin aggregate.
  - reclaimed asphalt pavement.
  - crushed concrete, etc.
- Chemical Stabilization – use one or more of the following options:
  - Portland cement (dry or slurry).
  - lime applied dry or in a slurry.
  - fly ash.
  - calcium chloride.
- Asphalt Stabilization – use the following options:
  - emulsified asphalt.
  - foamed asphalt.

Apply cementitious and pozzolanic materials as dry powder in front of the reclaimer, in slurry form together with the pre-pulverized material, or in suspension by using a spray bar. Pavements with severe deterioration and high deflections are excellent candidates for FDR with cement.

Apply liquid stabilizing/additives like calcium chloride ahead of the reclaimer, together with the pre-pulverized material, or by injection with the reclaimer additive system**.**

Asphalt stabilization reduces the effects of moisture and improves the strength of the reclaimed material. When compared with other chemical stabilizers it creates a more flexible base which is more resistant to fatigue. Asphalt can stabilize 100% RAP or a mix of RAP and granular base and subbase. Require that the fine materials have a plasticity index of no more than 6%.

The same considerations carried out for CIR apply to FDR. Table 4-2 provides general guidelines to select stabilizers for FDR (lab testing).

Table 4-2 General Guidelines for Selecting Stabilizers for FDR

	Characteristics of Reclaimed Pavement Materials
Hydrated lime or quicklime (2 to 6% by weight)	RAP having some amount of silty clay soil from subgrade with a plasticity index greater than 10.
Class C fly ash (8 to 14% by weight)	Materials consisting of 100% RAP or blends of RAP and underlying granular base or soil. The soil fraction can have plasticity or be similar to soils acceptable for lime treatment.
Portland cement (3 to 6% by weight). The maximum limit of Portland cement for airfields is 4%.	Materials consisting of 100% RAP, or blends of RAP and underlying granular base, or nonplastic or low plasticity soils. Sufficient fines are necessary to create an acceptable aggregate matrix for the cement treated base (CTB) (not less than 45% passing the 4.75 mm or No. 4 sieve preferred).
Emulsified or foamed asphalt (1 to 3% by weight)	Materials consisting of 100% RAP, or blends of RAP and underlying granular base, or nonplastic or low plasticity soils. Limit the maximum percent passing the 75 µm (No. 200) sieve to 25%. Limit the plasticity index to 6%. Limit the sand equivalent 30 or greater or the product of multiplying the P4 and the percent passing the 75 µm (No. 200) less than 72.
Calcium chloride (1% by weight)	Materials consisting of a blend of RAP and nonplastic base soil with 8 to 12% minus 75 µm (No. 200) material. Small amounts of clay (3 to 5%) are also beneficial.

4-4.3.4.2 Mechanical Stabilization.

Mechanical stabilization is simple and sometimes requires imported material such as virgin granular materials to improve the gradation of the reclaimed material. This increases the structural stability of the mixture and the excess bituminous material has more surface area to coat. In other cases, additional granular material is necessary to reach the specified thickness of the material.

4-4.3.4.3 Chemical Stabilization.

Portland cement is the most common additive used for chemical stabilization. The following sections discuss the main steps to stabilize FDR with cement.

a. Gradation. To achieve a suitable gradation, determine whether to add new material to the mixture. It is desirable to achieve a gradation similar to the Talbot's curve shown below:

$$y = 100 \times (d/D)^{0.4}$$

Where:
y = percentage passing sieve "d"
d = sieve size in mm (inch)
D = maximum aggregate size in mm (inch)

b. Water Content. Obtain the optimum water content of the reclaimed pavement material mixed with cement as the peak of the moisture-density tests. Use modified Proctor procedures for compaction (ASTM D1557).

c. Mix Density. Ensure that the mix density is at least 97% of the Modified Proctor laboratory density.

d. Optimum Cement Content. Ensure that the cement content provides the specified strength, is economically feasible, and keeps shrinkage cracks as fine as possible. On airfields limit the cement content to 4%.

Obtain the optimum cement content by running moisture-density tests. Prepare at least three sets of specimens with material obtained from the pavement incorporating imported material, as necessary, and compact to the minimum density expected. Test specimens to obtain the axial compression strength at 7 days.

Subsequently, prepare specimens by varying the initial amount of cement ± 2%. This approach guarantees that the amount of cement will include the target value. For larger projects, test the compressive and indirect tensile strengths at 28 and 90.

e. Types of Cement. Cements with a high percentage of pozzolans are best suited for FDR and for roller compacted cement treated materials.

The density and cement content are more important than limiting the type of cement. Review the available types of cement in the market. Test to ensure that the cement produces the required characteristics in terms of strength, workability, and mix homogeneity. Using high-strength cements can produce a very low cement content of 2 to 2.5% by weight of dry material.

Note: It is possible to meet strength requirements and lack adequate homogeneity. Other classes of cement may produce a mix with a cement content as high as 3 to 6%. In this case, recycled material incorporated into the mix design has fewer homogeneity and workability problems.

f. Workability Time. Evaluate the impact of a limited workability period, or setting time, for cement treated material carefully. Air temperature and humidity interfere with the period of workability. When cement starts hydrating, it binds the aggregates and the compaction may break these links. Complete compaction before the cement begins to set and bind the aggregate.

Check the workability time by verifying the decrease in sample density when compacted at increasing times. For practical purposes, the workability period ends when the density drops to 98% of the density obtained for specimens compacted immediately after mixing.

4-4.3.4.4 Determining the Proper Amounts of Virgin Aggregate to Add.

Apply the same steps described for CIR for FDR. As discussed above, obtain additional information when stabilizing with cement.

4-4.3.4.5 Requirements for Aggregates.

The requirements for aggregates are similar to those for granular base, soil-cement, and cement treated base.

4-4.3.4.6 Recycling Additives.

Recycling additives are the same as for CIR and as discussed in this section for FDR.

4-4.3.5 Structural Design.

Follow the discussion in Chapter 3 for structural design.

4-4.4 Construction.

The construction considerations for CIR apply to FDR principally regarding the use of asphalt materials as a stabilizer. Some additional considerations are necessary when cement is the additive. The following sections discuss important considerations when cement is the additive.

4-4.4.1 Types of Equipment.

In general, use the same equipment described for CIR for FDR. However, each project has unique equipment requirements. Tables 4-3 and 4-4 present the necessary equipment and operational steps for FDR stabilization with cement for low and medium/high volume roads.

Table 4-3 Steps for Recycling Low Volume Roads[2]

		Typical Equipment
Pavement scarification[1]	Loosen the existing pavement	• Front loader with ripper • Bulldozer with ripper • Recycler
Eliminating large particles	Eliminating large particles over 80 mm (3.2 inches): • By crushing • By removal	• Stationary or mobile crushing unit • Manual work • Agricultural equipment
Leveling	Distribution of milled material	• Motor grader
Adding imported aggregate (if needed)	• Improvement of aggregate gradation • Cross slope correction • Increasing treated surface thickness	• Aggregate spreader • Bituminous mix paver • Motor grader
Moistening[2]	Achieve optimum moisture content according to moisture- density test (Modified Proctor)	• Water tanker with spraying bar • Water tanker connected to recycler • Slurry mixer
Binder distribution	Introduction of binder in proportion to site requirements and working depth	• Manual spreading (grid of cement bags) • Binder spreader (cement as powder is spread ahead of mixing plant) • Slurry mixer (cement and water are mixed and introduced as slurry into the recycler)
Mixing	Homogeneous mix of loosened pavement material with binder, water and any additives	• Rotary plough • Pulvimixer with horizontal mixing rotor • Recycler
Trimming	Eliminating surplus material to achieve final level	• Grader
Transverse joint cutting	Prevention of reflective cracking	• Mechanically driven machines • Hand driven device (vibrating plate or roller with welded knife)
Compacting	Achieving required density	• Vibratory roller
Curing and protection seal	• Curing of recycled surface • Protection of applied seal	• Water tanker[3] • Emulsion spreader • Chip or sand spreader + pneumatic tire roller
(1) When using a recycler, if it is not necessary to eliminate large particles, perform this step after distributing the binder (or at the same time). (2) Allow excessively moist milled material to dry before incorporating the binder and any imported material. (3) During warm and dry weather conditions, have a water tanker readily available to moisten the surface before spraying the curing seal.		

[2]PIARC, 2003.

Table 4-4 Steps for Recycling of Medium and High-Volume Roads[3]

		Typical Equipment
Adding imported aggregate (if needed)	• Improvement of aggregate gradation • Cross slope correction • Increasing treated surface thickness	• Aggregate spreader • Bituminous mix paver • Motor grader
Moistening[1]	Achieve optimum moisture content according to moisture-density test (Modified Proctor, AASHTO 1557)	• Water tanker with spraying bar • Water tanker vehicle connected to recycler • Emulsion spreader
Binder distribution	Introduction of binder in proportion to site requirements and working depth	• Binder spreader (cement as powder spread ahead of mixing plant) • Slurry mixer (cement and water are mixed and introduced as slurry into the recycler)
Pavement scarification[2]	Loosen the existing pavement	• Recycler
Mixing	Homogeneous mix of loosened pavement material with binder, water and any additives	• Recycler
Transverse joint cutting	Prevention of reflective cracking	• Mechanically driven machines • Hand driven device (vibrating plate or roller with welded knife)
Initial compaction	Achieving 90-92% of reference density	• Vibratory roller
Trimming	• Eliminating surplus material to achieve final elevation • Improvement of surface evenness	• Grader
Final compaction	Achieving required density	• Vibratory roller + pneumatic-tire roller[3]
Curing and protection seal[4]	• Curing of recycled surface • Protection of applied seal	• Emulsion spreader • Chip or sand spreader + pneumatic tire roller

[1] Allow excessively moist milled material to dry before adding the binder and any imported material.
[2] In recycled pavement layers, crush or remove particles larger than 3.2 inches (80 mm),
[3] Or two vibratory rollers.
[4] During warm and dry weather conditions, have a water tanker readily available to moisten the surface before spraying the curing seal.

[3]PIARC, 2003.

4-4.4.2 Technical Aspects on FDR Construction.

In general, the process of laydown, compaction and overlaying the in-place cold recycling is the same as that for conventional stabilization operations. However, consider the uniqueness of each problem, type of additives, proposed technique and the variability found in FDR techniques.

Focus special attention on the variability of the strength of reclaimed pavement stabilized with cement. Research indicates that the tensile strength obtained from cores of cement-recycled pavements after 1 to 2 years was between 60 and 290 psi (0.4 and 2 MPa). The respective moduli of elasticity were between 508,000 and 5,438,000 psi (3,500 to 37,500 MPa) (PIARC, 2003). These are very highly variable results and the selected specifications, testing procedures and performance requirements must account for the possibility of highly variable results while using similar materials under the same environmental conditions.

4-4.4.2.1 Pavement Surface Cleanup.

See CIR section.

4-4.4.2.2 Cold Milling Process.

See CIR section.

4-4.4.2.3 Placing Recycled Material.

See CIR section.

4-4.4.2.4 Field Adjusting the Mix.

See CIR section.

4-4.4.2.5 Curing.

See CIR section.

4-4.4.2.6 Compaction.

Compact each strip within the workability timeframe prior to starting on a subsequent strip. When the time for compaction is within the workability time, the rollers will not damage the previous strip and form cold joints. Complete any trimming prior to starting the compaction process.

Ensure that cement recycled layers are no less than 8 inches (200 mm) and no more than 14 inches (350 mm) thick. The minimum thickness requirement avoids areas with insufficient thickness that leads to premature fatigue. The capacity of recyclers and compaction equipment limits the maximum layer thickness. Figure 4-12 shows an example of incorporating and spreading granular material on the top of old pavement to achieve the necessary compacted thickness.

Figure 4-12 Granular Material Added to Achieve Compacted Thickness*

*Source: PIARC, 2003.

4-4.4.2.7 Field Density.

Refer to the CIR section. However, the minimum field density suggested for FDR stabilized with cement is 97% of the maximum laboratory density obtained when compacted in accordance with Modified Proctor (ASTM D1557).

4-4.4.2.8 Surface Course.

The same considerations carried out for CIR are valid for FDR.

4-4.5 Specifications, Quality Control, Inspection and Acceptance.

See CIR section.

4-4.5.1 Specifications.

See CIR section. The UFGS specifications related to FDR are:

- UFGS 32 11 26.19, *Bituminous Stabilized Base and Subbase Courses*
- UFGS 32 01 16.70
- UFGS 32 11 36.13

4-4.5.2 Quality Control/Quality Assurance.

The QC/QA procedures for CIR apply to FDR. Because other stabilizers were included for FDR, Table 4-5 summarizes the methods for evaluating stabilized materials.

Table 4-5 Testing Methods for Evaluation of Stabilized Materials

	Applicable Testing Procedures
Hydrated lime or quicklime	Liquid Limit, Plastic Limit and Plasticity Index of Soils (ASTM D4318) Moisture Density Relations of Soils and Soil-Aggregate Mixtures (ASTM D698 or D1557) Unconfined Compressive Strength of Compacted Lime Mixtures (ASTM D5101, Procedure B)
Class C fly ash or cement	Moisture-Density Relations of Soil-Cement Mixtures (ASTM D558, Method B) Compressive Strength of Molded Soil-Cement Cylinders (ASTM D3633) Wetting and Drying Compacted Soil-Cement Mixtures (ASTM D559, Test Method B)
Asphalt emulsion or foamed asphalt	Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures (ASTM D3203) Effect of Moisture on Asphalt Concrete Paving Mixtures (ASTM D4867) Indirect Tension Test for Resilient Modulus Bituminous Mixtures (ASTM D4123)
Calcium chloride	Liquid Limit, Plastic Limit and Plasticity Index of Soils (ASTM D4318) Moisture-Density Relations of Soils and Soil-Aggregate Mixtures (ASTM D1557)

4-4.5.3 Inspection and Acceptance.

Apply the requirements for inspection and acceptance formulated for CIR to FDR and are supplement with the appropriate UFGS requirements.

CHAPTER 5 HOT RECYCLING FOR ASPHALT SURFACED PAVEMENTS

5-1 INTRODUCTION.

There are two basic methods of hot mix recycling: HR and HIR. HIR includes three sub-categories: The HIR Type I, Surface Recycling, HIR Type II, Remixing, and HIR Type III, Repaving. Table 5-1 presents the advantages and disadvantages of using HR and HIR Types I, II and III.

Hot mix recycling uses heated materials that combine RAP with virgin aggregates and, if necessary, new asphalt binder and recycling agents. HR and HIR mixes serve as base, intermediate and surface layer materials in all types of roadway pavements, but only as base or intermediate courses in airfield pavements. RCA may serve as a portion of the aggregate in HMA for some road and airfield specifications.

5-2 OVERVIEW OF HOT RECYCLING METHODS.

5-2.1 Hot Central Plant Recycling (HR).

HR combines RAP with new aggregates, new asphalt binder, and recycling agents, in a plant to produce recycled HMA. The process removes existing pavement, crushes the reclaimed mix, mixes the reclaimed mix with virgin aggregate, and virgin asphalt in a conventional asphalt plant, places and compacts the recycled mix using the same procedures and equipment as for a virgin mix. Figures 5-1 and 5-2 show schematics for two general types of asphalt plants used for HR.

HR is allowed for all pavement layers other than surface layers on airfields. HR is an excellent option for roadway pavements with high traffic volume. However, never use HR as the wearing surface for airfield pavements subjected to traffic. For airfields, HR mixes are allowed for shoulders and underlying layers in trafficked areas. HR is applicable to all levels of traffic and can use RAP from pavements with a range of asphalt mixture issues as long as the quality of the aggregate and asphalt binder is reasonable. Compared with other recycling processes, HR produces the highest quality pavement material because it provides uniform mix production and presents the lowest construction variability (Kandhal and Mallick, 1997).

5-2.1.1 Past and Current Use.

Currently, hot recycling of RAP in an asphalt plant is the most used asphalt recycling method. Prior to use of RAP many RAP stockpiles throughout the U.S. contained a large percentage of material that had to be wasted or utilized for other than HMA applications.

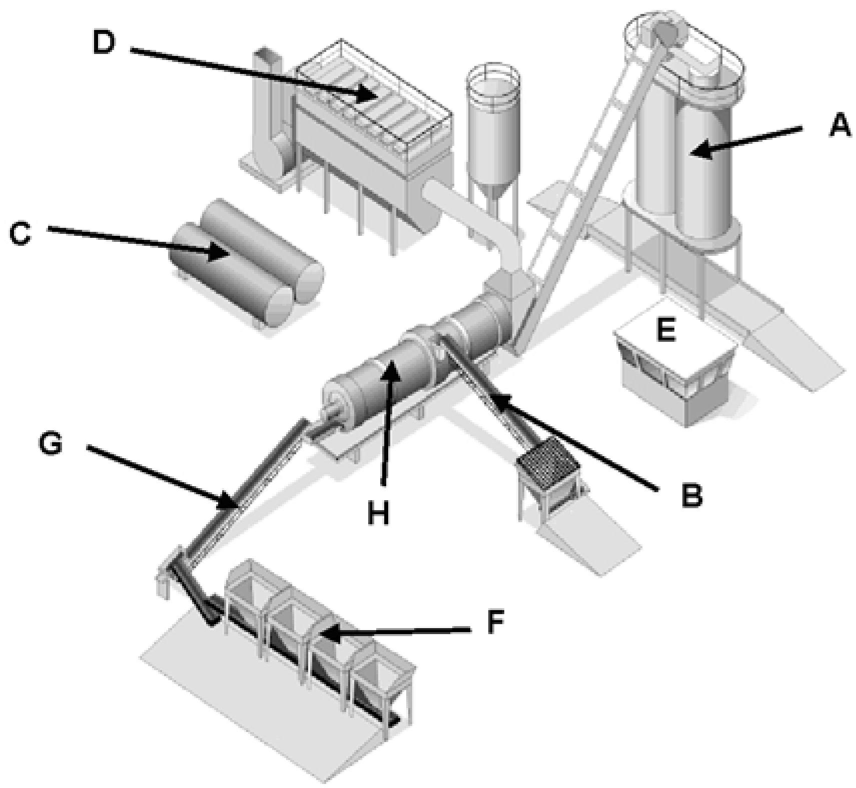
Table 5-1 Asphalt Recycling Technique Advantages and Disadvantages[4]

Technique	Advantages	Disadvantages
Applied to HIR in General	• Conservation of non-renewable resources. • Energy savings. • Less truck hauling at the work site. • No need for material removal. • Work the entire lane width at once. • Maintenance of curb height and overhead clearance. • Correction of aggregate and/or asphalt binder problems. • Remixing and recoating of aggregates with stripping problems. • Reduction of traffic disruptions and user nuisance. • Possibility of roadway opening to traffic at end of day. • Considerable economic savings.	• Does not improve load carrying capacity of pavement. • Not applicable to pavements with base failures and drainage problems. • Existing pavement surfaces should be at least 3 in (75 mm) thick. • Process does not correct large surface wavelengths or large changes in grades. • Difficult to use on narrow roads due to the width of the equipment. • Process not suited to streets with many utilities such as manholes, access covers, etc. • Cold weather can require more time for heating the pavement. • Surface treatments, like multiple chip seals affect pavement re-heating time. • Limitation for pavements with aggregate larger than 1 in (25 mm) diameter. • The heating process must be highly controlled to avoid creating air quality problems or overheating and damaging the asphalt binder.
Surface (HIR-I)	• Reduces frequency of reflection cracking. • Promotes bond between old pavement and thin overlay. • Provides a transition between new overlay and existing gutter, bridge, and/or pavement that is resistant to raveling (eliminates feathering). • Reduces localized roughness. • Treats a variety of low level pavement distresses (raveling, flushing, corrugations, rutting, oxidized pavement, faulting) at a reasonable initial cost. • Improves skid resistance.	• Provides limited structural improvement. • Heater-scarification and heater-planing have limited effectiveness on rough pavement without multiple passes of equipment. • Limited repair of flushed or unstable pavements. • Some air quality problems. • May damage vegetation close to the roadway. • Some equipment cannot treat mixtures with maximum aggregate sizes greater than 1 in (25 mm).

Technique	Advantages	Disadvantages
Remix and Repave (HIR-II and HIR-III)	• Provides structural improvement. • Treats all types of pavement distress. • Can reduce reflection cracking. • May reduce frost susceptibility. • Improves ride quality. • Improves skid resistance. • Minimizes hauling.	• Quality control not as good as central plant. • Traffic disruption. • PCC pavements cannot be recycled in-place. • Curing often required for strength gain.
Central (HR)	• Conservation of non-renewable resources. • Energy savings. • Provides significant structural improvements. • Treats all types and degrees of pavement distress. • Can eliminate reflection cracking if removing a sufficient depth of asphalt. • Improves skid resistance. • May reduce frost susceptibility. • More easily alters geometrics. • Improves ride quality.	• Traffic interruption. • Additional costs for transporting materials. • The recycled mix uses less than 100 percent RAP, so virgin aggregate and virgin binder are required. Typically up to approximately 20% RAP is used in recycled mixture.

[4]ARRA, 2001; Kandhal and Mallick, 1997.

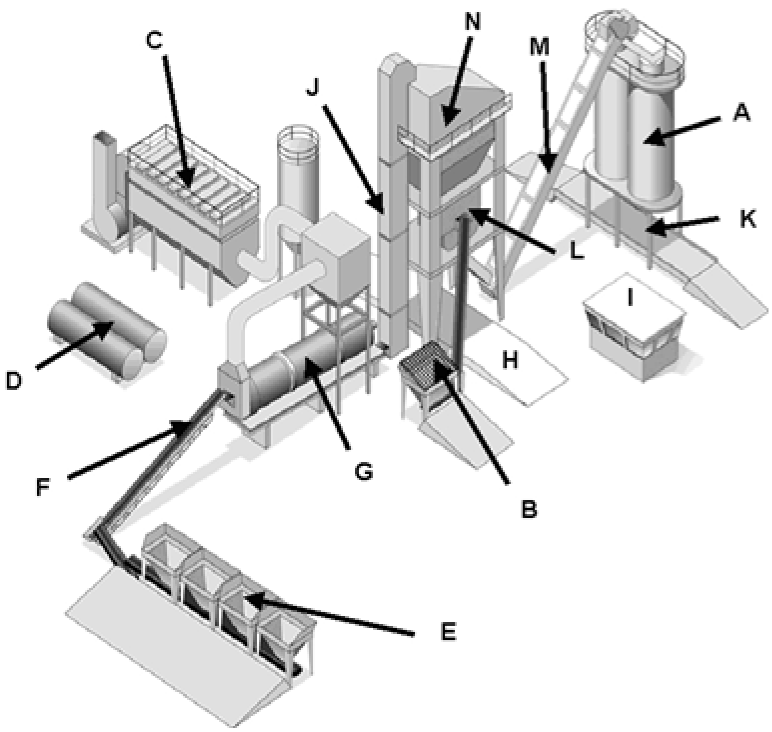
Figure 5-1 Drum Mix Asphalt Plant*



A- Storage Silo
B- RAP Feeder
C- Asphalt Cement Storage
D- Baghouse
E- Control House
F- Aggregate Feeders
G- Cold Elevator
H- Drum Mixer

*Source: NAPA.

Figure 5-2 Batch Asphalt Mix Plant*



A- Storage Silo
B- RAP Feeder
C- Baghouse
D- Asphalt Cement Storage
E- Aggregate Feeders
F- Cold Elevator
G- Drum Dryer
H- Truck Scales
I- Control House
J- Hot Elevator
K- Truck Scales
L- Pugmill
M- Slat Elevator
N- Screening Deck

*Source: NAPA.

The maximum amount of RAP allowed on DoD airfields projects is such that the asphalt binder from RAP cannot exceed 20 percent of the total asphalt content. RAP is not allowed in the surface course of airfield pavements. Other current requirements for use of RAP are in HMA on DoD airfield pavements is provided in UFGS 32 12 15.13.

The maximum amount of RAP allowed on DoD road and parking lot projects is such that the asphalt binder from RAP cannot exceed 30 percent of the total asphalt content. Other current requirements for use of RAP are in HMA on DoD roadway pavements is provided in UFGS 32 12 16.16.

Successfully using HR requires a good evaluation of the RAP, an adequate mix design, a rigorous QC/QA program and good construction practices (ARRA, 2001).

- When feeding RAP into the plant, ensure the maximum RAP chunk size does not exceed 2 inches (50 mm).
- Ensure the individual aggregates in a RAP chunk does not exceed the maximum size aggregate of the specified gradation.
- Use the procedures described in the Mix Design section of the UFGS cited in the paragraphs above to design recycled HMA

Many DOTs use Reclaimed Asphalt Shingles (RAS) to offset the cost of asphalt mixtures and utilize waste shingles that typically contain approximately 20 percent asphalt binder. RAS is not allowed on DoD airfield or roadway projects.

5-2.2 Hot In-place Recycling (HIR).

HIR can rehabilitate existing HMA pavements with distresses such as bleeding, shoving, raveling/segregation, corrugation, slippage, potholes, rutting, poor surface friction and cracking. HIR reprocesses existing HMA materials in-place at temperatures similar to conventional HMA by softening with heat, scarifying to depths of 3/4 to 2½ inches (20 to 60 mm), mixing new aggregate and binder, as required, placing and compacting (ARRA, 2001; Kandhal and Mallick, 1997; Hajek et al, 2005). The differences in the construction process and treatment of pavement distresses defines the three subcategories of HIR (Surface Recycling, Remixing, and Repaving).

HIR rejuvenates the surface of existing pavements having generally good structural capacity but that contain distresses in the surface layer. Conduct a comprehensive pavement evaluation prior to selection of HIR techniques to determine the asphalt concrete properties, the need for rejuvenators, and/or fine or coarse aggregates. Surface recycling is applicable for pavements that have no major distresses or deterioration and, hence, do not require additional material. Since repaving (HIR-III) is a combination of surface recycling or remixing with HMA overlay, it is applicable to high volume roads and airfield pavements.

Pavements without structural problems are ideal candidates for HIR. The type, extent, and severity of distress determines the applicable HIR type. Table 2-1 presents suggestions for selecting different HIR processes as a function of the pavement distress (ARRA, 2001).

5-2.2.1 Hot In-place Surface Recycling (HIR-I).

Surface recycling is the oldest HIR process. Formerly known by several names including heater-scarification, heater-planing, reforming, and resurfacing. It consists of heating, scarifying, adding asphalt binder or rejuvenator, leveling, reprofiling and compacting of the existing HMA mixture. The HIR-I process adds no new aggregates or new HMA. Treatment depth ranges between 3/4 to 1½ inches (20 to 40 mm).

Surface recycling prepares pavement for subsequent HMA overlay or chip seal. Steps in surface recycling are:

1. Dry and heat the upper HMA layers of the existing pavement such that surface temperatures range from 230 to 300 ºF (110 to 150 ºC) when at least two heaters are used in tandem.
2. Scarify the heated and softened HMA pavement.
3. Add a recycling agent if the mix design and JMF require.
4. Mix the loosened recycled mix.
5. Spread and place the recycled mix.
6. Compact the recycled mix using conventional HMA rollers and procedures.

5-2.2.2 Remixing (HIR-II).

Remixing consists of heating, softening and scarifying existing HMA pavement, adding virgin aggregate, new asphalt binder, recycling agent and new HMA, if necessary, followed by final mixing. HIR-II rehabilitates pavements that need an additional thickness of asphalt. The recycled mix acts as the wearing surface, but can be covered with a chip seal or overlaid with new HMA or HR to provide an improved surface that better resists traffic and environmental effects.

Perform remixing using a single or multi-stage approach. The single-stage approach successively heats and softens pavement to a specified full treatment depth followed by full material scarification. Multi-stage remixing heats thin layers of the pavement (normally between two to four layers), softens and scarifies them until achieving the desired full treatment depth. The scarified material is accumulated in a windrow to allow continued heating and scarification of underlying layers. The treatment depths for single-stage and multiple-stage are 1 to 2 inches (25 to 50 mm) and 1 ½ to 3 inches (40 to 75 mm), respectively (ARRA, 2001; Federation of Canadian Municipalities, 2005; Kandhal and Mallick, 1997).

5-2.2.3 Repaving (HIR-III)

Repaving combines surface recycling or remix with an HMA overlay and is frequently called the Cutler process. The surface recycled mix works like a leveling course and the new HMA as a wearing course. The thickness of the HMA overlay depends on the maximum aggregate size of the mix and varies between 3/4 inch (20 mm) and 3 inches (75 mm). The repaving process can significantly increase the pavement thickness (ARRA, 2001; Federation of Canadian Municipalities, 2005; Kandhal and Mallick, 1997).

Repaving is carried out by one unit equipped with several separate pieces of equipment including heaters, scarifiers, hot milling machines, pavers, and two screeds. The unit scarifies the heated and softened pavement at a temperature of approximately 375 ºF (190 ºC), adds the necessary quantity of recycling agent and mixes the recycled mix before the first screed. The screed levels and shapes the recycled material. Another screed on top of the recycled layer adds and spreads a new HMA layer. Rubber-tired and vibrating steel drum rollers compact the two layers as a single layer. The repaving process steps are:

1. Heat
2. Scarify using teeth or a rotary mill
3. Add recycling agent
4. Mix the recycling agent and loosened mixture
5. Spread and screed the recycled mixture
6. Place a new HMA overlay
7. Compact the two layers as a single layer

HIR-III recycling is only suitable for secondary or tertiary roads. Do not use this type of construction on airfields or parking areas subjected to heavy concentrated loads such as cargo yards, munitions haul roads, or similar critical roadways. For roads receiving HIR-III recycling, use the recycled layer as a base and determine the thickness of the new surface with the appropriate design analysis.

5-2.2.4 Past and Current Use.

Resistance to using HIR remains for the following reasons: (a) greater confidence in the conventional HMA overlay (b) lack of knowledge or appreciation of the new HIR technology, and (c) lack of appreciation of the quality of the pavement achieved with this technology. The quantity of the three types of HIR used in the United States is approximately the same (Emery, 2007; Kandhal and Mallick, 1997).

HR has been widely used in the US since the early 1980s. Most projects incorporate approximately 20 to 25 percent RAP or less.

5-2.3 Mix Design.

Follow the basic steps below for mix design for HIR/HR mixes.

1. Conduct analysis of existing pavement structure and surface condition.
2. Evaluate existing in-situ materials.
3. Sample the asphalt mixture selected for recycling by coring, sawing, or milling the pavement surface. Normally for HR, the contractor maintains RAP stockpiles as the RAP source.
4. Conduct either Marshall or Superpave mix design.

HIR is not normally recommended for airfield use, but has been used in conjunction with an HMA overlay. For roads, perform mix design with Marshall or Superpave mix design methods as specified in UFGS 32 12 16.16. For airfield pavements, perform mix design with Marshall or Superpave methods as specified in UFGS 32 12 15.13. Take samples of the surface pavement to be recycled, crush, and mix with asphalt binder or asphalt rejuvenator to determine the optimum asphalt content. Mix samples with various amounts of asphalt binder or rejuvenator and compact with a Marshall hammer or Superpave gyratory compactor. Select the asphalt content that provides approximately 4 percent air voids.

Design HR using the procedures addressed in Chapter 3. Use the two UFGS specifications (UFGS 32 12 15.13 and 32 12 16.16) to ensure production of a quality mix and successful placing and compaction.

5-2.3.1 Analysis of Existing Pavement Structure and Conditions.

Ideally, conduct a FWD evaluation and analysis prior to designing the pavement structure. If the structure is satisfactory or it needs only 1 or 2 inches (25 or 50 mm) of additional asphalt mixture, then HIR methods are suitable. If structural problems exist, or if the traffic volume or weight will increase, perform a structural analysis and design. See a description of design considerations above.

5-2.3.2 Samples.

See discussion on CIR and the following additional guidelines (NCHRP, 2001):

- For samples taken from a stockpile, take approximately 10 random samples from throughout the stockpile.
- For the samples taken from haul trucks, take samples from approximately three locations along the center of the truck bed. Take a sample approximately ¼ the way from front to back of the truck, approximately ½ the way from front to back, and about ¾ of the way from front to back. Samples should be taken underneath the surface by removing surface material with a shovel. All samples should be combined to obtain a representative sample of the truck.
- If the samples are for mix design, obtain at least 55 lbs. (25 kg) of RAP.
- If the samples are for gradation and asphalt content for QC testing, the sample size is approximately 22 lb (10 kg).

5-2.3.3 Identification of Distress Causes.

See Chapter 3 for common distresses and potential recycling methods that address distresses.

5-2.3.4 Analysis of Road Profile and Geometric Assessment.

Evaluating the existing pavement profile and cross slope can determine if a project is suitable for HR or HIR. A pavement that needs major realignments, drainage corrections or frost heave mitigation repairs, could use HR. In general, one of the three types of HIR can correct small problems with longitudinal or transverse profiles. In other circumstances, consider the following alternatives:

- Prior to overlay correct profile deficiencies by milling if the asphalt layer has sufficient thickness.
- Add granular material and new HMA or RAP to correct the profile. In this case, the options are Remix (HIR-II) or Repave (HIR-III).
- Correct what is possible during the HIR process and add HMA leveling or wearing course.
- If the HIR processes cannot correct the profile, then HR is a viable alternative.

5-2.3.5 Analysis of the Drainage Systems and Base Problems.

Thoroughly evaluate the drainage system to remove surface and subsurface water from the pavement structure. Solve drainage problems as part of any rehabilitation process. Otherwise, the problems will reoccur and significantly reduce the pavement life.

5-2.3.6 Selection of Materials and Methods.

Select satisfactory materials for use in HIR and HR. These include virgin aggregates to mix with existing materials to provide a satisfactory aggregate gradation. Select an appropriate asphalt binder so that when added to the RAP binder it produces satisfactory binder properties. With HIR, only limited additional materials can be used. Hence, improvement in the mix is limited.

5-2.3.7 Marshall and Superpave Mix Design Procedure.

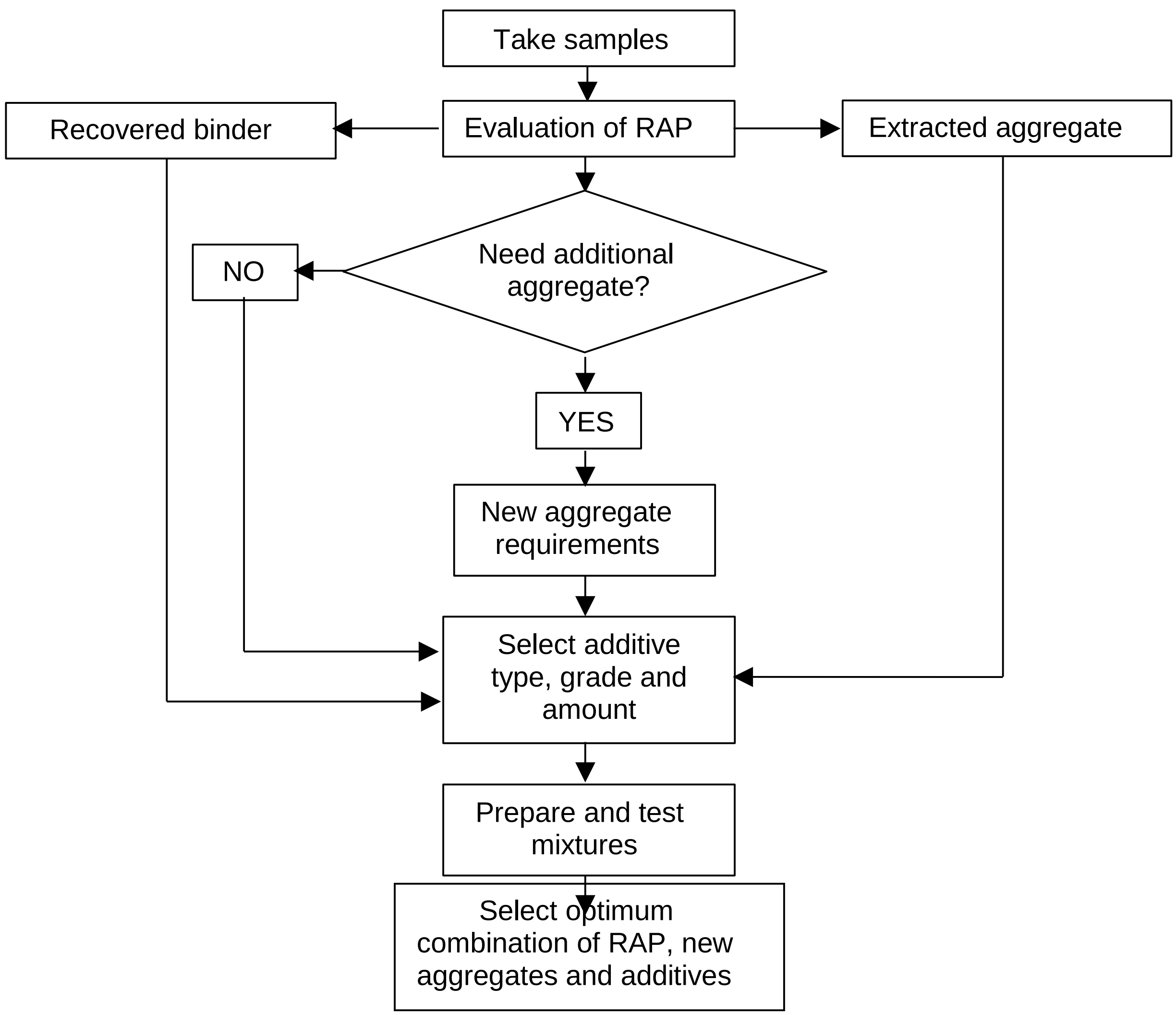
Perform a mix design to determine the percentages of RAP, new aggregate, recycling agent, and asphalt binder to use in the mixture. Base the amount of RAP used in a recycled mixture on the amount of the available reclaimed materials, the quality of the RAP, the desired properties of the recycled mix, aggregate gradation requirements, and economic considerations.

Figure 5-3 is a flowchart for the mix design procedure for the hot recycled mixtures. HIR adds very little or no additional virgin aggregates to the mixture, whereas, with HR there is at least 80% virgin aggregates in the mixture.

Compact samples of the recycled mixtures at various asphalt contents. Add the amount of new asphalt or recycling agent in 0.5 percent increments from 0 percent to 1.0 percent beyond the estimated optimum asphalt content. Compact the samples at the required effort, either 50 blows with a Marshall hammer (or 50 Superpave gyrations) for low-pressure tires (<100 psi or 6.9 kPa) or 75 blows with a Marshall hammer (or 75 Superpave gyrations) for high-pressure tires (>100 psi or 6.9 kPa), and determine the density, stability, flow, voids total mixture, and voids filled with asphalt. Only determine stability and flow with samples compacted with the Marshall hammer. Plot these determinations and draw curves to select the optimum asphalt content.

Determine the optimum asphalt content by selecting the virgin asphalt content equal to the amount that provides 3.5 percent air voids for HIR and 4.0 percent air voids for HR. The optimum additional asphalt binder is often between 0 and 1 percent for HIR mixtures. When the selected optimum additional asphalt is 0 percent or less, add no additional asphalt binder, since it may cause low voids in the asphalt mixture resulting in an asphalt mix that tends to bleed, rut, or shove under traffic. When the optimum asphalt content is very low use a recycling agent instead of asphalt binder.

Figure 5-3 Mix Design Procedure for Hot Recycled Mixtures



5-2.3.8 Evaluation of Existing Materials.

When evaluating existing materials, determine the properties of the RAP, extracted aggregate and recovered binder. Test samples of RAP, taken from stockpiles or directly from the existing pavement, in the laboratory. If performing a 5-point Marshall mix design, obtain a total of 18 to 20 cores, 2 inches (50 mm) thick and 6 inches (150 mm) in diameter or approximately 90 pounds (40 kilograms) of material.

5-2.3.8.1 RAP Properties.

Evaluate RAP properties to identify deficiencies to improve by adding rejuvenators, asphalt binder, fine and/or coarse aggregate or new hot mix for HIR. Determine the gradation of the RAP aggregate after solvent extraction (ASTM D2172) or ignition test (ASTM D6307) to remove asphalt binder. Determine the aggregate gradation using ASTM C136, the fractured faces by ASTM D5821, and flat and elongated particles by ASTM D4791. Properties of the combined aggregate from RAP and new aggregate sources must meet the same requirements as virgin aggregates in conventional HMA. It is difficult to recover enough aggregate from the RAP to conduct all of the required aggregate tests. Hence, the typical aggregate tests conducted are gradation, fractured faces, and fine aggregate angularity.

Determine the asphalt binder content of the asphalt mixture.

5-2.3.8.2 Virgin Aggregates.

a. Without adding significant amounts of new aggregate when producing HR, air pollution during mix production for most plants would exceed allowable levels. Adding new aggregate in a drum mix plant creates an aggregate shield preventing the flame from directly contacting the RAP and thereby burning the asphalt binder in the reclaimed asphalt pavement. Burning asphalt binder is the main source of air pollution during HR production.

b. Improve RAP aggregate gradation when using HR or HIR by adding virgin aggregates. Many times existing pavements do not contain the desired aggregate gradation. If they do contain a satisfactory gradation, this gradation may change during milling or crushing. Therefore, adding new aggregate modifies the recycled mix gradation to an acceptable level.

c. Often, the quality of the aggregates in an existing mix is not acceptable, even though the gradation is satisfactory. One cause of poor quality in an aggregate blend is an excessive amount of natural sand. Natural sand is a poor aggregate for asphalt mixtures, but because of its abundance and low cost, asphalt mix designs often use it in excess. The maximum amount of natural sand allowed by the airfield specifications is 15 percent, but many RAP stockpiles contain significantly more natural sand. Adding crushed stone decreases the relative percentage of natural sand in the mixture and improves the RAP aggregate quality.

d. Existing HMA pavements may contain filler (material passing the No.200 sieve) significantly higher than the 6 percent maximum allowed for HMA mixtures. Milling and crushing RAP generates up to 1 to 3 percent additional filler due aggregate breakdown. To control the filler use new aggregates with minimal filler content. In some cases, wash the virgin aggregates to minimize the filler material or screen the RAP into coarse and fine RAP stockpiles. The coarse RAP stockpile will have significantly less filler than the fine aggregate stockpile and thus less effect on the total amount of filler.

5-2.3.8.3 Recycling Additive.

a. The oxidized asphalt binder in existing HMA pavement requires some modification during recycling to produce an asphalt binder with acceptable binder properties. Ensure the mixture of old and new HMA material meet the specifications for the asphalt mixture using virgin materials. If not adding new aggregate to the mix, such as in HIR, adding asphalt or recycling agent to produce satisfactory asphalt binder properties may generate a rich mixture. The asphalt binder content of an existing pavement mixture is generally near the optimum asphalt content; thus, adding more asphalt binder or recycling agent for HIR mixtures generates excessive asphalt content. Not modifying the existing asphalt binder with low viscosity asphalt or recycling agent produces a brittle mixture. Using RAP in a mix such as for HR mixtures allows significant modification of the RAP aggregate quality and binder properties since there is significantly more virgin materials in the mixture. However, for HIR mixtures, most aggregate comes from the RAP, so this quality is much more important.

b. Restoring the existing asphalt binder is important for the success of a recycled mixture. Using a high amount of RAP in a mixture, such as for HIR, it is difficult to control the properties of combined binder as the amount of reclaimed asphalt binder likely exceeds the amount of virgin asphalt binder. For HIR, determine the amount and type of new asphalt binder required using the mix design process and to obtain the desired total binder properties. Recommendations for recycling additives for HIR are (ARRA, 2001):

- Use a recycling agent only to restore or rejuvenate the existing asphalt binder properties. Assume that the recycling agent thoroughly mixes with the aged asphalt binder during plant or in-place mixing.
- Use a performance grade (PG) binder with reduced high temperature grade as the new asphalt binder instead of a recycling agent. The assumption is that a new asphalt binder of lower PG grade will effectively combine with the aged binder resulting in an acceptable combined asphalt binder.
- Use a recycling agent and a soft new asphalt binder combined to rejuvenate the aged asphalt binder.

- Select asphalt binders according to the following standards (UFGS 32 12 15.13, UFGS 32 12 16.16):
  - ASTM D6373 for performance grade
  - ASTM D946 for penetration grade (penetration grading is used in some areas outside the U.S.)

c. When selecting PG asphalt binders in the U.S., consider adopting local DOT requirements for binder selection. Tweak the identified grades to meet mission needs. This makes it easier to obtain sources for asphalt binder and reduces the cost.

d. Typically, rutting is not a major problem on most airfield runways. However, for high traffic volumes on taxiways and at the end of runways, pavement rutting may occur under slow moving traffic with high tire pressures. High tire pressures exceeding 200 psi (1.4 MPa) may contribute to rutting. Some aircraft tire pressures exceed 300 psi and these high pressures can produce rutting in an asphalt mixture.

e. Use PG graded asphalts in HR mixture. Use recycling agents in HIR mixtures. Since a small amount of recycling agent will modify the RAP binder, ensure it contains an optimum residual asphalt content. Use the recycling additive to achieve the desired asphalt binder physical properties. Compare the physical properties of the combined asphalt binder (new recycling additive plus aged asphalt binder) with those of the original aged asphalt binder to establish the amount of recycling additive necessary.

f. In general, use softer recycling agents and lower new binder contents for HIR recycling methods (FHWA, 1997). Select the appropriate tests to ensure grade conformance of new asphalt specified, using the following guidance.

- If using a PG asphalt, use the dynamic shear rheometer and bending beam tests.
- If specifying a penetration grade asphalt, use a penetration test.

g. Ensure the new asphalt binder added to the HR mix has a grade that is no more than two PG grades different from that specified in paragraph ASPHALT CEMENT BINDER of the UFGS 32 12 15.13 or UFGS 32 12 16.16 specifications. Ensure the temperature of unmodified asphalts is no more than 325 ºF (160 ºC) when added to the aggregates and the temperature of modified asphalts is no more than 350 ºF (175 ºC) when added to aggregates.

5-2.3.8.4 Mix Properties.

Ensure the HR mix properties comply with the requirements indicated in Table 5-1 for airfields (UFGS 32 12 15.13) and Table 5-2 for roads (UFGS 32 12 16.16).

Table 5-2 Hot Mixed Recycled Properties for Airfields[5]

Parameter	Requirement	
	75 blows 75 gyrations	50 blows 50 gyrations
Minimum stability[4], pounds	2150	1350
Flow, 0.01 inch	8-16[1]	8-18[1]
Air voids, percent	4	4
Minimum percent voids in mineral aggregate	---[2]	---[2]
Dust proportion[3]	08-1.2	0.8-1.2
TSR, minimum percent	75	75

[1]The flow requirement is not applicable for polymer modified asphalts. Do not use flow with Superpave gyratory compactor.

[2]Aggregate gradation 1, minimum VMA = 13 percent; aggregate gradation 2, minimum VMA = 14 percent; aggregate gradation 3, minimum VMA = 15 % (see UFGS 32 12 15.13).

[3] Calculate dust proportion as the aggregate content, expressed as a percent of weight, passing the No. 200 sieve, divided by the effective asphalt content, in percent of total weight of the mixture.

[4]The stability requirement is not applicable when Superpave gyratory compactor is used.

Table 5-3 Recycled Asphalt Mix Properties for Roads[6]

Parameter	Requirement	
	75 blows 75 gyrations	50 blows 50 gyrations
Minimum stability[2], pounds	1800	1000
Flow[2], 0.01 inch	8-16	8-18
Air voids, percent	3-5	3-5
Minimum percent voids in mineral	---[1]	---[1]
TSR, minimum percent	75	75

[1] Aggregate gradation 1, minimum VMA = 13 percent; aggregate gradation 2, minimum VMA = 14 percent; aggregate gradation 3, minimum VMA = 15 % (See UFGS 32 12 16.16)

[2] Marshall stability and flow not used when compacted with Superpave gyratory compactor

UFC 3-250-03 presents additional information on mix properties and complete description on mix design.

[5]UFGS 32 12 15.13.

[6]UFGS 32 12 16.16.

5-2.3.9 Structural Design.

See guidance on structural design above.

The structural design of road and airfield pavements with hot recycled asphalt mixes (HR, HIR) follows the same criteria and procedure as for the conventional design for flexible pavements for roads and airfields. HIR and HR mixes perform the same as virgin asphalt mixtures. Use the same thickness design requirements for HIR and HR for conventional asphalt pavement design. For CBR design, the equivalency factors for HIR and HR are the same as for conventional asphalt mixture.

5-3 CONSTRUCTION.

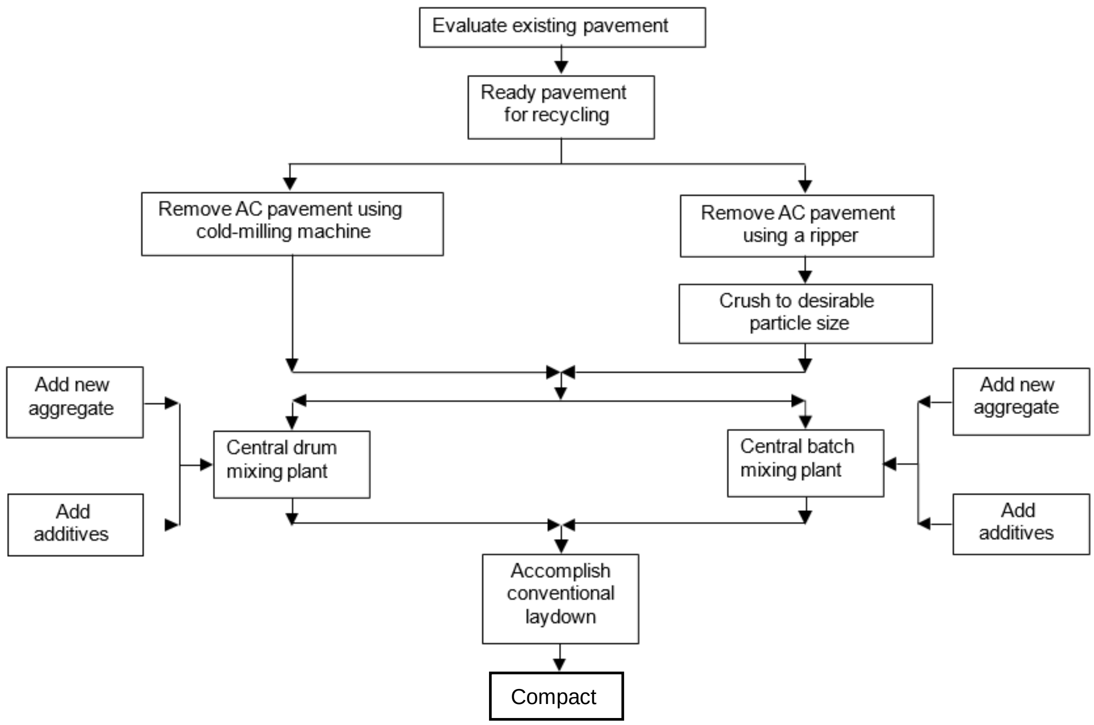
5-3.1 HR.

The HR process encompasses six basic construction steps (ARRA, 2001):

1. Remove the existing pavement materials to the desired depth.
2. Prepare the RAP for recycling (stockpiling and crushing).
3. Utilize RAP as available from other projects.
4. Blend old and new materials in a HMA production facility.
5. Mix the components in the proper proportions per the mix design.
6. Place the mixture and compact.

Figure 5-4 depicts these processes below.

Figure 5-4 Hot-Central Plant HR Recycling Process



HR mixture is a commonly used HMA mixture. In fact, most HMA mixtures now contain some amount of RAP in the mix. Asphalt mixtures on average among the various state DOTs contain approximately 20 percent RAP. The procedures used to produce and construct HR mixtures are essentially the same as used to construct HMA without RAP.

The construction equipment include: 1) equipment to remove existing material, 2) equipment for crushing RAP, 3) equipment for mixing and placing the HR, and 4) equipment for field compaction. The following sections discuss this equipment.

Transport HMA from the mixing plant to the site in clean, tight truck beds. Schedule deliveries for uniform placement and compaction of the mixture with minimum paver stopping and starting. Provide adequate artificial lighting for night placement. Do not permit hauling over freshly placed material until the material is compacted and allowed to cool to 140 ºF (60 ºC).

5-3.1.1 Removing and Processing Existing Material.

Remove asphalt mixtures with a milling machine to the desired depth. On some projects, a ripper tooth removes the asphalt mixture, but this requires crushing prior to re-use and is reserved for small jobs where full depth removal is required. A milling machine can remove up to 4 inches (100 mm) of HMA in one pass. It uses sensors that follow a grade reference and/or slope control to establish the finished grade. Since heat is not used, there is no smoke pollution. However, excess dust may occur, and this is solved by spraying a small amount of water onto the pavement in front of the milling machine. Milling machines are used during all weather conditions and produce finished milled surfaces that conform to the project specifications (UFGS 32 01 16.71). The milled HMA becomes RAP material to be used on the existing project or on future projects to produce HR. Ensure project specifications clearly state who owns the RAP since most state DOTs provide the RAP collected from a project to the contractor at the end of the project.

5-3.1.2 Mixing and Placing.

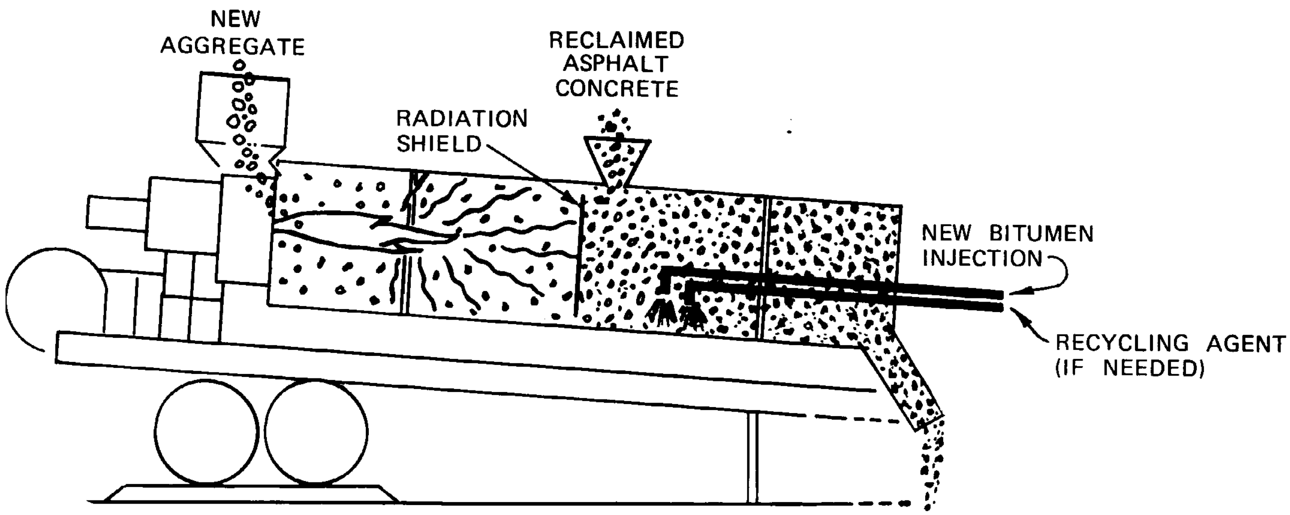
Use a batch or drum mix plant to blend recycled materials. Place recycled material with a conventional asphalt paver. When using a parallel flow drum mixer (aggregate flow and flame moving in same direction) for recycling, add the new aggregate at the high side of the drum near the flame, as indicated by Figure 5-5. The aggregate absorbs much of the heat from the burner and acts as a shield to protect the reclaimed asphalt concrete, new asphalt binder, and recycling agent from the adverse effects of the open flame. Add the RAP to the drum near the midpoint followed by the recycling agent and new asphalt. If air pollution is a problem, modify the mix design by lowering the percentage of RAP used in the mix to reduce emissions to an acceptable range.

When using a counter flow drum mix plant (aggregate flow and flame going in opposite directions), add the aggregate at the top of the drum and the flame is located at the bottom end of the drum. Add the RAP and asphalt binder in one of several processes, but in a way to keep the asphalt binder away from the open flame. This counter flow process has fewer emission issues when compared to the parallel flow drum plant.

Modify batch plants to produce recycled mixtures as shown in Figure 5-6. The modification consists of adding a feeder and conveyor to carry the reclaimed asphalt pavement directly to the weigh bucket. Superheat the new aggregate that passes through the dryer between 500 and 600 ºF (260 and 315 ºC) so that when blending, the resulting mix temperature is suitable for mixing and compaction. Increasing the amount of reclaimed asphalt in the mix requires an increase in the new aggregate temperature to achieve the desired mixture temperature. In addition, additional moisture in the new aggregate or reclaimed asphalt pavement stockpiles requires additional heat to dry and adequately mix the mixture components.

Place and compact the mix at a temperature suitable for obtaining density, surface smoothness, and other specified requirements (UFGS 32 12 15.13 and UFGS 32 12 16.16). Upon delivery, collect the mixture from the trucks and place across the full width of the pavement with an asphalt paver. Using a material transfer vehicle (MTV) allows the paver to move forward continuously and minimizes segregation. Airfield construction requires using an material transfer vehicle (MTV) (UFGS 32 12 15.13). Using an MTV, produces a smoother, more uniform pavement surface. Place the mixture uniformly at a depth that, when compacted, produces the required thickness and conforms to the specified grade and contour. Regulate paver speed to eliminate asphalt mat pulling and tearing. Unless otherwise permitted, begin placing the mixture along the centerline of a crowned section or on the high side of areas with a one-way slope.

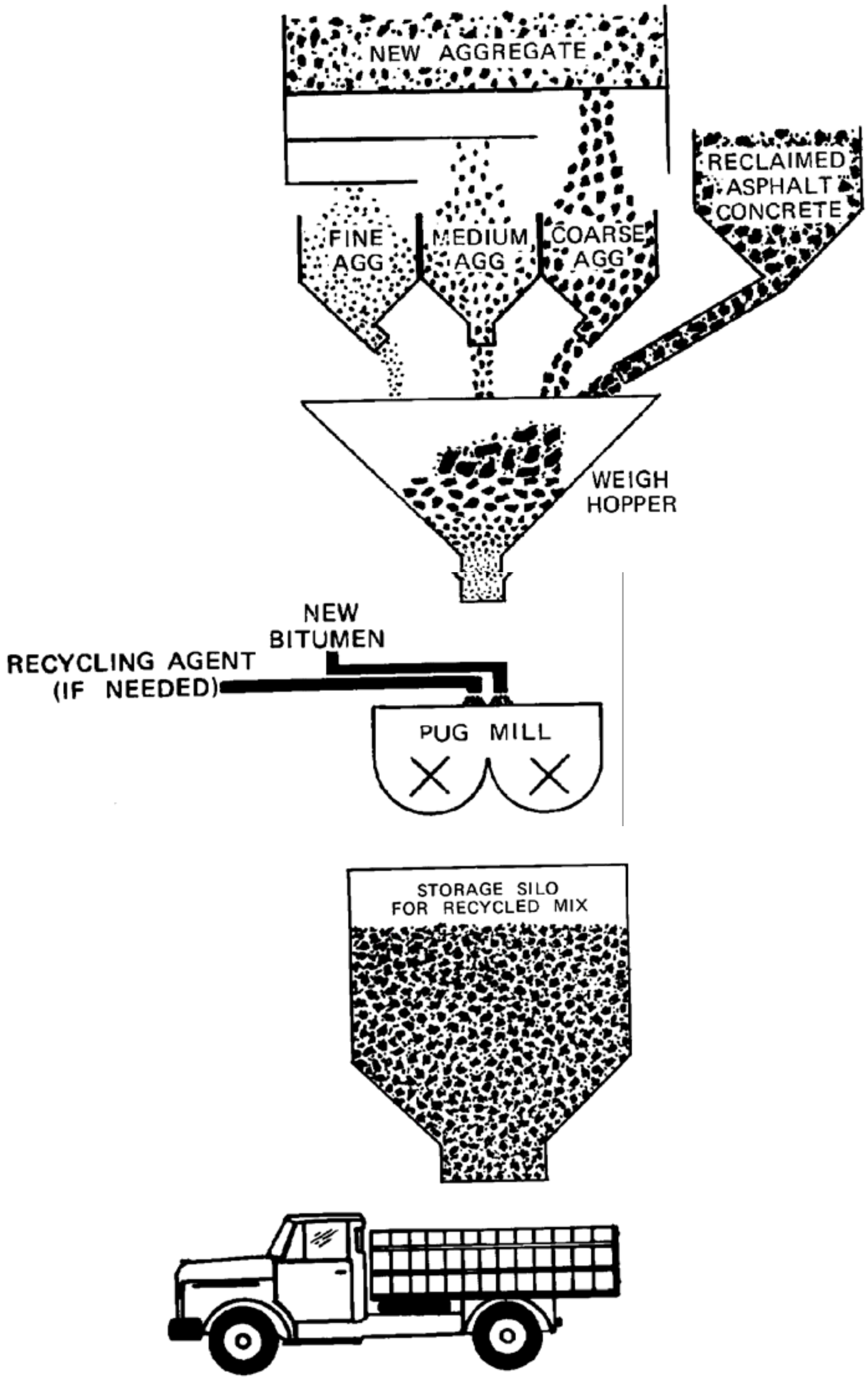
Figure 5-5 HR Production in a Parallel Flow Drum Mix Plant



5-3.1.3 Field Adjustments of the Mix.

The JMF obtained in the laboratory may require adjustments in the field to ensure that mixture and material properties meet the specifications. Make these adjustments based on the visual appearance of the recycled mix, test results obtained from samples of the HR, test results of the recovered aggregate, and test results from the recovered asphalt binder (ARRA, 2015).

Figure 5-6 Hot Recycled Asphalt Mix Production in a Batch Plant



5-3.1.4 Compaction.

Rollers used to compact asphalt mixtures include static steel-wheel, vibratory steel-wheel, and rubber-tired rollers. These rollers perform breakdown, intermediate, and finish rolling. Conduct breakdown rolling in vibratory mode, and occasionally, in static mode. Perform intermediate rolling in the vibratory mode while finish rolling in the static mode.

Rubber-tire rollers perform intermediate rolling of HMA mixtures. These rollers provide an increase in compaction after breakdown rolling and seal the surface. Ensure rubber-tired rollers are equipped with an operational watering system for the tires and that scrapers and pads affixed to prevent accumulation of materials on tires. Ensure rubber-tired rollers have skirts affixed to the roller that shield the tires from wind to prevent tire heat loss. Use a 10-ton or larger rubber-tired roller to compact all heavy-duty HMA pavements. Operate rollers at or below 3 to 5 mph (4.8 to 8 km/h) (fast walking speed). Make gradual starts and stops to avoid damaging the freshly laid mixture. Do not allow quick turns or any turns that cause cracking on freshly laid mixture. The contractor has discretion on sequence of rolling operations and the type of rollers used.

Compact the paving mixture while the mix is sufficiently hot, because rolling is relatively ineffective after the mixture cools below a minimum temperature and it is very difficult to obtain the required density. Following compaction and a cooling period, the pavement becomes very stable due to coarse and fine aggregate interlocking and adhesion of the asphalt binder as well as a high resistance to moisture penetration and frost damage.

Determine density results from 4 inch (100 mm) or 6 inch (150 mm) diameter cores randomly cut from the pavement. Use density gauges for QC testing, but not for final acceptance testing. Use cores for final acceptance of compaction.

5-3.2 HIR.

HIR treatment application is normally one lane wide (12 ft or 3.7 m). If pavement width is not a multiple of the treatment width, then overlap treatments. Limit overlaps to 2 to 6 inches (50 to 150 mm).

5-3.2.1 Construction Process.

5-3.2.1.1 Surface Recycling (HIR-I).

Major equipment includes brooms, trucks, front-end loaders, graders, asphalt distributors, self-contained heating units, heater-scarifiers, hot-milling machines, pavers, trucks, and/or cold-milling machines. Figures 5-7 through 5-9 show examples of a surface recycling heating unit, surface recycling scarification teeth, and surface recycling, respectively. There are single-pass (surface is recycled and left as final wearing course) and double-pass (surface is recycled and then an HMA overlay or a surface treatment is applied over it) procedures.

Figure 5-7 Surface Recycling Heating Unit

Figure 5-8 Surface Recycling Scarification Teeth*

*Source: ARRA, 2001.

Figure 5-9 Surface Recycle Mix Placement*

*Source: ARRA, 2001.

5-3.2.1.2 Remixing (HIR-II)

Hot in-place remixing operations encompass heating, scarifying, rejuvenating, mixing (and/or adding new HMA), leveling, re-profiling, and compacting. The remixing equipment heats, scarifies, or hot mills the existing pavement, mixes new materials, and lays the combined recycled and new mixtures. Figure 5-10 shows an example of a remixing train. Remove the existing pavement to depths of 0.4 to 2 inches (10 to 50 mm) (Kandhal and Mallick, 1997). Modern remixing equipment can work with up to 2 inches (50 mm) of the pavement and increase the pavement thickness by 1 inch (25 mm) (ARRA, 2001). There are two remixing methods:

a. Single Stage Remixing. Heat the existing asphalt pavement, soften with recycling agent or soft asphalt binder and scarify to the desired depth (1 to 2 inches [25 to 50 mm]), mix new HMA with the scarified material, and re-lay and compact the combined recycled mix. Figure 5-11 is an example of this method.

b. Multiple Stage Remixing. Heat the existing asphalt pavement, soften with recycling agent or soft asphalt cement, and scarify in a number of thin layers until achieving the pre-determined full treatment depth. Two to four layers are normally heated and scarified. Accumulate the scarified material is accumulated in a windrow to facilitate the continued heating and scarification of underlying layers. The range of treated depths is between 1-1/2 and 3 inches (40 to 75 mm). Figure 5-12 shows a windrow with scarified material.

Figure 5-10 Example of Remixing Train

Figure 5-11 Example of Single Stage Remixing Train

Figure 5-12 Multiple Stage Remixing with Windrow of Scarified Material

5-3.2.1.3 Repaving (HIR-III).

The equipment used in this process are the same as for HIR-I and HIR-II. In addition, ensure the repaving equipment can place an integral HMA overlay as thin as 1/2 inch (12.5 mm), using the appropriate HMA (use a fine graded mixture) (ARRA, 2001). As discussed earlier, repaving is a combination of surface recycling or remix with an overlay of HMA. The surface recycled or remixed layer and the HMA overlay are compacted simultaneously, which results in a thermal bond between the two layers. The surface recycled mix works as a leveling course and the HMA layer as a wearing course. The construction of HIR-III uses one of two approaches:

- Single Pass Repaving. Single Pass Repaving uses one unit equipped with two screeds. The unit scarifies the heated and softened pavement, adds the required amount of recycling agent, mixes the recycled mix prior to the first screed, receives the new HMA, and transports it over the recycled mix. The first screed places the recycled mix while the second screed places the new HMA overlay on top of the recycled mix. The two layers are then compacted.
- Multiple Pass Repaving. In this case, place the surface recycled mix and work with its own placing and screeding unit to meet the longitudinal profile and cross-slope requirements. Immediately place the new HMA overlay material on the hot uncompacted recycled mix with a conventional asphalt paver and then compact the two layers.

5-3.2.2 Placement of the HIR Material.

Place the recycled mixtures with a screed, often attached at the end of a recycling train or on a separate paver. After placement, compact the mix with rollers to achieve the desired density. Single-pass methods provide a relatively small opportunity for corrections from the existing grade.

Difficulty in placing the recycled material increases when the HMA overlay thickness and the underlying HIR treatment depth is greater than 3 to 4 inches (75 to 100 mm) (ARRA, 2001). Do not use layers greater than 3 inches (75 mm) compacted thickness.

5-3.2.3 Field Adjustments of the Mix.

See paragraph for HR.

5-3.2.4 Curing.

HIR mixes require no curing. Once these mixtures cool to 140 °F or lower, allow traffic.

5-3.2.5 Compaction.

See paragraph for HR.

5-3.2.6 Field Density.

See paragraph for HR.

5-3.2.7 Surface Course.

Add surface course over HIR mixtures to provide improved resistance to climatic conditions and traffic.

5-4 QUALITY CONTROL ISSUES.

5-4.1 Specifications.

Conduct all hot recycling projects (HR, HIR-I, HIR-II and HIR-III) in accordance with the respective UFGS specifications: UFGS 32 01 16.74, UFGS 32 01 16.75, UFGS 32 12 15.13 and UFGS 32 12 16.16.

5-4.2 Quality Control/Quality Assurance.

QC/QA practices for hot in-place recycling are the same as typically used for conventional HMA. QC/QA includes extracting, recovering, and testing of the blended asphalt binder. Consider variability of the RAP when preparing QC/QA limits and pay factors for individual projects, mainly for HIR (Kandhal and Mallick, 1997). Develop a Quality Control Testing Plan as part of the approved recycled mixture project. Ensure the plan addresses all elements that affect the quality of the pavement including, but not limited to, the following elements (UFGS 32 12 15.13 and UFGS 32 12 16.16):

- recovered asphalt binder properties
- mix design and unique JMF identification code
- aggregate grading, angularity, flat/elongated particles
- quality of materials
- stockpile management and procedures to prevent contamination
- proportioning
- mixing and transportation
- correlation of mechanical hammer to hand hammer
- moisture content of mixtures
- placing and finishing
- thickness
- joints
- field compaction, including joints
- surface smoothness
- truck bed release agent

When the contractor develops a Quality Control Plan, ensure performance of all required testing and inspection in accordance with the specification requirements. Ensure the plan clearly explains how the contractor will control the quality of work.

5-4.2.1 Field Sampling and QC Testing.

The field sampling and QC testing depend on the testing program requirements. The testing program, the main part of the QC/QA process, includes, but is not limited to,

- Tests for the control of asphalt content, aggregate gradation and specific gravity.
- Temperatures, aggregate moisture, and moisture in the asphalt mixture.
- Laboratory determined air voids (air voids in total mix (Va), voids in mineral aggregates (VMA), voids filled with asphalt (VFA)).
- Marshall stability and flow tests.
- In-place density (use a density gauge to monitor pavement density, when correlated to core samples but not for acceptance of density).
- Grade conformance and surface-smoothness.
- Perform additional testing at the discretion of the contractor as necessary to control the process. When field sampling follow UFGS requirements

(UFGS 32 01 16.74, UFGS 32 01 16.75, UFGS 32 12 15.13; UFGS 32 12 16.16).

Additional guidelines for preparing a field-sampling plan for roads are below (ARRA, 2001; FHWA, 1997):

- Divide the project into homogeneous sections (similar materials and/or performance.
- Design field sampling according to these homogeneous sections.
- Use random sampling methods for setting field sampling according to the homogeneous sections for adequate recycling mix.
- Use pavement coring to obtain field samples (typically, 6-inch (150-mm) diameter cores).
- If necessary, use sawing for block sampling.
- Determine number of samples according to the size of the project:
  - Large projects, with more than 4 miles (6.4 km), require at least two samples for every mile (1.6 km) with a minimum of 6 samples per project
  - Smaller projects, like in urban areas, would require at least 8 samples per mile (1.6 km) or one per block if the pavement is not homogeneous

To prepare a field sampling plan for airfields use the approach presented in Chapter 4.

CHAPTER 6 RECYCLING FOR CONCRETE SURFACED PAVEMENTS

6-1 INTRODUCTION.

Concrete pavement recycling is a rehabilitation technique that reuses PCC material in an existing concrete pavement structure. Accomplish the reuse through fractured slab technologies including break/crack-and-seat and rubblization. Alternatively, conduct slab demolition, removal, and reprocessing activities to produce RCA. Depending on the technique, the recycled material can serve as a base material or as aggregate in new PCC or lean concrete base. Recycle composite pavements, where HMA overlays PCC, by first milling off the existing HMA.

Concrete recycling offers significant savings in the cost of hauling and disposing of old concrete and it saves natural resources and reduces or eliminates the need for new virgin aggregates. In addition, compared to the conventional form of PCC rehabilitation, HMA overlay directly over existing PCC, recycling can provide substantial performance benefits in terms of alleviating or eliminating reflection cracking in the HMA surfacing.

As discussed in Chapter 2, concrete recycling techniques are mostly suitable for existing pavement with substantially reduced structural capacity. Other forms of rehabilitation better serve pavements with functional distresses or limited structural distress such as concrete pavement restoration (CPR) and HMA or bonded PCC overlays.

This chapter presents detailed information and guidance on the four basic forms of concrete recycling: (1) break-and-seat, (2) crack-and-seat, (3) rubblization, and (4) central plant recycling. Following an overview of the applications of each method, topic sections cover structural and mix design considerations, construction details, and QC/QA issues.

6-2 OVERVIEW OF RECYCLING METHODS.

6-2.1 Break/Crack and Seat.

The break-and-seat recycling process involves fracturing the slabs of JRCP into small segments (1.5 to 4 feet [0.5 to 1.2 m]) and adequately rupturing the bond between PCC and reinforcing steel to ensure discontinuity among the fractured pieces. Firmly seat the pieces in place in preparation for an overlay. Typically, the overlay is HMA, but PCC overlays are also successful. Similarly, the crack-and-seat recycling process involves fracturing the slabs of JPCP into small segments (2 to 6 feet [0.6 to 1.8 m]), which are then seated firmly into place in preparation for an overlay (again, typically HMA, but PCC can be an option). Typical HMA overlay thicknesses range between 4 to 8 inches (100 to 200 mm), depending on expected traffic loading and the strength characteristics of the fractured PCC and base layers.

Breaking/cracking and seating reduces joint and crack movement by shortening the effective slab length and seating the broken pieces into the supporting layer (Hoerner et al., 2001). Greater impact energy is required for the break-and-seat process in order to rupture the concrete bond to the steel in the slab. In both applications, consider incorporating edge drains to facilitate drainage, given that the fractured slab allows water to flow more freely into the underlying pavement layers (Hoerner et al., 2001).

Break/crack-and-seat techniques are most appropriate for concrete pavements experiencing significant load-related distresses (e.g., linear cracking, divided/shattered slabs, corner breaks), faulting, or environmental or materials related distresses (e.g., D-cracking, ASR, scaling). However, as noted below, existing PCC airfield pavements that exhibit ASR distress are subject to restrictions with this technique. Pavements with other distresses, such as patch deterioration and unstable or settled slabs, can also benefit from breaking/cracking and seating.

PCC pavements with many failed or shattered slabs are not suitable candidates for break/crack-and-seat techniques (Ahlrich, 1992). Moreover, in situations where the pavement foundation is weak or questionable, the fractured slabs will “float” on a soft layer, manifesting in vertical and/or rotational movement of the slabs. Since these movements seriously undermine the performance of the HMA overlay, use a great deal of caution in determining when the break/crack-and-seat procedure is effective under these circumstances.

DoD policy allows the use of break/crack-and-seat techniques on all auxiliary airfield pavements and on all roadway pavements. However, caution is warranted when considering break/crack-and-seat techniques for PCC airfield pavements suffering from ASR damage. Because of the uncertainty of the effects of this phenomenon on pavement performance, TSPWG M 3-250-04.06-2 recommends consulting with AFCEC on projects involving this situation. Additionally, TSPWG 3-250-07.07-6 provides a detailed procedure for assessing and controlling the risk of break/crack-and-seat applications involving PCC with ASR distress. Recycle ASR-infected PCC can be considered on roadway pavements that are not mission critical. Practitioners are encouraged to use the risk assessment procedure outlined in TSPWG 3-250-07.07-6.

6-2.1.1 Past and Current Use.

The practice of break/crack-and-seat on airfield and roadway pavements dates back to the 1980s and 1990s. Early successes in delaying the development of reflective cracking led to increased usage of this technique.

In recent years, the use of break/crack-and-seat has decreased due to variability in performance coupled with increased success with rubblization. While most studies have shown a considerable delay in the development of reflective cracking, some studies have shown that the severity of cracking in the long-term (5 to 7 years) is comparable to that of conventional HMA overlays over non-fractured concrete.

The use of a reinforcing fabric or SAMI following placement of the first lift of HMA (leveling layer) delays reflective cracking. Consider the use of an interlayer if representative data are available to show its cost-effectiveness.

6-2.2 Rubblization and Overlay.

Rubblization fractures existing PCC pavements (JRCP, JPCP, or CRCP) in-place into small, interlocked pieces that serve as a base course for a new HMA or PCC overlay (Buncher et al., 2008). The rubblized material, ranging from sand-sized particles to 6 inches (150 mm) at the surface and 6 to 15 inches (150 to 375 mm) at the slab bottom, resembles a dense aggregate base layer with a high degree of particle-to-particle interlock. Seat the rubblized layer using specific rolling protocols. Although the thickness of an HMA overlay depends largely on expected traffic loadings and the bearing capacity of the rubblized and foundational layers, thicknesses between 4 and 10 inches (100 to 250 mm) are most common. Installation of an edge drain system dramatically improves the constructability and performance of the rubblized layer.

Rubblization eliminates joint and crack movement. The resulting fractured particle sizes somewhat resemble crushed aggregate base material. Also, because of the type of equipment used—resonant and multi-head pavement breakers—the impact load is lighter, which minimizes disturbance to the support layers and any underground features (Hoerner et al., 2001).

Consider rubblization when the amount of deterioration of the existing pavement is so great that normal break/crack-and-seat methods would not be effective (Hoerner et al., 2001). Rubblization is generally a viable option for CRCP that is distressed beyond the point that restoration strategies, such as full-depth repairs and grinding, are no longer cost-effective. One advantage of rubblization over break-and-seat is that the steel reinforcement in the pavement does not require rupturing, as the concrete completely debonds from the steel. The main disadvantage of rubblization, compared to break/crack-and-seat, is that it requires a thicker HMA surface due to the lower structural capacity of the rubblized material.

Current DoD policy allows rubblization on all airfield pavements and on all roadway pavements. However, as with break/crack-and-seat, exercise caution in considering the use of rubblization on PCC airfield pavements suffering from ASR damage. Because of the uncertainty of the effects on pavement performance, TSPWG M 3-250-04.06-2 recommends consulting with AFCEC in projects involving this situation. Additionally, TSPWG 3-250-07.07-6 provides a detailed procedure for assessing and controlling the risk of rubblization applications involving pavements with ASR. Apply this risk assessment procedure to projects that rubblize ASR-infected PCC roadway pavements.

6-2.3 Past and Current Use.

Rubblization is currently the most widely used PCC slab fracturing technique.

6-2.4 RCA Applications.

a. RCA recycling involves demolishing existing concrete pavement on grade, loading and hauling the material to an off-site crushing plant, and processing (i.e., crushing, sizing, and steel removal) the material to produce recycled aggregate of specified sizes (Hoerner et al., 2001). Use RCA in unbound base/subbase layers, asphalt or cement-treated layers, lean concrete bases, or PCC surface courses (low-type facilities only).

b. RCA is best suited for existing PCC pavements that have reached the end of their useful life. Hence, pavements with extensive amounts of slab cracking, joint deterioration, slab settlement, faulting, or environmental or materials-related distresses are good candidates for this activity. Compared to conventional reconstruction using virgin materials, reconstruction using RCA conserves materials, reduces landfill requirements, and reduces project costs.

c. RCA recycling can be performed on any existing PCC pavement type—JPCP, JRCP, or CRCP (Hoerner et al., 2001). Reinforcing steel hampered the productivity and effectiveness of many early RCA recycling projects. Equipment innovations over the years have virtually eliminated problems in processing reinforced concrete material.

d. The coarse fraction of RCA retained on the 3/8-inch (9.5-mm) sieve is preferred for most applications. This is because of the high degree of angularity and high absorption capacity of the RCA fine fraction adversely affects the workability of a resulting mix (Hoerner et al., 2001). The addition of natural sand can restore workability.

e. Current DoD policy allows RCA as aggregate base and subbase material, and as aggregate for lean concrete base on all airfield and roadway pavements. The use of RCA in new PCC is limited to auxiliary airfields and minor roads. Do not use RCA from pavements with severe D-cracking in PCC surface courses. In addition, because of the uncertainty of the effects of ASR-infected RCA on pavement performance, TSPWG M 3-250-04.06-2 recommends that such material not be used in any application within an airfield pavement structure. Additionally, TSPWG 3-250-07.07-6 provides detailed procedures for assessing and controlling the risk of RCA applications involving ASR-infected pavements. Use this risk assessment procedure for roadway projects in which RCA from PCC pavement with ASR distress is used.

6-2.4.1 Past and Current Use.

RCA is used predominantly as a replacement for virgin aggregate in granular, cement-treated, or lean concrete base layers and, to a lesser extent, in PCC and HMA surface layers (Saeed et al., 2006). Roughly two-thirds of RCA usage in pavement applications is for unbound base or subbase layers.

RCA has been used at several DoD locations including Selfridge ANG, Shaw AFB and North Auxiliary Field in South Carolina, Grand Forks AFB in South Dakota, Mountain Home AFB in Idaho, Offutt AFB in Nebraska, and Holloman AFB in New Mexico (Saeed et al., 2006). Commercial airport applications include Atlanta Hartsfield-Jackson International Airport and the former Denver Stapleton International Airport.

Several State DOTs use RCA in pavement construction. A survey of state DOTs indicates the following usage (FHWA, 2005):

- RCA Used as Aggregate: 41 of 50 states.
- RCA Used as Base Aggregate: 38 of 50 states.
- RCA Used as PCC Aggregate: 11 of 50 states.
- RCA Used as HMA Aggregate: 8 of 50 states.

6-3 STRUCTURAL DESIGN CONSIDERATIONS.

6-3.1 Break/crack-and-seat and overlay.

a. The structural design of break/crack-and-seat and overlay projects centers on the structural characteristics of the fractured layer and underlying base and subgrade layers in response to anticipated traffic loading (Huang and White, 1995). The values selected for these parameters determine the thickness of the HMA overlay placed on the fractured PCC layer. Perform the HMA overlay thickness design using the flexible pavement design procedures provided in UFC 3-260-02.

b. Directly test fractured layer characteristics after completing the breaking/cracking process. Estimate initial values using the best available information. Key aspects include the condition/quality of the existing PCC, the presence of steel reinforcement, and the targeted size of PCC segments.

c. The size of the broken segments is critical to the performance of the HMA overlay (Hoerner et al., 2001). Small pieces generally reduce the likelihood of reflective cracking in the HMA overlay due to reduced horizontal thermal movements in the fractured layer. At the same time, a breaking or cracking concrete into smaller pieces produces an inherently weaker fractured layer (Ceylan et al., 2005). This places greater emphasis on the structural support from the underlying layers or may require a thicker, costlier overlay to meet the structural requirements of the rehabilitated pavement.

d. For crack-and-seat, broken pieces are limited to a maximum nominal diameter of 3 feet (0.9 m). For break-and-seat, 80 percent of fractured pieces must have a diameter smaller than 2 feet (0.6 m) with no pieces larger than 2.5 feet (0.8 m). These recommended values are variable based on the quality of the subgrade and base materials, and other factors. With regard to dimensions, several studies have recommended that broken/cracked pieces be nearly equal in length and width, or that the length be slightly greater than the width (Hoerner et al., 2001).

e. NDT testing of break/crack-and-seat airfield and highway pavements indicates that the range of back-calculated elastic moduli range from a few hundred thousand psi to a few million psi (National Asphalt Pavement

Association [NAPA], 1994). Similar testing of a crack-and-seat pavement at Hunter Army Airfield in Georgia yielded an average modulus of 590,750 psi (4,073 MPa) for the 6-inch (150-mm) fractured PCC layer (Buncher et al., 2008).

f. The Mechanistic Empirical Pavement Design Guide (MEPDG) produced under National Cooperative Highway Research Program (NCHRP) Project 1-37A recommends the design moduli (E_{fs}) shown below for break/crack-and-seat layers (ARA-ERES, 2004) based on a 75% reliability level. The MEPDG states that the values given for Level 3 are conservative and not for break-and-seat unless ensuring full debonding of PCC from reinforcing steel (ARA-ERES, 2004).

6-3.1.1 High-Level (Level 1) Design Analysis.

- Good to excellent slab fracture control expected (COV=25%): Efs = 600,000 psi (4,137 MPa)
- Fair to good slab fracture control expected (COV=40%): Efs = 450,000 psi (3,103 MPa)
- Poor to fair slab fracture control expected (COV=60%): Efs = 300,000 psi (2,069 MPa)

6-3.1.2 Low-Level (Level 3) Design Analysis.

- 12-in crack spacing: Efs = 200,000 psi (1,379 MPa)
- 24-in crack spacing: Efs = 250,000 psi (1,724 MPa)
- 36-in crack spacing: Efs = 300,000 psi (2,069 MPa)

For HMA overlay design using the layered elastic design (LED) procedure, use the MEPDG Level 3 moduli above as minimum values, with adjustments made upward based on the expected quality control of the cracking operation, as shown in Table 6-1.

Table 6-1 Recommended Elastic Moduli for Cracked and Seated PCC Layers

	Modulus for Various Levels of Expected Slab Fracture Control		
	Poor to Fair	Fair to Good	Good to Excellent
12 inches (300 mm)	200,000 psi (1,379 MPa)	300,000 psi (2,069 MPa)	400,000 psi (2,758 MPa)
24 inches (600 mm)	250,000 psi (1,724 MPa)	375,000 psi (2,586 MPa)	500,000 psi (3,448 MPa)
36 inches (900 mm)	300,000 psi (2,069 MPa)	450,000 psi (3,103 MPa)	600,000 psi (4,137 MPa)

For HMA overlay design using the CBR procedure, use CBR equivalency factors (i.e., thickness equivalent ratios of an unbound base or subbase material) for the fractured PCC layer. Equivalency factors between 1.2 and 1.6 are reasonable maximum values, with the lower end representative of shorter crack spacing and lower fracture control and the upper end representative of longer crack spacing and greater fracture control.

The minimum recommended HMA overlay thickness for a crack-and-seat project is 4 inches (100 mm). The use of a reinforcing fabric or SAMI following placement of the first lift of HMA (leveling layer) delays reflective cracking. Considered for use if representative data are available to show their cost-effectiveness. The HMA material recommended for use in a break/crack-and-seat project is a standard dense-graded asphalt mixture, conforming to UFGS 32 12 15.13 for airfield pavement applications or UFGS 32 12 16.16 for roadway pavement applications.

A final consideration in the design of break/crack-and-seat projects is subsurface drainage. The installation of edge drains is highly recommended where drainage problems exist. Thus, if pavement condition or evaluation data indicate serious moisture-related issues and the existing pavement is either not equipped with a drainage system or has an ineffective system, it is strongly recommended that a new system be installed. A properly installed and maintained retrofit drainage system can play an important role in achieving the intended design life of the HMA overlay (ARA-ERES, 2004).

6-3.2 Rubblization and Overlay.

As with overlay structural design for broken/cracked-and-seated PCC, the structural response characteristics of the rubblized layer is an important parameter in determining the thickness of the overlay. Rubblized layer characteristics are unknown at the time of design. Directly test the rubblized layer after rubblization is complete and the first lift of HMA placed. Make initial estimates using the best information available.

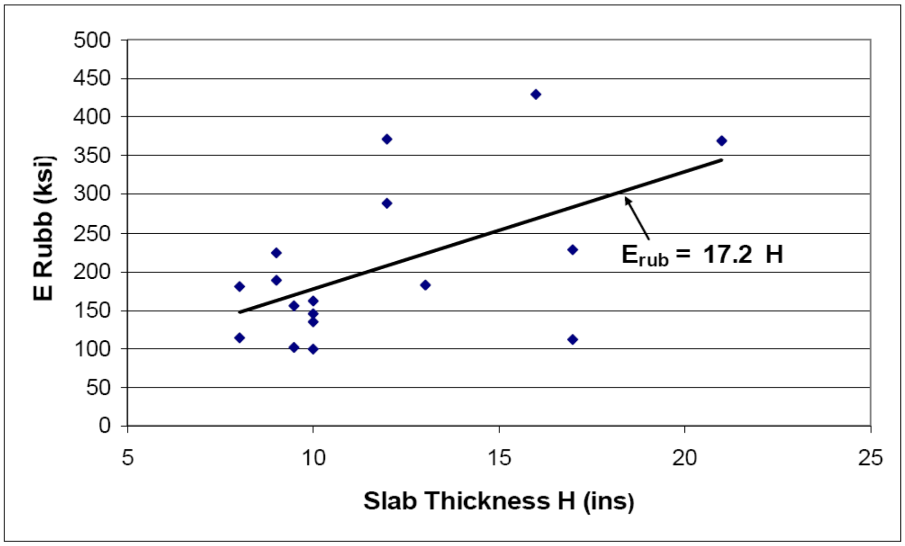
AAPTP Project 04-01, *Development of Guidelines for Rubblization*, is a comprehensive assessment on the rehabilitation of airfield pavements using rubblization. This report includes a very detailed assessment of back-calculated rubblized PCC moduli compiled from numerous studies and projects sponsored by agencies including USACE, FAA, Asphalt Institute, NAPA, FHWA, SHRP, airport authorities, state DOTs, and rubblization equipment manufacturers. Although it was acknowledged that various factors have an impact on the effective modulus of rubblized PCC (e.g., thicker slabs generally result in larger rubblized particles), results of the assessment indicated a general relationship between the modulus (E_{rub}) and slab thickness. Figure 6-1 shows this relationship. There is considerable scatter of the data points in the figure, and this sheds some concern as to its validity.

Combining this relationship with recommended moduli ranges given in the Asphalt Institute Manual Series No. 17, FAA *Engineering Brief No. 66* , American Association of State Highway and Transportation Officials (AASHTO) MEPDG, and other sources, the following ranges are recommended as design modulus values for rubblized PCC on airfield pavements (Buncher et al., 2008):

- For slabs 6 to 8 inches (150 to 200 mm) thick: moduli from 100,000 to 135,000 psi (690 to 931 MPa).

- For slabs 8 to 14 inches (200 to 350 mm) thick: moduli from 135,000 to 235,000 psi (931 to 1,620 MPa).
- For slabs >14 inches (>350 mm) thick: moduli from 235,000 to 400,000 psi (1,620 to 2,758 MPa).

Figure 6-1 Average Initial Modulus Versus Slab Thickness*



*Source: Buncher et al., 2008.

These moduli are substantially higher than that of crushed aggregate base (50,000 to 60,000 psi [345 to 414 MPa]) and are comparable to that of an asphalt-treated base (150,000 to 400,000 psi [1,034 to 2,758 MPa]). They are suitable for determining HMA overlay thickness when using LED procedures, including PCASE.

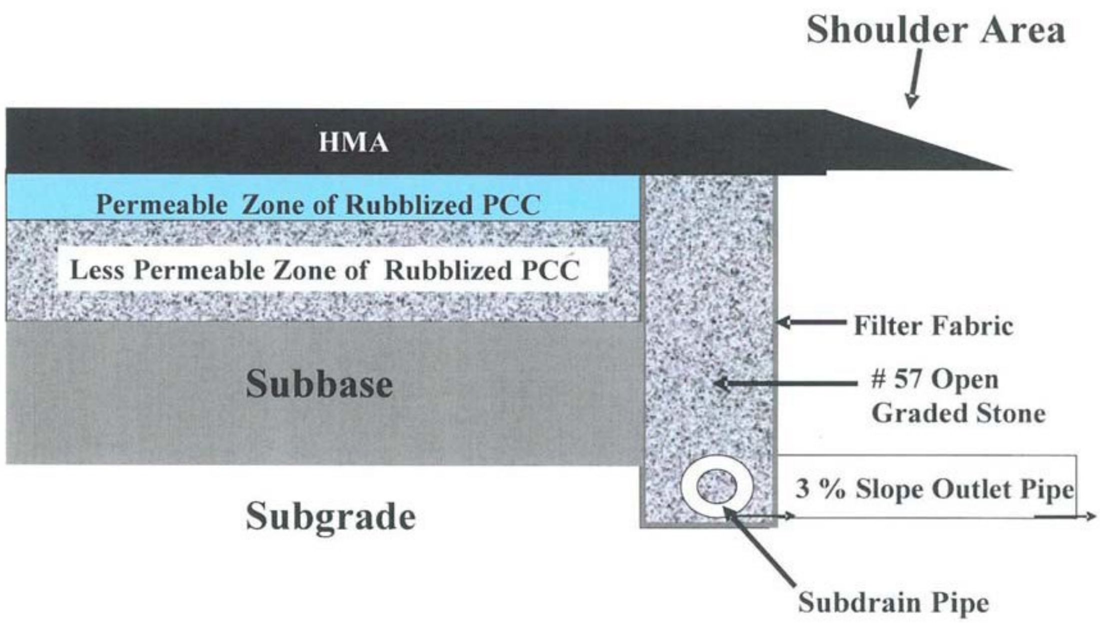
AAPTP Project 04-01 states that characterizing rubblized concrete as simply a crushed stone base layer with CBR = 100 is too conservative. The recommended method is to characterize the rubblized layer as a stronger material by using the following equivalency factors (EF) to convert the thickness of the rubblized layer to an "equivalent" thickness of crushed stone base:

- For rubblized layers 6 to 8 inches (150 to 200 mm) thick: EF = 1.2.
- For rubblized layers 8 to 14 inches (200 to 350 mm) thick: EF = 1.4.
- For rubblized layers >14 inches (>350 mm) thick: EF = 1.6.

The minimum recommended thickness of HMA overlay on a rubblized layer is 5 inches (125 mm) (Buncher et al., 2008). At least two lifts of HMA are necessary to meet grading and smoothness requirements. The minimum thickness of the first lift over the rubblized layer is 3 inches (75 mm) to prevent slippage at the interface between the HMA and the rubblized surface during compaction.

The issue of subsurface drainage is critical to the success of rubblization projects. Not only is it important in terms of the overall long-term performance of the pavement, but it can significantly affect the desired characteristics and long-term performance of the rubblized layer. A properly designed and installed edge drain system (Figure 6-2) facilitates the rubblization process by draining free water from the system, thereby yielding a stable platform for rubblizing the PCC.

Figure 6-2 Typical Longitudinal Edge Drain System for Rubblized PCC



6-3.3 Application.

When installing retrofit drains in conjunction with HMA overlays of fractured PCC slabs, consider the potential for fines generated during the slab fracturing process (particularly during rubblization) to clog the edge drain system. Carefully evaluate the potential for clogging. Choose the components of the drainage system to ensure the functionality of the drainage system. Further, since the slab fracturing process provides an open graded system, design the installed drains with adequate hydraulic capacity to handle the potential quantities of outflow. AASHTO MEPDG (ARA-ERES, 2004) provides additional guidance on edge drain systems for both break/crack-and-seat and rubblization projects.

6-3.4 RCA Applications.

Crush RCA and process to any desired grading (Saeed et al., 2006) to satisfy the intended application (unbound granular layer, lean concrete base, new PCC, etc.). Typical engineering and mechanical properties of RCA as compared to virgin aggregate materials are summarized in Table 6-2 (C). As can be seen, RCA possesses somewhat different properties than conventional virgin aggregates. Additionally, RCA typically has a lower dry density and higher optimum moisture content than virgin aggregate materials.

Table 6-2 Comparison of Typical Virgin Aggregate and RCA Properties[7]

Aggregate Property	Virgin Aggregate	RCA
Particle Shape and Texture	Well rounded, smooth (gravels) to angular and rough (crushed stone)	Angular with rough surface
Absorption Capacity, %	0.8 to 3.7	3.7 to 8.7
Specific Gravity	2.4 to 2.9	2.1 to 2.4
LA Abrasion Test Mass Loss, %	15 to 30	20 to 45
Sodium Sulfate Soundness Mass Loss, %	7 to 21	18 to 59
Magnesium Sulfate Soundness Mass Loss, %	4 to 7	1 to 9
Chloride Content, lb/yd^3 (kg/m^3)	0.00 to 2.03 (0.00 to 1.20)	1.01 to 12.00 (0.59 to 7.09)
California Bearing Ratio (CBR), %	25 to 100[a]	94 to 184[b]

[a]Typical CBR of crushed limestone is 100.

[b]Measured in lab to be up to 184, but set limit at 100 (UFC 3-250-01, UFC 3-260-02).

6-3.4.2 RCA as Unbound Base/Subbase Layer.

6-3.4.2.1 Mix Design.

UFGS 32 11 23 details the requirements for use of RCA (and other types of aggregate) as a base course in flexible pavements. Two different applications are covered, the first being an aggregate base course (ABC) having a CBR of 80 percent and the second being a graded-crushed aggregate (GCA) base course having a CBR of 100 percent.

In addition to meeting CBR, gradation, and density requirements, RCA under this specification requires the following:

- The subgrade soil contains less than 0.3 percent of sulfates to prevent expansive ettringite reaction with the RCA.
- The RCA material experience no greater than 0.08 percent expansion when tested for aggregate-alkali reactivity under ASTM C 1260 *Standard Test Method for Potential Alkali Reactivity of Aggregates (*mortar-bar method).

[7]Hoerner et al., 2001; Saeed et al., 2006.

RCA must meet all the same requirements as natural aggregates per UFGS 32 11 23.

Comparing these requirements with the typical values shown in Table 6-2, shows that abrasion resistance and soundness (sodium sulfate, in particular) are potential issues for RCA when it used as GCA base course in flexible pavements.

UFGS 32 11 20 details the requirements for use of RCA (and other types of aggregate) as a base course in rigid pavements (airfield and roadway) or as a subbase course in flexible pavements (airfield and roadway). In addition to meeting respective gradation requirements for subbase for flexible pavement, the combined aggregate must also meet the requirements for CBR equal to or larger than 50 and LA abrasion equal to or less than 50.

6-3.4.2.2 Structural Design.

The structural design of flexible pavements using RCA as an unbound granular base/subbase layer requires either a CBR or resilient modulus estimate for the subject layer. As shown previously in Table 6-2, RCA material generally exhibits CBR values between 94 and 184 that is considerable higher than crushed stone. Based on the design guides for flexible pavements (UFC 3-260-02 and UFC 3-250-01), the CBR used for base course is limited to 100 and the CBR for subbase is limited to 50.

For flexible or rigid pavement design using LED procedures in PCASE, the following relationship developed by the Transport Research Laboratory (TRL) can be used to convert CBR values to resilient modulus (psi) (ARA-ERES, 2004):

Equation 6-1. Conversion of CBR Values to Resilient Moduli

$$M_r = 2{,}555 \times (CBR)^{0.64}$$

This equation yields modulus values between 31,240 and 48,685 psi (215 and 336 MPa) for CBR values of 50 to 100 percent. Use higher modulus values (up to 70,000 psi [483 MPa]) if supported by actual test data.

For Westergaard design of rigid pavements using modulus of subgrade reaction, k, the design k-value is that effective on top of the aggregate base layer (UFC 3-260-02 for airfields; UFC 3-250-01 for roads). Derive this value using various relationships established between field plate-bearing tests performed on the subgrade (i.e., subgrade k-values) and the design thickness of the base layer (minimum of 4 to 6 inches [100 to 150 mm]). These relationships are valid for RCA base layer applications.

6-3.4.3 RCA in PCC (and Lean Concrete Base).

The following discussion focuses on new concrete mixes using RCA as aggregate for use in surface courses. Although some differences exist, the information and guidelines presented are generally applicable to RCA used in lean concrete base mixes.

6-3.4.3.1 Mix Design.

Ensure that the RCA meets the specification for aggregates. Additionally, if the original pavement being recycled is D-cracked, then crush the concrete to a maximum size of 0.75 inches (19 mm). Prohibit RCA exhibiting ASR in any airfield pavement structure.

Table 6-3 lists the effects that RCA has on PCC properties when used as the aggregate for the mix. In general, if only the coarse portion of RCA is used in the new mix, no significant changes are necessary in the mix design and workability should be unaffected (Hoerner et al., 2001). However, if recycled fines are used, the resulting mix can have reduced workability due to the highly angular nature of the recycled fines, and the mix can have a lower compressive strength due to higher water/cement ratio (greater demand for water caused by the higher absorption capacity of the recycled fines). Eliminate these problems by limiting the percentage of RCA fines to 20 percent and using natural sand for the remaining percentage.

Table 6-3 Effects of RCA on Properties of New Concrete[8]

Property	Range of Expected Changes from Similar Mixtures using Virgin Aggregates	
	Coarse RCA Only	**Coarse and Fine RCA**
Fresh Concrete Properties		
Water Demand	greater	much greater
Drying Shrinkage	20 to 50% more	70 to 100% more
Finishability	more difficult	more difficult
Mechanical Properties of Hardened Concrete		
Compressive Strength	5 to 24% less	15 to 40% less
Flexural Strength[a]	8% less	>8% less
Strength Variation	slightly greater	slightly greater
Modulus of Elasticity	10 to 33% less	25 to 40% less
Creep	30 to 60% greater	30 to 60% greater
Tensile Strength	10% less	10 to 20% less
Permeability	200 to 500% greater	200 to 500% greater
Specific Gravity	5 to 10% lower	5 to 10% lower

[a]From Hoerner et al., 2001. Assumes same water/cement ratio as conventional PCC.

[8]FHWA, 2007.

Other mix design considerations include:

- Crushing operations that are more effective at removing mortar from aggregate are desirable from the standpoint that the resulting RCA material performs more like a natural aggregate (Sturtevant et al., 2007).
- The higher mortar contents of RCA PCC mixes and the lower amounts of natural aggregate result in an increased coefficient of thermal expansion and a higher level of drying shrinkage. To reduce the potential for cracking due to drying shrinkage, shorter slab lengths (<18 feet [<5.5 m]) are used when using RCA PCC mixes (Sturtevant et al., 2007).
- Keep RCA material in a moistened state to help maintain uniformity of absorbed water during PCC production (FHWA, 2007).
- Where D-cracked pavement requires that the top size of RCA be reduced to 0.75 inches (19 mm), it is recommended that only short-jointed JPCP be constructed with this type of aggregate and that dowels be included at transverse joints (Hoerner et al., 2001). This reduces the potential for faulting and spalling at joints due to poorer aggregate interlock. As an alternative, supplement RCA with virgin aggregate with a larger maximum size.
- For applications involving ASR-infected RCA, employ proper ASR mitigation techniques, such as mandatory use of low alkali cement, use of Class F fly ash (25 to 30 percent) or ground granulated blast-furnace (GGBF) slag (40 to 50 percent), or blending of RCA with natural aggregates (HQUSACE, 2006; Sturtevant et al., 2007). Consider alkalis from deicing salts within the RCA.

6-3.4.3.2 Structural Design.

The structural design of PCC pavements using RCA is covered by UFC 3-260-02 and UFC 3-250-01. In addition to possible slab length reductions to prevent shrinkage cracking, the pavement designer must account for expected reductions in both the strength and modulus of elasticity of the RCA PCC. As seen in Table 6-3, these reductions depend significantly on whether only the coarse portion of RCA is included in the mix or both coarse and fine portions are included.

The lower effective modulus of the RCA reduces the modulus of elasticity for RCA PCC (Hoerner et al., 2001). The decreased compressive and flexural strengths of RCA PCC are primarily due to the following (Hoerner et al., 2001):

- Inherently weaker structure of the RCA (due to its cement paste–aggregate structure).
- Greater porosity of RCA PCC, due to the presence of the porous mortar component.

- Greater number of bonded interfaces in RCA PCC (i.e., between natural aggregate and the mortar [both old and new] and between the new and old mortars).
- Lower resistance of RCA concrete to mechanical action.

6-4 CONSTRUCTION.

This section describes the construction processes of each PCC recycling method. The following documents provide guide specifications covering the use of RCA in subbase and base layers or as aggregate in new PCC or lean concrete base mixtures:

- UFGS 32 11 20
- UFGS 32 11 23
- UFGS 32 11 36.13
- UFGS 32 13 14.13
- UFGS 32 13 13.06

TSPWG M 3-250-04.06-2 and 07-6 provide additional guidance concerning the use of PCC recycling methods when ASR is present in the existing PCC pavement.

6-4.1 Break/Crack-and-Seat and Overlay.

The major steps in performing rehabilitation via the break/crack-and-seat and overlay method are as follows (modified from Thompson, 1989):

1. Remove any existing HMA surfacing.
2. Isolate adjacent pavements.
3. Break/crack the existing PCC slabs.
4. Seat the fractured PCC pieces.
5. Apply special treatments.
6. Construct the HMA or PCC overlay (HMA leveling layer required for PCC overlays).

6-4.1.1 Step 1—Remove Existing HMA Surfacing.

In the case of breaking/cracking and seating of composite HMA/PCC pavements, remove the HMA surface layer for better efficiency and control of the slab fracturing process. The softer HMA layer may dissipate facture energy and slow the fracturing operation. Remove any HMA patches and any existing sealant and incompressible materials from joint reservoirs.

6-4.1.2 Step 2—Isolate Adjacent Pavement.

Prior to commencing with break/crack-and-seat operations, isolate adjacent pavement sections not subject to the fracturing work with full-depth saw cuts to prevent damage. All load-transfer devices (dowel bars, tie bars) between the pavement planned for fracturing and the adjacent pavement sections must be fully severed. At the same time, make transverse saw cuts at regular intervals along each fracture slab to ensure breakage of the reinforcing steel and disrupt continuity.

6-4.1.3 Step 3—PCC Slab Breaking/Cracking.

The purpose of slab breaking/cracking is to reduce existing PCC slabs into segments small enough to reduce movements caused by thermal stresses, yet segments are large enough to maintain structural stability (Hoerner et al., 2001). To achieve optimum success, the cracking must extend fully through the slab. In the case of JRCP, rupture/ shear the reinforcing steel at the pavement breaks and debond the concrete from the steel. To ensure that JRCP slabs are broken to size, the typical breaking pattern is somewhat smaller (nominal 1.5 to 2 feet [0.5 to 0.6 m]) than the pattern for crack-and-seat (nominal 2 to 4 feet [0.6 to 1.2 m]) (Morian et al, 2006). In addition, a significantly higher level of energy is required with breaking compared to cracking.

Various types of equipment are available for breaking/cracking PCC pavements, including impact hammers, gravity-drop hammers (Figure 6-3), guillotine hammers (Figure 6-4), and pile hammers (Figure 6-5). As Table 6-4 shows, some pieces of equipment are more suited for breaking operations than cracking operations. The effectiveness and production rates of breaking/cracking operations are highly dependent upon the equipment type and pavement thickness and other factors, such as, concrete strength and quality, foundation support conditions, presence and amount of reinforcing steel, and slab temperature.

Figure 6-3 Single-Head Hydraulic Drop Hammer*

*Source: Arrowmaster.

Figure 6-4 Guillotine Hammer

Figure 6-5 Trailer-Mounted Pile Hammer*

*Source: Buncher, et al; TRB Circular No. E-C087.

Table 6-4 Summary of Equipment for Break/Crack-and-Seat Applications[9]

Type of Equipment	Operating Procedure	Manufacturer	Type of Concrete	Advantages/ Disadvantages
Gravity Drop Hammer (single-head)	Operates by lifting a mass mechanically or hydraulically, and then releasing the mass. The impact force is delivered to the pavement through an impact foot.	Arrow-Master 1350T	JPCP and wire mesh-reinforced JRCP	▪ Effective on JRCP ▪ Can develop unusual cracking patterns on JRCP ▪ Several passes required
Gravity Drop Hammer (multi-head)	Same as single-head gravity drop hammers, only multiple hammers equipped on machine	Antigo MHB Badger Breaker®	JPCP and wire mesh-reinforced JRCP	▪ Fairly high productivity ▪ More break-up at surface

Type of Equipment	Operating Procedure	Manufacturer	Type of Concrete	Advantages/ Disadvantages
Guillotine Hammer	JPCP and JRCP	Antigo 8600 Badger Breaker®, Antigo T8600 Badger Breaker®	JPCP and JRCP	▪ Versatile-effective with JPCP and JRCP ▪ Preferred by many agencies ▪ High productivity ▪ Covers full lane width ▪ Impacts adversely affected by uneven PCC surfaces
Impact Hammer	Hydraulic or pneumatic hammer commonly mounted on backhoes or skid steers	Brokk 250 Various skid steer models with hammer attachments	JPCP	▪ Low productivity ▪ Less effective on thicker PCC ▪ Typically used for localized removal of pavement
Pile Hammer (i.e., modified pile-driver)	Trailer-mounted diesel hammers		JRCP	▪ Covers full lane width ▪ Low productivity

[a]Breaking width = 8 feet (2.4 m)

Successful breaking/cracking largely depends on the equipment and the type and thickness of the pavement. The most common fracturing device, the guillotine hammer (Figure 6-4), typically requires one or two passes to break/crack the full width of a 12-ft or 12.5-ft (3.7- to 3.8-m) wide slab. Other breakers such as pile hammers and hydraulic drop hammers require multiple passes to deliver the grid pattern of strikes on the pavement. A test strip will define the desired breaking/cracking process (see the QC/QA section later in this chapter).

6-4.1.4 Step 4—Seat the Fractured PCC Pieces.

In the fourth step of the break/crack-and-seat technique, seat the PCC pieces with rolling equipment to ensure they are in contact with the supporting layer and achieve a relatively uniform grade for subsequent paving operations (Thompson, 1989; Freeman, 2002). During this process, identify unstable or soft areas (rocking or deflecting pieces) for appropriate action under Step 5.

[9]Hoerner et al, 2001; Antigo, 2009; Thompson, 2006.

Seating uses a heavy pneumatic-tire roller that “massages” each PCC piece into the foundation, while maintaining aggregate interlock (Hoerner et al., 2001). Steel-wheel static and vibratory rollers are generally not appropriate, as they tend to bridge over the high spots on the fractured PCC surface. Good results have been obtained with two passes of a 50-ton (45.4-metric ton) pneumatic roller for crack-and-seat operations and a minimum of five passes of the same equipment for break-and-seat operations. Employ additional passes for the latter since the slabs in the break-and-seat applications more thoroughly broken. For thin pavements on a weak foundation, use more passes (3 to 7) with a lighter roller (30 to 35 tons [27.2 to 31.8 metric tons]) (Buncher et al., 2008).

Avoid excessive rolling and rolling on wet subgrade. Excessive rolling breaks down the aggregate interlock between slab segments and overstress the foundational layers, leading to excessive deflection. Rolling in wet conditions causes non-uniform or excessive deformation of the fractured slabs. It can in turn result in some mixing of the subgrade and base, ultimately reducing the structural capacity of the final pavement.

6-4.1.5 Step 5—Apply Special Treatments.

The fifth step involves final preparations to the broken/cracked-and-seated pavement prior to placement of the HMA overlay. Repair or stabilize weak areas, punch-throughs, and shift-prone pieces detected during seating operations by surface patching or removal and replacement with HMA. Clear or sweep all sizeable loose debris atop the fractured pavement surface (Thompson, 1989). On projects designed to include a new edge drain system, install all system components (longitudinal edge drain, lateral outlets, etc.) as part of this step. Install underdrains at least two weeks prior to the cracking process.

6-4.1.6 Step 6—Construct HMA or PCC Overlay.

The sixth and final step is placement of the HMA or unbonded PCC overlay. Conventional construction procedures are used in this step, beginning with the application of a bituminous tack coat (0.07 to 0.10 gal/yd^2 [0.32 to 0.45 L/m^2] application rate) for use with an HMA overlay or an HMA leveling or bond breaker course (1 to 2 inches [25 to 50 mm] thick) for use with an unbonded PCC overlay.

To avoid incremental cracking of partial overlays carrying construction or other forms of traffic, it is recommended that the full HMA overlay thickness be placed promptly after application of the tack coat and the installation of edge drains (Thompson, 1989). For projects designed to include reinforcing fabric or a SAMI as part of the HMA overlay, apply the material at the specified location within the HMA paving layers.

6-4.2 Rubblization and Overlay.

The construction process for rubblization and overlay is similar to that of break/crack-and-seat and overlay. Installing a longitudinal edge drain system is the primary exceptions and fracturing the existing pavement into smaller sizes requires more time. In addition, the type of rolling equipment used to seat the rubblized layer may differ.

Rubblization and overlay consists of the following major steps (AI, 2000; Thompson, 2006; Buncher and Jones, 2006; Buncher et al. 2008):

1. Remove any existing asphalt surfacing.
2. Install drainage system (if specified).
3. Isolate adjacent pavement.
4. Rubblize PCC pavement.
5. Roll rubblized PCC.
6. Construct the HMA or PCC overlay.

6-4.2.1 Step 1—Remove Existing Asphalt Surfacing.

When rubblizing composite HMA/PCC pavements, first remove the HMA surfacing layers to allow application of the optimal amount of energy. Remove any HMA patches.

6-4.2.2 Step 2—Install Drainage System (If Specified).

On projects designed to include an edge drain system, install all system components including longitudinal edge drains and lateral outlets as part of this step. Ensure the installed drainage system is properly functioning for a minimum of 2 weeks prior to rubblization activities.

If no edge drains are specified, remove shoulders to the level of the PCC pavement base to allow water to drain from problem areas.

6-4.2.3 Step 3—Isolate Adjacent Pavement.

To prevent damage, isolate adjacent pavement sections that are not subject to the fracturing work with full depth saw cuts. Fully sever all load-transfer devices between the rubblized pavement and the adjacent pavement sections severed prior to rubblization.

6-4.2.4 Step 4—PCC Slab Rubblization.

Rubblization fractures existing PCC into small aggregate-sized pieces to eliminate the underlying slab integrity and movement that cause reflection cracking in HMA overlays. As with break/crack-and-seat operations, the cracking must extend fully through the slab and, in the case of JRCP and CRCP, debond the concrete from the reinforcing steel to achieve optimum success.

Rubblization is performed using two different types of equipment—the resonant pavement breaker (RPB) and the multi-head breaker (MHB). The RPB (Figure 6-6) typically applies a 2,000-lb (8,900-N) impact force at a frequency of 44 impacts/sec to the pavement surface through a breaking shoe attached to a massive steel beam (Hoerner et al., 2001). The vibrating beam acts like a “giant tuning fork,” shattering the pavement in narrow strips (6 to 12 inches [150 to 300 mm]) as the machine moves forward along the unfractured edge of the existing pavement (Buncher and Jones, 2006). The impact loads delivered through the shoe, induce diagonal cracks that extend the depth of the PCC slab, as illustrated in Figure 6-7.

The MHB (Figure 6-8) fractures concrete by lifting and dropping rows of steel hammers onto the pavement (Hoerner et al., 2001). The hammers are mounted laterally in pairs, with half the hammers in a forward row and the remainder diagonally offset in a rear row (Thompson, 2006). The MHB is a low-frequency, high-amplitude process (Buncher and Jones, 2006). It produces irregular-shaped PCC pieces, as compared to the highly angular, sheared pieces generated by the RPB.

Table 6-5 provides additional information about each type of equipment. The effectiveness and production rates are highly dependent upon the pavement type and thickness, and foundational support conditions and other factors, such as, concrete strength, presence and amount of reinforcing steel, and slab temperature.

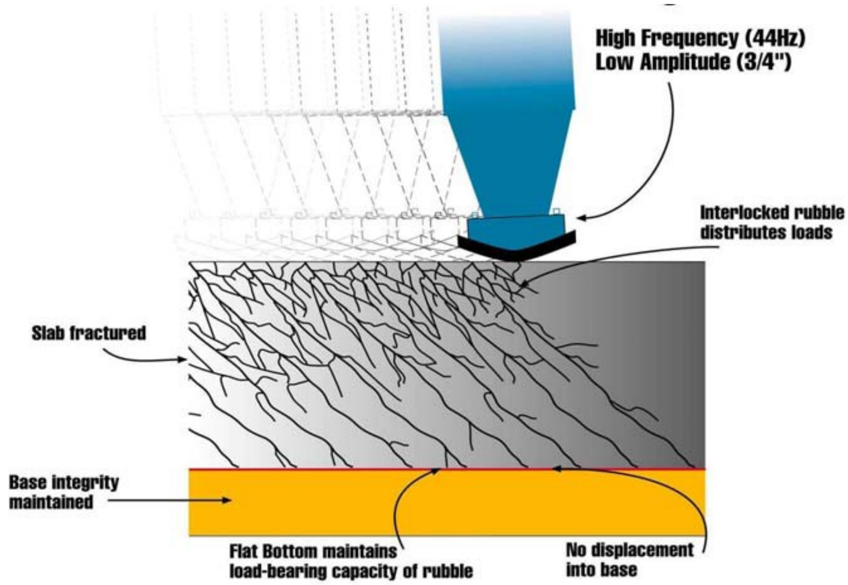
The equipment defines the rubblizing process. RPB rubblization starts at a free or unfractured edge and continues with successive passes until the equipment has moved transversely across the width of the pavement (Buncher and Jones, 2006).

MHB rubblization entails a single pass covering the width of the slab.

Figure 6-6 Rubblization Using RPB*

*Source: Buncher et al, 2008

Figure 6-7 Illustration of Rubblized PCC Using Resonant Breaking Process*



*Source: RMI, 2009.

Figure 6-8 Rubblization Using MHB*

*Source: Thompson, 2006.

Table 6-5 Summary of Pavement Rubblization Equipment[10]

Equipment	Manufacturer	Concrete Type	Advantages/ Disadvantages
Resonant Pavement Breaker (RPB)	RMI™	JPCP, JRCP, CRCP	▪ High degree of angular particle interlock due to diagonal (near 45° angle) fracturing. ▪ Potential for rutting by RPB tires on thin PCC/weak subgrade combinations
Multi-Head Breaker (MHB) (i.e., multi-head gravity drop hammer)	Antigo MHB Badger Breaker®	JPCP, JRCP, CRCP	▪ Equipment operates off of unfractured pavement, thereby minimizing operational problems associated with rubblizing pavements with thin PCC and/or weak foundation ▪ For slabs over 14 inches (350 mm) thick, pre-fracturing using guillotine hammer may be needed

On marginally stable and thin PCC pavements, the rubblization is not always effective. The deficient structural conditions cause problems with achieving full-depth fractures and result in overly large, disoriented PCC segments that make a very rough, uneven surface. In these instances, try a “modified rubblization” technique using the MHB with lowered drop heights and greater separations between impacts (achieved by increasing the equipment speed) (Buncher et al., 2008). Although this process produces larger pieces (nominal 8 to 18 inches [200 to 450 mm]) than specified with conventional rubblization, fracturing is more complete and the pieces remain better oriented for subsequent seating and overlay operations.

Pavements with thickened edges require adjustments to the RPB fracture energy or to the MHB hammer drop height to achieve the specified fracture size. Upon completion of the rubblization process, cut flush any exposed reinforcing steel at the surface or slightly below the surface, so that subsequent rolling operations are not adversely impacted.

6-4.2.5 Step 5—Roll Rubblized PCC.

In the fifth step, roll the rubblized layer to tighten the surface by seating loose particles and to smooth the surface in preparation for the HMA overlay (Buncher and Jones, 2006). During the rolling process, identify weak or unstable areas by observing significant deflection or settlement and repair by removing and replacing. Such

[10]Hoerner et al, 2001; Antigo, 2009, RMI, 2009; Buncher et al., 2008; Thompson, 2006.

detection is particularly important for MHB rubblization, since the rubblizing machine operates on the non-fractured portion of PCC pavement. With RPB rubblization, some level of detection is possible since the machine operates in a straddle position over the fractured and non-fractured portions of the pavement.

The rubblization equipment used dictates the rolling process. Start with the following standard rolling processes (roller weights as per Buncher and Jones [2006]):

6-4.2.5.1 RPB—Minimum of three passes with a vibratory steel-drum roller (minimum 10 tons [9.1 metric tons]) following completion of step 4.

6-4.2.5.2 MHB—Two passes with Z-grid roller (i.e., a vibratory steel-drum roller with Z-pattern grid on the drum face) (minimum 14 tons [12.7 metric tons]) and one pass with pneumatic-tired roller (25 tons [22.7 metric tons]), following completion of step 4. Immediately prior to HMA overlay, apply one pass with a vibratory steel-drum roller (10 tons [9.1 metric tons]).

Use of the Z-grid roller for MHB applications helps reduce the size of “flaky” particles (Thompson, 2006), leading to a tighter, smoother surface (Figure 6-9).

Figure 6-9 Z-Grid Roller Used on MHB Rubblized Pavement*

*Source: Thompson, 2006.

For the RPB process, apply a limited amount of water to the rubblized layer during the rolling process. The moisture lubricates particle surfaces and facilitates particle orientation (Buncher et al, 2008), leading to a tighter, more interlocked layer.

It is important to avoid excessive rolling and rolling in wet conditions. The former can destroy particle interlock and cause a weakening of the rubblized layer, while the latter can cause non-uniform or excessive deformation of the rubblized layer.

6-4.2.6 Step 6—Construct HMA or PCC Overlay.

The sixth and final step is placing the HMA or PCC overlay. In general, construction of the HMA overlay will proceed in the same manner as for a new or reconstructed HMA pavement structure. Two key exceptions are as follows:

6-4.2.6.1 Where marginally stable pavements are involved, such as a thin rubblized layer on a weak foundation, or there is difficulty in achieving a relatively smooth rubblized layer, consider applying a minimum 4-in (100-mm) thick aggregate leveling course (Buncher et al., 2008). Such a layer comprised of dense crushed aggregate, RAP, or RCA, provides a more stable and smoother platform for constructing the overlay.

6-4.2.6.2 A tack/prime coat on the rubblized layer is not needed (Buncher et al., 2008). The use or lack of use of a tack/prime coat has not been reported to impact pavement performance (Buncher et al, 2008), and its use increases project costs.

Depending on the overlay thickness and traffic control requirements, place the HMA overlay in two or three lifts (Buncher et al, 2008). Start with a minimum lift thickness of 3 inches (75 mm) for the first lift of HMA to increase the probability of achieving the in-place density requirements (Buncher et al., 2008). Windrow feeding the first lift of HMA is prohibited, due to the risk of disturbing/dislodging particles at the surface of the rubblized layer (Buncher et al., 2008).

If a PCC overlay is used, place a 1 to 2-in (25 to 50-mm) thick HMA leveling course or bond breaker on the rubblized layer.

6-4.3 RCA.

The construction process for RCA recycling involves the following seven steps:

1. Remove any existing asphalt surfacing.
2. Demolish existing PCC pavement.
3. Load and transport PCC material to crushing plant.
4. Crush PCC material.
5. Remove steel.
6. Size the aggregate.
7. Stockpile for use in aggregate subbase, base, lean concrete base, and/or PCC

The following sections review each step and discuss construction considerations for pavements using RCA materials.

6-4.3.1 Step 1—Remove Existing HMA Surface Layer.

Prior to breaking up the existing PCC pavement, remove any HMA patches or HMA surface layers (Hoerner et al., 2001). These materials slow the demolition process and contaminate the RCA material, which is especially important if using RCA in PCC or lean concrete. Although the amount of joint sealant material, if present, in the total volume of concrete rubble is very small, remove it as well.

6-4.3.2 Step 2—Demolish Existing PCC Pavement.

Pavement demolition breaks the PCC pavement into 18- to 24-in (450 to 600 mm) pieces small enough to lift and load into trucks (Hoerner et al., 2001). Typical equipment includes the excavator with ram hoe attachment shown in Figure 6-10. Table 6-6 lists the various types of equipment and their attributes.

Figure 6-10 Excavator W/Hydraulic Impact Hammer (Ram Hoe) Attachment*

*Source: Saeed et al., 2006.

Table 6-6 Summary of Equipment Used for Pavement Demolition[11]

Equipment	Description	Manufacturer	Pavement Type	Advantages/ Disadvantages
Drop Ball	A crane hoists and drops a heavy steel ball (2 to 7 tons [1.8 to 6.3 metric tons) onto pavement.		JPCP, JRCP, CRCP	▪ Not generally recommended because it breaks the pavement into excessively small pieces that are less salvageable

Equipment	Description	Manufacturer	Pavement Type	Advantages/ Disadvantages
Spring-Arm Whip Hammer	Uses a flexible arm made up of leaf springs that increase the velocity of the tool head and insulates the machine from reverse shock.		JPCP	▪ Covers full lane width through arc-like striking pattern ▪ Not particularly effective on thick PCC or on JRCP
Gravity Drop Hammer (single- head)	See Table 6-4	Arrow-Master 1350T	JPCP and wire mesh-reinforced JRCP	▪ Effective on JRCP ▪ Can develop unusual cracking patterns on JRCP ▪ Several passes required
RPB	See Construction-Rubblization section	RMI™ RB600	JPCP, JRCP, CRCP	▪ Rapid process but lower coverage rate (multiple pass) ▪ Good quality control
MHB (i.e., multi-head gravity drop hammer)	See Construction-Rubblization section	Antigo MHB Badger Breaker®	JPCP, JRCP, CRCP	▪ Relatively rapid process with higher coverage rate (single pass) ▪ Good quality control
Impact Hammer (i.e., ram hoe)	Hydraulic or pneumatic hammer commonly mounted on excavators	Brokk 250 Various models with hammer attachments	JPCP	▪ Limited power that can only be used with JPCP ▪ Typically used for localized removal of pavement
Impact Roller	Towed roller with heavy (19,000 to 29,000 lb. [8,597 to 13,122 kg]) cam-shaped drum that delivers impacts to pavement through its rotations	Impact Roller Technology (IRT) Impactor 2000/3000	JPCP and JRCP	▪ Rapid process with high coverage rate ▪ Quality control not as good
Pile Hammer (i.e., modified pile-driver)	See Table 6-4	???	JRCP	▪ Covers full lane width ▪ Low productivity

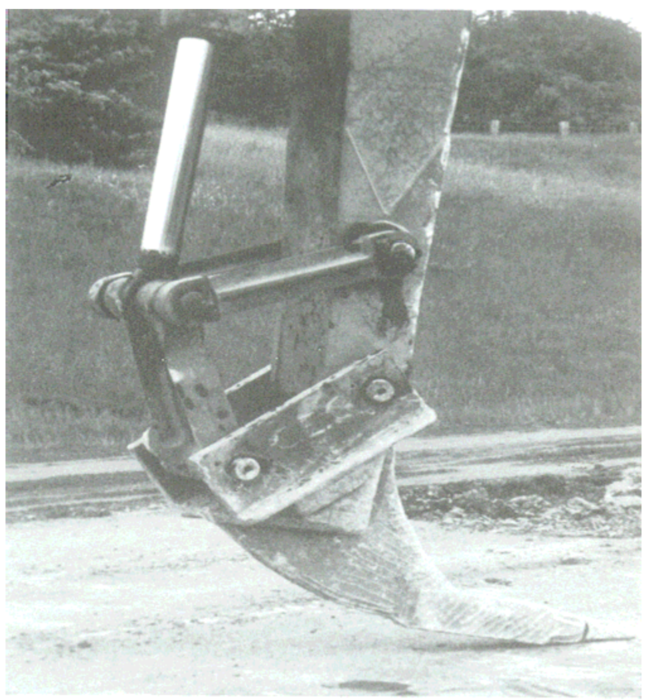
Besides the equipment itself, the most notable factors affecting production are slab thickness, concrete strength, quantity and type of steel reinforcement, and foundation support (Buncher, et al; TRB Circular No. E-C087.). Apply greater impact energy to thicker, stronger, and more heavily reinforced pavements as well as pavements resting on weaker foundations. Some control of the break energy is necessary to minimize damage to the subgrade and any underlying drainage features or utilities and to avoid pushing PCC pieces into the underlying granular layers (Buncher, et al; TRB Circular No. E-C087.). Keep disturbance of the foundation to a minimum.

[11] Hoerner et al., 2001; Antigo, 2009; IRT, 2009.

The breaking operation for CRCP pavement requires breaking rebar free of the concrete and removing prior to loading. Excavators with multi-processor attachments such as pulverizer jaws, shear jaws, and rakes effectively handle rebar as they can easily break concrete away from steel, rake steel from concrete rubble, and cut steel to size. A backhoe or front-end loader equipped with a rhino horn attachment (Figure 6-11) hooks and pulls the steel from the concrete rubble, but is less productive than equipment with multi-processor attachments.

Demolition operation generally severs mesh reinforcement (ACPA 1993). Break pieces too large for the primary crusher with multi-processor attachments or the rhino horn. Dowel bars and tie bars are typically removed during the crushing operation (Hoerner et al., 2001). However, during the demolition many of these pieces are loose and pop out.

Figure 6-11 Close-Up of Rhino Horn Attachment*



*Source: Buncher, et al; TRB Circular No. E-C087.

6-4.3.3 Step 3—Load and Transport PCC Material to Crushing Plant.

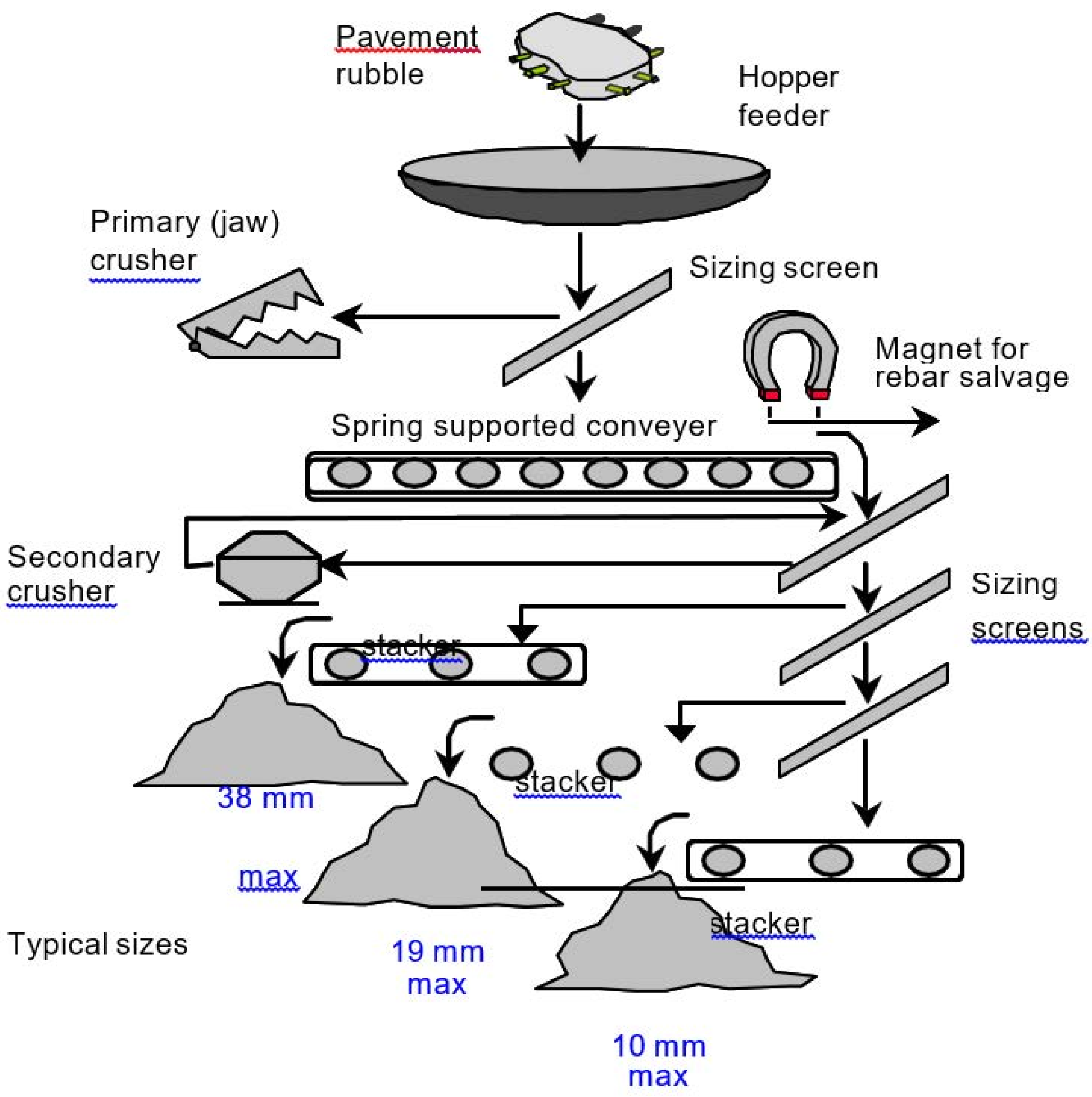
In off-site crushing and processing operations, load pavement rubble into dump trucks using an excavator with a shovel attachment or a front-end loader. Transport the material and stockpile at the crushing plant. During the loading operations, limit the amount of base material scooped up with the PCC rubble. Rubber-tired loaders are better at minimizing base disturbance than tracked loaders (Buncher, et al; TRB Circular No. E-C087.).

On-site crushing and processing operations negates the need for loading and hauling, as the excavators and/or front-end loaders perform the stockpiling work.

6-4.3.4 Steps 4 to7—Crush PCC Material, Remove Steel, Size Aggregate, and Stockpile for Use.

Process pavement rubble at the crushing plant to produce RCA. Figure 6-12 depicts the processes discussed in Steps 4 through 7 of RCA recycling (Hoerner et al., 2001).

Figure 6-12 Illustration of Operation Sequence at a PCC Recycling Plant*



*Source: Hoerner et al., 2001.

In the crushing step, load pavement rubble into a hopper that regulates the flow of the rubble onto the sizing screen (Hoerner et al., 2001). Divert pieces larger than 1 inch (25 mm) to a primary crusher that breaks the concrete away from the reinforcing steel and into pieces of a maximum size of 3 to 4 inches (75 to 100 mm). As the material transfers to a secondary crusher, an electromagnetic separator removes any remaining steel. The secondary crusher further breaks down the PCC material for screening to the desired gradation.

The two basic types of crushers are compression crushers and impact crushers (see Figure 6-13) (Buncher, et al; TRB Circular No. E-C087.). Compression crushers are either jaw or cone designs, and typically serve as the primary crusher. The jaw crusher (see Figure 6-14) provides a cyclic compression force to fracture the PCC while the cone crusher uses an eccentric rotating cone to do the same. The jaw crusher is often preferred as it can handle large PCC pieces. Impact crushers are either vertical or horizontal rotary designs and typically serve as the secondary crusher. These crushers use repeated blows from the rotary blow bars to reduce the size of concrete fragments (Buncher, et al; TRB Circular No. E-C087).

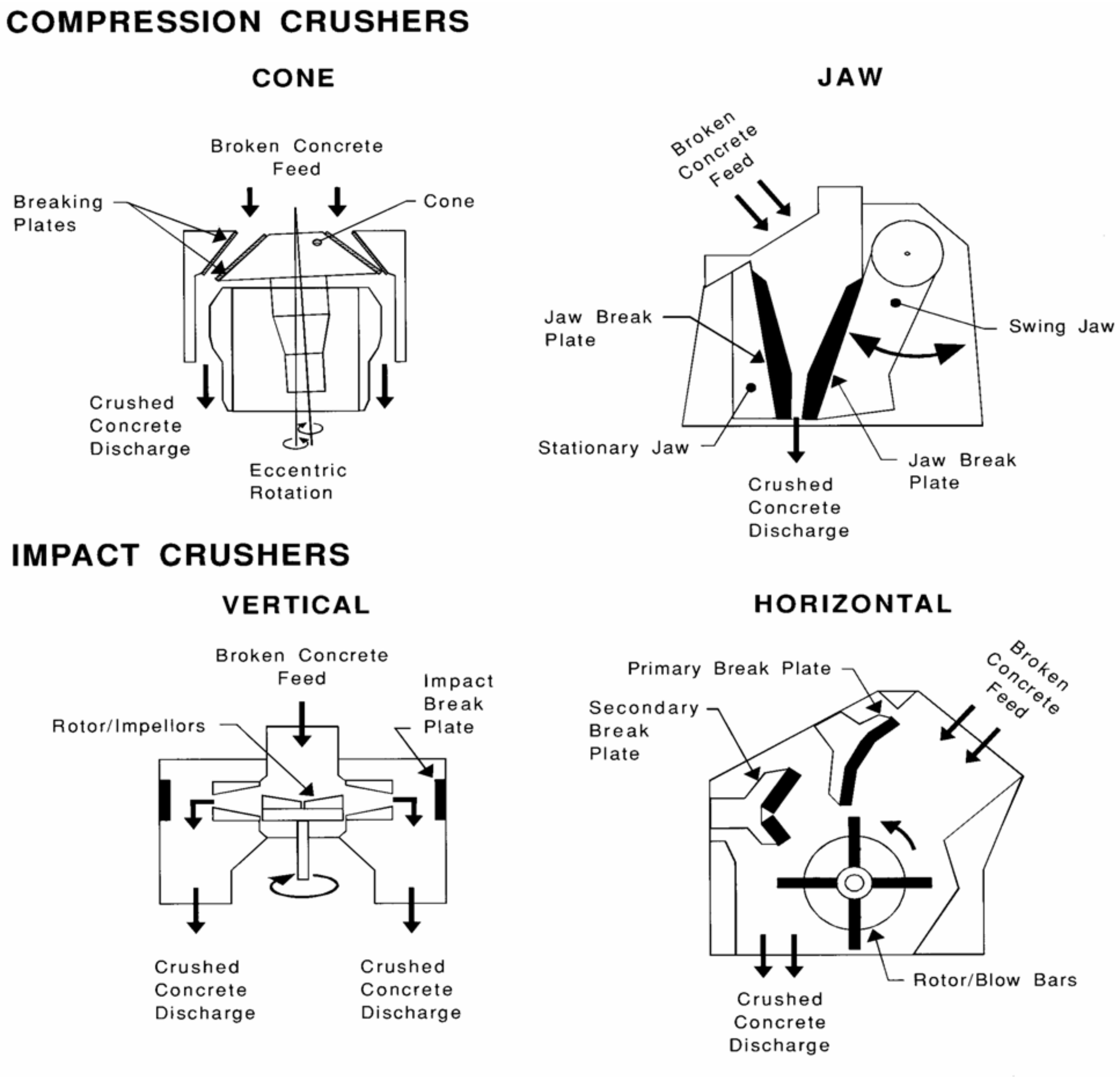
The primary crusher (e.g., jaw crusher) breaks the reinforcing steel from the concrete and reduces the concrete rubble to a maximum size of 3 to 4 inches (75 to 100 mm) (Buncher, et al; TRB Circular No. E-C087). The material processed by the primary crusher discharges onto a conveyor belt and moves to a screening dock. An electromagnetic separator removes virtually all steel present in the crushed material. Secondary crushing further breaks down the RCA for screening to the desired gradation. Pieces larger than the desired max size recirculate through a secondary cone crusher until all material passes through the screening sizes (Hoerner et al., 2001).

Typically, crushing operations yield about 75 percent coarse and 25 percent fine aggregate (Buncher, et al; TRB Circular No. E-C087). The ratio varies depending on the pavement type, broken concrete size, and the crushing plant design. When using RCA in new PCC, adjust the crushing operation to maximize the recovery of coarse aggregate, since the RCA fine aggregate is typically not used or is greatly limited in the new PCC. With a 0.75-inch (19-mm) top size, a coarse aggregate recovery of 55 to 60 percent is typical, while at a 1.5-inch (38-mm) top size, up to 80 percent or more can be recovered (Hoerner, et al., 2001).

6-4.3.5 Construction Considerations for Pavements Utilizing RCA.

Once processed, use the RCA material in an aggregate base or subbase layers or feed into a portable or central-plant mixer to produce lean concrete base material or new PCC. Listed below are several construction considerations for pavements that utilize RCA materials.

Figure 6-13 Types of Crushers used for PCC Recycling*



*Source: Buncher, et al; TRB Circular No. E-C087.

Figure 6-14 Jaw-Type Compression Crusher

6-4.3.5.1 RCA Unbound Base/Subbase.

To prevent segregation problems, use proper stockpiling and spreading techniques. Box spreaders or HMA pavers are preferred over motor graders (Saeed et al., 2006). Avoid excessive working of the RCA base or subbase material.

Ensure RCA base or subbase is in a saturated state to aid in compaction and migration of fines throughout the mix.

Suitable compaction equipment for RCA base and subbase layers includes static and vibratory steel-wheeled rollers and pneumatic-tire rollers.

6-4.3.5.2 RCA Used in New PCC or Lean Concrete Base.

Constructing PCC pavements containing RCA requires no special techniques or paving equipment (Hoerner et al., 2001). Use conventional mix plants, paving equipment, and normal paving and finishing practices.

The use of RCA in new PCC creates problems with mix workability, due to the high absorption capacity of the aggregate and the difficulty in maintaining a consistent and uniform saturated surface dry condition of the RCA. Overcome this problem by keeping stockpiles moist and by frequently testing aggregate for moisture content.

6-5 QUALITY CONTROL/QUALITY ASSURANCE.

6-5.1 Break/Crack-and-Seat.

6-5.1.1 Use a test strip to establish an acceptable breaking/cracking pattern for moderate to high-level projects. Examining the pavement and extracted cores resulting from varying degrees of energy and various strike patterns helps identify the procedure that best meets the design requirements.

6-5.1.2 Check crack patterns created by breaking/cracking operations at least twice a day by wetting the concrete surface with water and observing the appearance of cracks as the surface dries. If adjusting the crack pattern, consider coring to verify the full penetration of cracking.

6-5.1.3 Use NDT equipment to monitor the construction quality of cracking operations. Perform NDT testing on all broken-and-seated concrete to verify destruction of the bond between concrete and reinforcing steel in JRCP. Assure that the back-calculated modulus for broken JRCP (based on NDT performed directly on the fractured layer) is greater than 500,000 psi (3,448 MPa) and less than 1,000,000 psi (6,895 MPa) for 95 percent or more of the project area.

6-5.1.4 In the absence of NDT testing protocols conduct such testing every 500 to 1,000 feet (150 to 300 m) per paving lane with a typical width of 12 ft or 12.5 ft (3.7 or 3.8 m) wide directly on the fractured layer. Also, test that portion of the test strip in which the formal breaking/cracking pattern was established. Use test data to back calculate the elastic moduli for QC/QA purposes.

6-5.1.5 In the event that a break/crack-and-seat project includes an edge drain system, whether pre-existing or retrofit, visually inspect the system outlets for clogging issues. Properly clean and flush any segments with clogging problems.

6-5.2 Rubblization.

6-5.2.1 Use a test strip to optimize equipment operations and establish acceptable rubblizing and rolling practices on moderate to high-level projects. Use a test pit within the test strip to determine if a) the rubblizing procedure is producing pieces of the specified size, b) the fracturing is extending fully through the slab, and c) concrete is debonding from steel reinforcement. Use multiple test strips and test pits on projects with varying pavement structure conditions (Buncher et al., 2008).

6-5.2.2 Typical rubblization criteria are as follows:

- Resonate Pavement Breaker—Break slabs into pieces ranging from sand-sized to 6 inches. Ensure the majority of pieces are between 1 and 3 inches (25 and 75 mm) and ensure no individual piece exceeds 8 inches (200 mm). For JRCP, debond steel from concrete and leave in place and ensure no individual PCC piece exceeds 8 inches (200 mm).

- Multi-Head Breaker—Break slabs into pieces, with sizes in the top half of the slab generally ranging from sand-sized to 3 inches (75 mm) and sizes in the bottom half not exceeding 9 inches (225 mm). For reinforced PCC, debond steel from concrete and leave in place and ensure no individual PCC piece exceeds 9 inches (225 mm).
- Both RPB and MHB—Due to lack of edge support, the maximum size of PCC pieces below steel in reinforced PCC is 12 inches (300 mm).

6-5.2.3 The surface of the rubblized pavement is difficult to test and leads to wide levels of test variability. If the opportunity for NDT testing on a particular project exists, use the equipment on the pre-rubblized pavement to identify potential areas and localized weak spots that affect the rubblization process.

6-5.2.4 In the event that a rubblization project includes an edge drain system, visually inspect the system outlets for clogging. Properly clean and flush any segments with notable clogging problems to restore flow.

6-5.3 RCA Production.

QC/QA of the RCA production process focuses primarily on pavement demolition, the removal of steel and other contaminants, and the proper sizing and stockpiling of RCA material. Key considerations or measures to ensure the production of quality RCA for re-use in pavement structures are as follows:

- Evaluation and testing (ASTM C1260, ASTM C1293, ASTM C1567) of the old concrete is important in determining the severity of aggregate or mix problems, such as D-cracking and ASR.
- Careful monitoring of the pavement demolition operation to minimize the disturbance of the existing base and severely limit the amount of base material removed.
- Ensuring RCA consists of clean, sound, and durable crushed particles and is free of silt, clay, organic matter, AC, steel reinforcement, and other objectionable material (Saeed et al., 2006). While incidental amounts of AC, soil, base aggregates, or joint sealant are allowable for RCA used as unbound base or subbase, much tighter restrictions are necessary for RCA used in new PCC or lean concrete base.
- Monitoring crushing operations to ascertain that the yield of coarse aggregate is sufficient for the intended re-use application. Additionally, in the case of RCA PCC, monitor the amount of mortar retained on the coarse aggregate fraction to minimize the adverse effects of the mortar on PCC performance.
- To avoid segregation of the RCA material, use conveyor belts to create RCA stockpiles and carefully control stockpile heights.

6-5.4 RCA Re-Use.

QC/QA of re-used RCA material entails a variety of laboratory and field tests that are specific to the paving application. See the pertinent UFGS documents for further discussion of these tests. Key material and construction quality parameters are as follows:

6-5.4.1 RCA Base or Subbase.

- UFGS 32 11 20; RCA gradation, abrasion/wear, compaction/density (percent of laboratory maximum dry density), and thickness.
- UFGS 32 11 23: RCA gradation, wear, soundness, shape, angularity, density, and thickness.

6-5.4.2 RCA in Lean Concrete Base.

- UFGS 32 11 36.13: RCA gradation, slump, air content, temperature, compressive strength (7- and 28-day cylinders), and thickness (cores).

6-5.4.3 RCA in New PCC.

- UFGS 32 13 13.06: RCA gradation, workability and coarseness factors, unit weight, temperature, slump, air content, flexural strength (28- or 90-day values converted from compressive strength values on 7-day cylinders or from flexural strength values on 7-day beams), and thickness (cores).
- UFGS 32 13 14.13: RCA gradation, slump, air content, flexural strength (28- and 90-day beams), and thickness (cores).

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APPENDIX A BEST PRACTICES

A-1 RESERVED FOR FUTURE USE.

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APPENDIX B SUPPLEMENTAL RESOURCES

OTHER

A Pocket Guide to Asphalt Pavement Preservation
www.pavementpreservation.org/toolbox/links/PPGuide.pdf

Resonant Machines, Inc. (RMI)
www.resonantmachines.com.

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APPENDIX C GLOSSARY

C-1 ACRONYMS

°C	degree(s) Celsius
°F	degree(s) Fahrenheit
AAPTP	Airfield Asphalt Pavement Technology Program
AASHTO	American Association of State Highway and Transportation Officials
AC	asphalt concrete
ACPA	American Concrete Pavement Association
ARRA	Asphalt Recycling and Reclaiming Association
ARRA	American Recovery and Reinvestment Act
ANG	Air National Guard
ASR	alkali silica reaction
ASTM	American Society for Testing and Materials
CBR	California bearing ratio
CCPR	cold central plant recycling
CIR	cold in-place recycling
CM	cold milling
COV	coefficient of variation
CRCP	continuously reinforced concrete pavement
DCP	dynamic cone penetrometer
DOT	Department of Transportation
EF	equivalency factor
Efs	design moduli for break/crack-and-seat layers
FAA	Federal Aviation Administration
FDR	full-depth reclamation

ft	foot
FHWA	Federal Highway Administration
FOD	foreign object debris
FWD	falling weight deflectometer
g	gram
gal	gallon
GCA	graded-crushed aggregate
GGBF	ground granulated blast furnace
GPR	ground penetrating radar
HFMS	high float medium setting
HMA	hot mix asphalt
HIR	hot in-place recycling
HR	hot recycling
HWD	heavy-weight deflectometer
in.	inch
IPRF	Innovative Pavement Research Foundation
JMF	job mix formula
JPCP	jointed plain concrete pavement
JRCP	jointed reinforced concrete pavement
kg	kilogram
km	kilometer
km/h	kilometer per hour
ksf	thousand square feet
L	liter
L&T	longitudinal and transverse (cracking)

lb	pound
lb/in^2	pound per square inch
LCCA	life cycle cost analysis
LED	layered elastic design
M&R	maintenance and rehabilitation
m	meter
MEPDG	Mechanistic Empirical Pavement Design Guide
MHB	multi-head breaker
mm	millimeter
MPa	megapascal
mph	mile per hour
MTV	material transfer vehicle
N/A	not applicable
NAPA	National Asphalt Pavement Association
NAVFAC	Naval Facilities Command
NCHRP	National Cooperative Highway Research Program
NDT	nondestructive deflection testing
NHI	National Highway Institute
NPW	net present worth
PCASE	Pavement-Transportation Computer Assisted Structural Engineering
PCC	Portland cement concrete
PCI	pavement condition index
PG	performance grade
PI	plasticity index
PIARC	World Road Association (originally “Permanent International Association of Road Congresses”)

PMS	Pavement Management System
POL	petroleum, oil, lubricants
psi	pound per square inch
QA	quality assurance
QC	quality control
RAP	reclaimed asphalt pavement
RAS	reclaimed asphalt shingle
RCA	recycled concrete aggregate
RPB	resonant pavement breaker
SAMI	stress absorbing membrane interlayer
SCI	structural condition Index
SS	slow-setting
TSMCX	Transportation Systems Center
TSPWG	Tri-Service Pavements Working Group
TSR	tensile strength ratio
UFC	Unified Facilities Criteria
UFGS	Unified Facility Guide Specification
U.S.	United States
USACE	United States Army Corps of Engineers
VFA	voids filled with asphalt
VMA	voids in mineral aggregates
VTM	voids total mix
yd	yard

C-2 TERMS

Additive Stabilization: Achieve stabilization by adding the proper percentages of additives to the soil. Select the type and determine the percentage of an additive depends on; the soil classification, amount of deleterious materials, such as, sulfates and organics, and the degree of soil quality improvement desired. Non-traditional additives, such as, polymer, fiber, lignin derivatives, enzymes, acids, etc. are addressed where appropriate. This UFC does not define specific criteria for all additives. Generally, smaller amounts of additives are required when only modifying soil properties, such as, gradation, workability, and plasticity. Obtaining significant strength and durability improvement requires greater quantities of additive. After mixing the additive with the soil at the optimum moisture content, spread and compact by conventional means.

Additives: Manufactured commercial products, when added to the soil in the proper quantities, improve some engineering characteristics of the soil such as strength, texture, workability, and plasticity are termed “traditional” additives and include materials such as lime, cement, fly ash, and asphalt emulsions. “Non-traditional” additives such as polymer emulsions, fiber, lignin derivatives, enzymes, acids, and other materials used to improve soil qualities are newer with little history of use. Additives addressed in this UFC are portland cement, lime, fly ash, bitumen, polymer emulsion, fiber, and select combinations of these.

Durability: Durability refers to the resistance of the soil to weathering, primarily by the action of water and abrasion after wet-dry and freezing and thawing cycles (ASTM D559 and D560).

Mechanical Stabilization: Mechanical stabilization mixes or blend soils of two or more gradations to obtain a material meeting the required specification. Soil blending may take place whenever convenient. Spread and compact the blended material to required densities at the optimum moisture content by conventional means. Compaction and fiber addition are also mechanical stabilization methods. Compaction consists of the mechanical rearrangement of soil particles into a denser configuration, typically resulting in increased strength and/or durability. The addition of fibers into a soil can mechanically stabilize the soil by creating interlock between particles.

Modification: Modification refers to the stabilization process that improves some material property of the soil, such as, the plasticity index (PI) but does not, by design, result in a significant increase in soil strength and durability.

Optimum Moisture Content: The optimum moisture content of soil is the water content, measured as a percentage by unit weight, that achieves the maximum dry unit weight for a given compactive effort. (See ASTM D1557 for further information.) A higher or lower moisture content produces a lower maximum dry unit weight after compaction.

Soils: Soils are naturally occurring materials used for the construction of all layers of concrete and asphalt pavements, except the surface, and is subject to classification tests (ASTM D2487) to provide a general concept of their engineering characteristics.

Stabilization: Stabilization is the process of blending and mixing materials with a soil to improve engineering properties of the soil. The process may include blending soils to achieve a desired gradation or mixing additives to alter the; chemistry, gradation, texture, plasticity, or water absorption or act as a binder for cementation of the soil. Stabilization significantly increases the strength and/or durability of the stabilized material.

Strength: In the context of this UFC, “strength” refers to the unconfined compressive tests measured using ASTM D1633.

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UFC 3-250-11
30 November 2020

UNIFIED FACILITIES CRITERIA (UFC)

SOIL STABILIZATION AND MODIFICATION FOR PAVEMENTS

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

UNIFIED FACILITIES CRITERIA (UFC)

SOIL STABILIZATION AND MODIFICATION FOR PAVEMENTS

U.S. ARMY CORPS OF ENGINEERS (Preparing Activity)

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER CENTER

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

Change No.	Date	Location

This UFC supersedes UFC 3-250-11, *Soil Stabilization for Pavements*, dated January 16, 2004.

FOREWORD

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

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

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

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

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

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UNIFIED FACILITIES CRITERIA (UFC)
REVISION SUMMARY SHEET

Document: UFC 3-250-11, *Soil Stabilization and Modification for Pavements*

Superseding: This UFC supersedes UFC 3-250-11, *Soil Stabilization for Pavements*, dated January 16, 2004.

Description: This UFC documents the standard practice of stabilizing and modifying soil for use in pavement and operating surfaces. It provides guidance for improving the engineering properties of soils used for pavement base courses, subbase courses, and subgrades by the use of additives mixed into the soil to effect the desired improvement. This UFC is also applicable to roads, airfields, and construction platforms having a stabilized surface layer.

Reasons for Document: This update brings the document in compliance with UFC 1-300-01, *Criteria Format Standard*. Editorial changes were made to improve readability, correct typographical errors, and update outdated references.

Impact: Cost impact is negligible; improved guidance typically results in improved performance and reduced lifecycle cost.

Unification Issues: None

CONTENTS

FIGURES

TABLES

CHAPTER 1 INTRODUCTION

1-1 PURPOSE.

This UFC documents the standard practice for improving the engineering properties of soils used for operating surfaces, pavement base courses, subbase courses, and subgrades by the use of additives mixed into the soil to effect the desired improvement. It also provides criteria and guidance for the stabilization and modification of soils for pavements, operating surfaces, and construction platforms. This UFC is also applicable to roads, airfields, and construction platforms having a stabilized surface layer. These soil improvements consist of applying a chemical such as lime, cement, or bitumen to a layer of soil or aggregate that will be included within a pavement area. Stabilization or modification measures discussed herein are useful to limit expansive soil's ability to expand and contract due to changes in moisture content, increase the soil's shear strength to prevent or minimize pumping, or to bind soils or aggregates.

1-2 SCOPE.

This UFC prescribes the appropriate type(s) of additive to be used with different soil types, procedures for determining a design treatment level for each type of additive, and standard construction practices for incorporating the additive into the soil. This UFC provides criteria and guidance on stabilization or modification using portland cement, lime, lime-fly ash, lime-cement-fly ash, bitumen, polymer, lime-cement, lime-bitumen, or geo-synthetic fibers.

1-3 APPLICABILITY.

Soil stabilization and modification are optional. The installation, in conjunction with the designers of record, determines whether to include soil stabilization or modification in the pavement design. Apply the requirements in this UFC when soil stabilization or modification is included in the design. These requirements are dependent upon each individual site's soil conditions.

1-4 USES OF STABILIZATION/MODIFICATION.

Pavement design is based on the premise that the specified structural quality will be achieved for each layer of material in the pavement system. Each layer resists shearing, avoids excessive deflections that cause cracking within the layer or in overlying layers, and prevents excessive permanent deformation. As the quality of a soil layer is increased, the ability of that layer to distribute the load over a greater area is increased so a reduction in the required thickness of the soil and surface layers is achieved.

1-4.1 Quality Improvement.

The most common improvements achieved through stabilization/modification include better soil gradation, reduced plasticity index (PI) or swelling potential, and increased durability and strength. Stabilization may be used to provide a working platform for construction.

1-4.2 Thickness Reduction.

The strength of a soil layer can be improved through the use of additives to permit a reduction in design thickness of the stabilized material compared with an unstabilized or unbound material. Procedures for designing and evaluating pavements that include stabilized soils are presented in UFC 3-250-01, *Paving Design for Roads and Parking Areas*, UFC 3-250-03, *Standard Practice Manual for Flexible Pavements*, and UFC 3-260-02, *Pavement Design for Airfields*. The design thickness of a base or subbase course can be reduced if the stabilized material meets the specified gradation, strength, stability, and durability requirements indicated in this UFC for the particular type of material. See Appendix A for examples of reducing design thickness when using stabilized materials.

1-4.3 Operating Surfaces.

Stabilized materials can be used to construct operating surfaces. These cases are typically for temporary construction platforms, roads, or airfields where poor soils exist and conventional pavements cannot be feasibly constructed. For roads and airfields, adhere to the strength, durability, and construction criteria in this UFC.

1-5 DEFINITIONS.

Appendix B contains a list of acronyms and definitions.

1-6 REFERENCES.

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

CHAPTER 2 SELECTION OF ADDITIVE

2-1 FACTORS TO CONSIDER.

In the selection of a stabilizer, the factors to consider are the type of soil to be stabilized, the purpose for which the stabilized layer will be used, the type of soil improvement desired, the required strength and durability of the stabilized layer, the type and availability of the additive, the cost, and environmental conditions.

2-1.1 Soil Types and Additives.

There may be more than one candidate stabilizer applicable for an individual soil type; however, there are general guidelines that make specific stabilizers more desirable based on soil granularity, plasticity, or texture. Portland cement, for example, is used with a variety of soil types; however, since it is imperative the cement be mixed intimately with the fines fraction (< 0.074 mm), avoid plastic soils unless steps are taken to reduce the plasticity. Generally, well-graded granular materials that possess fines to produce homogenous mixtures are best suited for portland cement stabilization. Lime will react with soils of medium to high plasticity to lower its plasticity, increase workability, reduce swell potential, and increase shear strength. In some cases, adding lime prior to adding soil cement will improve the workability of the soil cement. Lime is used to stabilize a variety of materials, including weak subgrade soils, transforming them into a "working table" or subbase; with marginal granular base materials (i.e., clay-gravels and "dirty" gravels) lime forms a strong, high-quality base course. Fly ash is a pozzolanic material—it reacts with lime and is therefore almost always used in combination with lime in soils that have little or no plastic fines. The use of portland cement with lime and fly ash for added strength is often required. This combination of lime-cement-fly ash (LCF) has been used successfully in base course stabilization. Asphalt, bituminous, or polymer materials are used for waterproofing and gaining strength. Generally, soils suitable for asphalt or polymer stabilization are silty sands and granular materials because thoroughly coating all the soil particles is desirable. Fibers may be used in combination with some additives to improve strength and crack resistance, but they severely limit workability after mixing with soil.

Do not create a solid, rigid, or brittle surface that will lead to reflective cracking of the surface pavement when designing stabilized base and subbase layers for pavements. Each type of stabilization method has limitations and appropriate uses; therefore, create and test a representative mix design for each individual scenario of the planned field operations. Evaluate each stabilized soil layer to establish the appropriate thickness of stabilized soil to prevent undesired effects to the finished pavement surfaces. Include a bond breaker when overlaying a stabilized layer using portland cement.

2-1.1.1 Portland Cement Stabilization.

Cement stabilization utilizes mixing dry portland cement powder into the subbase soils to increase the shear strength within the treated layer. Typically, this is accomplished by using a dosage rate of 3 to 6 percent by weight portland content and mixing it approximately 1 to 2 feet (0.3 to 0.6 m) in depth. These are general estimations; the procedure to determine the dosage rate is described in paragraph 3-1 and its subparagraphs. Use layered elastic pavement design procedures described in UFC 3-260-02 to determine the depths to which mixing must occur.

2-1.1.2 Lime Stabilization or Modification.

Lime modification utilizes mixing dry hydrated lime (powder) or quicklime (granulated) into the subgrade/subbase soils to lower the PI of the soil to control the shrink/swell potential of the soil. Lime stabilization utilizes mixing lime or quicklime into the subgrade, select fill, and or subbase material to increase the pH to generate a pozzolanic reaction that increases the soil's shear strength. This requires fine-grained soils with a minimum fraction of silt and clay to be reactive and is not effective on granular materials. Typically, lime modification is performed on the upper layer of subgrade, select fill, and/or subbase and mixing is approximately 0.75 to 2 feet (0.2 to 0.6 m) in depth**.** These are general estimations; the procedure to determine the dosage rate is described in paragraph 3-2 and its subparagraphs. Use layered elastic pavement design procedures described in UFC 3-260-02 to determine the depths to which mixing must occur.

2-1.1.3 Lime-Fly Ash or Lime-Cement-Fly Ash Stabilization.

Fly ash acts similarly to portland cement and is used to reduce the quantity of lime or portland cement necessary to achieve the desired stabilization/modification effect. Fly ash is a cheaply obtained industrial byproduct used for cost reduction and can stabilize more coarse gradations than lime alone. Fly ash physical and chemical properties can vary widely. Investigate each locally available product for its applicability to the specific project. Additional information is in paragraph 3-3.

2-1.1.4 Bitumen or Polymer Stabilization.

Bitumen and polymer stabilization increases adhesive properties, the shear strength of the soils, and decreases the effects of water on the treated soils. Bitumen and polymers are not effective against freeze-thaw action and testing the durability of the finished product is not possible. Additional information is in paragraph 3-4.

2-1.1.5 Lime-Cement or Lime-Bitumen Stabilization.

A lime-cement and lime-bitumen combination is used primarily when lime is needed to control the shrink/swell potential of soils and the treated soil has a low shear strength. Portland cement-bitumen is used to increase the shear strength to a desired minimum strength. Bitumen and polymers are not effective against freeze-thaw action and testing the durability of the finished product is not possible. Additional information is in paragraph 3-5.

2-1.1.6 Geosynthetic Fiber Stabilization.

Geosynthetic fiber stabilization increases the shear strength of the soils. It is not effective in controlling shrink/swell characteristics of soils. Installation of the fibers can be problematic in the field. It requires material-specific experience and attentive quality control and quality assurance to ensure proper construction. Additional information is in paragraph 3-6.

2-1.2 Screening Tests for Organic Matter and Sulfates.

The presence of organic matter and/or sulfates frequently has deleterious effects on stabilized soil or the additives used, preventing the stabilization process from occurring. Perform testing for detection of these materials if their presence is suspected.

2-1.2.1 Organic Matter.

A soil may be acidic, neutral, or alkaline and still respond well to cement treatment. Although certain types of organic matter, such as undecomposed vegetation, may not adversely influence stabilization, organic materials such as humic acid act as hydration retarders and reduce strength. When such organics are present, they inhibit the normal hardening process. A pH test to determine the presence of organic material is presented in Appendix A. If the pH of a 10:1 mixture (by weight) of soil and cement 15 minutes after mixing is at least 12.0, it is probable that any organics present will not interfere with normal hardening. Refer to ACI 230.1R, *Report on Soil Cement*, for additional guidance. Limit soil organic content to a maximum of 2 percent by weight and a minimum pH of 5.3 or more prior to the addition of soil cement, lime, or fly ash.

2-1.2.2 Sulfates.

Cements in contact with sulfates can generate a reaction that is expansive in nature and can damage aboveground, below ground, and nearby facilities if present with cement, lime, or fly ash-stabilized soils. The resistance to sulfate attack differs for cement-treated coarse-grained and fine-grained soils and is a function of sulfate concentrations. If sulfate concentration exceeds 0.1 percent by weight do not use cement or fly ash stabilization without prior authorization by the Pavements Discipline Working Group (DWG). Use the procedure in Appendix A or the current version of ASTM C1580, *Standard Test Method for Water-Soluble Sulfate in Soil*, to determine the concentrations of sulfate in the existing soil and groundwater. Do not design, specify, construct, or install soil cement, lime, or fly ash for soils containing more than 0.1 percent sulfate.

2-1.3 Traditional Additives.

2-1.3.1 Cement.

Portland cement can be used either to modify and improve the quality of the soil or transform the soil into a cemented mass with increased strength and durability. Cement can be used effectively as a stabilizer for a wide range of materials; however, the soil should have a PI less than 30 or the stabilization effects will be minimal. For coarse-grained soils, the amount passing the No. 4 (4.75 mm) sieve should be greater than 45 percent or the stabilization effects will be minimal. The amount of cement used depends on whether the soil is to be modified or stabilized.

When designing, specifying, or constructing using cement to stabilize base material for support of a rigid pavement, a bond breaker between the pavement concrete and the cement-stabilized base material to prevent adhesion at that interface is required. Adhesion of the concrete pavement to the cement-stabilized base results in unacceptable cracking. An asphalt emulsion bond breaker is not recommended because once the emulsion begins to dry and harden it does not perform as a bond breaker and instead causes further adherence problems. To create a bond break, install a layer of #89 stone meeting ASTM C33, *Standard Specification for Concrete Aggregates*, specifications between 0.25 and 0.5 inches (6.3 and 12.7 mm) in thickness. Then install a fabric meeting the requirements of AASHTO M288, *Standard Specification for Geosynthetic Specification for Highway Applications*, class I fabric with elongation less than 50 percent at the specified strengths, or install a double layer of liquid membrane-forming compound on the stabilized base prior to the placement of concrete. Do not design, specify, or install a layer of plastic or rubberized sheet material as a bond breaker without prior approval of the Pavements DWG. Do not design, specify, or construct PCC pavement slabs with joint spacing greater than 13 feet (4 m) over cement-stabilized base.

2-1.3.2 Lime.

Experience shows that lime will react with many medium-, moderately fine-, and fine-grained soils to produce decreased plasticity, increased workability, reduced swell, and increased strength. Consider using lime to stabilize soils classified according to the Unified Soil Classification System (USCS) as CH, CL, MH, ML, OH, OL, SC, SM, GC, GM, SW-SC, SP-SC, SM-SC, GW-GC, GP-GC, ML-CL, and GM-GC. Consider lime with all soils having a PI greater than 12 and more than 25 percent of the soil passing the No. 200 (0.075 mm) sieve. Do not design, specify, or construct lime-stabilized subgrade, subbase, or base soils with a sulfate content greater than 0.1 percent.

2-1.3.3 Fly Ash.

Fly ash, when mixed with lime, can effectively stabilize most coarse- and medium-grained soils; however, the PI cannot be greater than 25 and remain effective. Soils classified by the USCS as SW, SP, SP-SC, SW-SC, SW-SM, GW, GP, GP-GC, GW-GC, GP-GM, GW-GM, GC-GM, and SC-SM can be stabilized with fly ash. Some sources of fly ash may contain high amounts of sulfates. In some soils, this may lead to the formation of ettringite, which may swell excessively. Do not design, specify, or construct fly ash-stabilized subgrade, subbase, or base soils with a sulfate content greater than 0.1 percent.

2-1.3.4 Bituminous.

Most bituminous soil stabilization has been performed with asphalt cement, cutback asphalt, and asphalt emulsions. Soils that can be stabilized effectively with bituminous materials usually contain less than 30 percent passing the No. 200 (0.075 mm) sieve and have a PI less than 10. Soils classified by the USCS as SW, SP, SW-SM, SP-SM, SW-SC, SP-SC, SM, SC, SM-SC, GW, GP, SW-GM, SP-GM, SW-GC, GP-GC, GM, GC, and GM-GC can be effectively stabilized with bituminous materials, provided the above-mentioned gradation and plasticity requirements are met.

2-1.3.5 Combination.

Combinations of lime and cement are often acceptable expedient stabilizers. Lime can be added to the soil to increase the soil’s workability and mixing characteristics as well as reduce its plasticity. Cement or fly ash can then be mixed into the soil to provide rapid strength gain. Combinations of lime and asphalt are often acceptable stabilizers. The lime addition may prevent stripping at the asphalt-aggregate interface and increase the mixture’s stability. Do not design, specify, or construct lime cement combination-stabilized subgrade, subbase, or base soils with a sulfate content greater than 0.1 percent.

2-1.4 Non-Traditional Additives.

2-1.4.1 Polymers.

Polymer emulsions (sometimes referred to as latex) can be used for soil stabilization. The most common types of polymer emulsions used for soil stabilization are polyvinyl acetate-based copolymers. These materials have excellent adhesive characteristics and provide stiffness, toughness, and water resistance. Polymer emulsions typically consist of 45 to 60 percent polymer content by weight and cure mainly by water loss. These materials may be limited by shelf life. Do not mix polymer emulsions with gray water or salt water for dilution. Soils that can be stabilized with polymer emulsions are similar to those that can be stabilized by bitumen.

2-1.4.2 Fibers.

Numerous fiber types (e.g., polypropylene, polyvinyl alcohol, nylon, and natural) and morphologies (monofilament, fibrillated, and tape) are available. Most soils can be stabilized with fibers; however, mixing may be difficult in highly plastic soils. This difficulty limits the use of fibers for stabilizing fine-grained soils.

2-1.4.3 Non-traditional Additives.

A variety of other non-traditional soil stabilization and modification additives, such as acids, lignin derivatives, enzymes, tree resin emulsions, and silicates, are available from the commercial sector. These additives vary widely in their chemical composition and action mechanism, may be liquid or solid, and are often touted to be applicable for most soils. Research studies in this area have demonstrated that many non-traditional soil additives have little to no benefit for granular soil types. Sandy and gravelly soils are often problematic for stabilization, requiring a binder such as cement, polymer, or asphalt emulsion to provide cohesion between soil grains. Medium- and fine-grained soils are likely to benefit most from the other non-traditional stabilizers; however, these are treated on a case-by-case basis. Do not design, specify, or construct otherwise stabilized subgrade, subbase, or base soils without prior approval by the Pavements DWG.

2-1.4.4 Non-traditional Combinations.

Soil blended with combinations of traditional and non-traditional additives has been shown to be more effective than soil blended with a single additive. Polymer emulsions and hydraulic cements with and without synthetic fibers combine well, as do synthetic fibers and hydraulic cements. These combinations have shown promise in laboratory testing and field demonstrations. A synergism exists between emulsions and hydraulic cement: the water in the emulsion hydrates the cement and the polymer adds flexibility, water resistance, and crack resistance. The use of fibers improves the resistance of the soil to deformation and resists the tensile stresses that lead to cracking. However, fibers are difficult to use during construction as they reduce workability and are difficult to place in wind as they blow around and even be blown completely out of the construction area.

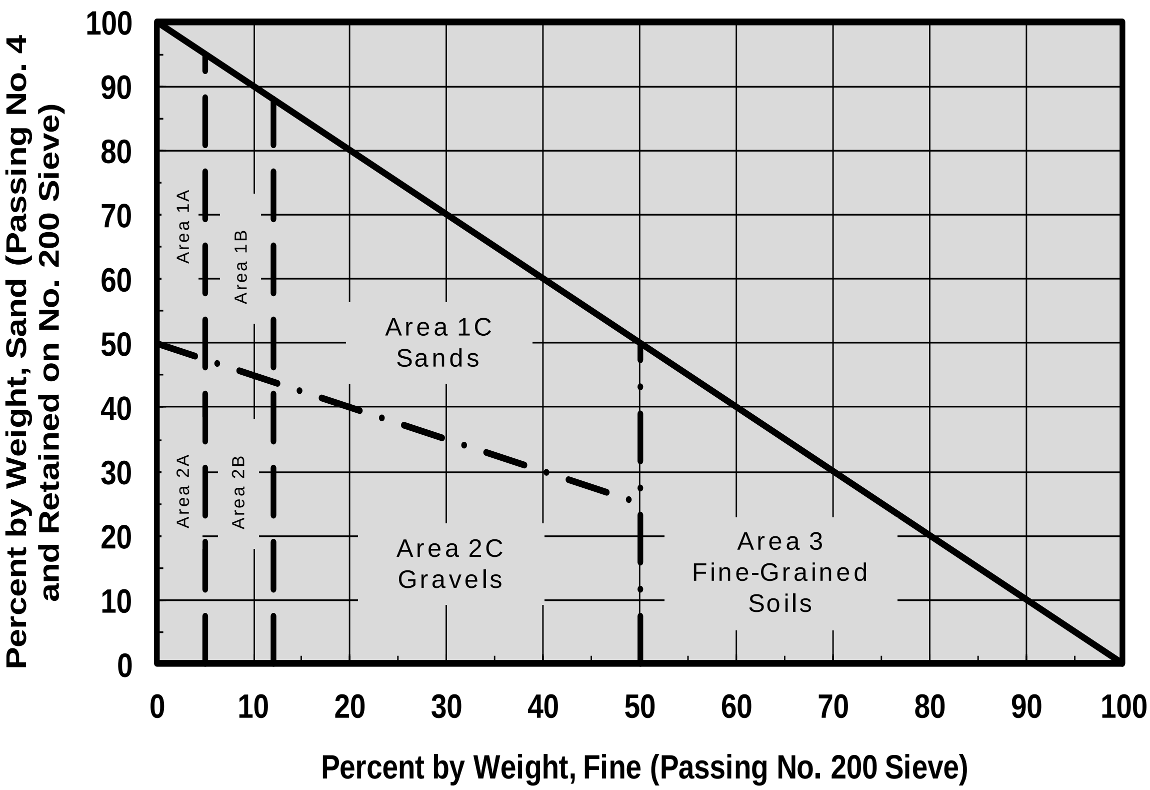
2-1.5 Selection of Candidate Additives.

2-1.5.1 Candidate Stabilizers.

The selection of candidate stabilizers is made using Figure 2-1 and Table 2-3. The soil gradation triangle in Figure 2-1 is based upon the soil grain-size characteristics. The triangle is divided into areas of soils with similar grain size and therefore pulverization characteristics. The selection process is continued with Table 2-3, which indicates candidate stabilizers for each area shown in Figure 2-1, with restrictions-based percent passing the No. 200 (0.075

mm) sieve, on grain size and/or PI. Also provided in the second column of Table 2-3 is a listing of soil classification symbols applicable to the area determined from Figure 2-1. This is an added check to ensure the proper area has been selected. Thus, the soil is characterized in terms of grain-size distribution and Atterberg limits to initiate the additive selection process. Data required to enter Figure 2-1 are (1) percent material passing the No. 200 (0.075 mm) sieve and (2) percent material passing the No. 4 (4.75 mm) sieve but retained on the No. 200 (0.075 mm) sieve (i.e., total percent material between the No. 4 (4.75 mm) and the No. 200 (0.075 mm) sieves). The triangle is entered with these two values and the applicable area (1A, 2A, 3, etc.) is found at their intersection. The area determined from Figure 2-1 is then found in the first column of Table 2-3 and the soil classification is checked in the second column. Candidate stabilizers for each area are indicated in the third column and restrictions for the use of each material are presented in the subsequent columns.

Figure 2-1 Gradation Triangle for Aid in Selecting Commercial Stabilizing Agent



2-1.5.2 Restrictions.

These restrictions prevent the use of stabilizing agents that are not applicable for the particular soil type under consideration. For example, assume a soil classified as an SC, with 93 percent passing the No. 4 (4.75 mm) sieve and 25 percent passing the No. 200 (0.075 mm) sieve with a liquid limit (LL) of 20 and a plastic limit of 11. Thus, 68 percent of the material is between the No. 4 and No. 200 (0.075 mm) sieves and the PI is 9. Entering Figure 2-1 with the values of 25 percent passing the No. 200 (0.075 mm) sieve and 68 percent between the No. 4 (4.75 mm) and No. 200 (0.075 mm) sieves, the intersection of these values is found in area 1-C. Then, going to the first column of Table 2-3, we find area 1-C and verify the soil classification, SC, is included in the second column. From the third column, all four stabilizing materials are found to be potential candidates. The restrictions in the following columns are now examined. Bituminous/polymer stabilization is acceptable since the PI does not exceed 10 and the amount of material passing the No. 200 (0.075 mm) sieve does not exceed 30 percent. However, note that the soil barely qualifies under these criteria and bituminous/polymer stabilization is probably not the first choice. The restrictions under portland cement indicate the PI is less than the equation indicated in footnote b. Since the PI, 9, is less than that value, portland cement is a candidate material. The restrictions under lime indicate that the PI not be less than 12; therefore, lime is not a candidate material for stabilization. The restrictions under LCF stabilization indicate that the PI does not exceed 25; thus, LCF is also a candidate stabilizing material. At this point, the designer makes the final selection based on other factors, such as availability of material, economics, etc. Once the type of stabilizing agent to be used is determined, samples are prepared and tested in the laboratory to develop a design mix meeting minimum engineering criteria for field stabilization.

2-1.5.3 Fibers.

Fibers can be used in many soil types because they provide mechanical stabilization. Monofilament, tape, and fibrillated fibers are most common for improving soils. They provide immediate improvements in load bearing and crack resistance by enhancing strain resistance. Fibers mixed into soil without adhesives (i.e., cement) rely on mechanical interlock, friction, and fiber entanglement between themselves and soil particles to anchor the fiber in place. Thus, a high surface area fiber (such as a tape fiber) may be more efficient in a fine-grained clay soil than in a coarse-grained soil such as gravel, where fewer soil grains are in contact with the fiber. Longer fibers generally result in improved performance but hamper construction. They are more difficult to mix and considerable “balling” may occur, diminishing efficiency. After mixing, workability is sharply reduced, making blade work and grading difficult.

2-2 USE OF STABILIZED SOILS IN FROST AREAS.

2-2.1 Frost Considerations.

Pavement systems may experience two general types of freeze-thaw action. Cyclic freeze-thaw occurs in the material when freezing occurs as the advancing frost line moves by and thawing subsequently occurs. Heaving conditions develop when a quasi-equilibrium frost line condition is established in the stabilized material layer. If the material is frost-susceptible, the static frost line situation provides favorable conditions for moisture migration and subsequent ice lens formation and heaving. While bituminous, polymer, portland cement, lime, and LCF stabilization are the most common additives, other stabilizers may be used for pavement construction in areas of frost design but only with approval from the Pavements DWG. Additives and cold weather placement techniques are also available for portland cement stabilization and are addressed in Chapter 4.

2-2.2 Limitations.

In frost areas, stabilized soil is used in one of the upper elements of a pavement system only if the cost is justified by the reduced pavement thickness. Use a soil treatment with a lower degree of additive than that indicated for stabilization (i.e., soil modification) in frost areas only with caution and after intensive tests because weakly cemented material usually has less capacity to endure repeated freezing and thawing than firmly cemented material. A possible exception is modifying a soil that will be encapsulated within an impervious envelope as part of a membrane-encapsulated-soil-layer pavement system. A soil unsuitable for encapsulation due to excessive moisture migration and thaw weakening may be made suitable by moderate amounts of a stabilizing additive. Test modified materials to ascertain the desired improvement is durable through repeated freeze-thaw cycles. Do not stabilize soils to improve the strength at the expense of making the soil more susceptible to ice segregation.

2-2.3 Construction Cutoff Dates.

Construct materials stabilized with cement, lime, or LCF early enough during the construction season to allow the development of adequate strength before the first freezing cycle begins. The rate of strength gain is substantially lower at 50 °F (10 °C) than at 70 °F or 80 °F (21 °C or 27 °C). Chemical reactions will not occur rapidly for (1) lime-stabilized soils when the soil temperature is less than 60 °F (16 °C) and is not expected to increase for one month or (2) cement-stabilized soils when the soil temperature is less than 40 °F (4 °C) and is not expected to increase for one month. In frost areas, set a construction cutoff date well in advance of the onset of freezing conditions (e.g., 30 days) because it is not adequate to protect the mixture from freezing during a seven-day curing period as required by the applicable guide specifications if the lime or cement reactions continue past the seven-day period.

2-3 THICKNESS REDUCTION FOR BASE AND SUBBASE COURSES.

Ensure the stabilized base and subbase course materials meet the requirements of gradation, strength, and durability to qualify for reduced layer thickness design. Gradation requirements are presented in paragraphs 3-1 through 3-6 covering design with each type of stabilizer. Unconfined compressive strength and durability requirements for bases and subbases treated with cement, lime, lime-cement, lime-fly ash (LF), and LCF are indicated in Tables 2-1 and 2-2, respectively. For bituminous-stabilized materials to qualify for reduced thickness, ensure they meet strength requirements in UFC 3-260-02. Polymer emulsion materials qualify for reduced thickness when they meet a minimum unconfined compressive strength of 400 psi (2.76 MPa). Ensure all stabilized materials except those treated with bitumen and polymer emulsion meet minimum durability criteria to be used in pavement structures. There are no durability criteria for bituminous- or polymer emulsion-stabilized materials since it is assumed they will be waterproof if properly designed and constructed.

Table 2-1 Minimum Unconfined Compressive Strength for Cement-, Lime-, Lime-Cement, and Lime-Cement-Fly Ash-Stabilized Soils

Stabilized Soil Layer	Minimum Unconfined Compressive Strength psi (MPa)[a]	
	Flexible pavement	Rigid pavement
Base course	750 (5.17)	500 (3.45)
Subbase course, select material or subgrade	250 (1.72)	200 (1.38)

[a] Unconfined compressive strength determined at 7 days for cement stabilization and 28 days for lime, LF ash, or LCF ash stabilization.

Table 2-2 Durability Requirements

Type of Soil Stabilized	Maximum Allowable Weight Loss After 12 Wet-Dry or Freeze-Thaw Cycles (Percent of Initial Specimen Weight)
Granular, PI < 10	11
Granular, PI > 10	8
Silt	8
Clays	6

2-4 DRYING WET SOILS.

2-4.1 Chemicals.

The chemicals of choice for drying are oxides of calcium and magnesium, generally referred to as quicklime. Depending on the source, they may be further defined as high-calcium quicklime, magnesium quicklime, or dolomitic quicklime. These substances contain metal oxides (e.g., calcium oxide, CaO) that react with water to form the metal hydrate (e.g., $CaO{\cdot}(OH)_2$). As quicklime hydrates with water in the soil, it releases considerable heat (i.e., is exothermic), which in turn evaporates more water and further reduces the moisture content of the soil. Because this reaction is fast and exothermic, it is effective for drying soils down to freezing temperatures.

2-4.2 Lime.

Lime is a generic term used to cover a variety of materials. Only quicklime is effective for drying soils. Hydrated lime has already combined with water and will not draw moisture into new chemical forms. It will have certain chemical reactions (cation exchange) with some clay minerals that will make them less plastic and easier to dry by conventional methods, but this is much different from the avid drying of quicklime that is not related to soil type. Be aware that “agricultural lime” has no value for engineering stabilization or drying uses. Do not construct stabilized soil materials using agricultural lime.

Any product that contains free quicklime (CaO) can be used as a drying agent. The more CaO it contains, the more effective it will be as a drying agent. Portland cement, fly ash (particularly high calcium Class C ashes), and kiln dust are examples of common industrial materials with significant CaO content that can be used for soil drying. Their effectiveness for drying is directly dependent on their free CaO content. Quicklime is a caustic material; hence, normal safety precautions for such materials need to be followed (long sleeves and pants, rubber gloves, goggles, and mask). Quicklime is a relatively granular material and does not dust like the much finer hydrated lime. While safety precautions are required to handle this material, they are within the range of precautions used on construction sites. Quicklime is a commonly used industrial and construction material and the safety precautions required are reasonable to comply with in the field to ensure worker health and safety. Delivery is typically by dump truck and mixing is typically with a conventional field rotary mixer. Thorough mixing enhances uniform drying.

2-4.3 Amounts.

Amounts for use are generally by trial and error. Take a known weight of a wet soil sample and mix with a known amount of quicklime and see visually and texturally if it dries the wet soil sample. The reaction with CaO is quick and results will be evident very rapidly. Repeat but vary the amount of additive. This is a practical way to ascertain if non-quicklime materials such as portland cement, fly ash, or kiln dust have free CaO to be effective to dry the soil. A qualitative assessment of a simple test of this sort is generally all that is justified for military engineering applications. This will also provide a rough initial estimate of the amount of additive to use for drying.

2-4.4 Factors.

Three factors are involved with drying of the soil: chemical hydration of CaO, exothermic-reaction-caused evaporation, and normal evaporation because of ambient conditions. Therefore, trying to assign exact formulas for how much quicklime to add to gain a specific reduction in moisture content is not justified. It is better to make multiple additions to close in on the desired moisture content. One to two percent quicklime for each percent reduction in desired moisture content is a good starting point.

Table 2-3 Guide for Selecting a Stabilizing Additive

Area	Class (b)	Type of Stabilizer	Restriction (LL and PI)	RESTRICTION (% PASS NO. 200) (c)	REMARK
1A	SW or SP	1. Polymer/bituminous emulsion and cement 2. Portland cement 3. Lime-cement-fly ash 4. 2 and 3 with fiber (a)	PI not to exceed 25	3 & 4. Lime requires at least 25% passing the No. 200 (0.075 mm) sieve	Soils near or above their optimum moisture content may require drying prior to emulsion stabilization.
1B	SW-SM or SP-SW or SW-SC or SP-SC	1. Polymer/bituminous emulsion and cement 2. Portland cement and fiber (a) 3. Lime and fiber (a) 4. Lime-cement-fly ash and fiber (a) 5. 2, 3, and 4 with fiber (a)	1. PI not to exceed 10 2. PI not to exceed 30 3. PI not less than 12 4. PI not to exceed 25	3, 4, 5. Lime requires at least 25% passing the No. 200 (0.075 mm) sieve	Soils near or above their optimum moisture content may require drying prior to emulsion stabilization.
1C	SM or SC or SM-SC	1. Polymer/bituminous emulsion and cement 2. Portland cement and fiber (a) 3. Lime and fiber (a) 4. Lime-cement-fly ash and fiber (a) 5. 2, 3, and 4 with fiber (a)	1. PI not to exceed 10 2. (b) 3. PI not less than 12 4. PI not to exceed 25	1. Not to exceed 30% by weight 3, 4, 5. Lime requires at least 25% passing the No. 200 (0.075 mm) sieve	Soils near or above their optimum moisture content may require drying prior to emulsion stabilization.
2A	GW or GP	1. Polymer/bituminous emulsion and cement 2. Portland cement and fiber (a) 3. Lime-cement-fly ash and fiber (a) 4. 2 and 3 with fiber (a)	PI not to exceed 25	3 & 4. Lime requires at least 25% passing the No. 200 (0.075 mm) sieve	Well-graded material only. Material to contain at least 45% by weight of material passing No. 4 (4.75 mm) sieve. Soils near or above their optimum moisture content may require drying prior to emulsion stabilization.
2B	GW-GM or GP-GM or GW-GC or GP-GC	1. Polymer/bituminous emulsion and cement 2. Portland cement and fiber (a) 3. Lime and fiber (a) 4. Lime-cement-fly ash and fiber (a) 5. 2, 3, and 4 with fiber (a)	1. PI not to exceed 10 2. PI not to exceed 30 3. PI not less than 12 4. PI not to exceed 25	3, 4, 5. Lime requires at least 25% passing the No. 200 (0.075 mm) sieve	Well-graded material only. Material to contain at least 45% by weight of material passing No. 4 (4.75 mm) sieve. Soils near or above their optimum moisture content may require drying prior to emulsion stabilization.
2C	GM or GC or GM-GC	1. Polymer/bituminous emulsion and cement 2. Portland cement and fiber (a) 3. Lime and fiber (a) 4. Lime-cement-fly ash and fiber (a) 5. 2, 3, and 4 with fiber (a)	1. PI not to exceed 10 2. (c) 3. PI not less than 12 4. PI not to exceed 25	1. Not to exceed 30% by weight 3, 4, 5. Lime requires at least 25% passing the No. 200 (0.075 mm) sieve	Well-graded material only. Select Material to contain at least 45% by weight of material passing No. 4 (4.75 mm) sieve.
3	CH or CL or MH or ML or OH or OL or ML-CL	1. Portland cement and fiber (a) 2. Lime (a) 3. 2 with fiber (a)	1. LL less than 40 and PI less than 20 2. PI not less than 12	2 & 3. Lime requires at least 25% passing the No. 200 (0.075 mm) sieve	Organic and strongly acidic soils falling within this area are not susceptible to stabilization by conventional means.

(a) Monofilament polypropylene fiber – Length and denier will vary depending on soil type
(b) Soil classification corresponds to ASTM D2487-17. Restriction on liquid limit (LL) and plasticity index (PI) is in accordance with ASTM D4318-17e1.
(c) PI ≤ 20 + 50 – percent passing No. 200 (0.075 mm) sieve

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CHAPTER 3 DETERMINING STABILIZER CONTENT

3-1 STABILIZATION WITH PORTLAND CEMENT.

Portland cement can be used either to modify and improve the quality of the soil or to transform the soil into a cemented mass with increased strength and durability. The amount of cement used will depend upon whether the soil is to be modified or stabilized.

3-1.1 Types of Portland Cement.

Several different types of cement have been successfully used for stabilizing soils. Type I normal portland cement and Type IA air-entraining cements were used extensively in the past with similar results. At the present time, Type II cement has greater sulfate resistance obtained while the cost is often the same. High early strength cement (Type III) has been found to give higher strength in certain soils and cures much faster than Type I or Type II. Type III cement has a finer particle size than the other cement types. Chemical and physical property specifications for portland cement can be found in ASTM C150, *Standard Specification for Portland Cement*.

3-1.2 Water for Hydration.

Potable water is normally used for cement stabilization, although seawater has been found to be satisfactory.

3-1.3 Gradation Requirements.

Gradation requirements for cement-stabilized base and subbase courses are in Table 3-1.

Table 3-1 Gradation Requirements for Cement-Stabilized Base and Subbase Courses

Type Course	Sieve Size	Percent Passing
Base	1.5 inch (37.5 mm)	100
	0.75 inch (19 mm)	70–100
	No. 4 (4.75 mm)	45–70
	No. 40 (0.425 mm)	10–40
	No. 200 (0.075 mm)	0–20
Subbase	1.5 inch (37.5 mm)	100
	No. 4 (4.75 mm)	45–100
	No. 40 (0.425 mm)	10–50
	No. 200 (0.075 mm)	0–20

3-1.4 Cement Content for Modifying Soils.

3-1.4.1 Improved Plasticity.

In a majority of cases, lime is preferred over soil cement to reduce the PI or control expansive behavior. If lime is not locally or economically available for a project, it is possible to use cement to reduce the plasticity. Do not design, specify, or install soil cement to reduce the PI of a soil without prior authorization by the Pavements DWG. The amount of cement required to improve the quality of the soil through modification is determined by the trial-and-error approach, as described below.

To reduce the PI of the soil, prepare successive samples of soil-cement mixtures prepared at different treatment levels and the PI of each mixture determined in accordance with ASTM D4318, *Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils*. The minimum cement content that yields the desired PI is selected but, since it was determined based upon the minus No. 40 (0.425 mm) sieve material, this value is adjusted to find the design cement content based upon total sample weight expressed as:

$$A = 100BC$$

where

A = design cement content, percent total weight of soil
B = percent passing No. 40 (0.425 mm) sieve size, expressed as a decimal
C = percent cement required to obtain the desired PI of minus No. 40 (0.425 mm) sieve material, expressed as a decimal

3-1.4.2 Improved Gradation.

If the objective of modification is to improve the gradation of a granular soil through the addition of fines then conduct a particle size analysis (ASTM D7928, *Standard Test Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis*) on samples at various treatment levels to determine the minimum acceptable cement content.

3-1.4.3 Reduced Swell Potential.

Portland cement may reduce swell potential of certain expansive soils. However, portland cement is not as effective as lime in reducing swell potential and may be considered too expensive for this application. Determining cement content to reduce the swell potential of fine-grained plastic soils can be accomplished by molding several samples at various cement contents and soaking the specimens along with untreated specimens for four days. The lowest cement content that eliminates the swell potential or reduces the swell characteristics to the minimum is the design cement content. Procedures for measuring swell characteristics of soils are found in ASTM D4546-14e1, *Standard Test Methods for One-Dimensional Swell or Collapse of Soils*. Check the cement content found to accomplish soil modification to determine whether it provides an unconfined compressive strength great enough to qualify for a reduced thickness design in accordance with criteria established for soil stabilization.

3-1.4.4 Frost Areas.

Cement-modified soil may also be used in frost areas but, in addition to the procedures for mixture design described in paragraphs 3-1.5.1 through 3-1.5.5, cured specimens are subjected to the 12 freeze-thaw cycles prescribed by ASTM D560, *Standard Test Methods for Freezing and Thawing Compacted Soil-Cement Mixtures* (but omitting wire-brushing). Follow the determination of frost design soil classification by means of standard laboratory freezing tests. If cement-modified soil is used as subgrade, its frost susceptibility, determined after freeze-thaw cycling, is used as the basis of the pavement thickness design if the reduced subgrade design method is applied.

3-1.5 Cement Content for Stabilized Soil.

Determine the design cement content for cement-stabilized soils using the following procedure.

3-1.5.1 Step 1.

Determine the gradation, Atterberg limits, and classification of the untreated soil following procedures in ASTM D7928, ASTM D4318, and ASTM D2487, *Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)*, respectively.

3-1.5.2 Step 2.

Using the soil classification, select estimated cement content for moisture-density tests from Table 3-2.

Table 3-2 Cement Requirements for Various Soils

Soil Classification	Initial Estimated Cement Content (percent dry weight)
GW, SW	5
GP, GW-GC, GW-GM, SW-SC, SW-SM	6
GC, GM, GP-GC, GP-GM, GM-GC, SC, SM, SP-SC, SP-SM, SM-SC, SP	7
CL. ML, MH	9
CH	11

3-1.5.3 Step 3.

Conduct moisture-density tests at the estimated cement content and at cement contents 2 percent above and 2 percent below the initial estimated cement content from Table 3-2 to determine the maximum dry density and optimum water content of the soil-cement mixtures at each cement content. Use the procedure in ASTM D558, *Standard Test Methods for Moisture-Density (Unit Weight) Relations of Soil-Cement Mixtures*, to prepare the soil-cement mixture and make the necessary calculations. Use the procedures in ASTM D1557, *Standard Test Methods for Laboratory Compaction*

Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3)), to conduct the moisture density test. The maximum dry density determined in the laboratory will be used to set an allowable range for field density (see ASTM D1557, Section 12). In most cases, the density of the cement-treated soil will be higher than for the untreated soil due to the high specific gravity of portland cement; so, as the amount of cement dosage increases, the density may increase slightly.

3-1.5.4 Step 4.

Prepare triplicate samples of the soil-cement mixture for unconfined compression and durability tests at the cement content selected in step 2 and at cement contents 2 percent above and 2 percent below that determined in step 2. Prepare the samples at compaction time and minimum density to be expected in field construction. For example, if the design field density is 97 ± 2 percent of the laboratory maximum density at 9 ± 2 percent moisture content, prepare the samples at 97 percent density and 9 percent moisture content. If field compaction will be not be immediate then compact the samples at a time after mixing representative of when field compaction will occur. Prepare the samples in accordance with ASTM D1632, *Standard Practice for Making and Curing Soil-Cement Compression and Flexure Test Specimens in the Laboratory*, except that when more than 35 percent of the material is retained on the No. 4 (4.75 mm) sieve, use a 4-inch (100-mm) -diameter by 8-inch (200-mm) -high mold to prepare the specimens. Cure the specimens for seven days in a humid room before testing. Test three specimens using the unconfined compression test in accordance with ASTM D1633, *Standard Test Methods for Compressive Strength of Molded Soil-Cement Cylinders*, and subject three specimens to durability tests, either wet-dry (ASTM D559, *Standard Test Methods for Wetting and Drying Compacted Soil-Cement Mixtures*) or freeze-thaw (ASTM D560) tests, as appropriate. Determine the frost susceptibility of the treated material as indicated in UFC 3-260-02.

3-1.5.5 Step 5.

Compare the results of the average of the three unconfined compressive strength and durability tests with the requirements shown in Tables 2-1 and 2-2. The lowest cement content that meets the required unconfined compressive strength requirement <u>and</u> demonstrates the required durability is the design cement content. If the mixture meets the durability requirements but not the strength requirements, the mixture is considered to be a modified soil. If the results of the specimens tested do not meet both the strength and durability requirements then higher cement content may be selected and steps 3 and 4 above repeated.

3-2 STABILIZATION WITH LIME.

Generally, lime-treated, fine-grained soils exhibit decreased plasticity, improved workability, and reduced volume change characteristics. However, not all soils exhibit improved strength characteristics. Note that the properties of soil-lime mixtures are dependent on many variables. Soil type, lime type, lime percentage, and curing conditions (time, temperature, and moisture) are the most important. Perform preliminary lime reactivity testing on each soil type intended for use on a project as not all soil-lime combinations are reactive.

Prior to designing a stabilization program to treat a shrink/swell soil, thoroughly examine the geological/geotechnical conditions with respect to the groundwater and runoff water. Eliminate or mitigate the water source that causes expansive soil to swell rather than treating the soil or reduce the treatment regimen to save costs as much as possible. This requires the initial design study to be robust and thorough, with specific attention paid to the water conditions above and below the surface. Modifying the soils at the surface without mitigating water intrusion to the expansive soils at or below the surface will result in premature failure and poor performance of the soil layer.

Designing a lime treatment based on the potential vertical rise (PVR) has the potential to overestimate the actual vertical rise and therefore over-prescribe the amount of lime treatment depth and quantity required once the water source is mitigated. Conversely, if the water source is not removed, diverted, or mitigated in some way, the stabilization treatment will likely not be adequate to handle the swell induced during a surge of water flow into the expansive zone.

3-2.1 Types of Lime.

Various forms of lime have been successfully used as soil-stabilizing agents for many years. However, the most commonly used products are hydrated high-calcium lime, monohydrated dolomitic lime, calcitic quicklime, and dolomitic quicklime. Hydrated lime is used most often because it is much less caustic than quicklime. Under certain circumstances, the quantity of lime may be reduced if quicklime is used in lieu of hydrated lime; however, only reduce the amount of lime prescribed by the mix design at the direction of the Pavements DWG. Specifications for quicklime and hydrated lime may be found in ASTM C977, *Standard Specification for Quicklime and Hydrated Lime for Soil Stabilization*.

3-2.2 Gradation Requirements.

Consider lime stabilization of soils containing a minimum of 25 percent passing the No. 200 (0.075 mm) sieve.

3-2.3 Lime Content for Lime-Modified Soils.

The amount of lime required to improve the quality of a soil is determined through the same trial-and-error process used for cement-modified soils. Highly weathered soils may require higher lime content than usually specified by previous guideline documents. The following procedures are recommended for determining the lime content of lime-stabilized soils.

3-2.3.1 Step 1.

The preferred method for determining initial design lime content is the pH test (ASTM D6276, *Standard Test Method for Using pH to Estimate the Soil-Lime Proportion Requirement for Soil Stabilization*). In this method, several lime-soil slurries are prepared at different lime treatment levels, such as 2, 4, 6, and 8 percent lime, and the pH of each slurry is determined. The lowest lime content at which a pH of at least 12.4 (the pH of free lime) is obtained is the initial design lime content. This is the initial starting point and is the minimum required lime content for the pozzolanic reactions to occur.

3-2.3.2 Step 2.

Using the initial design lime content, conduct moisture-density tests to determine the maximum dry density and optimum water content of the soil-lime mixture. Use the procedures in ASTM D3551, *Standard Practice for Laboratory Preparation of Soil-Lime Mixtures Using Mechanical Mixer*, to prepare the soil-lime mixture. Conduct the moisture density test following procedures in ASTM D1557.

3-2.3.3 Step 3.

Prepare samples of the soil-lime mixture—three each for unconfined compression and durability tests at the initial design lime content and at lime contents 2 and 4 percent above design if based on the preferred method, or 2 percent above and 2 percent below design if based on the alternate method. Prepare the mixture as indicated in ASTM D3551. If less than 35 percent of the soil is retained on the No. 4 (4.75 mm) sieve, mold approximately 2-inch (50 mm) -diameter and 4-inch (100 mm) -high samples. If more than 35 percent is retained on the No. 4 (4.75 mm) sieve, mold 4-inch (100 mm) -diameter and 8-inch (200 mm) -high samples. Prepare the samples at the density and water content expected in field construction. For example, if the design density is 95 percent of the laboratory maximum density, prepare the sample at 95 percent density. Cure specimens in a sealed container to prevent moisture loss and lime carbonation. Sealed metal cans, plastic bags, and so forth are satisfactory. The preferred method of curing is 73 °F (23 °C) for 28 days. Accelerated curing at 120 °F (49 °C) for 48 hours has also been found to give satisfactory results; however, conduct additional check tests at 73 °F (23 °C) for 28 days. Research has shown that if accelerated curing temperatures are too high, the pozzolanic compounds formed during laboratory curing differ substantially from those that develop in the field.

3-2.3.4 Step 4.

Test three specimens using the unconfined compression test in accordance with ASTM D2166/D2166M, *Standard Test Method for Unconfined Compressive Strength of Cohesive Soil*. If frost design is a consideration, subject an additional three specimens to 12 cycles of freeze-thaw durability tests (ASTM D560), except omit wire brushing. Determine the frost susceptibility of the treated material as indicated in UFC 3-260-02.

3-2.3.5 Step 5.

Compare the results of the unconfined compressive strength and durability tests with the requirements shown in Tables 2-1 and 2-2. The lowest lime content that meets the unconfined compressive strength requirement and demonstrates the required durability is the design lime content. Ensure the treated material also meets frost susceptibility requirements as indicated in UFC 3-260-02. If the mixture meets the durability requirements but not the strength requirements, it is considered to be a modified soil. If results of the specimens tested do not meet both the strength and durability requirements, higher lime content may be selected and steps 1 through 5 repeated.

3-3 STABILIZATION WITH LIME-FLY ASH (LF) AND LIME-CEMENT-FLY ASH (LCF).

Stabilization of coarse-grained soils having little or no fines can often be accomplished by the use of LF or LCF combinations. Fly ash, also termed coal ash, is a mineral residual from the combustion of pulverized coal. It contains silicon and aluminum compounds that, when mixed with lime and water, form a hardened cementitious mass capable of obtaining high compressive strengths. Lime and fly ash in combination can often be successfully used to stabilize granular materials since the fly ash provides an agent with which the lime can react; thus, LF or LCF stabilization is often appropriate for base and subbase course materials.

3-3.1 Types of Fly Ash.

Fly ash is classified according to the type of coal from which the ash was derived. Class C fly ash is derived from the burning of lignite or subbituminous coal and is often referred to as "high lime" ash because it contains a high percentage of lime. Class C fly ash is self-reactive or cementitious in the presence of water, in addition to being pozzolanic; however, using Class C fly ash has proven to be sensitive and difficult at times. Class F fly ash is derived from the burning of anthracite or bituminous coal and is sometimes referred to as "low lime" ash, depending on locale. It requires the addition of lime to form a pozzolanic reaction. Volcanic ash, rice hull ash (Type N natural pozzolans), and slag (ground-granulated blast-furnace slag [GGBFS]) may be used as stabilizers, where available. In certain geographic locations, they are widely available and have been used successfully as stabilizers for many years.

3-3.2 Evaluation of Fly Ash.

Fly ash used for stabilization is acceptable quality when it meets the requirements indicated in ASTM C593, *Standard Specification for Fly Ash and Other Pozzolans for Use with Lime for Soil Stabilization*.

3-3.3 Gradation Requirements.

LF and LCF stabilization are useful only in soils with a PI less than 25 and less than 50 percent passing the No. 200 (0.075 mm) sieve.

3-3.4 Selection of Lime-Fly Ash Content for LF and LCF Mixtures.

Design with LF is different from stabilization with lime or cement. For a given combination of materials (aggregate, fly ash, and lime), a number of factors—such as percentage of lime-fly ash, the moisture content, and the ratio of lime to fly ash—can be varied in the mix design process. In general, engineering characteristics such as strength and durability are directly related to the quality of the matrix material. The matrix material is that part consisting of fly ash, lime, and minus No. 4 aggregate fines. Higher strength and improved durability are achievable when the matrix material is able to "float" the coarse aggregate particles. In effect, the fine-sized particles overfill the void spaces between the coarse aggregate particles. For each coarse aggregate material, a quantity of matrix is required to effectively fill the available void spaces and "float" the coarse aggregate particles. The quantity of matrix required for maximum dry density of the total mixture is referred to as the optimum fines content. In LF mixtures, it is recommended that the quantity of matrix be approximately 2 percent above the optimum fines content. At the recommended fines content, the strength development is also influenced by the ratio of lime to fly ash. Adjustment of the lime-fly ash ratio will yield different values of strength and durability properties.

3-3.4.1 Step 1.

The first step is to determine the optimum fines content that will give the maximum density. This is done by conducting a series of moisture-density tests using different percentages of fly ash and determining the mix level that yields maximum density. Start with the initial fly ash content of approximately 10 percent based on dry weight of the mix. It is recommended that material larger than 0.75 inch (19 mm) be removed and the test conducted on the minus 0.75 inch (19 mm) fraction. Tests are run at increasing increments of fly ash (e.g., 2 percent) up to a total of about 20 percent. Conduct moisture-density tests following procedures in ASTM D1557. The design fly ash content is then selected at 2 percent above that yielding maximum density. An alternate method is to conduct single-point compaction tests at fly ash contents of 10 to 20 percent of the estimated optimum water content, make a plot of dry density versus fly ash content, and determine the fly ash content that yields maximum density. The design fly ash content is 2 percent above this value. A moisture-density test is then conducted to determine the optimum water content and maximum dry density for the LF-stabilized soil.

3-3.4.2 Step 2.

Determine the ratio of lime to fly ash that will yield highest strength and durability. Using the design fly ash content and the optimum water content determined in step 1, prepare triplicate specimens, each set at three different lime-fly ash ratios, following procedures in ASTM D1557. Use LF ratios of 1:3, 1:4, and 1:5. If desired, about 1 percent of portland cement may be added at this time.

3-3.4.3 Step 3.

Test three specimens using the unconfined compression test in ASTM D2166/D2166M. If frost design is a consideration, subject three additional specimens to 12 cycles of freeze-thaw durability tests (ASTM D560) but omit wire brushing. Determine the frost susceptibility of the treated material as indicated in UFC 3-260-02.

3-3.4.4 Step 4.

Compare the results of the unconfined compressive strength and durability tests with the requirements shown in Tables 2-1 and 2-2. The lowest LF ratio content (i.e., the ratio with the lowest lime content, which meets the required unconfined compressive strength requirement and demonstrates the required durability) is the design LF content. Also, meet frost-susceptibility requirements as indicated in UFC 3-260-02 for the treated material. If the mixture meets the durability requirements but not the strength requirements, it is considered to be a modified soil. If the results of the specimens tested meet neither the strength nor the durability requirement, select a different LF content or use additional portland cement and repeat steps 2 through 4.

3-3.5 Selection of Cement Content for LCF Mixtures.

Portland cement may also be used in combination with LF for improved strength and durability. If it is desired to incorporate cement into the mixture, follow the same procedures indicated for LF design but include cement beginning at step 2. Generally, about 1 to 2 percent cement is used. Cement may be used in place of or in addition to lime; however, maintain the total fines content. Conduct strength and durability tests on samples at various LCF ratios to determine the combination that gives best results.

3-4 STABILIZATION WITH BITUMEN AND POLYMER EMULSION.

Stabilizing soils and aggregates with asphalt and polymer emulsion differs greatly from stabilizing soils with cement and lime. The basic mechanism involved in stabilizing fine-grained soils is a waterproofing phenomenon. Soil particles or soil agglomerates are coated with an asphalt or polymer film that prevents or slows the penetration of water, which typically results in a decrease in soil strength. In addition, asphalt or polymer stabilization can improve durability characteristics by making the soil resistant to the detrimental effects of water, such as volume changes. In non-cohesive materials—such as sands and gravel, crushed gravel, and crushed stone—two basic mechanisms are active: waterproofing and adhesion. The asphalt or polymer coating on the cohesionless materials provides a membrane that prevents or hinders the penetration of water, thereby reducing the tendency of the material to lose strength in the presence of water. The second mechanism is adhesion. The aggregate particles adhere to the binder and the binder acts as a cement between soil particles. The cementing effect thus increases shear strength by increasing cohesion. Criteria for design of bitumen-stabilized soils are based almost entirely on stability and soil gradation requirements. For polymer emulsions, the criteria are based solely on unconfined compressive strength. Freeze-thaw and wet-dry durability tests are not applicable for asphalt-stabilized or polymer-stabilized mixtures.

3-4.1 Types of Bituminous-Stabilized Soils.

3-4.1.1 Sand Bitumen.

A mixture of sand and bitumen in which the sand particles are cemented together to provide a material of increased stability.

3-4.1.2 Gravel or Crushed Aggregate Bitumen.

A mixture of bitumen and a well-graded gravel or crushed aggregate that, after compaction, provides a stable, waterproof mass of subbase or base course quality.

3-4.1.3 Bitumen Lime.

A mixture of soil, lime, and bitumen that, after compaction, may exhibit the characteristics of any of the bitumen-treated materials indicated above. Lime is used with material that has a high PI (i.e., above 10).

3-4.2 Types of Bitumen.

3-4.2.1 Bituminous stabilization is generally accomplished using asphalt cement, cutback asphalt, or asphalt emulsions. The type of bitumen to be used depends upon the type of soil to be stabilized, location, method of construction, and weather conditions. Generally, the most satisfactory results are obtained when the most viscous liquid asphalt that can be readily mixed into the soil is used. For higher quality mixes in which a central plant is used, use viscosity-grade asphalt cements. Much bituminous stabilization is performed in place, with the bitumen being applied directly on the soil or soil-aggregate system and the mixing and compaction operations being conducted immediately thereafter. For this type of construction, liquid asphalts (i.e., cutbacks and emulsions) are used. Emulsions are preferred over cutbacks because of safety, reduced energy consumption, and environmental regulations. The specific type and grade of bitumen will depend on the characteristics of the aggregate, the type of construction equipment, and the climatic conditions. Generally, the following types of bituminous materials will be used for the soil gradation indicated:

3-4.2.1.1 Open-graded Aggregate.

- Rapid- and medium-curing liquid asphalts RC-250, RC-800, and MC-3000
- Medium-setting asphalt emulsion MS-2 and CMS-2

3-4.2.1.2 Well-graded Aggregate with Little or No Material Passing the No. 200 (0.075 mm) Sieve.

- Rapid- and medium-curing liquid asphalts RC-250, RC-800, MC-250, and MC-800
- Slow-curing liquid asphalts SC-250 and SC-800
- Medium-setting and slow-setting asphalt emulsions MS-2, CMS-2, SS-1, and CSS-1

3-4.2.1.3 Aggregate with a Considerable Percentage of Fine Aggregate and Material Passing the No. 200 (0.075 mm) Sieve.

- Medium-curing liquid asphalts MC-250 and MC-800
- Slow-curing liquid asphalts SC-250 and SC-800
- Slow-setting asphalt emulsions SS-1, SS-01h, CSS-1, and CSS-1h

3-4.2.2 The simplest type of bituminous stabilization is applying liquid asphalt to the surface of an unbound aggregate road. For this type of operation, slow- and medium-curing liquid asphalts—SC-70, SC-250, MC-70, and MC-250—and slow-setting emulsions as defined in paragraph 3-4.2.1 are used.

3-4.3 Soil Gradation.

The recommended soil gradations for subgrade materials and base or subbase course materials are shown in Tables 3-3 and 3-4, respectively.

Table 3-3 Recommended Gradations for Bituminous-Stabilized Subgrade Materials

Sieve Size	Percent Passing
3 inch (75 mm)	100
No. 4 (4.75 mm)	50–100
No. 30 (0.600 mm)	38–100
No. 200 (0.075 mm)	2–30

Table 3-4 Recommended Gradations for Bituminous-Stabilized Base and Subbase Materials

Sieve Size	1.5 inch (37.5 mm) Maximum	1 inch (25 mm) Maximum	0.75 inch (19 mm) Maximum	0.5 inch (12.5 mm) Maximum
1.5 inch (37.5 mm)	100	--	--	--
1 inch (25 mm)	84 ± 9	100	--	--
0.75 inch (19 mm)	76 ± 9	83 ± 9	100	--
0.5 inch (12.5 mm)	66 ± 9	73 ± 9	82 ± 9	100
3/8 inch (9.5 mm)	59 ± 9	64 ± 9	72 ± 9	83 ± 9
No. 4 (4.75 mm)	45 ± 9	48 ± 9	54 ± 9	62 ± 9
No. 8 (2.36 mm)	35 ± 9	36 ± 9	41 ± 9	47 ± 9
No. 16 (1.18 mm)	27 ± 9	28 ± 9	32 ± 9	36 ± 9
No. 30 (0.600 mm)	20 ± 9	21 ± 9	24 ± 9	28 ± 9
No. 50 (0.300 mm)	14 ± 7	16 ± 7	17 ± 7	20 ± 7
No. 100 (0.150 mm)	9 ± 5	11 ± 5	12 ± 5	14 ± 5
No. 200 (0.075 mm)	5 ± 2	5 ± 2	5 ± 2	5 ± 2

3-4.4 Mix Design.

Guidance for the design of bituminous-stabilized base and subbase courses is in UFC 3-250-01. For subgrade stabilization, the following equation may be used for estimating the preliminary quantity of cutback asphalt to be selected:

$$p = \frac{0.02(a) + 0.07(b) + 0.15(c) + 0.20(d)}{(100 - S)} \times 100$$

where

p = percent cutback asphalt by weight of dry aggregate
a = percent of mineral aggregate retained on No. 50 (0.300 mm) sieve
b = percent of mineral aggregate passing No. 50 (0.300 mm) sieve and retained on No. 100 (0.150 mm) sieve
c = percent of mineral aggregate passing No. 100 (0.150 mm) sieve and retained on No. 200 (0.075 mm) sieve
d = percent of mineral aggregate passing No. 200 (0.075 mm) sieve
S = percent solvent

The preliminary quantity of emulsified asphalt to be used in stabilizing subgrades can be determined from Table 3-5. Select the final design content of cutback or emulsified asphalt based upon the results of the Marshall Stability Test (ASTM D6927, *Standard Test Method for Marshall Stability and Flow of Asphalt Mixtures*). The minimum Marshall Stability recommended for subgrades is 500 lb (227 kg). If a soil does not show increased stability when reasonable amounts of bituminous materials are added, modify the gradation of the soil or use another type of bituminous material. Poorly graded materials may be improved by the addition of suitable fines containing considerable material passing the No. 200 (0.075 mm) sieve. The amount of bitumen required for a given soil increases with an increase in percentage of the finer sizes.

Table 3-5 Emulsified Asphalt Requirements

Percent Passing No. 200 (0.075 mm) Sieve	Pounds (kg) of Emulsified Asphalt per 100 Pounds (45 kg) of Dry Aggregate at Percent Passing No. 10 (2 mm) Sieve					
	< 50	60	70	80	90	100
0	6.0 (2.7)	6.3 (2.8)	6.5 (2.9)	6.7 (3.0)	7.0 (3.2)	7.2 (3.3)
2	6.3 (2.8)	6.5 (2.9)	6.7 (3.0)	7.0 (3.2)	7.2 (3.3)	7.5 (3.4)
4	6.5 (2.9)	6.7 (3.0)	7.0 (3.2)	7.2 (3.3)	7.5 (3.4)	7.7 (3.5)
6	6.7 (3.0)	7.0 (3.2)	7.2 (3.3)	7.5 (3.4)	7.7 (3.5)	7.9 (3.6)
8	7.0 (3.2)	7.2 (3.3)	7.5 (3.4)	7.7 (3.5)	7.9 (3.6)	8.2 (3.7)
10	7.2 (3.3)	7.5 (3.4)	7.7 (3.5)	7.9 (3.6)	8.2 (3.7)	8.4 (3.8)
12	7.5 (3.4)	7.7 (3.5)	7.9 (3.6)	8.2 (3.7)	8.4 (3.8)	8.6 (3.9)
14	7.2 (3.3)	7.5 (3.4)	7.7 (3.5)	7.9 (3.6)	8.2 (3.7)	8.4 (3.8)
16	7.0 (3.2)	7.2 (3.3)	7.5 (3.4)	7.7 (3.5)	7.9 (3.6)	8.2 (3.7)
18	6.7 (3.0)	7.0 (3.2)	7.2 (3.3)	7.5 (3.4)	7.7 (3.5)	7.9 (3.6)
20	6.5 (2.9)	6.7 (3.0)	7.0 (3.2)	7.2 (3.3)	7.5 (3.4)	7.6 (3.4)
22	6.3 (2.8)	6.5 (2.9)	6.7 (3.0)	7.0 (3.2)	7.2 (3.3)	7.5 (3.4)
24	6.0 (2.7)	6.3 (2.8)	6.5 (2.9)	6.7 (3.0)	7.0 (3.2)	7.2 (3.3)
25	6.2 (2.8)	6.4 (2.9)	6.6 (3.0)	6.9 (3.1)	7.1 (3.2)	7.3 (3.3)

3-4.5 Polymer Emulsion.

Due to the wide variety of polymer emulsion properties, it is best to follow the manufacturer’s recommendations for starting dosage amounts for the classification and gradation of the soil.

3-4.5.1 Polymer Content for Stabilized Soil.

The following procedure is recommended for determining the design polymer content. It is similar to that for cement and lime stabilization where the optimum moisture content is first determined for the initial trial polymer content followed by a trial-and-error approach to determine the design polymer content.

3-4.5.1.1 Step 1.

Determine the gradation, Atterberg limits, and classification of the untreated soil following procedures in ASTM D6913/D6913M-17, *Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis*, D4318-17e1, and D2487-17, respectively.

3-4.5.1.2 Step 2.

Using the manufacturer's recommendation as a starting point, select an initial polymer content for moisture-density tests (ASTM D1557).

3-4.5.1.3 Step 3.

Using the initial polymer emulsion content, determine the amount of water that will be added to the soil from the polymer emulsion based upon its percent solids. Then conduct moisture-density tests to determine the maximum dry density (MDD_{OMC}) and optimum water content (OMC) of the soil-polymer mixture at each polymer emulsion content. Use the procedure in ASTM D558 to prepare the soil-polymer mixture and make the necessary calculations; however, use the procedures in ASTM D1557 to conduct the moisture-density tests.

3-4.5.1.4 Step 4.

Prepare triplicate samples of the soil-polymer mixture for unconfined compression tests at the initial polymer content selected in step 2 and at polymer contents 1 percent above and 1 percent below that determined in step 2. For example, if the design field density is 97 ± 2 percent of the laboratory maximum density at 9 ± 2 percent moisture content, prepare the samples at 97 percent density and 9 percent moisture content. If field compaction will not be immediate then compact the samples at a time after mixing representative of when field compaction will occur. Prepare the samples in accordance with ASTM D1632 except that when more than 35 percent of the material is retained on the No. 4 (4.75 mm) sieve, use a 4-inch (100 mm) -diameter by 8-inch (200 mm) -high mold to prepare the specimens. Cure the specimens for seven days at 77 °F (25 °C) in a 50 percent humidity environment before testing. Test three specimens using the unconfined compression test in accordance with ASTM D1633.

3-4.5.1.5 Step 5.

Ensure the average of the three tests are above 400 psi (2.76 MPa). The lowest polymer content that meets the required unconfined compressive strength is the design polymer content. If the results of the specimens tested do not meet the strength requirements then lower or higher polymer content may be selected and steps 1 through 4 above repeated.

3-4.5.2 Portland Cement Content for Polymer-Stabilized Soil.

Portland cement may be used in combination with polymer emulsion. The polymer provides strength, flexibility, and water resistance while the cement provides strength and helps the emulsion cure by reacting with the emulsion water. The mix design procedure is the same as described in paragraph 3-4.5.1. Begin the initial trial with a polymer emulsion content suggested by the manufacturer. If used in combination, the initial trial cement is 1 percent and does not exceed the design polymer emulsion content.

3-5 STABILIZATION WITH LIME-CEMENT AND LIME-BITUMEN.

The advantage in using combination stabilizers is that one of the stabilizers in the combination compensates for the lack of effectiveness of the other in treating a particular aspect or characteristics of a given soil. For instance, in clay areas devoid of base material, lime has been used jointly with other stabilizers, notably portland cement or asphalt, to provide acceptable base courses. Since portland cement or asphalt cannot be successfully mixed with plastic clays, the lime is incorporated into the soil to make it friable, thereby permitting the cement or asphalt to be adequately mixed. While this stabilization practice may be more costly than the conventional single stabilizer methods, it may still prove to be economical in areas where base aggregate costs are high. Two combination stabilizers are considered in this section: lime-cement and lime-asphalt.

3-5.1 Lime-Cement.

Lime can be used as an initial additive with portland cement or alone as the primary stabilizer. The main purpose of lime is to improve workability characteristics, mainly by reducing the plasticity of the soil. The design approach is to add enough lime to improve workability and reduce the PI to acceptable levels. The design lime content is the minimum that achieves desired results. The design cement content is arrived at following procedures for cement-stabilized soils in paragraph 3-1.

3-5.2 Lime-Asphalt.

Lime can be used as an initial additive with asphalt as the primary stabilizer. The main purpose of lime is to improve workability characteristics and act as an anti-stripping agent. In the latter capacity, the lime acts to neutralize acidic chemicals in the soil or aggregate that tend to interfere with bonding of the asphalt. Generally, about 1 to 2 percent lime is all that is needed for this objective. When asphalt is the primary stabilizer, follow the procedures for asphalt-stabilized materials in paragraph 3-4.

3-5.3 Lime Treatment of Expansive Soils.

Expansive soils as defined for pavement purposes are those that exhibit swell in excess of 3 percent. Expansion is characterized by heaving of a pavement or road when water is imbibed in the clay minerals. The plasticity characteristics of a soil are often a good indicator of the swell potential, as indicated in Table 3-6. If it has been determined that a soil has potential for excessive swell, lime treatment may be appropriate. Lime will reduce swell in an expansive soil to greater or lesser degree, depending on the activity of the clay minerals present. The amount of lime to be added is the minimum amount that will reduce swell to acceptable limits, less than 1 percent swell. Use the procedure for conducting swell tests described in ASTM D4546-14e1. The maximum depth that the lime is incorporated into the soil is typically limited by the construction equipment used. However, 2 to 3 feet (0.6 m to 0.9 m) generally is the maximum depth that can be treated directly without removal of the soil. Once the design lime content has been determined, perform testing to verify the intended lime stabilization will also prevent soil expansion. The lime content necessary to reduce the PI is not always suitable to control shrink/swell.

Table 3-6 Swell Potential of Soils

Liquid Limit	Plasticity Index	Potential Swell
> 60	> 35	High
50–60	25–35	Marginal
< 50	< 25	Low

3-6 STABILIZATION WITH FIBERS.

Fiber stabilization in soils is an emerging field. Polypropylene fibers are the most common for soil applications. It is best to follow manufacturer's recommendations for starting dosage amounts for the classification and gradation of the soil. Fibers are very efficient at adding toughness to the soil; they usually do not add stiffness but improve ductility. Fibers may be used alone but are recommended to be used with an adhesive (cement, bitumen, or polymer). Fibers blended with cement reduce the amount of shrinkage cracking. Criteria on the amount of fibers to use are not available at this time; however, there are general guidelines to follow. Refer to UFC 3-220-08FA, *Engineering Use of Geotextiles*, for additional guidance in using geosynthetic materials.

Testing has shown that monofilament and tape fibers are more efficient for rapid stabilization. Fibrillated fibers require extensive mixing (multiple passes of a soil mixer) to effectively defibrillate the fiber for maximum efficiency. Fibers mixed into soil without adhesives (i.e., cement) rely exclusive on mechanical interlock, friction, and fiber entanglement with other fibers and between soil particles to anchor the fiber in place. Thus, a high surface area fiber (such as a tape fiber) may be more efficient in a fine-grained clay soil than in a coarse-grained soil such as gravel, where fewer soil grains are in contact with the fiber.

Fiber amounts will vary depending on the length, denier, and morphology. Fiber lengths for soils typically range from 0.5 to 3 inches (13 to 76 mm). Longer fibers are recommended if no adhesives are used. Successful soil stabilization projects have been performed on virgin granular soils with 2 inch (51 mm) long discrete fibers. Longer fibers generally result in improved performance but hamper construction, as they are more difficult to mix due to entanglement. Shorter fibers (less than 1 inch [25 mm]) are recommended when using adhesives, as the adhesive helps to create a composite network of fiber through the soil. A recommended fiber starting dosage is 0.1 percent with a maximum of 0.8 percent. Increased amounts of fiber may reduce the stiffness of the soil and become difficult to mix with soil.

CHAPTER 4 CONSTRUCTION PROCEDURES

4-1 CONSTRUCTION WITH PORTLAND CEMENT.

4-1.1 General Construction Steps.

In soil-cement construction, the objective is to thoroughly mix a pulverized soil material and cement in correct proportions with moisture to permit maximum compaction. Construction methods are simple and follow a specific procedure:

4-1.1.1 Initial Preparation.

4-1.1.1.1 Shape the area to crown and grade.

4-1.1.1.2 If necessary, scarify, pulverize, and pre-wet the soil.

4-1.1.1.3 Reshape to crown and grade.

4-1.1.1.4 Precompact.

4-1.1.2 Processing.

4-1.1.2.1 Spread portland cement and mix.

4-1.1.2.2 Apply water, if necessary, to achieve the optimum moisture content.

4-1.1.2.3 Mix the additive and soil thoroughly.

4-1.1.2.4 Compact.

4-1.1.2.5 Finish.

4-1.1.2.6 Cure.

4-1.2 Mixing Equipment.

Soil, cement, and water can be mixed in place using traveling mixing machines or mixed in a central mixing plant.

4-1.2.1 Traveling Mixing Machines.

4-1.2.1.1 Transverse single-shaft mixer

4-1.2.1.2 Windrow-type pugmill

4-1.2.2 Central Mixing Plants.

4-1.2.2.1 Continuous flow-type pugmill

4-1.2.2.2 Batch-type pugmill

4-1.2.3 Principles and Objectives.

Regardless of the type of mixing equipment used, the general principles and objectives are the same. Certain soil materials cannot be pulverized and mixed in central mixing plants because of their high silt and/or clay content and plasticity. If necessary, determine if the soil materials can be pulverized and mixed by running a trial batch. Almost all types of soil materials, from granular to fine-grained, can be adequately pulverized and mixed with transverse-shaft mixers, given proper moisture control. The exception is material containing predominantly highly plastic clays. These clays may require more mixing effort to obtain pulverization. Revolving-blade central mixing plants and traveling pugmills can be used for non-plastic to slightly plastic granular soils. For coarse, non-plastic granular materials, a rotary-drum mixer can provide a suitable mix; however, if the material includes a small amount of slightly plastic fines, mixing may not be adequate. For plastic soils, it is very important to pulverize the soil thoroughly prior to mixing with the additive to reduce the “clod” size. Reducing the average particle size through pulverization increases the specific surface area of the soil, thereby improving the coating and ability of the additive to penetrate further into the particles.

4-1.3 Equipment for Handling and Spreading Cement.

There are a number of methods for handling cement. For mixed-in-place construction using traveling mixing machines, bulk cement is spread on the area to be processed in required amounts by mechanical bulk cement spreaders. It is permissible to use bag cement on jobs that are too limited in size to require mass quantities of cement. Cement spreaders for mix-in-place construction are of two general types: those that spread cement over the soil material in a blanket and those that deposit cement on top of a partially flattened or slightly trenched windrow of soil material. For centrally mixed soil-cement projects, cement meters on continuous-flow central mixing plants are of three types: the belt with strikeoff, screw, or vane. The cement for batch-type pugmill mixers and rotary drum-mixers is batch weighed.

4-1.4 Construction*.*

Construction with soil cement involves two steps: preparation and processing. Variations in these steps, dictated by the type of mixing equipment used, are discussed in this chapter. Regardless of the equipment and methods used, it is essential to have an adequately compacted, thorough mixture of pulverized soil material and proper amounts of cement and moisture. Adequately cure the completed soil-cement.

4-1.4.1 Preparation.

Before construction starts, check the crown and grade and complete fine grading. Since there is little displacement of material during processing, grade at the start of construction will determine final grade to a major extent. If borrow material is to be used, compact and shape the subgrade to the proper crown and grade before the borrow material is placed. Correct any soft subgrade areas. To avoid costly delays, carefully check all equipment to ensure it is in proper operating condition and meets construction requirements of the job. Utilize guide stakes and string lines to control the width and guide the operators during construction. Make arrangements to receive, handle, and spread the cement and water efficiently. The number of cement and water trucks required depends on length of haul, condition of haul roads, and anticipated rate of production. For maximum production, an adequate cement and water supply is essential. The project engineer establishes the limits of the different materials and their corresponding cement requirements. Pre-wetting the soil by adding moisture before cement is applied often saves time during actual processing. Friable granular materials, which are most commonly used, require little or no scarification or pulverization. Silty and clayey soils may require extra effort to pulverize them, particularly if they are too dry or too wet. Soils that are difficult to pulverize when dry and brittle can be broken down readily if water is added and allowed to soak in, whereas sticky soils can be pulverized more easily when they have been dried out slightly. Most specifications require that the soil material be pulverized so that at the time of compaction 100 percent of the soil-cement mixture will pass a 1 inch (25 mm) sieve and a minimum of 80 percent will pass a No. 4 (4.75 mm) sieve, exclusive of any gravel or stone. Ensure gravel or stone are no more than 2 inch (50 mm) maximum size or the stabilization effects will be minimal. Test the final pulverization at the conclusion of mixing operations. When borrow material is specified, distribute it on an accurately graded, well-compacted roadway in an even layer or uniform windrow, depending on the type of mixing equipment to be used. Place the fill by weight or volume as required by the specifications. Pre-compaction of the soil can help ensure the target design cement content and proper layer thickness are reached as well as provide a stable construction platform for equipment operation.

4-1.4.2 Processing.

For maximum efficiency and to meet specification time limits, break down a day's work into several adjacent sections rather than one or two long sections. This procedure will result in maximum daily production and will prevent a long stretch of construction from being rained out in case of a sudden severe rainstorm. This will help reduce issues from compaction of adjacent sections due to rapid cement curing.

4-1.4.2.1 Handling and Spreading Cement.

Bulk cement is typically trucked to the jobsite in bulk transport trucks or shipped to the nearest railroad siding in enclosed hopper cars. Compressed air or vibrators are used to loosen the cement in the hopper cars during unloading. Transfer to cement trucks is done pneumatically or by a screen or belt conveyor. The trucks are usually enclosed or fitted with canvas covers. The cement is weighed in truckloads on portable platform scales or at a nearby scale. Soil materials that contain excessive amounts of moisture will not mix readily with cement. Sandy soils can be mixed with moisture content at optimum or slightly above. Ensure that clayey soils have a moisture content below optimum when cement is spread. Do not apply cement onto puddles of water. If the soil material is excessively wet, aerate it to dry it before cement is applied. Handling and spreading procedures for different types of equipment are presented below.

(1) **Mechanical Cement Spread, Mixed-In-Place Construction*.*** Mechanical cement spreaders may be built into a truck, attached to a dump truck, or pulled behind a vehicle. As the vehicle moves forward, cement flows through the spreader, which regulates the quantity of cement placed on the prepared soil. To obtain a uniform cement spread, operate the spreader at a constant, slow speed and with a constant level of cement in

the hopper. Maintain a true line at the pavement edge with a string line. To produce a uniform cement spread, ensure the mechanical spreader has adequate traction. Traction can be aided by wetting and rolling the soil material before spreading the cement. When operating in loose sands or gravel, slippage can be overcome by the use of cleats on the spreader wheels or by other modifications; sometimes, the spreader is mounted on a tractor or high lift. The mechanical cement spreader can also be attached directly behind a bulk cement truck. Cement is then moved pneumatically from the truck through an air separator cyclone that dissipates the air pressure and falls into the hopper of the spreader. Operate the spreader with a slow, even forward speed to avoid variation in the spread rate. Sometimes a motor grader or loader pulls the truck to maintain this slow, even forward speed. Pipe cement spreaders attached to cement transport trucks have been used in some areas with variable results. Many modern cement spreaders utilize automated controls to ensure the correct amount of cement is metered during placement.

(2) **Bagged-Cement Spread, Mixed-In-Place Construction.** When bags of cement are used on small jobs, a simple but exact method for properly placing the bags is necessary. A grid or lane placement may be used. For grids, space the bags at approximately equal transverse and longitudinal intervals that will ensure the proper percentage of cement. For lanes, the bags are spaced equally within the lane. Positions can be spotted by flags or markers fastened to lines at proper intervals to mark the transverse and longitudinal rows. When the bags are opened, dump the cement so it forms fairly uniform transverse windrows across the area being processed. A spiketooth harrow, nail drag, or length of chain-link fence can be used to spread the cement evenly. Make at least two round trips using the drag over the area to uniformly spread the cement.

(3) **Cement Application, Central-Mixing-Plant Construction.** When a continuous-flow central mixing plant is used, the cement is usually metered onto the soil aggregate and the two materials are carried to the pugmill mixer on the main feeder belt. Variations in moisture and gradation of the soil aggregate will result in variations in the amount of material being fed onto the feeder belt. A high bulkhead placed in front of the soil hopper will help obtain a more uniform flow through the soil material feeder. The chance of loss of cement due to wind can be minimized by the use of a small plow attachment that forms a furrow for the cement in the soil aggregate. After the cement is added, a second plow attachment a little farther up on the main feeder belt closes the furrow and covers the cement. A cover on the main feeder belt will also minimize cement loss due to wind. One of three types of cement meters—belt, screw, or vane—can be used to proportion the cement on a volumetric basis. Each requires a 450- to 750-lb (204- to 340-kg) -capacity surge tank or hopper between the cement silo and the cement feeder. This tank maintains a constant head of cement for the feeder, thus providing a more uniform cement discharge. Use compressed air of 2- to 4-lb/in.^{2} pressure to prevent arching of cement in the silo and the surge tank. Portable vibrators

attached to the surge tank can be used instead of air jets. Include a positive system to automatically stop the plant if the cement flow suddenly stops. The correct proportion of cement, soil material, and water entering the mixing chamber is determined by calibrating the plant before mixing and placing operations begin.

4-1.4.2.2 Mixing and Applying Water.

Procedures for applying water and mixing depend on the type of mixing machine used. Thoroughly mix the pulverized soil material, cement, and water. Uniformity of the mix is easily checked by digging trenches or a series of holes at regular intervals for the full depth of treatment and inspecting the color of the exposed soil-cement mixture. Uniform color and texture from top to bottom indicate a satisfactory mix; a streaked appearance indicates improper mixing. Proper width and depth of mixing are also important. Following are methods of applying water and mixing for the different types of mixing machines.

(1) **Windrow-Type Traveling Mixing Machine.** Windrow-type traveling mixing machines will pulverize friable soil materials. Other soils, however, may need preliminary pulverizing to meet particle-size specification requirements. This is usually done before the soil is placed in windrows for processing. The prepared soil material is bladed into windrows and a proportion pulled along to make them uniform in cross-section. When borrow materials are used, a windrow spreader can be used to proportion the material. Non-uniform windrows cause variations in cement content, moisture content, and pavement thickness. The number and size of windrows needed depend on the width and depth of treatment and on the capacity of the mixing machine. Cement is spread on top of the partially flattened or slightly trenched, prepared windrow. The mixing machine then picks up the soil material and cement and dry-mixes them with the first few paddles in the mixing drum. At that point, water is added through spray nozzles and the remaining paddles complete the mixing. A strike-off attached to the mixing machine spreads the mixed soil-cement. If a motor grader is used to spread the mixture and a tamping roller is used for compaction, first loosen the mixture to ready it for compaction. If two windrows have been made, the mixing machine progresses 350 to 500 feet (107 to 152 m) along one windrow and then is backed up to process the other windrow for 700 to 1,000 feet (213 to 305 m). The cement-spreading operation is kept just ahead of the mixing operation. Water is supplied by tank trucks. A water tank installed on the mixer will permit continuous operation while the tank trucks are being switched. As soon as the first windrow is mixed and spread on one section of the roadway, it is compacted. At the same time a second windrow is being mixed and spread. It in turn is then compacted. Finishing the entire roadway is completed in one operation. Water requirements are based on the quantity of soil material and cement per unit length of windrow.

(2) **Single-Shaft Traveling Mixing Machine.** The only preparation required is shaping the soil material to the approximate required crown and grade. If

an old roadbed is extremely hard and dense, prewetting and scarification will facilitate processing. Applying water at this stage of construction saves time during actual processing operations because most of the required water will already have been added to the soil material. In very granular materials, pre-wetting prevents cement from sifting to the bottom of the mix by causing it to adhere more readily to the sand and gravel particles. Mixing the soil material and cement is easier if the moisture content of the raw material is two or three percentage points below optimum; however, very sandy materials can be mixed, even if the moisture content is one or two percentage points above optimum. Apply moisture uniformly during pre-wetting. By mixing it into the soil material, evaporation losses are reduced. Because of the hazard of night rains, some contractors prefer to do the pre-wetting in the early morning. After scarifying and pre-wetting, the loose, moist soil material is shaped to crown and grade. Pre-compaction of the soil can help ensure the target design cement content and proper layer thickness are achieved and provide a solid working platform for the spreading and mixing equipment. Cement is spread by a mechanical cement spreader or from bags. The mixer picks up the soil material and cement and mixes them in place. Water, supplied by a tank truck, is usually applied to the mixture by a spray bar mounted in the mixing chamber or it can be applied ahead of the mixer by water distribution equipment. Blend the soil material and cement when free water contacts the mixture to prevent the formation of cement balls. Accomplish processing in lanes 250 to 500 feet (76 to 152 m) long and as wide as the mixing machine. Cement is spread on the soil material in front of the mixing machine. Complete cement spreading in the first working lane and begin cement spreading in the second lane before mixing operations are begun. This ensures a full-width cement spread without a gap between lanes and keeps spreading equipment out of the way of mixing equipment. If water is being applied by injection, not the mixing chamber, then minimize the overlap of additional lanes to prevent overwatering. This can be readily accomplished using string lines.

4-1.4.2.3 Central Mixing Plant.

Central mixing plants are often used for projects involving borrow materials. The basic principles of thorough mixing, adequate cement content, proper moisture content, and adequate compaction apply. Friable granular borrow materials are generally used because of their low cement requirements and ease in handling and mixing. Pugmill-type mixers, either continuous flow or batch, and rotary-drum mixers are used for this work. Generally, the twin-shaft continuous-flow pugmill is used on highway projects. Provide facilities for efficiently storing, handling, and proportioning materials at the plant. Quantities of soil material, cement, and water can be proportioned by volume for achieving the desired mixture based upon dry unit weight. Mixing is continued until a uniform mixture of soil material, cement, and water is obtained. Equip haul vehicles with protective covers to reduce evaporation losses due to excessive temperature, high winds, and to protect the mixture against sudden rain. To prevent excessive haul time, do not allow more than 60 minutes to elapse between the start of moist-mixing and the start of compaction. Haul time is usually limited to 30 minutes. Place the mixed soil-cement on the subgrade without segregation in a quantity that will produce a compacted base of uniform density conforming to the specified grade and cross-section. Spread the mixture to full roadway width, either by one full-width spreader or by two or more spreaders operating in staggered positions across the roadway. Less preferable is the use of one piece of spreading equipment operating one lane at a time in two or more lanes. Do not spread cement so far ahead of the adjoining lane that a time lapse of more than 30 minutes occurs between the times of placing material in adjoining lanes at any location. Dampen the subgrade immediately prior to placing the soil-cement. Bituminous pavers have been used for spreading soil-cement, although modification may be necessary to increase volume capacity before they can be used. Perform compaction immediately behind the spreader. Leave a narrow, compacted ridge adjacent to the second lane during compaction of the first lane to serve as a depth guide when placing the mix in the second lane. Make equipment and water available and within reach to keep the joint areas damp. The amount of water needed to bring the soil-cement mixture to required moisture content in continuous-flow-type mixing plants is based on the amount of soil material and cement coming into the mixing chamber per unit of time. The amount of water required in batch-type central mixing plants is similarly calculated, using the weights of soil material and cement for each batch.

4-1.4.3 Compaction.

The principles governing compaction of soil-cement are the same as those for soil materials without cement treatment. Compact the soil-cement mixture at optimum moisture to maximum density and finish immediately. Treat moisture loss by evaporation during compaction, indicated by a graying of the surface, with light applications of water. Tamping rollers are generally used for initial compaction except for the more granular soils. Self-propelled, vibratory, and pneumatic rubber-tired models are also used. To obtain adequate compaction, it is sometimes necessary to operate the rollers with ballast to give greater unit pressure, depending on the soil characteristics as determined in the field at the time of construction. The general rule is to use the greatest contact pressure that will not exceed the bearing capacity of the soil-cement mixture and that will still "walk out" in a reasonable number of passes. Friable silty and clayey sandy soils will compact satisfactorily using rollers with unit pressures of 75 to 125 lb/in^2. Clayey sands, lean clays, and silts that have low plasticity can be compacted with 100- to 200-lb/in^2 rollers. Medium to heavy clays and gravelly soils require greater unit pressure: 150 to 300 lb/in^2. Compacted thickness up to 8 or 9 inch (200 to 230 mm) can be compacted in one lift. Greater thicknesses can be compacted with equipment designed for deeper lifts. When tamping rollers are used for initial compaction, ensure the mixed material is in a loose condition at the start of compaction so the feet will pack the bottom material and gradually walk out on each succeeding pass. If penetration is not being obtained, the scarifier on a motor grader or a traveling mixer can be used to loosen the mix during start of compaction, thus allowing the feet to penetrate. Vibratory-steel-wheeled rollers and grid and segmented rollers can be used to satisfactorily compact soil-cement that contains granular soil materials. Vibratory-plate compactors are used on non-plastic granular materials. Pneumatic rubber-tired rollers can be used to compact coarse sand and gravel soil-cement mixtures with very little plasticity and very sandy mixtures with little or no binder material, such as dune, beach, or blow sand. Some rollers are fabricated to permit rapid inflation and deflation of the tires while compacting to increase their versatility. Heavy three-wheeled steel rollers can be used to compact coarse granular materials containing little or no binder material. Gravelly soils that contain up to about 20 percent passing the No. 200 (0.075 mm) sieve and have low plasticity are best suited for compaction with these rollers. Tandem-steel-wheeled rollers are often used during final rolling to press down or set rock particles and smooth out ridges.

There are two general types of road cross-sections: trench and featheredge. Both can be built satisfactorily with soil-cement. In trench-type construction, the shoulder material gives lateral support to the soil-cement mixture during compaction. In the featheredge type of construction, the edges are compacted first to provide edge stability while the remaining portion is being compacted. Do not construct the edge slope steeper than 2:1 to facilitate shaping and compacting. Shoulder material is placed after the soil-cement has been finished. Occasionally, during compaction and finishing, a localized area may yield under the compaction equipment. This may be due to one or more causes: the soil-cement mix is much wetter than optimum moisture; the subsoil may be wet and unstable; or the roller may be too heavy for the soil. If the soil-cement mix is too damp, aerate it with a cultivator, traveling mixer, or motor grader. After it has dried to near-optimum moisture, it can be compacted. For best results, start compaction immediately after the soil material, cement, and water have been mixed. It is critical that compaction occur as soon after mixing the materials as possible because hydration of the cement will begin as soon as the dry cement comes into contact with moist soil or free mixing water added to achieve optimum moisture content for compaction. Required densities are then obtained more readily, there is less water evaporation, and daily production is increased. Perform compaction by moving side-to-side over an area and not back and forth in a lane until the required number of passes is reached. This will help incrementally compact the soil and knead the soil back and forth across adjacent lanes to prevent a seam.

4-1.4.4 Finishing.

There are several acceptable methods for finishing soil-cement. The exact procedure depends on the available equipment, job conditions, and soil characteristics. Regardless of method, meet all fundamental requirements of adequate compaction, close to optimum moisture, and remove all surface compaction planes to produce a high-quality surface. It is critical that the design crown and grade be established prior to mixing to minimize the corrections required after mixing and compaction when the stabilized material is hardening due to hydration. If proper preparation and mixing are achieved, finishing is typically not necessary except at construction joints. If finishing is needed, finish the surface smooth, dense, and free of ruts, ridges, or cracks. When shaping is done during finishing, scarify (scratch) all smooth surfaces, such as tire imprints and blade marks, with a weeder, nail drag, coil spring, or spiketooth harrow to remove cleavage or compaction planes from the surface. Scratching may be done on all soil-cement mixtures except those containing appreciable quantities of gravel. Keep the surface damp during finishing operations. Steel-wheeled rollers can be used to smooth out ridges left by the initial pneumatic-tire rolling. Steel-wheeled rollers are particularly advantageous when rock is present in the surface. A broom drag can be used advantageously to pull binder material in and around pieces of gravel that have been set by the steel-wheeled roller. Instead of using a steel roller, surfaces can be shaved with the motor grader and then rerolled with a pneumatic rubber-tired roller to seal the surface. Shaving consists of lightly cutting off any small ridges left by the finishing equipment. Only a very thin depth is cut and all material removed is bladed to the edge of the road and wasted. The final operation usually consists of a light application of water and rolling with a pneumatic rubber-tired roller to seal the surface. Any surface corrections are achieved immediately after compaction since the stabilized soil will be rapidly gaining strength. The finished soil-cement is then cured.

4-1.4.5 Curing.

Compacted and finished soil-cement contains moisture for cement hydration. A moisture-retaining cover is placed over the soil-cement soon after completion to retain this moisture and allow the cement to hydrate. Most soil-cement is cured with a bituminous material surface application but other materials such as polymer emulsion, waterproof paper or plastic sheets, wet straw or sand, fog-type water spray, and wet burlap or cotton mats are satisfactory. The type of bituminous material most commonly used is emulsified asphalt SS-1. Polymer emulsions may also be used. The rate of application varies from 0.15 to 0.30 US gal/sq yd (0.68 to 1.36 liter/sq m). At the time of application, ensure the soil-cement surface is free of all dry, loose, and extraneous material. Moisten the surface with a fog spray before emulsion materials are applied. In most cases, a light application of water is placed immediately ahead of the emulsion application. This helps improve penetration into the surface and increases adhesion.

4-1.4.6 Construction Joints.

After each day's construction, form a transverse vertical construction joint by cutting back into the completed soil-cement to the proper crown and grade. This is usually the last task performed at night or the first task performed the following morning. This may be accomplished using the mixer or a dry-cut walk-behind saw can be used to provide a clean cutting edge. Ensure the joint is vertical and perpendicular to the centerline. After the next day's mixing has been completed at the joint, clean the area of all dry and unmixed material and re-trim if necessary. Mixed moist material is then bladed into the area and thoroughly compacted. The joint is left slightly high until final rolling when it is trimmed to grade with the motor grader and rerolled. Joint construction requires special attention to make sure the joints are vertical and the material in the joint area is adequately mixed and thoroughly compacted. When bituminous material is used as a curing agent, apply it right up to the joint and sanded to prevent pickup.

4-1.4.7 Multiple-Layer Construction.

When the specified thickness of soil-cement base course exceeds the depth (usually 8 or 9 inches [200 to 230 mm] compacted) that can be compacted in one layer, construct in multiple layers. Construct all layers to be less than 4 inches (100 mm) thick. The lower layer does not have to be finished to exact crown and grade nor do surface compaction planes have to be removed since they are too far from the final surface to be harmful. The lower layer can be cured with the moist soil that will subsequently be used to build the top layer, which can be built immediately, the following day, or at a later time. With mixed-in-place construction, take care to eliminate any raw-soil seams between the layers.

4-1.5 Special Construction Problems.

4-1.5.1 Rainfall.

Attention to a few simple precautions before processing will greatly reduce the possibility of serious damage from wet weather. For example, crown any loose or pulverized soil so it will shed water and trench low places in the grade where water can accumulate so the water will freely drain off. As shown by the construction of millions of square yards of soil-cement in all climates, it is unlikely that rainfall during actual construction will be a serious problem to the experienced engineer or contractor. Usually, construction requires the addition of water equivalent to 1 to 1.5 inches (25 to 37.5 mm) of rain. If rain falls during cement-spreading operations, stop spreading cement and quickly mix the cement already spread into the soil mass. A heavy rainfall that occurs after most of the water has already been added, however, can be serious. The best defense against rainfall is not to allow the cement placement to exceed the mixing and compaction. It is easy for the placement and mixing to outpace compaction because compaction is usually the slowest step. Then, if rainfall becomes imminent, try to obtain rapid compaction by using every available piece of equipment so the section will be compacted and shaped before too much damage results. In such instances, it may be necessary to complete final blade work later; any material bladed from the surface is wasted. After the mixture has been compacted and finished, rain will not harm it.

4-1.5.2 Wet Soils.

Excessively wet material is difficult to mix and pulverize. Experience has shown that cement can be mixed with sandy materials when the moisture content is as high as 2 percent above optimum with adequate results. For clayey soils, the moisture content needs to be below optimum for efficient mixing. It may be necessary to dry out the soil material by aeration prior to mixing. This can be done by using single-shaft traveling mixers with the hood in a raised position or by cutting out the material with the tip of a motor grader blade and working and aerating with a disc. The maintenance of crown and surface grade to permit rapid runoff of surface water before soil-cement processing is the best insurance against excessive amounts of wet material.

4-1.5.3 Cold Weather.

Soil-cement, like other cement-using products, hardens as the cement hydrates. Since cement hydration practically ceases when temperatures are near or below freezing, do not place soil-cement when the temperature is 40 °F (4.4 °C) or below. Moreover, protect it to prevent its freezing for a period of seven days after placement and until it has hardened by a suitable covering of hay, straw, or other protective material.

4-2 CONSTRUCTION WITH LIME.

4-2.1 Lime Stabilization Methods.

There are three recognized lime-stabilization methods: in-place mixing, plant mixing, and pressure injection.

4-2.1.1 In-Place Mixing.

In-place mixing may be subdivided into three methods: mixing lime with the existing materials in place at the construction site or pavement; off-site mixing in which lime is mixed with borrow and the mixture is then transported to the construction site for final manipulation and compaction; and mixing in which the borrow source soil is hauled to the construction site and processed in place as in the first method.

The following procedures are for in-place mixing:

4-2.1.1.1 One increment of lime is added to clays or granular base materials that are easy to pulverize. The material is mixed and compacted in one operation and no mellowing period is required. (The term "mellow" refers to the reaction of the lime on clay to make it more friable and easier to pulverize.)

4-2.1.1.2 One increment of lime is added and the mixture is allowed to mellow for a period of 1 to 7 days to assist in breaking down heavy clay soils.

4-2.1.1.3 One increment of lime is added for soil modification and pulverization before treatment with cement or asphalt.

4-2.1.1.4 One increment of lime is added to produce a working table. Proof rolling is required instead of pulverization and density requirements.

4-2.1.1.5 Two increments of lime are added for soils that are extremely difficult to pulverize. Between the applications of the first and second increments of lime, the mixture is allowed to mellow.

4-2.1.1.6 Deep stabilization may be accomplished by one of two approaches.

- One increment of lime is applied to modify soil to a depth of 24 inches (600 mm). Greater depths are possible but to date have not been attempted. A second increment of lime is added to the top 6 to 12 inches (130 to 300 mm) for complete stabilization. Plows and rippers are used to break down the clay chunks in the deep treatment. Heavy disc harrows and blades are also used in pulverization of these clay soils. In frost zones, the use of lime for soil modification under certain circumstances results in a frost-susceptible material that can produce a weak sublayer. Perform trial batches to determine these characteristics prior to construction.
- One increment of lime is applied for complete stabilization to a depth of 18 in (460 mm). Mechanical mixers are now available to pulverize the lime-clay soil to the full depth by progressive cuts as follows: first-pass cut to a depth of 6 inches (150 mm), second to 9 inches (230 mm), third to 12 inches (300 mm), fourth to 15 inches (380 mm), and then a few passes to a depth of 18 inches (460 mm) to accomplish full pulverization. The full 18 inch (460 mm) is compacted from the top by vibratory and conventional heavy rollers. Make all attempts to compact in normal 8- to 9-inch (200 to 230 mm) lifts if the stabilized soil will be used near the surface of a pavement.

4-2.1.2 Plant Mixing.

The plant-mix operation usually involves hauling the soil to a central plant where lime, soil, and water are uniformly mixed and then transported to the construction site for further manipulation. The amount of lime for either method is usually predetermined by test procedures. Specifications may be written to specify the actual strength gain required to upgrade the stabilized soil and notations can be made on the plans concerning the estimated percent of lime required. This note stipulates that changes in lime content may be necessary to meet changing soil conditions encountered during construction.

4-2.1.3 Pressure Injection.

Pressure injections of lime slurry to depths of 7 to 10 feet (2.1 to 3 m) for control of swelling and unstable soils on highways and under building sites are usually placed on 5-foot (1.5-m) spacing and attempts are made to place horizontal seams of lime slurry at 8 to 12 inches (200 to 300 mm) intervals. Stabilize the top 6- to 12-inch (150 to 300 mm) layer by conventional methods.

4-2.2 Construction Steps.

4-2.2.1 Soil Preparation.

Bring the in-place subgrade soil to final grade and alignment. The finished grade elevation may require adjustment because of the potential fluff action of the lime-stabilized layer because soils tend to increase in volume when mixed with lime and water. This volume change may be exaggerated when the soil-lime is remixed over a long period of time, especially at moisture contents less than optimum moisture. The fluff action is usually minimized if adequate water is provided and mixing is accomplished shortly after lime is added. For soils that tend to fluff with lime, lower the subgrade elevation slightly or the excess material trimmed. Trimming can usually be accomplished by blading the material onto the shoulder of embankment slopes. The blading operation is desirable to remove the top 0.25 inch (6 mm) because this material is not often well-reacted due to lime loss during construction. Excess rain and construction water may wash lime from the surface and carbonation of lime may occur in the exposed surface. If dry lime is used, ripping or scarifying to the desired depth of stabilization can be accomplished either before or after lime is added. If the lime is applied in a slurry form, scarify prior to adding lime.

4-2.2.2 Lime Application.

4-2.2.2.1 Dry Hydrated Lime.

Dry lime can be applied either in bulk or by bag. The use of bagged lime is generally the simplest but also the costliest method of lime application. Fifty-pound bags of lime are delivered in dump or flatbed trucks and placed by hand to give the required distribution. After the bags are placed, they are slit and the lime is dumped into piles or transverse windrows across the roadway. The lime is then leveled either by hand-raking or by a spike-tooth harrow or drag pulled by a tractor or truck. Immediately after, the lime is sprinkled with water to reduce dusting. The major disadvantages of the bag method are the higher costs of lime because of bagging costs, greater labor costs, and slower operations. Nevertheless, bagged lime is often the most practical method for small projects or for projects in which it is difficult to utilize heavy equipment. For stabilization projects, particularly where dusting is no problem, the use of bulk lime has become common practice. Lime is delivered to the job in self-unloading transport trucks. These trucks are efficient, being capable of hauling 15 to 24 tons (13,600 to 21,800 kg). One type is equipped with one or more integral screw conveyors that discharge at the rear. Pneumatic trucks have increased in popularity and are preferred over the older auger-type transports. With the pneumatic units, the lime is blown from the tanker compartments through a pipe or hose to a cyclone spreader or pipe spreader bar-mounted at the rear. Bottom-dump hopper trucks have also been tried but they are undesirable because of difficulty in unloading and obtaining a uniform rate of discharge. With auger trucks, spreading is handled by means of a portable, mechanical-type spreader attached to the rear or through metal downspout chutes or flexible rubber boots extending from the screw conveyors. The mechanical spreaders incorporate belt, screw, rotary vane, or drag-chain conveyors to uniformly distribute the lime across the spreader width. When boots or spouts are used, the lime is deposited in windrows but, because of lime's lightness and flowability, the lime becomes distributed rather uniformly across the spreading lane. Whether mechanical spreaders, downspouts, or boots are used, the rate of lime application can be regulated by varying the spreader opening, spreader drive speed, or truck speed so the required amount of lime can be applied in one or more passes. With pneumatic trucks, spreading is generally handled with a cyclone spreader mounted at the rear, which distributes the lime through a split chute or with a spreader bar equipped with several downspout pipes. Fingertip controls in the truck cab permit the driver to vary the spreading width by adjusting the air pressure. Experienced drivers can adjust the pressure and truck speed so accurate distribution can be obtained in one or two passes. When bulk lime is delivered by rail, a variety of conveyors can be used for transferring the lime to transport trucks, including screw, belt, or drag-chain conveyors, bucket elevators, and screw elevators. The screw-type conveyors are most commonly used, with units of 10 to 12 inches (254 to 305 mm) in diameter being recommended for high-speed unloading. To minimize dusting, enclose all conveyors. Rail-car unloading is generally facilitated by means of poles and mechanical or air-type vibrators. Lime has also been handled through permanent or portable batching plants; the lime is weigh-batched before loading. Generally, a batch plant setup is practical only on exceptionally large projects such as a runway, airport, or main apron at an installation. Obviously, the self-unloading tank truck is the least costly method of spreading lime because there is no rehandling of material and payloads can be carried and spread quickly.

4-2.2.2.2 Dry Quicklime.

Quicklime may be applied in bags or bulk. Because of higher cost, bagged lime is used only for drying of isolated wet spots or on small jobs. The distribution of bagged quicklime is similar to that of bagged hydrated lime except that an emphasis on safety is needed. First, the bags are accurately spaced on the area to be stabilized and, after spreading, water is applied and mixing operations started immediately. The fast watering and mixing operation helps minimize the danger of burns. Quicklime may be applied in the form of pebbles of approximately 3/8 inch (9.5 mm), granular, or pulverized. The first two are more desirable because less dust is generated during spreading. Bulk quicklime may be spread by self-unloading auger or pneumatic transport trucks, similar to those used for dry hydrated lime. However, because of its coarser size and higher density, quicklime may also be tailgated either from a regular dump truck with tailgate-opening controls to ensure accurate distribution or from a bulk transport truck. Because quicklime is anhydrous and generates heat on contact with water, take special care during stabilization to avoid lime burns. Where quicklime is specified, provide the engineer with a detailed safety program covering precautions and emergency treatment available on the jobsite. Include in the program protective equipment for eyes, mouth, nose, and skin, as well as a first-aid kit containing an eyewash station. Ensure this protective equipment is available on the jobsite during spreading and mixing operations. Actively enforce this program for protecting workers and others in the construction area.

4-2.2.2.3 Slurry Method.

In this method either hydrated lime or quicklime and water are mixed into a slurry. With quicklime, the lime is first slaked and excess water added to produce the slurry.

4-2.2.2.4 Slurry Made with Hydrated Lime.

This method was first used in the 1950s and remains popular, especially where dust from using dry lime is a problem. The hydrated lime-water slurry is mixed either in a central mixing tank, jet mixer, or in a tank truck. The slurry is spread over the scarified roadbed by a tank truck equipped with spray bars. One or more passes may be required over a measured area to achieve the specified percentage based on lime solids content. To prevent runoff and consequent nonuniformity of lime distribution that may occur under certain conditions, it may be necessary to mix the slurry and soil immediately after each spreading pass. A typical slurry mix proportion is 1 ton (907 kg) of lime and 500 gal (1893 L) of water, which yields about 600 gal (2271 L) of slurry containing 31 percent lime solids. At higher concentrations there is difficulty in pumping and spraying the slurry; 40 percent solids is the maximum pumpable slurry. The actual proportion used depends on the percentage of lime specified, the type of soil, and its moisture condition. When small lime percentages are required, the slurry proportions may be reduced to 1 ton (907 kg) of lime per 700 to 800 gal (2650 to 3028 L) of water. Where the soil moisture content is near optimum, a stronger lime concentration is typically required. In plants employing central mixing, agitation is usually accomplished by using compressed air and recirculating pumps, although pugmills have also been used. The typical slurry plant incorporates slurry tanks that handle whole tanker truckloads of hydrated lime of approximately 20 tons (18,144 kg). The mixer and auxiliary equipment can be mounted on a small trailer and readily transported to the job, giving great flexibility to the operation. In another type of slurry setup, measured amounts of water and lime are charged separately to the tank truck, with the slurry being mixed in the tank either by compressed air or by a recirculating pump mounted at the rear. The water is metered and the lime proportioned volumetrically or by means of weight batchers. Spreading from the slurry distributors is effected by gravity or pressure spray bars, the latter being preferred because of better distribution. The use of spray deflectors is also recommended for proper distribution. The general practice in spreading is to make either one or two passes per load; however, several loads may be needed to distribute the required amount of lime. The total number of passes will depend on the lime requirement, the optimum moisture of the soil, and the type of mixing employed. Windrow mixing with the grader generally requires several passes.

4-2.2.2.5 Double Application of Lime.

In areas where extremely plastic clay (PI 50+) abounds, it may prove advantageous to add the requisite amount of lime in two increments to facilitate adequate pulverization and obtain complete stabilization. For example, 2 or 3 percent lime is added first, partially mixed, then the layer is sealed and allowed to mellow for up to a week. The remaining lime is then added before final mixing. The first application mellows the clay and helps achieve final pulverization and the second application completes the lime-treatment process.

4-2.2.2.6 Slurry Made with Quicklime.

A slurry lime rig consists of a 10-foot (3 m) -diameter by 40-foot (12.2 m) tank that incorporates a 5-foot (1.5 m) -diameter single-shaft agitator turned by a diesel engine. The batch slaker can handle 20 to 25 tons (18,144 to 22,680 kg) of quicklime and about 25,000 gal (94,635 L) of water, producing the slurry in about 1 to 1.5 hours. Because of the exothermic action of quicklime in water, the slurry is produced at a temperature of about 185 °F (85 °C).

4-2.2.2.7 Advantages and Disadvantages of Dry Hydrated Lime.

(1) Advantages:

- Dry lime can be applied two or three times faster than a slurry.
- Dry lime is very effective in drying out soil.

(2) Disadvantages:

- Dry lime produces a dusting problem that makes its use undesirable in urban areas.
- The fast-drying action of the dry lime requires an excess amount of water during dry, hot seasons.

4-2.2.2.8 Advantages and Disadvantages of Dry Quicklime.

(1) Advantages:

- Dry quicklime is more economical since it contains approximately 25 percent more available free lime.
- It has greater bulk density for smaller-sized silos.
- It has faster drying action in wet soils and faster reaction with all soils. Construction season can be extended in both spring and fall because of faster drying.

(2) Disadvantages:

- The field hydration of dry quicklime, which produces a coarser material with poorer distribution in soil mass, is less effective than commercial hydration.
- Quicklime requires more water than hydrated lime for stabilization, which may present a problem in dry areas.
- Workers with dry quicklime have greater susceptibility to skin and eye burns.

4-2.2.2.9 Advantages and Disadvantages of Lime Slurry.

(1) Advantages:

- Dust-free application is more desirable from an environmental standpoint.
- Better distribution is achieved with the slurry.
- In the lime slurry method, the lime spreading and watering operations are combined, reducing job costs.
- During summer months, a slurry application wets the soil and minimizes drying action.
- The added heat when slurry is made from quicklime speeds the drying action, which is especially desirable in cooler weather.

(2) Disadvantages:

- Application rates are slower. High-capacity pumps are required to achieve acceptable application rates.
- Extra equipment is required; therefore, costs are higher.
- Extra manipulation may be required for drying purposes during cool, wet, or humid weather, which occurs during the fall, winter, and spring construction season.
- Lime slurries are not practical for use with very wet soils.

4-2.2.3 Pulverization and Mixing.

To obtain satisfactory soil-lime mixtures, achieve adequate pulverization and mixing. For heavy clay soils, two-stage pulverization and mixing may be required but, for other soils, one-stage mixing and pulverization may be satisfactory. The difference is primarily due to heavy clays being more difficult to break down. Perform a test strip at the beginning of new projects to establish the most efficient pulverization, additive distribution, and mixing process for the available equipment and existing site conditions.

4-2.2.3.1 Two-stage Mixing.

Construction steps in two-stage mixing consist of preliminary mixing, moist curing for 24 to 48 hours (or more), and final mixing or remixing. The first mixing step distributes the lime throughout the soil, thereby facilitating the mellowing action. For maximum chemical action during the mellowing period, ensure the clay clods are less than

2 inches (50 mm) in diameter or the reaction will not completely reach all soils. Before mellowing, liberally sprinkle the soil to bring it up to at least two percentage points above optimum moisture to aid the disintegration of clay clods. The exception to excess watering is in cool, damp weather when evaporation is at a minimum. In hot weather and coarser gradations, it may be difficult to add too much water. After preliminary mixing, lightly seal the roadway with a pneumatic rubber-tired roller as a precaution against heavy rain because the compacted subgrade will shed water, thereby preventing moisture increases that might delay construction. Generally, in 24 to 48 hours the clay becomes friable enough so desired pulverization can be easily attained during final mixing. Additional sprinkling may be necessary during final mixing to bring the soils to optimum moisture or slightly above. In hot weather, more than optimum moisture is needed to compensate for loss through evaporation. Although disc harrows and grader scarifiers are suitable for preliminary mixing, high-speed rotary mixers or one-pass travel plant mixers are required for final mixing. Motor graders are generally unsatisfactory for mixing lime with heavy clays.

4-2.2.3.2 One-stage Mixing.

Both blade and rotary mixing, or a combination, have been used successfully in projects involving granular base materials. However, rotary mixers are preferred for more uniform mixing, finer pulverization, and faster operation. They are generally required for highly plastic soils that do not readily pulverize and for reconstructing worn-out roads to pulverize the old asphalt.

4-2.2.3.3 Blade Mixing.

When blade mixing is used in conjunction with dry lime, the material is generally bladed into two windrows, one on each side of the roadway. Lime is then spread on the inside of each windrow or down the centerline of the road. The soil is then bladed to cover the lime. After the lime is covered, the soil is mixed dry by blading across the roadway. After dry mixing is completed, water is added to slightly above the optimum moisture content and additional mixing is performed. To ensure thorough mixing by this method, handle the material on the moldboard at least three times. When blade mixing is used with the slurry method, the mixing is done in thin lifts that are bladed to windrows. One practice is to start with the material in a center windrow then blade aside a thin layer after the addition of each increment of slurry, thereby forming side windrows. The windrowed material is then bladed back across the roadway and compacted, provided that its moisture content is at optimum. A second practice is to start with a side windrow then blade in a thin 2-inch (50 mm) layer across the roadway, add an increment of lime, and blade this layer to a windrow on the opposite side of the road. This procedure is repeated several times until all the material is mixed and bladed to the new windrow. Because only half of the lime has been added at this time, the process is repeated, moving the material back to the other side. This procedure is slow but it may be necessary when rotary mixing equipment cannot be easily obtained.

4-2.2.3.4 Central Mixing.

Premixing lime with granular base materials is common on new construction projects, particularly where marginal gravels are used. Because the gravel has to be processed anyway to meet gradation specifications, it is a relatively simple matter for the contractor to install a lime bin, feeder, and pugmill at the screening plant. The general practice is to add the optimum moisture at the pugmill, thereby permitting immediate compaction after laydown.

4-2.2.3.5 Pulverization and Mixing Requirements.

Pulverization and mixing requirements are generally specified in terms of percentages passing the 1.5 inch (37.5 mm) or 1 inch (25 mm) screen and the No. 4 (4.75 mm) sieve. Typical requirements are 100 percent passing the 1 inch (25 mm) screen and 60 percent passing the No. 4 (4.75 mm) sieve, exclusive of nonslaking fractions. In certain expedient construction operations, formal requirements are eliminated and the "pulverization and mixing to the satisfaction of the engineer" clause is employed.

4-2.2.4 Compaction.

For maximum development of strength and durability, properly compact lime-soil mixtures to at least 95 percent of ASTM D698, *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3))*, density for subbase and 90 percent for bases for roads and non-traffic areas. Frequently, agencies require 95 percent ASTM D1557 maximum density, particularly for airfield projects. Although such densities can be achieved for granular soil-lime mixtures, it is difficult to achieve this degree of compaction for lime-treated, fine-grained soils. If a thick soil-lime lift is to be compacted in one lift, some project specifications require 95 percent of ASTM D698 maximum density in the upper 6 to 9 inches (150 to 230 mm) while 90 to 92 percent is acceptable in the bottom portion of the lift. However, do not use deep mixing techniques routinely for airfield projects. To achieve maximum densities, compacting at near optimum moisture content with appropriate compactors is necessary. Granular soil-lime mixtures are generally compacted as soon as possible after mixing, although delays of up to two days are not detrimental, especially if the soil is not allowed to dry out and lime is not allowed to carbonate. Fine-grained soils can also be compacted soon after final mixing, although delays of up to four days are not detrimental. When longer delays (two weeks or more) cannot be avoided, it may be necessary to incorporate a small amount of additional lime into the mixture (0.5 percent) to compensate for losses due to carbonation and erosion. Various rollers and layer thicknesses have been used in lime stabilization. The most common practice is to compact in one lift by first using the sheepsfoot roller until it "walks out" and then use a multiple-wheel pneumatic rubber-tired roller. Occasionally, a flat wheel roller is used in finishing. Single-lift compaction can also be accomplished with vibrating impact rollers or heavy pneumatic rollers, and light pneumatic or steel rollers can be used for finishing. When light pneumatic rollers are used alone, compaction is generally done in thin lifts, usually less than 6 inches (150 mm). During compaction, light sprinkling may be required, particularly during hot, dry weather, to compensate for evaporation losses.

4-2.2.5 Curing.

Maximum development of strength and durability also depends on proper curing. Favorable temperature and moisture conditions and the passage of time are required for curing. Temperatures higher than 40 °F to 50 °F (4.4 °C to 10 °C) and moisture contents around optimum are conducive to curing. Although some project specifications require a three- to seven-day undisturbed curing period, other agencies permit the immediate placement of overlaying paving layers if the compacted soil-lime layer is not rutted or distorted by the equipment. This overlying course maintains the moisture content of the compacted layer and is an adequate medium for curing. Two types of curing can be employed: moist and asphaltic membrane. In the first, the surface is kept damp by sprinkling, with light rollers being used to keep the surface knitted together. In membrane curing, the stabilized soil is sealed with asphalt at a rate of 0.10 to 0.25 gal/sq yd (0.45 to 1.13 liter/sq m). The membrane may need to be applied in multiple applications, depending on how much can be applied to the surface at one time without running off.

4-3 CONSTRUCTION WITH LIME-FLY ASH (LF) AND LIME-CEMENT-FLY ASH (LCF).

Construction procedures for LF and LCF are similar to those used for lime stabilization. Although both field in-place and central plant mixing may be used with LF and LCF, the latter procedure is recommended to obtain adequate proportioning and mixing. With LCF, note that the presence of cement requires the stabilized mixture be compacted as soon as possible.

4-4 CONSTRUCTION WITH BITUMEN OR POLYMER EMULSION.

Bituminous stabilization can involve either hot-mix or cold-mix materials. Bitumen and aggregate or soil can be blended in place or in a central plant. Construction procedures presented in this UFC are for cold-mix materials that are mixed in place (asphalt or polymer emulsions) or in a central plant. Construction procedures for hot-mix hot-laid materials are similar to those used for asphalt concrete. Follow applicable standard construction procedures when these materials are involved. Foamed bitumen stabilization is an in-place technique that involves injecting water into hot bitumen to create a foaming effect that efficiently coats soil particles. The use of cutback asphalts (asphalt mixed with solvent such as diesel or naphtha) as stabilizing materials are generally not acceptable due to environmental and health safety concerns. Procedures described below are applicable to a variety of liquid stabilizers.

4-4.1 Equipment for Mixed-in-Place Materials.

Some pieces of equipment used for mixed-in-place bituminous stabilization are similar to those used in standard construction and will not be described here. These include water distributors, compaction equipment, graders, and windrow sizers. Only equipment especially associated with or having special features applicable to liquid stabilization will be discussed.

4-4.1.1 Mixing Equipment.

4-4.1.1.1 Travel Plants.

Travel plants are a less common method of stabilization. Travel plants are self-propelled pugmill plants that proportion and mix aggregates and asphalt as they move along the road. There are two general types of travel plants: one that moves through a prepared aggregate windrow on the roadbed, adds and mixes the asphalt as it goes, and discharges a mixed windrow to the rear of the machine ready for aeration and spreading, and one that receives aggregate into its hopper from haul trucks, adds and mixes asphalt, and spreads the mix to the rear as it moves along the roadbed. Certain features and performance capabilities are common to all travel plants, enabling them to operate effectively and produce a mix meeting design and specification criteria.

4-4.1.1.2 Rotary-type Mixers.

Rotary or mechanical onsite mixing is the most common form of stabilization and is accomplished by what is essentially a mobile mixing chamber mounted on a self-propelled machine. A reclaimer-stabilizer machine is the most versatile mixing machine as it can mill asphalt and mix most soils. Within the chamber, usually about 6 to 8 feet (1.8 to 2.4 m) wide and open at the bottom, is a rotating drum with cutting blades or milling teeth that revolve at relatively high speed. A dedicated soil mixer can also be used but has only tines for mixing and is much less powerful. As the machine moves ahead, it strikes off behind it a uniform course of soil. Most single-shaft mixers are equipped with a liquid injection system (LIS) that adds water or emulsion by spraying it directly into the mixing chamber as the machine moves ahead, with the flow rate of liquid being synchronized with the travel speed to reach a prescribed dosage. This is an excellent method for achieving proper mixing of liquid and soil. If not equipped with an LIS, use the mixer in conjunction with a liquid distributor that sprays the liquid onto the aggregate or soil immediately ahead of the mobile mixer. Both types of machines have the common capability of effecting a smooth bottom cut and then blending the material into the specified mixture. Ensure machines with an LIS have the capability for accurate metering and blending of liquid into the in-place materials in synchronization with a continuous forward movement, have spray bars that will distribute the liquid uniformly across the mixer's width, and are equipped for controlling the depth of cutting. Foamed asphalt stabilization is accomplished using a reclaimer-stabilizer machine specially outfitted for injecting foamed asphalt into the mixing chamber.

4-4.1.1.3 Motor Graders.

Blade mixing is the onsite mixing of materials on the roadbed by a motor grader. This is also a common form of in-place mixing, albeit slow and less efficient than mixing machines. The stabilizing material (generally a slow-setting asphalt or polymer emulsion) is applied directly ahead of the motor grader by an asphalt distributor or other spray device. For most effective blade mixing, equip the motor grader with a blade at least 10 feet (3 m) long and a wheelbase of at least 15 feet (4.6 m). Equip motor graders used for final layout and finishing of the surface with smooth, rather than treaded, pneumatic tires. Scarifier or plow attachments may be mounted before, behind, or both before and behind the blade. This method is not generally recommended for bitumen or polymer emulsion mixing due to the adhesive nature of the additives and the propensity to form pockets of unmixed additive.

4-4.1.1.4 Liquid Distributor.

The liquid distributor is a key piece of equipment in cold mix construction with liquid additives, particularly when rotary mixers without built-in liquid injection systems are used or when blade mixing is utilized. The liquid distributor, either truck or trailer-mounted, may consist of an insulated tank, self-contained heating system, a pump, and a spray bar and nozzles through which the liquid is applied under pressure onto the prepared aggregate materials. The most common liquid distributors are made for asphalts and range in performance and capability. It is important to keep an adequate supply of asphalt or polymer emulsion at or near the jobsite to avoid delays. In rural areas, it may be advisable to have a bulk supply truck at the project.

4-4.2 Mixed-in-Place Construction.

4-4.2.1 Windrows.

Several types of cold-mix construction require the aggregates be placed in windrows prior to mixing and spreading. If windrows are to be used, clear the area of all vegetation to a width to accommodate both windrow and traffic while the mixture cures. Because the thickness of the new pavement is directly proportional to the amount of aggregate in the windrow(s), accurate control and measurement of the volume of the windrowed material is necessary. Usually, there is not enough loose material on the road surface to use in the road mix. In this case, it is best to blade the loose material onto the shoulder rather than perform the several operations necessary to blend it with the material brought in from other sources. However, sometimes incorporating the existing material on the roadbed into the mixture is considered practical if it is uniform and the necessary quantity is available. When this is done, the loose aggregate is first bladed into a windrow and measured. Next, it is made to meet grading specifications by adding other aggregates as necessary. Finally, the windrow is built up to the required volume with implanted material that meets the specifications. If two or more materials are to be combined on the road to be surfaced, place each in its own windrow. These windrows are then thoroughly mixed together before asphalt is added.

4-4.2.2 Determining Liquid Stabilizer Application Rate.

Before mixing operations begin, determine the correct asphalt or polymer emulsion application rate and forward speed of the spray bar-equipped mixer or liquid distributor for the quantity of aggregate in the windrow. Also, when using emulsified asphalt or polymer, it is necessary to moisten the aggregate before applying the emulsion.

For polymer emulsions, ensure the starting soil moisture content is well below optimum. If not, the additional moisture present in the emulsion will result in a moisture content above optimum, leading to lower density during compaction. Although this is also true for asphalt emulsions, the asphalt coating is capable of lubricating the soil for compaction. Therefore, aerating the material to moisture contents below optimum is acceptable for asphalt emulsion stabilization but not for a polymer emulsion.

4-4.2.3 Control of Liquid Stabilizers.

Liquid stabilizer is added to the aggregate from an asphalt distributor or by a travel mixer. Whichever method is used, close control of quantity, dilution, and viscosity is required to ensure a proper mixture. Maintaining the correct and consistent viscosity is critical to ensure the liquid material is fluid enough to move easily through the spray nozzles at the correct flow rate, adequately coat the aggregate particles, and reach the target moisture content necessary for compaction of the stabilized soil. Cutback asphalts, and occasionally emulsified asphalts, even though already fluid, may require heating to bring them to a viscosity suitable for spraying. If the proper grade of asphalt has been used and the mixing is done correctly, the cutback or emulsified asphalt will remain fluid until the completion of mixing. As the actual temperature of the mixture is controlled by that of the aggregate, take care to see that mixing is not attempted at aggregate temperatures below 50 °F (10 °C).

4-4.2.4 Mixing.

4-4.2.4.1 Travel Plant Mixing.

Travel-plant mixing offers the advantage of closer control of the mixing operation than possible with other common mixing methods. With the windrow-type travel plant, the machine moves along the windrow, picking up the aggregate, mixing it with asphalt in the pugmill, and depositing the mixture in a windrow, ready for aerating or spreading. For this type of plant, match the liquid application rate accurately with the width and thickness of the course, the forward speed of the mixer, and the density of the in-place aggregate. As the thickness is specified, the density is fixed and the liquid application rate is set; the variable is the forward speed. If the aggregate windrow is such that all of the liquid cannot be incorporated in one mixing pass, split it into two or more windrows and the proper amount of liquid added to each windrow as it is mixed. Further mixing of the windrowed material may be necessary after adding the liquid. Unless the travel mixer can be used as a multiple-pass mixer, this additional mixing is usually accomplished with a motor grader. This ensures all of the windrowed material is incorporated into the mix. It also aerates the mixture for the removal of diluents if cutback asphalt is used. The number of passes with the motor grader required for this purpose varies with job conditions. After the mixing and aeration procedure is completed, move the windrow to one side of the area to be surfaced in preparation for spreading.

4-4.2.4.2 Rotary Mixing.

- Liquid Stabilizers.

  As with windrow travel plants, rotary mixers equipped with built-in liquid injection systems require the liquid application rates be accurately matched with the width and thickness of the course, the forward speed of the mixer, the target design stabilizer content, and the optimum moisture content to reach the target density of the in-place aggregate. However, when utilizing a rotary mixer not equipped with a spraybar, a liquid distributor may be used to apply liquid to the aggregate/soil ahead of the mixer. Incremental applications of liquid and passes of the mixer are usually necessary to achieve the specified mixture. Most rotary mixers are now equipped with a spray system. Note that when using water-based liquid stabilizers, ensure the soil moisture content is well below optimum. To reach the design stabilizer content and the optimum moisture content for the mixed soil, properly dilute the mix. Prepare the soil to proper grade and cross-section. If possible, pre-compaction of the soil can help ensure the target design stabilizer content and proper layer thickness are reached. Usually, mixing is accomplished in a single pass of a rotary mixer for efficiency. This requires strict control of mixing speed and pump rates to achieve the desired dosage rate of stabilizer and moisture.

- Foamed Asphalt Stabilization.

  Foamed asphalt stabilization is an efficient and economical method for stabilizing soil. Water is injected into a stream of hot asphalt, causing the asphalt to foam. The hot foam is then immediately sprayed onto the soil inside the mixing chamber of a reclaimer-stabilizer machine. The foaming action provides an efficient coating of asphalt, effectively waterproofing the soil particles. It is best used on sandy and gravelly soils and is gaining popularity for full-depth reclamation of old asphalt pavements.

4-4.2.4.3 Blade Mixing.

Use a slow-setting stabilizer-applied liquid with blade mixing. The imported or in-place material is shaped into a measured windrow, either through a spreader box or by running through a windrow shaper. The windrow is then flattened with the blade to about the width of the distributor spraybar. The liquid is applied by successive passes of the asphalt distributor over the flattened windrow. After each pass of the distributor, the mixture is worked back and forth across the roadbed with the blade. Prior to each succeeding application of asphalt, the mixture is reformed into a flattened windrow. The material in the windrow is subjected to as many mixings, spreading, shapings, and flattenings as needed to disperse the asphalt thoroughly throughout the mixture and effectively coat the aggregate particles. During mixing, the vertical angle of the moldboard may require adjustment from time to time to achieve a complete rolling action of the windrow as it is worked. Carry as much material in a roll as possible ahead of the blade since pressure from the weight of the aggregate facilitates mixing. During mixing, take care to ensure that neither extra material be taken from the mixing table and incorporated into the windrow nor any of the windrow be lost over the edge of the mixing table or left on the mixing table without being treated. When the blade-mixing technique is used, the formation of "additive balls," or concentrated clusters of fine aggregate saturated and coated with excessive amounts of liquid additive, can make a mix difficult to spread and compact. For bitumen, asphalt emulsions, or cutback asphalts, this condition can be corrected by windrowing the mixture into a tight windrow and allowing it to cure for a few days. After mixing and aeration have been completed, the windrow is moved to one side of the roadbed in readiness for subsequent spreading. If it is left for any length of time, cut periodic breaks in the windrow to ensure drainage of rainwater from the roadbed. Unfortunately, the formation of “additive balls” with polymer emulsions is more difficult to correct since polymer emulsions harden as the emulsion water evaporates. For polymer emulsions, obtain a rotary mixer if the blade-mixing technique produces significant “additive balls” after reasonable attempts to blade-mix the additive with the soil.

4-4.2.5 Aeration.

4-4.2.5.1 Emulsified Asphalts and Polymers.

Begin compaction of emulsified liquids immediately before, or at the same time as, the emulsion starts to break (indicated by a marked color change from brown to black).

About this time, the moisture content of the mixture acts as a lubricant between the aggregate particles but is reduced to the point where it does not fill the void spaces, thus allowing their reduction under compactive forces. Also, by this time the mixture is able to support the roller without undue displacement or pickup onto the roller surface. Begin compaction of polymer emulsions immediately after mixing.

4-4.2.5.2 Cutback Asphalt Mixes.

When using cutback asphalt, correct aeration will be achieved when the volatile content is reduced to about 50 percent of that contained in the original asphaltic material and the moisture content does not exceed 2 percent by weight of the total mixture. Before compaction for cutback asphalt, allow most of the diluents that have made the mix workable to evaporate. In most cases, this occurs during mixing and spreading and very little additional aeration is required but extra manipulation on the roadbed is occasionally needed to help speed the process and dissipate the excess diluents. Until the mix is aerated, it usually will not support rollers without excessive shoving. Generally, the mixture is aerated when it becomes tacky and appears to "crawl." Fine-grained and well-graded mixtures will require longer aeration than open-graded and coarse-grained mixtures, all else being equal. Also, if an asphalt cold-mix base course is to be surfaced within a short length of time, aerate the surface before compaction more completely than if the course is not to be surfaced for a longer period of time; the surface acts as a seal, greatly retarding the removal of diluents.

4-4.2.6 Spreading and Compacting.

With mixing and aeration completed, spreading (if necessary) and compacting the cold mix follows. Achieving a finished section and smooth riding surface conforming to the plans is the objective of these final two construction steps. Always spread the mixture to a uniform thickness (whether in a single pass or in several thinner layers) so no thin spots exist in the final mat. Mixtures that do not require aeration may be spread to the required thickness immediately after mixing and then compacted with pneumatic-tired vibratory or steel-tired rollers. Mixtures that require aeration, however, are generally deposited upon the roadbed in windrows and then spread from these windrows. The windrow may be placed along the centerline of the road or along one side if the mixture is to be spread by blade. Because there is a tendency to leave a hump in the road when blade-spreading from a center-line windrow, it is considered better practice to place the windrow to the side for spreading. Accomplish spreading by blade in successive layers, with no layer thinner than approximately 1.5 times the diameter of the maximum particle size. As each layer is spread, compact the layer immediately with a pneumatic-tired roller as soon as the layer will bear the effort without shoving. Because the tires of the motor grader compact the freshly spread mix, their tracks will appear as ridges in the finished mat unless there is adequate rolling between the spreading of each successive layer. Eliminate ridge marks by rolling directly behind the motor grader. If, at any time during compaction, the asphalt mixture exhibits undue rutting or shoving, stop rolling. After one course is thoroughly compacted and cured, other courses may be placed over it. Repeat this operation as many times as necessary to bring the pavement to proper grade and crown. For a smooth riding surface, use the motor grader to trim and level as the rollers complete compaction of the upper layer. After the mat has been shaped to its final required cross-section, then finish roll, preferably with a steel-wheeled roller, until all roller marks are eliminated. A completed course may have to be temporarily opened to traffic. In this event, to prevent tire pickup, it may be advisable to seal the surface by applying a dilution of slow-setting emulsified asphalt and potable water (in equal parts) at a rate of approximately 0.10 gal/sq yd (0.45 liter/sq m). Allow this to cure until no pickup occurs. For immediate passage of traffic, sanding may be desirable to avoid pickup.

4-4.3 Central Plant Mix Construction.

4-4.3.1 Preparation of Mixture.

In batch-type plants, mixing is usually accomplished by a twin-shafted pugmill having a capacity of not less than 2,000 lb (907 kg). The correct amounts of asphalt and aggregate, generally determined by weight, are fed into the pugmill. The batch is then mixed and discharged into a haul truck before another batch is mixed. In the continuous-mixing plant, the devices feeding asphalt, aggregate, and water, if needed, are interlocked to automatically maintain the correct proportions. Typically, automatic feeders measure and govern the flow of aggregates in relation to the output of a positive displacement asphalt-metering pump. A spray nozzle arrangement at the mixer distributes the asphalt over the aggregate. As the proportioned materials move through the pugmill, completely mixed material, ready for spreading, is discharged for subsequent hauling to the road site.

4-4.3.2 Aerating Plant Mix.

Mixtures that require aerating are generally deposited upon the roadbed in windrows and then spread from these windrows. The cold mix is spread with a motor grader and aerated by blading it back and forth or aerated by rotary tiller mixing equipment.

4-4.3.3 Spreading and Compacting Plant Mix.

If aeration is not required, as is generally the case with plant-mixed emulsified asphalt mixes, the mixture is most effectively spread with asphalt pavers having automatic controls. For deep lifts, however, other equipment such as the Jersey Spreader type, towed spreaders, cutter-trimmer-spreaders, or motor graders may be used. Similar to mixed-in-place, central plant cold mixes gain stability as the diluents, which have made the mix workable, evaporate. It is important not to hinder this process; therefore, lift thicknesses are limited by the rate that the mixture loses its diluents. The most important factors affecting this loss are the type of asphalt, diluent content, gradation, and temperature of the aggregate; wind velocity; ambient temperature; and humidity. Because of these variables, local experience is likely to be the best guide in determining allowable placement thicknesses. Spread the mixture uniformly on the roadbed, beginning at the point farthest from the mixing plant. Hauling over freshly placed material is not permitted except when required for completion of the work.

4-5 CONSTRUCTION WITH FIBERS.

Equipment for placing fibers has not reached a commercial stage. Generally, fibers are placed manually by spacing bags of discrete fibers in a grid pattern or by lanes, similar to the way bagged cement and lime are placed. Like cement, spread the fibers uniformly within the area. Using the backside of a rake will help, as the rake tines drag the fibers. Placing fibers on days with winds above 15 miles per hour (24 kilometers per hour) is not recommended. Wetting the fibers after spreading will help hold them in place, if necessary. Fibers are difficult to efficiently mix and may require multiple passes of a rotary mixer to achieve even dispersal throughout the soil. Fibrillated fibers may also require multiple passes of a rotary mixer to “open” the fibrils. If using cement or lime, spread the dry material first then follow with the fibers.

It is very important to start with the soil well-prepared and properly graded to minimize or even eliminate any post-mixing soil work. After mixing, working the fibrous soil can be very difficult. It is not recommended to grade or move the material unless absolutely necessary. Before compaction, it can be moved with graders and rakes and mildly graded, but once compacted, grading the surface results in tears and rips that make repair problematic. After compaction, the material is best handled by remixing with a rotary mixer to loosen it before working the soil.

CHAPTER 5 QUALITY CONTROL

5-1 PURPOSE

Quality control is essential to ensure the final product will be adequate for its intended use and ensure the contractor has performed in accordance with the plans and specifications, as this is a basis for payment. This chapter identifies those control factors that are most important in soil stabilization construction with cement, lime, lime-fly ash, bituminous additives, and polymer emulsions.

5-2 CEMENT STABILIZATION.

The most important factors from a quality control standpoint in cement stabilization are pulverization, cement content, moisture content, uniformity of mixing, time sequence of operations, compaction, and curing. These are described in detail below.

5-2.1 Pulverization.

Pulverization is generally not a problem in cement construction unless clayey or silty soils are being stabilized. A sieve analysis is performed on the soil during the pulverization process, with the No. 4 (4.75 mm) sieve used as a control. The percent pulverization can then be determined by calculation. Proper moisture control is also essential to achieve the required pulverization. Most specifications require the soil material be pulverized so at the time of compaction 100 percent of the soil-cement mixture will pass a 1 inch (25 mm) sieve and a minimum of 80 percent will pass a No. 4 (4.75 mm) sieve, exclusive of any gravel or stone. Ensure gravel or stone are no more than a 2 inch (50 mm) maximum size or the cement cannot effectively stabilize the soil. Perform the final pulverization test at the conclusion of mixing operations.

5-2.2 Cement Content.

Cement content is typically expressed in terms of a percentage of the dry weight of the soil being treated. Occasionally, cement content is expressed in terms of volume; however, this is less frequent due to the complication it adds in calculating quantities for batching. Be aware of quantities of cement required per linear foot or per square yard of pavement. Spot checks can be performed to assure the proper quantity of cement is being applied by using a canvas of known area or, as an overall check, the area over which a known tonnage has been spread.

5-2.3 Moisture Content.

The optimum moisture content for the soil-additive mixture determined in the laboratory is used as an initial guide when construction begins. Make allowance for the in situ moisture content of the soil when construction starts. The optimum moisture content and maximum density can then be established for field control purposes. Mixing water requirements can be determined on the raw soil or on the soil-cement mix before adding the mixing water. Nuclear methods can be used to determine moisture content at the time construction starts and during processing. In general, field compaction equipment imparts more energy into the soil than laboratory equipment and the field optimum moisture content may be slightly lower than that reported in laboratory results.

5-2.4 Uniformity of Mixing.

A visual inspection is performed to assure the uniformity of the mixture throughout the treated depth. Check uniformity across the width of the pavement and to the desired depth of treatment. Trenches can be dug and then visually inspected. A satisfactory mix will exhibit a uniform color throughout, whereas a streaked appearance indicates a non-uniform mix. Pay special attention to the edges of the pavement.

5-2.5 Compaction.

Equipment used for compaction is the same used if no cement were present in the soil and is therefore dependent upon soil type. Two methods can be used to determine compacted density: sand-cone (ASTM D1556, *Standard Test Method for Density and Unit Weight of Soil in Place by Sand-Cone Method*) and nuclear (ASTM D6938, *Standard Test Methods for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)*). It is important to determine the depth of compaction and pay special attention to compaction at the edges.

5-2.6 Curing.

To assure proper curing, a bituminous or polymer emulsion or liquid curing compound is frequently applied over the stabilized areas. Ensure the surface of the soil cement is free of dry, loose material and in a moist condition. It is important the soil-cement mixture be kept continuously moist until the membrane is applied. The recommended application rate is 0.15 to 0.30 gal/sq yd (0.68 to 1.36 liter/sq m).

5-3 LIME STABILIZATION.

The most important factors to control during soil-lime construction are pulverization and scarification, lime content, uniformity of mixing, time sequence of operations, compaction, and curing.

5-3.1 Pulverization and Scarification.

Before application of lime, the soil is scarified and pulverized. To assure the adequacy of this phase of construction, a sieve analysis is performed. Most specifications are based upon a designated amount of material passing the 1 inch (25 mm) and No. 4 (4.75 mm) sieves. The depth of scarification or pulverization is also of importance as it relates to the specified depth of lime treatment. For heavy clays, adequate pulverization can best be achieved by pretreatment with lime, but if this method is used, agglomerated soil-lime fractions may appear. These fractions can be easily broken down with a simple kneading action and are not necessarily indicative of improper pulverization.

5-3.2 Lime Content.

When lime is applied to the pulverized soil, the rate at which it is being spread can be determined by placing a canvas of known area on the ground and, after the lime has been spread, weighing the lime on the canvas. Charts can be made available to field personnel to determine if this rate of application is satisfactory for the specified lime content. To accurately determine the quantity of lime slurry required to provide the desired amount of lime solids, it is necessary to know the slurry composition. This can be done by checking the specific gravity of the slurry, either by a hydrometer or volumetric-weight procedure.

5-3.3 Uniformity of Mixing*.*

The major goal is to obtain uniform lime content throughout the depth of treated soil. This presents one of the most difficult factors to control in the field. It has been reported that mixed soil with lime has more or less the same outward appearance as mixed soil without lime. The use of phenolphthalein indicator solution for control in the field has been recommended. This method, while not sophisticated enough to provide an exact measure of lime content for depth of treatment, will give an indication of the presence of the minimum lime content required for soil treatment. The soil will turn a reddish pink color when sprayed with the indicator solution, indicating that free lime is available in the soil (pH = 12.4). Alternatively, soil samples can be collected at various locations and depths and subjected to pH tests using field portable equipment.

5-3.4 Compaction*.*

The most important compaction factor is the proper control of moisture and density. Conventional procedures such as sand cone (ASTM D1556) and nuclear methods (ASTM D6938) have been used for determining the density of compacted soil-lime mixtures. Moisture content can be determined by either oven-dry methods (ASTM D2216, *Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass*) or nuclear methods (ASTM D6938). The influence of time between mixing and compacting has been demonstrated to have a pronounced effect on the properties of treated soil. Begin compaction as soon as possible after final mixing has been completed. The National Lime Association recommends an absolute maximum delay of one week. The use of phenolphthalein indicator solution has also been recommended for lime content control testing, as stated in paragraph 5-3.3. The solution can be used to distinguish between areas that have been properly treated and those that have received only a slight surface dusting by wind action. This will aid in identifying areas to perform density testing.

5-3.5 Curing*.*

Curing is essential to assure the soil-lime mixture will achieve the final properties desired. Curing is accomplished by one of two methods: (1) moist curing, involving a light sprinkling of water and rolling; or (2) membrane curing, which involves sealing the compacted layer with a bituminous seal coat or liquid curing compound. Regardless of the method used, properly protect the entire compacted layer to ensure the lime will not become nonreactive through carbonation. Inadequate sprinkling, which allows the stabilized soil surface to dry, will promote carbonation.

5-4 LIME-FLY ASH (LF) AND LIME-CEMENT-FLY ASH (LCF).

The nature of LF and LCF stabilization is similar to that for lime only. Consequently, the same factors involved for quality control are suggested.

5-5 BITUMINOUS AND POLYMER STABILIZATION.

The factors that seem most important to control during construction with bituminous and polymer stabilization are moisture content, viscosity of the liquid, additive content, uniformity of mixing, aeration, compaction, and curing.

5-5.1 Moisture Content.

The moisture of the soil to be stabilized is of concern. Moisture content can be determined by conventional methods, such as oven-drying (ASTM D2216), or by nuclear methods (ASTM D6938). The Asphalt Institute recommends surface moisture of up to 3 percent or more for use with emulsified asphalt and a moisture content of less than 3 percent for cutback asphalt. The gradation of the aggregate is significant to moisture content. With densely graded mixes, more water is needed for mixing than compaction. Generally, a surface moisture content that is too high will delay compaction of the mixture. Higher PI soils require higher moisture content. For polymer emulsions, ensure the starting soil moisture content is well below optimum. If not, the additional moisture present in the emulsion will result in a moisture content above optimum, leading to lower density during compaction. Although this is also true for asphalt emulsions, the asphalt coating is capable of lubricating the soil for compaction. Therefore, aerating the material to moisture contents below optimum is acceptable for asphalt-emulsion stabilization but not for polymer emulsion.

5-5.2 Viscosity of Asphalt.

The Asphalt Institute recommends avoiding cold-mix construction at temperatures below 50 °F (10 °C). The asphalt will rapidly reach the temperature of the aggregate to which it is applied and, at the lower temperature, difficulty mixing will be encountered. On occasion, heating is necessary with cutback asphalts to assure the soil aggregate particles are thoroughly coated. For emulsions, ensure the temperature is above the minimum film-forming temperature, a basic property of all emulsions.

5-5.3 Asphalt and Polymer Content.

Information that will enable field personnel to determine a satisfactory application rate can be provided to them. Maintain the asphalt content at optimum or slightly below for the specified mix. Excessive quantities of asphalt may cause difficulty in compaction and result in plastic deformation in service during hot weather.

Similarly, maintain the actual polymer content at or slightly below optimum for the design mix. The actual polymer content is computed based upon the percent solids of the polymer emulsion. In addition, check the polymer emulsion for consistency in terms of percent solids of the delivered product at random.

5-5.4 Uniformity of Mixing.

Visual inspection can be used to determine the uniformity of the mixture. With emulsified asphalts, a color change from brown to black indicates the emulsion has broken. The Asphalt Institute recommends control of three variables to assure uniformity for mixed-in-place construction: travel speed of application equipment;

volume of aggregate being treated; and flow rate (volume per unit time) of emulsified asphalt being applied. In many cases, an asphalt content above design is necessary to assure uniform mixing. The inspection of polymer-stabilized soil is less obvious; take extreme care to ensure the material is mixed thoroughly and to full depth.

5-5.5 Aeration.

Prior to compaction, allow the diluents that facilitated the cold-mix operation to evaporate. If the mix is not aerated, it cannot be compacted to acceptable limits. The Asphalt Institute has determined that the mixture has aerated when it becomes tacky and appears to "crawl." Most aerating occurs during the mixing and spreading stage but occasionally additional work on the roadbed is necessary. The Asphalt Institute has reported that overmixing in central plant mixes can cause emulsified asphalts to break early, resulting in a mix that is difficult to work with in the field.

5-5.6 Compaction.

Begin compaction when the aeration of the mix is completed. The Asphalt Institute recommends that rolling begin when an emulsified asphalt mixture begins to break (color change from brown to black). Early compaction can cause undue rutting or shoving of the mixture due to overstressing under the roller. The density of emulsion-stabilized bases has often been found to be higher than that obtained on unstabilized bases for the same compaction effort.

5-5.7 Curing.

Curing presents the greatest problem in asphalt soil stabilization. The Asphalt Institute has determined that the rate of curing is dependent upon many variables: the quantity of asphalt applied, the prevailing humidity and wind, the amount of rain and sunlight, and the ambient temperature. Allow initial curing in order to support compaction equipment. This initial curing, which allows the evaporation of diluents, occurs during the aeration stage. If compaction is started too early, the pavement will be sealed, delaying dehydration, which lengthens the time before design strength is reached. The heat of the day may cause the mixture to soften, which prohibits equipment from placing successive lifts until the following day. This emphasizes the need to allow curing time when lift construction is employed. The Asphalt Institute recommends a two- to five-day curing period under recommended conditions when emulsified bases are being constructed. Cement has been used to accelerate curing. Polymeric emulsions cure by evaporation of the dilution water. Thus, the use of a curing membrane is not recommended.

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APPENDIX A BEST PRACTICES

A-1 THICKNESS CRITERIA-STABILIZED SOIL LAYERS

A-1.1 Equivalency Factors.

The use of stabilized soil layers within a flexible pavement provides the opportunity to reduce the overall thickness of the pavement structure required to support a given load. To design a pavement containing stabilized soil layers requires applying equivalency factors to a layer or layers of a conventionally designed pavement. To qualify for application of equivalency factors, ensure the stabilized layer meets appropriate strength and durability requirements set forth in this UFC. An equivalency factor represents the number of inches (millimeters) of a conventional base or subbase that can be replaced by 1 inch (25 mm) of stabilized material. Equivalency factors for stabilized materials are determined as shown in Table A-1. Limit the cement content to 4 percent by weight or less to prevent excessive reflective cracking. Selecting an equivalency factor from the table is dependent upon the classification of the soil to be stabilized.

Table A-1 Equivalency Factors for Stabilized Material

Material	Equivalency Factors	
	Base	Subbase
Asphalt-stabilized		
All-bituminous concrete	1.15	2.30
GW, GP, GM, GC	1.00	2.00
SW, SP, SM, SC	(*)	1.50
Cement-stabilized		
GW, GP, SW, SP	1.15	2.30
GM, GC	1.00	2.00
ML, MH, CL, CH	(*)	1.70
SC, SM	(*)	1.50
Lime-stabilized		
ML, MH, CL, CH	(*)	1.00
SC, SM, GM, GC	(*)	1.10
Lime, Cement, Fly Ash-Stabilized		
ML, MH, CL, CH	(*)	1.30
SC, SM, GM, GC	(*)	1.40
Unbound crushed stone	1.00	2.00
Unbound aggregate	(*)	1.00
* Not used for base course material.		

A-1.2 Thickness Design for Stabilized Soil Layers.

To use the equivalency factors requires that a conventional flexible pavement be designed to support the design load conditions. If it is desired to use a stabilized base or subbase course, the thickness of the conventional base or subbase is divided by the equivalency factor for the applicable stabilized soil.

A-1.2.1 Example 1.

Assume a conventional flexible pavement has been designed that requires a total thickness of 16 inches (406 mm) above the subgrade. The minimum thicknesses of the AC and the base are 2 and 4 inches (51 and 102 mm), respectively, and the thickness of the subbase is 10 inches (254 mm). It is desired to replace the base and the subbase with a cement-stabilized gravelly soil (GP) having an unconfined compressive strength of 890 psi (6.14 MPa). The material qualifies for application as a base course since its strength is greater than 750 psi (5.17 MPa), as required by this UFC. From Table A-1, the equivalency factor for a base is 1.15. Therefore, 4 inches ÷ 1.15 = 3.48 inches (102 mm ÷ 1.15 = 88.7 mm) of stabilized base course. Since the minimum required thickness is 4 inches (102 mm), the excess of stabilized base course of 4 inches – 3.48 inches = 0.52 inches (102 mm – 88.7 mm = 13.3 mm) is computed as the equivalent thickness of non-stabilized subbase material, which is equal to 0.52 inches * 2.3 = 1.12 inches (13.3 mm * 2.3 = 30.6 mm). This equivalent subbase thickness is accounted for in the stabilized base; therefore, the needed non-stabilized subbase is thinner than 10 inches (254 mm) and equal to 10 inches – 1.12 inches = 8.88 inches (254 mm – 21.2 mm = 232.8 mm). The next step includes calculating the equivalent thickness of the subbase stabilized material as 8.88 inches ÷ 2.3 = 3.86 inches (223.4 mm ÷ 2.3 = 97.1 mm). The required minimum thickness for the stabilized subbase is 4 inches (102 mm). Therefore, the total thickness of the cement-stabilized pavement is 2 inches (51 mm) of AC, 4 inches (102 mm) of cement-stabilized gravelly soil base, and 4 inches (102 mm) of cement-stabilized gravelly soil subbase.

A-1.2.2 Example 2.

Assume a conventional flexible pavement has been designed that requires 3.5 inches (89 mm) of AC surface, 4 inches (102 mm) of crushed stone base, and 18 inches (458 mm) of subbase. It is desired to construct an all-bituminous pavement (ABC). The equivalency factor from Table A-1 for a base course is 1.15 and for a subbase, 2.30. The thickness of AC required to replace the base is 4 inches ÷ 1.15 = 3.48 inches (102 mm ÷ 1.15 = 88.7 mm). Since the minimum required thickness is 4 inches (102 mm), the excess of stabilized base course of 4 inches – 3.48 inches = 0.52 inches (102 mm – 88.7 mm = 13.3 mm) is computed as the equivalent thickness of non-stabilized subbase material, which is equal to 0.52 inches * 2.3 = 1.12 inches (13.3 mm * 2.3 = 30.6 mm). This equivalent subbase thickness is accounted in the stabilized base; therefore, the needed non-stabilized subbase is thinner than 18 inches (459 mm) and equal to 18 inches – 1.12 inches = 16.88 inches (458 mm – 21.2 mm = 437 mm). The next step computes the equivalent thickness of subbase-stabilized material as 16.88 inches ÷ 2.3 = 7.34 inches (437 mm ÷ 2.3 = 190 mm). The total thickness of the ABC pavement is 3.5 inches + 4 inches + 7.34 inches = 14.84 inches ~15 inches (89 + 102 + 190 = 381 mm ~390 mm)

A-2 PH TEST ON SOIL-CEMENT MIXTURES

A-2.1 Materials.

Portland cement will be used for soil stabilization.

A-2.2 Apparatus.

Apparatus are the pH meter (equip the pH meter with an electrode having a pH range of 14), 150-ml plastic bottles with screw-top lids, 500-ml plastic beakers, distilled water, balance, oven, and moisture cans.

A-2.3 Procedure.

A-2.3.1 Standardization. Standardize the pH meter with a buffer solution having a pH of 12.00.

A-2.3.2 Representative Samples. Weight to the nearest 0.01 g representative samples of air-dried soil passing the No. 40 (0.425 mm) sieve and equal to 25.0 g of oven-dried soil.

A-2.3.3 Soil Samples. Pour the soil samples into 150-ml plastic bottles with screw-top lids.

A-2.3.4 Portland cement. Add 2.5 g of portland cement.

A-2.3.5 Mixture. Thoroughly mix soil and portland cement.

A-2.3.6 Distilled Water. Add distilled water to make a thick paste. (Caution: Too much water will reduce the pH and produce an incorrect result.)

A-2.3.7 Blending. Stir the soil-cement and water until thorough blending is achieved.

A-2.3.8 Transferal. After 15 minutes, transfer part of the paste to a plastic beaker and measure the pH.

A-2.3.9 Interference. If the pH is 12.1 or greater, the soil organic matter content should not interfere with the cement-stabilizing mechanism.

A-3 DETERMINATION OF SULFATE IN SOILS - GRAVIMETRIC AND TURBIDIMETRIC METHOD

A-3.1 Gravimetric Method.

A-3.1.1 Scope.

Applicable to all soil types with the possible exception of soils containing certain organic compounds, this method permits the detection of as little as 0.05 percent sulfates as SO_4.

A-3.1.2 Reagents.

Reagents include barium chloride ($BaCl_2$), 10 percent solution of $BaCl_2 \bullet 2H_2O$ (Add 1 ml 2 percent HCI to each 100 ml of solution to prevent formation of carbonate.); hydrochloric acid, 2 percent solution (0.55 Normal); magnesium chloride, 10 percent solution of $MgCl_2 \bullet 6H_2O$; demineralized water; and silver nitrate, 0.1 Normal solution.

A-3.1.3 Apparatus.

Apparatus used are a 100-ml beaker, a burner and ring stand, a 500-ml filtering flask, a 90-ml Buchner funnel, 90-ml Whatman No. 40 filter paper, 90 ml Whatman No. 42 filter paper, Saran Wrap, a crucible or heavy-grade aluminum foil, ignition, an analytical balance, and an aspirator or other vacuum source.

A-3.1.4 Procedure.

A-3.1.4.1 Select a representative sample of air-dried soil weighing approximately 10 g. Weigh to the nearest 0.01 g. (Note: When sulfate content is anticipated to be less than 0.1 percent, a sample weighing 20 g or more may be used.) (Measure the moisture content of the air-dried soil for later determination of dry weight of the soil.)

A-3.1.4.2 Boil for 1.5 hours in a beaker with mixture of 300-ml water and 15-ml HCl.

A-3.1.4.3 Filter through Whatman No. 40 paper, wash with hot water, and dilute combined filtrate and washings to 50 ml.

A-3.1.4.4 Take 100 ml of this solution and add $MgCl_2$ solution until no more precipitate is formed.

A-3.1.4.5 Filter through Whatman No. 42 paper, wash with hot water, and dilute combined filtrates and washings to 200 ml.

A-3.1.4.6 Heat 100 ml of this solution to boiling and add $BaCl_2$ solution very slowly until no more precipitate is formed. Continue boiling for about five minutes and let stand overnight in a warm place, covering the beaker with Saran Wrap.

A-3.1.4.7 Filter through Whatman No. 42 paper. Wash with hot water until free from chlorides (filtrate should show no precipitate when a drop of $AgNO_3$ solution is added or continue washing).

A-3.1.4.8 Dry filter paper in crucible or on sheet of aluminum foil. Ignite paper. Weight residue on analytical balance as $BaSO_4$.

A-3.1.5 Calculation.

$$Percent\ SO_4 = \frac{Weight\ of\ residue}{Oven\ dry\ weight\ of\ initial\ sample} \times 411.6$$

Where:

$$\text{Oven-dry weight of initial sample} = 1 + \frac{\frac{air-dry\ \ weight\ of\ initial\ sample}{air-dry\ moisture\ content\ (percent)}}{100\ percent}$$

Note: If precipitated from cold solution, barium sulfate is so finely dispersed that it cannot be retained when filtering by the above method. Precipitation from a warm, dilute solution will increase crystal size. Due to the absorption (occlusion) of soluble salts during the precipitation by $BaSO_4$, a small error is introduced. This error can be minimized by permitting the precipitate to digest in a warm, dilute solution for a number of hours. This allows the more soluble small crystals of $BaSO_4$ to dissolve and recrystallize on the larger crystals.

A-3.2 Turbidimetric Method.

A-3.2.1 Reagents.

Reagents include $BaCl_2$ crystals (grind analytical reagent-grade $BaCl_2$ to pass a 1-mm sieve), ammonium acetate solution (0.5 N) (add dilute hydrochloric acid until the solution has a pH of 4.2), and distilled water.

A-3.2.2 Apparatus.

Apparatus used are a moisture can, an oven, a 200-ml beaker, a burner and ring stand, a filtering flask, a 90-ml Buchner funnel, 90 ml Whatman No. 40 filter paper, a vacuum source, a spectrophotometer and standard tubes (Bausch and Lomb Spectronic 200 or equivalent), and a pH meter.

A-3.2.3 Procedure.

A-3.2.3.1 Take a representative sample of air-dried soil weighing approximately 10 g and weight to the nearest 0.01 g. (Measure the moisture content of the air-dried soil for later determination of dry weight of the soil.)

A-3.2.3.2 Add the ammonium acetate solution to the soil until the ratio of soil to solution is approximately 1:5 by weight.

A-3.2.3.3 Boil for about five minutes.

A-3.2.3.4 Filter through Whatman No. 40 filter paper. If the extracting solution is not clear, filter again.

A-3.2.3.5 Take 10 ml of extracting solution (this may vary, depending on the concentration of sulfate in the solution) and dilute with distilled water to about 40 ml. Add about 0.2 g of $BaCl_2$ crystals and dilute to make the volume exactly equal to 50 ml. Stir for one minute.

A-3.2.3.6 Immediately after the stirring period has ended, pour a portion of the solution into the standard tube and insert the tube into the cell of the spectrophotometer. Measure the turbidity at 30-second intervals for four minutes. Maximum turbidity is usually obtained within two minutes and the readings remain constant thereafter for three to ten minutes. Consider the turbidity to be the maximum reading obtained in the four-minute interval.

A-3.2.3.7 Compare the turbidity reading with a standard curve and compute the sulfate concentration (as SO_4) in the original extracting solution. (The standard curve is secured by carrying out the procedure with standard potassium sulfate solutions.)

A-3.2.3.8 Correct for the apparent turbidity of the samples by running blanks in which no $BaCl_2$ is added.

A-3.2.4 Sample Calculation.

Given:		
	Weight of air-dried sample	= 10.12 g
	Water content	= 9.36 percent
	Weight of dry soil	= 9.27 g
	Total volume of extracting solution	= 39.1 ml

10 ml of extracting solution was diluted to 50 ml after addition of $BaCl_2$ (see paragraph A-3.2.3, step 5). The solution gave a transmission reading of 81. From the standard curve, a transmission reading of 81 corresponds to 16.0 parts per million. (See Figure A-1.)

Concentration of original extracting solution = 16.0 × 5 = 80.0 parts per million

$$Percent\ SO_4 = \frac{80.0 \times 39.1 \times 100}{1{,}000 \times 1{,}000 \times 9.27} \times 0.0338\ percent$$

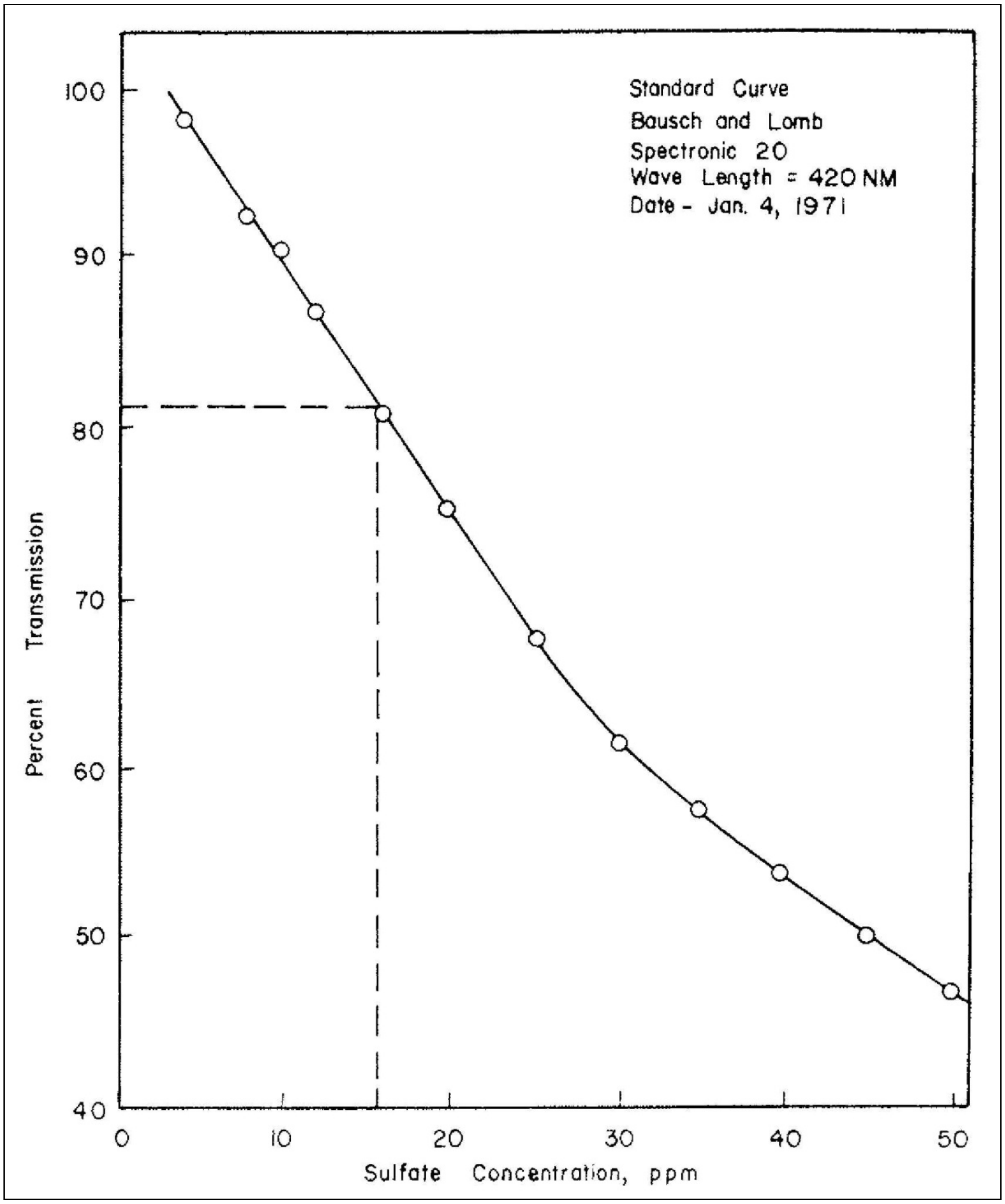
A-3.2.5 Determination of Standard Curve.

A-3.2.5.1 Prepare sulfate solutions of 0, 4, 8, 12, 16, 20, 25, 30, 35, 40, 45, and 50 parts per million in separate test tubes. The sulfate solution is made from potassium sulfate salt dissolved in 0.5 Normal ammonium acetate (with pH adjusted to 4.2).

A-3.2.5.2 Continue steps 5 and 6 in the procedure (paragraph A-3.2.3).

A-3.2.5.3 Draw a standard curve as shown in Figure A-1 by plotting transmission readings for known concentrations of sulfate solutions.

Figure A-1 Example Standard Curve for Spectrophotometer



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APPENDIX B GLOSSARY

B-1 ACRONYMS

°C	degree Celsius
°F	degree Fahrenheit
AASHTO	American Association of State Highway and Transportation Officials
ABC	all-bituminous pavement
ACI	American Concrete Institute
$AgNO_3$	Silver nitrate
$BaCl_2$	Barium chloride
$BaSO_4$	Barium sulfate
CaO	calcium oxide
DWG	Discipline Working Group
FAA	Federal Aviation Administration
ft	foot
g	gram
gal	gallon
gal/sq yd	gallon per square yard
H_2O	water
HCl	hydrochloric acid
in.	inch
kg	kilogram
L	liter
lb	pound
lb/in^2	pound per square inch
LCF	lime-cement fly ash
LF	lime-fly ash

LIS	liquid injection system
LL	liquid limit
m	meter
$MgCl_2$	magnesium chloride
ml	milliliter
mm	millimeter
MPa	megapascal
N	Normal
pH	scale of acidity
PI	plasticity index
psi	pound per square inch
USCS	Unified Soil Classification System

B-2 TERMS

Additive Stabilization: Stabilization is achieved by adding the proper percentages of additives to the soil. Selecting the type and determining the percentage of additive to be used is dependent upon the soil classification, conservation of deleterious materials such as sulfates and organics, and the degree of improvement in soil quality desired. Non-traditional additives such as polymer, fiber, lignin derivatives, enzymes, acids, etc. will be addressed where appropriate; however, due to the specialized nature of many of these materials, defining specific criteria for all additives is beyond the scope of this UFC. Generally, smaller amounts of additives are required when only modification of soil properties such as gradation, workability, and plasticity is desired. When significant strength and durability improvement is desired, greater quantities of additive are needed. After the additive has been mixed with the soil at the optimum moisture content, spreading and compaction are achieved by conventional means.

Additives: Manufactured commercial products that, when added to the soil in the proper quantities, improve some engineering characteristics of the soil such as strength, texture, workability, and plasticity are termed “traditional” additives and include materials such as lime, cement, fly ash, and asphalt emulsions. “Non-traditional” additives such as polymer emulsions, fiber, lignin derivatives, enzymes, acids, and other materials used to improve soil qualities are more recent entries into the commercial market. Additives addressed in this UFC are portland cement, lime, fly ash, bitumen, polymer emulsion, fiber, and select combinations of these.

Durability: Durability refers to the resistance of the soil to weathering, primarily by the action of water and abrasion after wet-dry and freezing and thawing cycles (ASTM D559 and D560).

Mechanical Stabilization: Mechanical stabilization is accomplished by mixing or blending soils of two or more gradations to obtain a material meeting the required specification. The soil blending may take place at the construction site, a central plant, or a borrow area. The blended material is then spread and compacted to required densities at the optimum moisture content by conventional means. Compaction and fiber addition are also means of mechanical stabilization. Compaction consists of the mechanical rearrangement of soil particles into a denser configuration, typically resulting in increased strength and/or durability. The addition of fibers into a soil can mechanically stabilize the soil by creating interlock between particles.

Modification: Modification refers to the stabilization process that results in improvement in some material property of the soil such as the plasticity index (PI) but does not, by design, result in a significant increase in soil strength and durability.

Optimum Moisture Content: The optimum moisture content of soil is the water content, measured in percentage by unit weight, at which a maximum dry unit weight can be achieved after a given compactive effort. (See ASTM D1557 for further information.) A higher or lower moisture content will result in a lower maximum dry unit weight after compaction.

Soils: Soils are naturally occurring materials used for the construction of all except the surface layers of pavements (i.e., concrete and asphalt) and subject to classification tests (ASTM D2487) to provide a general concept of their engineering characteristics.

Stabilization: Stabilization is the process of blending and mixing materials with a soil to improve engineering properties of the soil. The process may include the blending of soils to achieve a desired gradation or the mixing of additives that may alter the chemistry, gradation, texture, plasticity, or water absorption or act as a binder for cementation of the soil. Stabilization results in a significant increase in the strength and/or durability of the stabilized material.

Strength: In the context of this UFC, “strength” refers to the unconfined compressive tests measured using ASTM D1633.

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APPENDIX C REFERENCES

DOD

https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc

UFC 3-220-08FA, *Engineering Use of Geotextiles*

UFC 3-250-01, *Paving Design for Roads and Parking Areas*

UFC 3-250-03, *Standard Practice Manual for Flexible Pavem*ents

UFC 3-260-02, *Pavement Design for Airfields*

AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS (AASHTO)

AASHTO M288, *Standard Specification for Geosynthetic Specification for Highway Applications*, https://store.transportation.org/

AMERICAN CONCRETE INSTITUTE (ACI)

ACI 230.1R, *Report on Soil Cement*, https://www.concrete.org/

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

https://www.astm.org/

C33, *Standard Specification for Concrete Aggregates*

C150, *Standard Specification for Portland Cement*

C593, *Standard Specification for Fly Ash and Other Pozzolans for Use with Lime for Soil Stabilization*

C977, *Standard Specification for Quicklime and Hydrated Lime for Soil Stabilization*

C1580, *Standard Test Method for Water-Soluble Sulfate in Soil*

D6913/D6913M-17, *Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis*

D558, *Standard Test Methods for Moisture-Density (Unit Weight) Relations of Soil-Cement Mixtures*

D559, *Standard Test Methods for Wetting and Drying Compacted Soil-Cement Mixtures*

D560, *Standard Test Methods for Freezing and Thawing Compacted Soil-Cement Mixtures*

D698, *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft³ (600 kN-m/m³))*

D1556, *Standard Test Method for Density and Unit Weight of Soil in Place by Sand-Cone Method*

D1557, *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft³ (2,700 kN-m/m³))*

D1632, *Standard Practice for Making and Curing Soil-Cement Compression and Flexure Test Specimens in the Laboratory*

D1633, *Standard Test Methods for Compressive Strength of Molded Soil-Cement Cylinders*

D2216, *Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass*

D2487, *Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)*

D3551, *Standard Practice for Laboratory Preparation of Soil-Lime Mixtures Using Mechanical Mixer*

D4546-14e1, *Standard Test Methods for One-Dimensional Swell or Collapse of Soils*

D4318-17e1, *Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils*

D2166/2166M, *Standard Test Method for Unconfined Compressive Strength of Cohesive Soil*

D6276, *Standard Test Method for Using pH to Estimate the Soil-Lime Proportion Requirement for Soil Stabilization*

D6927, *Standard Test Method for Marshall Stability and Flow of Asphalt Mixtures*

D6938, *Standard Test Methods for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)*

D7928, *Standard Test Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis*

UFC 3-260-01
4 February 2019
Change 1, 5 May 2020

UNIFIED FACILITIES CRITERIA (UFC)

AIRFIELD AND HELIPORT PLANNING AND DESIGN

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

UNIFIED FACILITIES CRITERIA (UFC)

AIRFIELD AND HELIPORT PLANNING AND DESIGN

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER CENTER (Preparing Activity)

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

Change No.	**Date**	**Location**
1	5 May 2020	Updated Tables 3-5 and 8-4, Figures 8-23, 8-25, and 8-46, and paragraphs 6-5.7, 7-9, 7-12.1, 7-10.2.5, 8-5.4.4, 8-5.9, B1-2.1.4, B11-5.1, B13-2.2, and B13-2.21.2.10. Added new paragraph B13-2.2.2.5 on perimeter fencing in the MFZ. Replaced all references to AFI 32-1042, AFI 32-1043, and AFI 32-1044 with superseding AFMAN 32-1040. Updated references in Appendix A.

This UFC supersedes UFC 3-260-01, dated 17 November 2008.

FOREWORD

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

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale should be sent to the respective service proponent office by the following electronic form: Criteria Change Request (CCR). The form is also accessible from the Internet sites listed below.

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

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

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

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UNIFIED FACILITIES CRITERIA (UFC)
REVISION SUMMARY SHEET

Document: UFC 3-260-01, *Airfield and Heliport Planning and Design*

Superseding: UFC 3-260-01, dated 17 November 2008

Description of Changes: This update to UFC 3-260-01:

- Updates Chapter 1, *General Requirements* to clarify text per review comments. In particular, clarified applicability to existing facilities in Para 1-3.
- Updates Chapter 2, *Aviation Facilities Planning* to clarify text per comments. In particular, a) added paragraph 2-5.5 regarding stormwater management facilities near airfields; b) unified nomenclature to apply to all DoD services; c) updated Navy exceptions from criteria in Para 2-11; d) added paragraph 2-12 regarding design requirements for buried utility structures on airfields.
- Updates Chapter 3, *Runways (Fixed-Wing) and Imaginary Surfaces* to clarify text per review comments. In particular, a) clarified MV-22 applicability in paragraph 3-3.3; b) revised Table 3-1 to update for current aircraft; c) added paragraph 3-9 regarding runway end siting requirements; c) updated figures to improve resolution; d) deleted design requirements for underground structures in paragraphs 3-9.1 and 3-9.2;
- Updates Chapter 4, *Rotary-Wing Runways, Helipads, Landing Lanes, and Hoverpoints* to clarify text per review comments. In particular, a) clarified MV-22 applicability in paragraph 4-3.4; b) added paragraph 4-4.4 describing elevated helipads.
- Updates Chapter 5, *Taxiways* to clarify text per review comments. In particular, deletes paragraph 5-8.2 and Figure 5-6. This aligns Navy intersection fillet design criteria with previously published Army and Air Force criteria.
- Updates Chapter 6, *Aprons and Other Pavements* to clarify text per review comments. In particular, a) adds criteria for CH-53 helicopters including parking layout; b) adds criteria for protective barriers or shelters on parking spaces for rotary-wing aircraft in paragraph 6-7.4.3; c) adds paragraph 6-7.6 providing considerations for hot refueling operations for rotary-wing aircraft; d) adds Aircraft Wash Racks content passed from UFC 4-211-02; e) updated Compass Calibration Pad requirements.
- Updates Chapter 7 to incorporate Air Force ETL 09-6, *C-130 and C-17 Landing Zone (LZ) Dimensional, Marking and Lighting Criteria*.
- Deletes Chapter 8, Aircraft Hangar Pavements.
- Adds new Chapter 8, *Fixed-Wing Short Takeoff and Vertical Landing (STOVL) Facilities.* This chapter incorporates information from Air Force ETL 14-4, *Vertical Landing Zone (VLZ) And Other Airfield Pavement Design and Construction Using High Temperature Concrete* and *F-35 Lightning II STOVL Airfield Facilities and Airspace Criteria Engineering Technical Letter (ETL), document No: 2PSS00040, Rev 1 dated 30 July 2010.* In addition, added F-35B related content and standard drawings for LHD and VL Pad facilities.

- Adds new Chapter 9, *Unmanned Aircraft Systems (UAS)*. This chapter incorporates Army ETL 1110-3-510 *Aviation Complex Planning and Design Criteria for Unmanned Aircraft Systems (UAS)*.
- Updates Glossary to include new acronyms and new terms.
- Moves Glossary to Appendix C to follow UFC template format.
- Updates Appendix A, References, to update hyperlinks.
- Updates Appendix B, Section 1 to incorporate Army, Air Force and Navy revisions to clarify waiver procedures for each service.
- Updates Appendix B, Section 2, deleting Tables B2-1 thru B2-7 and instead providing facility space planning cross references for each service.
- Updates Appendix B, Section 3 by deleting all text and tables, but providing cross references to DoD, Air Force and Navy source documents
- Updates Appendix B, Section 5 to delete Part 77 text and include only cross-references to the Part 77 document.
- Updates Appendix B, Section 6 to change reference for Aircraft Characteristics to Army Technical Reports.
- Updates Appendix B, Section 7.
- Updates Appendix B, Section 10, Compass Calibration Pad siting, survey and marking guidance.
- Updates Appendix B, Section 11 to remove descriptions of static grounding points and cross-referencing to UFC 3-575-01.
- Deleted Appendix B, Section 12. Replaced with content from AF ETL 07-3: *Jet Engine Thrust Standoff Requirements for Airfield Asphalt Edge Pavements.*
- Updates Appendix B, Section 13 to incorporate Army and Air Force revisions, adding new systems and deleting old systems.
- Updates Appendix B, Section 14 to incorporate some features of FAA Advisory Circular 150/5370-2F.
- Updates Appendix B, Section 15 to incorporate Air Force ETL 01-10, *Design and Construction of High Capacity Trim Pad Anchoring Systems*.
- Deletes Appendix B, Section 16.
- Updates and Renumbers Appendix B, Section 17 now be Section 16 and to delete detailed facility requirements and provide cross-reference to UFC 4-133-01.
- Updates and Renumbers Appendix B, Section 18 now be Section 17.

Reasons for Changes:

- Incorporate new guidance scattered throughout Army and Air Force Engineering Technical Letters.
- Incorporate guidance for STOVL facilities to be used by aircraft such as F-35B.
- Clarified MV-22 Content.
- Incorporate UAS Content.
- Response to Criteria Change Requests (CCR).

- Response to review comments made by a wide variety of UFC users among the DoD agencies, including engineers, planners, airfield managers, and air traffic controllers.
- Improvement to readability of figures and addition of information via new tables and figures

Impact: There are negligible cost impacts; however, these benefits should be realized:

- Reduced confusion in interpreting guidance.
- Tri-service criteria for C-130 and C-17 Landing Zones.
- Consistent and clear tri-service criteria for STOVL facilities.
- Consistent and clear tri-service criteria for UAS facilities.
- Improved waiver processing guidelines

Non-Unification Issues: Due to differences in mission, aircraft, tactics, mishap potential and mishap rates for specific aircraft, not all criteria within this UFC are unified. The primary elements of criteria that are not unified are clear zone and accident potential zone (APZ) shapes and sizes, separation distances between runways and taxiways, and size and implementation dates for certain protected air space elements. Maintaining these differences allows the Services to avoid costs associated with non-mission-driven changes in airfield configuration and mapping, and acquisition of real property or avigation easements.

- Planning: The processes vary among the Services due to differing organizational structures and are delineated in separate Service-specific directives.
- Clear zone and APZ shapes and sizes: These areas are different for each Service and class of runway because they are based on the types of aircraft that use the runways and Service-specific accident potential.
- Distances between fixed and rotary-wing runways: The distance is greater for Air Force and Navy/Marine Corps runways due to the frequency of operations by high-performance aircraft.
- Increased width of landing lanes for Navy/Marine Corps: The width is increased to prevent rotor wash damage to landing lane shoulders and subsequent potential foreign object damage (FOD) from large rotary-wing aircraft.
- No Navy/Marine Corps requirement for paved shoulders on Class A taxiways: Same rationale as for the width of Class A taxiways above.
- Reduced site distance for Air Force taxiways: Enables the Army and Navy/Marine Corps to operate with uncontrolled taxiways.
- Increased clearance from taxiway centerlines to fixed or mobile obstacles: The Air Force routinely operates C-5 aircraft on all Air Force airfields. Use of the reduced clearances slows taxi speeds and hinders expedient operations.
- Towway width differences: The Navy/Marine Corps base towway width on three general aircraft types; the Air Force and Army base towway width on mission aircraft.

- Clearance from towway centerline to fixed or mobile obstacles: The Navy/Marine Corps require distance be based on towway type; the Air Force and Army require clearance be based on mission aircraft.
- Vertical clearance from towway pavement surface to fixed or mobile obstacles: The Navy/Marine Corps require distance be based on towway type; the Air Force and Army require clearance be based on mission aircraft.
- Differences in apron spacing for parking aircraft: The Navy/Marine Corps apron spacing requirements are developed for each aircraft in the inventory. Air Force and Army requirements are based on aircraft wingspan.
- Differences in Air Force and Army apron clearance distance: The Army requires a 38-meter (125-foot) clearance distance for all Class B aircraft aprons. This distance is sufficient to accommodate C-5 aircraft. The Air Force formerly used the same criteria but recently began basing the required distance on the most demanding aircraft that uses the apron. This is because all aprons will not accommodate C-5 aircraft.
- Differences in apron layout for rotary-wing aircraft: Formerly, Air Force and Army rotary-wing criteria were slightly different. The Air Force has adopted Army rotary-wing criteria as optional and will standardize these criteria in the next revision of AFH 32-1084, *Facility Requirements*.

CONTENTS

FIGURES

i

TABLES

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CHAPTER 1
GENERAL REQUIREMENTS

1-1 BACKGROUND.

This Unified Facilities Criteria (UFC), UFC 3-260-01, provides requirements for evaluating, planning, programming, and designing airfields and heliports. The requirements contained in this UFC apply to Army, Navy, and Air Force facilities unless specifically referenced to a single service. This UFC is not intended as a substitution for thorough review during design by individual Program Managers, Engineers and Operations Staff in the appropriate service.

The desired goal of this UFC is to maintain consistency in Airfields and Heliports requirements across the Army, Navy and Air Force. This UFC is not intended as an operational manual.

Each service has unique requirements to fulfill specific missions. This document will highlight any key differences that impact the airfield or heliport layout and design. Where one Service's criteria vary from the other Services' criteria, it is noted in the text.

1-2 PURPOSE AND SCOPE.

1-2.1 Purpose.

This manual provides standardized airfield, heliport, and airspace criteria for the geometric layout, design, and construction of runways, helipads, taxiways, aprons, landing zones (LZs), short take-off and vertical landing (STOVL) facilities, unmanned aircraft system (UAS) facilities and related permanent facilities to meet sustained operations.

1-2.2 Scope.

This manual prescribes dimensional and geometric layout criteria for safe standards for airfields, landing zones, heliports and helipads, and related permanent facilities, as well as the navigational airspace surrounding these facilities. Manned aircraft facilities are addressed in Chapters 1 through 6. Landing Zones used by C-130 and C-17 aircraft are addressed in Chapter 7. Airfield facilities used by Short Take-off Vertical Landing (STOVL) aircraft are addressed in Chapter 8. Airfield facilities for Unmanned Aircraft Systems (UAS) are addressed in Chapter 9. Criteria in this manual pertain to all Department of Defense (DoD) military facilities in the United States, its territories, trusts, and possessions, and unless otherwise noted, to DoD facilities overseas on which the United States has vested base rights. For DoD facilities overseas; if a written agreement exists between the host nation and the DoD that requires application of either North Atlantic Treaty Organization (NATO), International Civil Aviation Organization (ICAO), or Federal Aviation Administration (FAA) standards, those standards will apply as stipulated within the agreement; however, DoD proponents will apply the criteria within this manual to the maximum extent practicable. United States Air Force (USAF) bases within the European theater may be authorized by Headquarters United States Forces in Europe (HQ USAFE) to use NATO criteria (See USAFEI 32-1007). Tenant organizations on civil airports in the continental United States (CONUS) will use these criteria to the extent practicable; otherwise, FAA criteria will apply. Specifically, on airfield areas that are joint-use or with restrictions and clear zones generated by joint-use areas, the FAA criteria contained in FAA Advisory Circular (AC) 150/5300-13 is applicable. For areas where airfield surfaces are National Guard Bureau (NGB), Army Reserve or Air Force Reserve controlled, whether fee-owned or exclusive use leased, the criteria contained in this manual are applicable.

1-2.2.1 Terminal Instrument Procedures (TERPS).

In addition to a local TERPS review, modifications to existing facilities, temporary construction, airfield surface modifications, maintenance or construction requiring equipment on or near the airfield flying environment, and construction of new facilities must be closely coordinated with the Air Force major command (MAJCOM), US Army Aeronautical Services Agency (USAASA) and United States Army Aeronautical Services Detachment, Europe (USAASDE), and Naval Flight Information Group (NAVFIG) to determine the impact to existing and planned instrument approach and departure procedures . The criteria in this manual do not address instrument flight procedures. TERPS evaluations and processes are described in FAA Order 8260.3 and Air Force Instruction (AFI) 11-230. TERPS criteria shall be considered when designing or modifying airfields and facilities on airfields that are used under instrument flight rules (IFR).

1-2.2.2 Objects Affecting Navigable Airspace.

Modifications to existing facilities and construction of new facilities must consider effects on navigable airspace IAW Federal Aviation Regulation (FAR) Part 77 and may require that an FAA Form 7460-1 and/or 7460-2 be filed with the administrator. See Appendix B, Section 5, to determine when the FAA Form 7460-1 must be filed. FAA Form 7460-2 is used to notify the FAA of progress or abandonment, as requested, on the form. The FAA Service Area routinely includes this form with a determination when such information will be required. The information is used for charting purposes, to change affected aeronautical procedures, and to notify pilots of the location of the structure. Go to https://oeaaa.faa.gov/oeaaa/external/portal.jsp for more information on these forms and instructions for using E-file to submit the form to FAA. The criteria for determining obstructions to navigable airspace have been identified in this manual. The designer must consult this manual during the design process to identify obstructions to airspace and file FAA Form 7460-1 when required. The Construction Proponent/Community Planner will coordinate with the airfield/airspace manager and aviation safety officer before filing the form with the FAA. For facilities outside the United States (US) and its trust territories, host nation criteria apply off base. If the criteria in this manual are more stringent, this manual should be used to the maximum extent practical.

1-2.2.3 Navigational Aids (NAVAIDS) and Lighting.

NAVAIDS and airfield lighting are integral parts of an airfield and must be considered in the planning and design of airfields and heliports. NAVAID location, airfield lighting, and the grading requirements of a NAVAID must be considered when locating and designing runways, taxiways, aprons, and other airfield facilities.

1-2.2.4 Special Tilt-Rotor Aircraft Considerations (V-22).

The V-22 is a tilt-rotor aircraft that can operate both as a fixed-wing aircraft or a rotary-wing aircraft. At permanent shore establishments, the V-22 will be considered a fixed-wing aircraft for the purposes of determining facilities requirements. The runway will be planned according to critical field length. Chapter 3 contains V-22 fixed-wing criteria with noted exceptions. Additionally, rotary-wing facilities such as helipads may be utilized for V-22 operations. Chapter 4 contains V-22 rotary-wing criteria with noted exceptions. V-22 facilities require upgraded high temperature materials where stationary operations are expected for extended periods of times. V-22 apron requirements are provided in Chapter 6.

1-3 APPLICABILITY.

1-3.1 Existing Facilities.

Existing airfield facilities built under a previous standard need not be immediately modified nor upgraded to conform to the criteria in this manual if these facilities meet current mission requirements. This includes cases where runways may lack paved shoulders or other physical features because they were not previously required or authorized. However, when a change in the facility mission occurs, new features are added, or the facility is repaired (when repair is accomplished by replacement), the airfield facilities must be re-evaluated and upgraded where deficient using current criteria and the new mission requirements to eliminate the deficiency. A change in the facility mission can be a new aircraft or weapons platform, revised facility use, facility re-purposing, or other change that may present a new risk, assumption, or loading not previously considered or evaluated for the existing facility.

The criteria in this UFC apply to DoD aviation facilities located in the US, its territories, trusts and possessions. Where a DoD aviation facility is a tenant on a civil airport see paragraph 1-3.5.

Where a DoD aviation installation complex is host to a civilian aviation operation, the criteria in this UFC applies. Apply this criteria to the extent practicable at overseas locations where the DoD have vested rights. While the criteria in this UFC is not intended for use in theater of operations situations, it may be used as a guideline when prolonged use is anticipated and no other standard has been designated. Once upgraded, facilities must be maintained at a level that will sustain compliance with current standards. DoD personnel must identify the status of features and facilities on airfield maps as exempt (because they were constructed under a previous, less stringent standard), as a permissible deviation (authorized as a deviation to airfield criteria and sited appropriately), or as a violation, with or without approved waiver. For the Air Force only, Building Restriction Lines (BRLs) encompass vertical facilities along the flight line that are exempt because they were constructed under previous standards. For other items or features, annotate the airfield map to identify the status of the facility or feature and the date of construction or waiver number. See Appendix B, Section 17, for the guidelines used to establish the BRL.

1-3.2 Modification of Existing Facilities.

When existing airfield facilities are modified, construction must conform to the criteria established in this manual unless the criteria is waived in accordance with paragraph 1-7. Modified portions of facilities must be maintained at a level that will sustain compliance with the current standards. Exception: For the USAF, parallel taxiways constructed less than 305 meters (m) (1,000 feet (ft)) from the runway centerline may be resurfaced or extended without a waiver if the extension is less than 50 percent of the total taxiway length and the location does not impact TERPS criteria.

1-3.3 New Construction.

The criteria established in this manual apply to all new facilities. All new construction will comply with the criteria established in this manual unless the appropriate waivers are obtained as outlined in Appendix B, Section 1. For the USAF, new facilities within the appropriate category code may be constructed without a waiver if they are behind and beneath the boundaries of the BRL (see Appendix B, Section 17). All site plans for new facilities that will be sited within this area will clearly delineate the limits (including elevation) of the BRL and the relationship to the proposed facility. New facilities must be maintained at a level that will sustain compliance with the current standards.

1-3.4 Metric Application.

Geometric design criteria established in this manual are expressed in SI units (metric) and inch-pound units (English). These metric values are based on aircraft-specific requirements rather than direct conversion and rounding. This results in apparent inconsistencies between metric and inch-pound (English) dimensions. For example, 150-ft-wide runways are shown as 46 m, and 150-ft-wide aircraft wash racks are shown as 45 m. Runways need the extra meter in width for aircraft operational purposes; wash racks do not. English dimensions apply to new airfield construction at US facilities. At OCONUS facilities, apply dimensional units customarily used for construction at the facility. To avoid changes to existing airfield obstruction maps and compromises to flight safety, airfield and heliport imaginary surfaces and safe wingtip clearance dimensions are shown as a direct conversion from inch-pound to SI units.

1-3.5 Military Activities on Civil Owned Airfields.

DoD installations on municipal airports or FAA-controlled airfields must apply FAA criteria to facilities such as runways and taxiways that are jointly used by civilian and military aircraft. The portions of facilities that are for military use only, such as aircraft parking aprons, must apply DoD criteria.

1-3.6 USAFE Installations.

HQ USAFE Instruction (USAFEI) 32-1007 provides guidance for when NATO criteria may be used in lieu of the standards provided in this manual.

1-3.7 Gravel Runways at Radar Sites.

As much as possible, the criteria from Chapter 7 will be applied to the gravel runways currently in use at radar sites throughout Alaska. It is understood that many of these runways were constructed in such a way that terrain constraints allow traffic in only one direction, and that slope and obstacle clearances can be well outside normal criteria.

1-4 GENERAL BUILDING REQUIREMENTS.

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

1-4.1 Explosives Safety.

This document does not contain requirements for explosives safety. Facilities that involve DoD Ammunition and Explosives (AE) storage, handling, maintenance, manufacture or disposal, as well as facilities within the explosives safety quantity distance (ESQD) arcs of AE facilities, must comply with the requirements found in DoD 6055.09-M, as well as implementing Service criteria found in DA PAM 385-64 (Army), NAVSEA OP 5 (Navy and Marine Corps), and AFMAN 91-201 (Air Force). DoD facilities exposed to potential explosion effects from AE belonging to other nations are also required to meet DoD and Service explosives safety criteria. See also Appendix B Section 9.

1-4.2 Physical Security.

That part of security concerned with physical measures designed to safeguard personnel; to prevent or delay unauthorized access to equipment, installations, material, and documents; and to safeguard them against espionage, sabotage, damage, and theft.

Regulatory requirements for security of assets can have a significant impact on the planning and design of airfields and heliports. The arms, ammunition, explosives, and electronic devices associated with aircraft, as well as the aircraft themselves, require varying types and levels of protection. Operational security of the airfield is also a consideration.

Protective features such as barriers, fences, lighting, access control, intrusion detection, and assessment must be integrated into the airfield planning and design process to minimize problems with aircraft operations and safety requirements. This is discussed further in Chapter 2 and in unified facilities criteria UFC 4-020-01, DoD Security Engineering Facilities Planning Manual. The protective measures will be included in the design based on risk and threat analyses with an appropriate level of protection, or will comply with security-related requirements.

1-5 SERVICE REQUIREMENTS.

When criteria differ among the various Services, the criteria for the specific Service are noted. For the USAF, all work orders processed for work within the airfield environment must be signed by the airfield manager before work may proceed in accordance with paragraph 1-8, "USAF Work Order Coordination and Authorization."

1-6 THEATER OF OPERATIONS.

Standards for theater-of-operations facilities are contained in US Army TM 3-34.48-2. For C-17 and C-130 landing zones see Chapter 7 of this manual.

1-7 WAIVERS TO CRITERIA.

Mil-STD 3007 contains the overarching process for "waivers" or "exemptions" to this and all UFCs even though this UFC details additional waiver processes for operational and safety authorities. The term "waiver" herein may refer to either a temporary "waiver" or permanent "exemption" with regard to Mil-STD 3007. Each DoD Service component is responsible for setting the administrative procedures necessary to process and grant formal design or operational waivers. "Waivers" in general herein is a term that also indicates intent to seek approval for some non-compliance to criteria in this UFC. This document is intended for new construction; however, it is acknowledged that other authorities may reference it for other supplemental uses and purposes. Although this is not an operational document, these other authorities may require their own respective waiver processes. Waivers to the criteria contained in this manual will be processed in accordance with Appendix B, Section 1. If a waiver affects instrument approach and departure procedures as defined in TERPS (FAA Order 8260.3/ TM 95-226/OPNAVINST 3722.16C), the DoD Service component processing the waiver must also coordinate its action with the applicable TERPS approving authority. Certain existing facilities may require the supported aircraft activity to have an operational waiver to continue to operate, such as to land/takeoff on a shorter runway, operate on a taxiway that is not wide enough, or operate with reduced wingtip clearances for interior hangars or sunshades. These are operational/safety waivers and not design criteria waivers for new construction. Design criteria waivers address design considerations of new facilities while operational/safety waivers address airfield safety/risk considerations and operational mitigations. The Service authority owning the airfield and/or the mission aircraft will determine the requirements needed to safely operate on the existing facilities as described in Appendix B, Section 1.

1-8 USAF WORK ORDER COORDINATION AND AUTHORIZATION.

All work orders processed for work in the airfield environment must first be coordinated with communications, civil engineering, safety, security forces, and TERPS, and then signed by the airfield manager before work may proceed. The airfield manager (AM) and flight safety must be notified no less than five working days prior to beginning construction/work on the airfield. This does not apply to emergency repairs.

1-9 FAA NOTICE OF PROPOSED CONSTRUCTION OR ALTERATION.

Construction of new airfields, heliports, helipad or hoverpoints, or modifications to existing facilities affecting the use of airspace or changes in aircraft densities may require notification to the FAA Administrator. When a new runway, heliport, helipad or hoverpoint is planned or an existing landing surface will be extended or modified, in addition to local permitting requirements, file FAA Form 7480-1 in accordance with FAA Order 7400.2 via https://oeaaa.faa.gov/oeaaa/external/portal.jsp. Additionally, the FAA must be notified of all construction that affects air navigation at DoD airfields and civil airports in the US and its territories. FAA Form 7460-1 must be submitted to the FAA at least 45 days prior to the start of construction, in accordance with Federal Aviation Regulations (FAR), Part 77, subpart B. Airspace surface penetrations will be noted. Applications may be obtained and are filed with the appropriate FAA Service Area. For DoD facilities overseas, similar requirements by the host country, NATO, or ICAO may be applicable.

1-10 CONSTRUCTION PHASING PLAN.

A construction phasing plan, as discussed in Appendix B, Section 14, must be included in the contract documents. This is a mandatory requirement for USAF and Army installations whether work will be accomplished by contract or in-house (see Appendix B, Section 14). Also see the procedures for obtaining temporary waivers for construction in Appendix B, Section 1.

1-11 ZONING.

Existing facilities should be modified, and new facilities will be sited and constructed consistent with Service-specific AICUZ compatible land use standards and in a manner that will encourage local municipalities to adopt land use plans and zoning regulations to protect people, property and the installation's flying mission. Land uses compatible with flight operations are defined in DoD Instruction (DoDI) 4165.57 and Service-specific AICUZ directives.

1-12 REFERENCES.

Appendix A contains a list of documents referenced in this manual.

1-13 GLOSSARY.

Appendix C contains acronyms, abbreviations and terms.

1-14 USE OF TERMS.

These terms, when used in this manual, indicate the specific requirements listed here:

- Will or Must: Indicates a mandatory and/or required action.
- Should: Indicates a recommended, advisory, and/or desirable action.
- May or Can: Indicates a permissible action.

CHAPTER 2
AVIATION FACILITIES PLANNING

2-1 APPLICABILITY.

The criteria in this chapter apply to DoD aviation facilities planning, but may be supplemented by additional service-specific guidance. Navy aviation planning is covered in NAVFAC publication UFC 2-000-05N. Aviation facilities planning for the Air Force is discussed in AFIs 32-7062, 32-7063, 32-1024, and Air Force Manual (AFMAN) 32-1084. In some cases, Army, Air Force and Navy agencies reference documents have been noted.

2-1.1 Manual Usage.

Integration of aviation facilities planning with other DoD planning processes entails broad considerations. For example, the National Environmental Policy Act of 1969 (NEPA) has significantly affected aviation facilities planning by requiring that environmental impacts be considered early and throughout the planning process. In using this manual, planners should recognize that planning an aviation facility requires not only planning for runways, taxiways, aprons, and buildings, but also considering environmental factors, land use considerations, airspace constraints, and surrounding infrastructure.

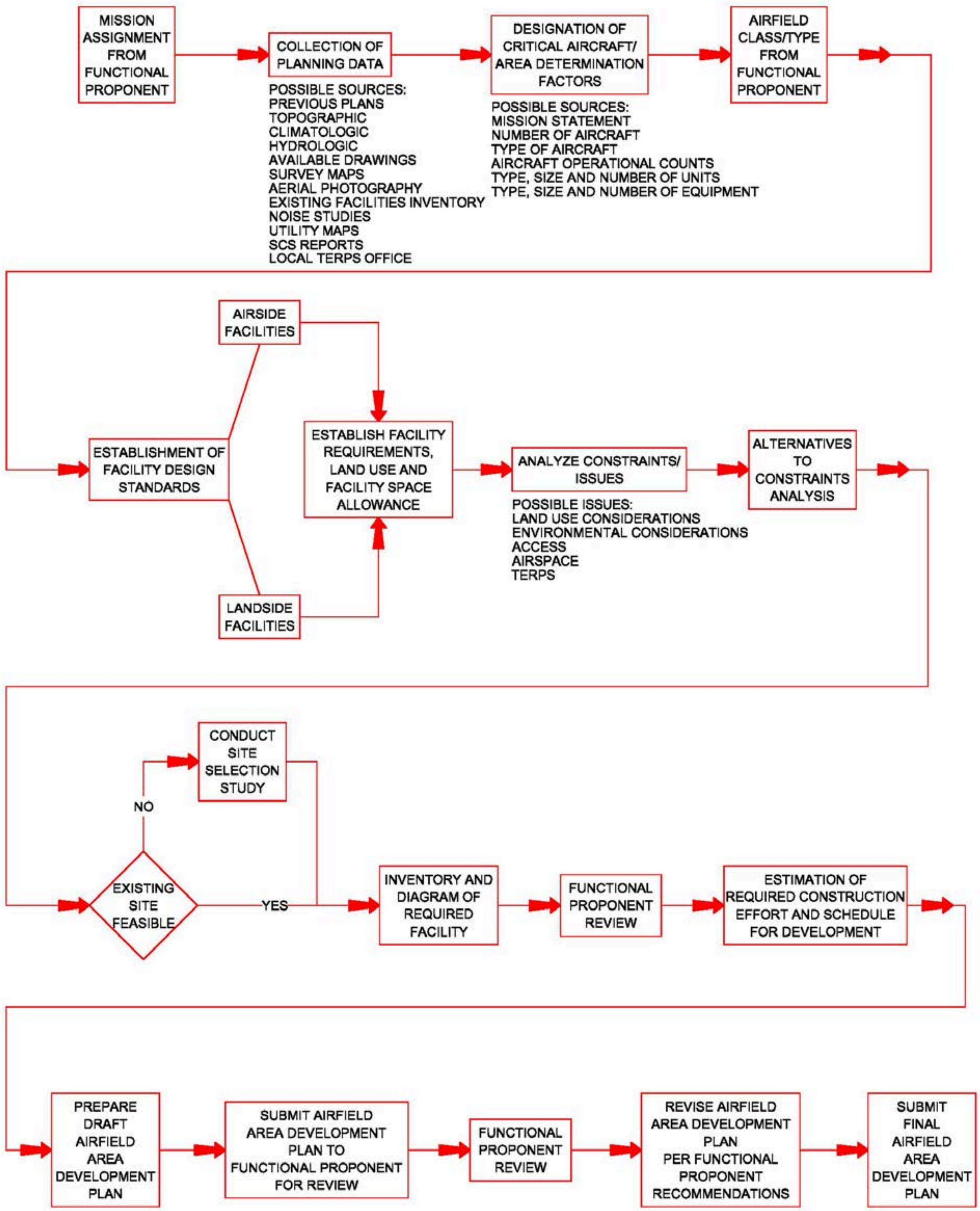
2-1.2 Planning Process.

Aviation facilities planning involves collecting data, forecasting demand, determining facility requirements, analyzing alternatives, and preparing plans and schedules for facility development. The aviation facilities planning process must consider the mission and use of the aviation facility and its effect on the general public. The planning process cannot be completed without knowing the facility's primary mission and assigned organization and types of aircraft. Figure 2-1 provides general steps in the aviation facilities planning process.

2-1.3 Planning Elements.

The elements of an aviation facility's planning process will vary in complexity and degree of application, depending on the size, location, function, and problems of the facility. The technical steps described in this manual should be undertaken only to the extent necessary to produce a well-planned aviation facility. Each DoD installation with an airfield should have an airfield Area Development Plan (ADP) to address airfield development, i.e., projects (such as pavement, lighting, grading, tree removal), waivers, and obstruction removal. The ADP is a part of the base comprehensive plan.

Figure 2-1. Aviation Facilities Planning Process



2-1.4 Guidance.

This chapter is structured and organized to provide guidance to planners intending to plan, design, or modify an aviation facility to comply with standardized criteria.

2-1.5 Additional Planning Factors.

As discussed in Chapter 1, additional planning factors such as pavement design, airfield marking, and TERPS must be considered when planning aviation facilities.

2-1.6 Space Allowances.

The primary source for determining authorized space allowances for Army aviation facilities is the Facility Planning System (FPS) contained in the Real Property Planning and Analysis System (RPLANS). Space allowances are presented in UFC 2-000-05N for Navy facilities and AFMAN 32-1084 for Air Force facilities.

2-2 JUSTIFICATION.

2-2.1.1 Aviation Facilities Planning.

Aviation facilities must be planned, programmed, and constructed in accordance with the Area Development Plan process. An ADP is developed and approved through an established planning process as discussed in paragraph 2-4. The master plan process requires assessing alternatives to determine the best alternative, or the best combination of alternatives, to overcome deficiencies at an aviation facility. Consideration must be given to construction alternatives (to construct new, modify, or upgrade a substandard facility) combined with operational alternatives (rescheduling and sharing facilities, changing training or mission) to determine the best plan for meeting facility requirements. As a minimum, each alternative considered must identify the changes to the mission, personnel, weapons systems and equipment, and any other impact to the facility. Construction of a new aviation facility is authorized when: (1) operational alternatives have been assessed and the conclusion is that the alternatives are not viable or executable options; or (2) existing facilities have been assessed as inadequate to meet the mission, and new airside and/or landside facilities are not feasible.

2-2.2 Existing Facility Assessment.

When the mission to be supported changes, a determination must be made if a facility built to a previous design standard meets or exceeds the current design standard and is no longer needed by the current mission, such as wider/longer runway/taxiway/apron or multiple runways (crosswind/parallel, etc.) than currently required. In these cases, the long term cost of keeping the excess pavement as is, must be documented and analyzed to determine if keeping the facility or bringing the facility into current required design standards is safer and/or cost effective in the long term.

2-2.2.1 Navy/Marine Corps

Approval from Headquarters Naval Facilities Engineering Command (NAVFACENGCOM) must be obtained before revising safety clearances at existing airfield pavements to conform to new standards herein. NAVFACENGCOM will coordinate the approval with the Naval Air Systems Command (NAVAIR) and Chief of Naval Operations (CNO)/Commandant Marine Corps (CMC), as required.

2-2.3 Joint Use Facilities.

Use of existing facilities on a civil airfield, or the airfield of another Service, should be considered when feasible.

2-3 GENERAL PLANNING CONSIDERATIONS.

2-3.1 Goals and Objectives.

The goals and objectives of planning an aviation facility, as set forth in this manual, are to ensure sustained, safe, economical, and efficient aircraft operations and aviation support activities. Planners must consider both the present and potential uses of the aviation facility during peacetime, mobilization, and emergency operations. Engineers/planners should assist operations personnel with the planning and programming, definition and scope, site selection, and design of the facility. See UFC 2-100-01, Installation Master Planning, for additional guidance.

2-3.2 Requirements.

Each functional proponent is responsible for providing the appropriate operational information to be used in the planning of an aviation facility. In addition, planning should be coordinated with all users (operations, air traffic control, and safety) of the aviation facility, including the FAA, to determine immediate and long-range uses of the aviation facility.

2-3.2.1 Operational Information.

Functional proponents will provide, at a minimum, the existing and projected operational information needed for planning aviation facilities:

- Mission statements
- Aircraft operational counts, traffic levels, and traffic density
- Type, size, and number of units/organizations and personnel
- Type, size, and number of equipment (e.g., aircraft, weapons systems, vehicles)
- Once these items are established, land requirements to support the aircraft mission can be established.

2-3.2.2 Engineering Information.

Engineering information provided will include, as a minimum: graphical maps and plans, facility condition assessments, and tabulation of existing facilities.

2-3.3 Safety.

The planning and design of an aviation facility will emphasize safety for aircraft operations. This includes unobstructed airspace and safe and efficient ground movements. Protect air space by promoting conscientious land use planning, such as compatible zoning and land easement acquisition.

2-3.3.1 Wildlife Hazards Mitigation.

Planning and design must comply with installation specific bird and animal strike hazard or other wildlife hazards mitigation plans and FAA/AC150/5200-33B to minimize aircraft wildlife strikes.

- For Navy and Marine Corps: Use the Installation specific Wildlife Hazards Mitigation Plan (WHMP) in accordance with CNICINST 3750.1.
- For Army: The requirements for a Wildlife Hazard Management Plan as spelled out in AR 95-2 shall be adhered to.
- For Air Force: Use AFI 91-212 Bird/Wildlife Aircraft Strike Hazard (BASH) Management Program. New proposed storm water features on airfields will be coordinated with and through the local Bird Hazard Working Group during the design stage.

2-3.4 Design Aircraft.

Typically, aviation facilities are designed for a specific aircraft known as the "critical" or "design" aircraft, which is the most operationally and/or physically demanding aircraft to make substantial use of the facility. The critical or design aircraft is used to establish the dimensional requirements for safety parameters such as approach protection zones; lateral clearance for runways, taxiways and parking positions; and obstacle clearance. In many cases, the "geometric" design aircraft (most demanding based on size or performance) may not be the same aircraft as the "pavement" design aircraft (most demanding for pavement load design).

2-3.5 Airspace and Land Area.

Aviation facilities need substantial air space and land area for safe and efficient operations and to accommodate future growth or changes in mission support.

2-3.5.1 Ownership of Clear Zones and Accident Potential Zones.

When planning a new aviation facility or expanding an existing one, clear zones should, to the maximum extent possible, be either owned or protected through restrictive use easements. Ownership/control of the APZ should follow guidance in DoDI 4165.57.

2-3.5.2 Land Use within the Clear Zone and Accident Potential Zones.

The AICUZ Program is the governing authority for land use in clear zones and accident potential zones (APZ). Requirements for land use in clear zones and APZs are provided in DoDI 4165.57 and Service-specific AICUZ directives. Additional restrictions for the graded area of the clear zone are provided in this manual.

2-3.5.3 Explosives.

Where explosives or hazardous materials are handled at or near aircraft, safety and separation clearances are required. The clearances are based on quantity-distance criteria as discussed in Appendix B, Section 9.

2-3.5.4 Landside Safety Clearances.

Horizontal and vertical operational safety clearances must be applied to landside facilities and will dictate the general arrangement and sizing of facilities and their relationship to airside facilities. Landside facilities will vary in accordance with the role of the mission. There are, however, general considerations that apply in most cases, such as:

- Adherence to standards in support of safety in aircraft operations
- Non-interference with line of sight or other operational restrictions
- Use of existing facilities
- Flexibility in being able to accommodate changes in aircraft types or missions
- Efficiency in ground access
- Priority accorded aeronautical activities where available land is limited

2-3.5.5 Helipads.

Helipads are authorized at locations where aircraft are not permanently assigned but have a need for access based on supporting a continuing and recurrent aviation mission. For example, hospitals, depot facilities, and headquarters buildings are authorized one or more helipads. These facilities must be included in the approved airfield master plan.

2-3.5.6 Facilities Used by Multiple Services.

At airfields used by multiple Services, the planning and design of facilities will be coordinated between the appropriate Services. The lead for coordination is the appropriate facilities/engineering echelon of the Service that owns the facilities.

2-3.5.7 Air Force Airfield Obstruction Mapping.

The requirements and specifications for mapping are contained in AFI 32-7062.

2-4 PLANNING STUDIES.

2-4.1 Master Plan.

Knowledge of existing facilities, mission, and aircraft, combined with a realistic assumption of future requirements, is essential to the development of master plans. Principles and guidelines for developing master plans at an aviation facility are contained in UFC 2-100-01, Installation Master Planning, and these publications:

- Army: AR 210-20, Real Property Master Planning for Army Installations
- Air Force: AFI 32-7062
- Navy/Marines: NAVFAC, Naval Shore Infrastructure, Installation Development Plan Consistency Guide

2-4.2 Land Use Studies.

Long-range land use planning is a primary strategy for protecting a facility from problems that arise from aviation-generated noise and incompatible land uses. Aircraft noise can adversely affect the quality of the human environment. Federal agencies are required to work with local, regional, state, and other Federal agencies to foster compatible land uses, both on and off the boundaries of the aviation facility. The Air Installations Compatible Use Zones (AICUZ) and Installation Compatible Use Zone (ICUZ) programs promote land use compatibility through active land use planning.

2-4.3 Environmental Studies.

Development of an aviation facility, including expansion of an existing aviation facility, requires compliance with a variety of laws, regulations, and policies. The National Environmental Policy Act (NEPA) requires all Federal agencies to consider the potential environmental impacts of certain proposed projects and activities, as directed by DoD Directive (DoDD) 6050.7. Implementation of these regulations is defined for each Service in these documents: Army: AR 200-1, Environmental Protection and Enhancement; Air Force: Title 32, Code of Federal Regulations, Part 989 (32 CFR 989); and Navy and Marine Corps: OPNAVINST 5090.1B (MCO 5090.2). Four broad categories of environmental review for a proposed action exist. The decision to conduct one study or another depends on the type of project and the potential consequences of project to various environmental categories. Criteria for determining which type of study should be undertaken are defined in the environmental directives and regulations for each Service. Environmental studies should be prepared and reviewed locally. When additional assistance or guidance is necessary, this support may be obtained through various agencies such as the USA Army Air Traffic Services Command (ATSCOM)the US Army Corps of Engineers Transportation Systems Center (USACE TSC), the US Army Corps of Engineers District Offices, NAVFAC Headquarters and Engineering Field Divisions, and the Air Force Civil Engineer Center (HQ AFCEC).

2-4.3.1 Environmental Assessment (EA).

The EA serves to analyze and document the extent of the environmental consequences of a proposed action. It evaluates issues such as existing and future noise, land use, water quality, air quality, and cultural and natural resources. The conclusion of the assessment will result in either a Finding of No Significant Impact (FONSI), or, if the consequences are significant and cannot be mitigated to insignificance, the decision to conduct an Environmental Impact Statement (EIS). This decision is typically made by the authority approving the study.

2-4.3.2 Environmental Impact Statement (EIS).

An EIS is the document that identifies the type and extent of environmental consequences created if the proposed project is undertaken. The primary purpose of the EIS is to ensure that NEPA policies and goals are incorporated into the actions of the Federal government. The EIS defines the impact and details what measures will be taken to minimize, offset, mitigate, or avoid any adverse effects on the existing environmental condition. Upon completion of an EIS, the decision maker will file a Record of Decision (ROD), which finalizes the environmental investigation and establishes consent to either abandon or complete the project within the scope of measures outlined in the EIS.

2-4.3.3 Categorical Exclusion (CATEX).

A CATEX is defined as a category of proposed action(s) that does not individually or cumulatively have the potential for significant effect on the environment and does not, therefore, require further environmental analysis in an EA or EIS. A list of actions that are categorically excluded is contained in the regulatory directives for each service.

2-4.3.4 Exemption By Law and Emergencies.

In specific situations, Congress may exempt the DoD from compliance with NEPA for particular actions. Emergency situations do not exempt the DoD from complying with NEPA but do allow emergency response while complying with NEPA.

2-4.4 Aircraft Noise Studies.

AICUZ and ICUZ are programs initiated to implement Federal laws concerning land compatibility from the perspective of environmental noise impacts. The ICUZ program is the Army's extension of the AICUZ program, which was initiated by the DoD and undertaken primarily by Air Force and Navy aviation facilities. Noise studies conducted under these programs describe the airfield noise environment and provide the installation with noise contour maps for use in managing noise and planning for compatible land use.

2-4.4.1 Analysis.

Due to the widely varied aircraft, aircraft power plants, airfield traffic volume, and airfield traffic patterns, aviation noise at installations depends on both aircraft types and operational procedures. Aircraft noise studies should be prepared for aviation facilities to quantify noise levels and possible adverse environmental effects, ensure that noise reduction procedures are investigated, and plan land for uses that are compatible with higher levels of noise. While many areas of an aviation facility tolerate higher noise levels, many aviation landside facilities and adjoining properties do not. Noise contours developed under the AICUZ and ICUZ studies are used to graphically illustrate noise levels and provide a basis for land use management and impact mitigation. The primary means of noise assessment is mathematical modeling and computer simulation. Guidance regarding when to conduct noise studies is contained in the environmental and AICUZ directive for each Service.

2-4.5 Instrumented Runway Studies.

The requirement to conduct an instrumented runway study is issued by the functional proponent. It is important to recognize that instrument landing capability provides for aircraft approaches at very low altitude ceilings or visibility distance minimums. Consequently, these lower approach minimums demand greater safety clearances, larger approach surfaces, and greater separation from potential obstacles or obstructions to air navigation.

2-5 SITING AVIATION FACILITIES.

NOTE: While the general siting principles below are applicable to Navy aviation facilities, see UFC 2-000-05N for Navy-specific data and contacts.

2-5.1 Location.

The general location of an aviation facility is governed by many factors, including base conversions, overall defense strategies, geographic advantages, mission realignment, security, and personnel recruitment. These large-scale considerations are beyond the scope of this manual. The information in this chapter provides guidelines for siting aviation facilities where the general location has been previously defined.

2-5.2 Site Selection.

2-5.2.1 Site Conditions.

Site conditions must be considered when selecting a site for an aviation facility. The site considerations include, but are not limited to: topography, vegetative cover, existing construction, weather elements, wind direction, soil conditions, flood hazard, natural and man-made obstructions, adjacent land use, availability of usable airspace, accessibility of roads and utilities, and future expansion capability.

2-5.2.2 Future Development.

Adequate land for future aviation growth must be considered when planning an aviation facility. An urgent requirement for immediate construction should not compromise the plan for future development merely because a usable, but not completely satisfactory, site is available. Hasty acceptance of an inferior site can preclude the orderly expansion and development of permanent facilities. Initial land acquisition (fee or lease) or an aviation easement of adequate area will prove to be the greatest asset in protecting the valuable airfield investment.

2-5.2.3 Sites not on DoD Property.

Site selection for a new airfield or heliport not located on a DoD- or Service-controlled property must follow FAA planning criteria and each Service's established planning processes and procedures for master planning as previously discussed in paragraph 2-4.1. Siting the aviation facility requires an investigation into the types of ground transportation that will be required, are presently available, or are capable of being implemented. All modes of access and transportation should be considered, including other airports/airfields, highways, railroads, local roadways, and internal roads. The facility's internal circulation plan should be examined to determine linear routes of movement by vehicles and pedestrians to ensure that an adequate access plan is achievable.

2-5.3 Airspace Approval.

See Chapter 1, Paragraph 1-9.

2-5.4 Airfield Safety Clearances.

2-5.4.1 Dimensional Criteria.

The dimensions for airfield facilities, airfield lateral safety clearances, and airspace imaginary surfaces are provided in this UFC.

2-5.4.2 Air Force Missions at Army Facilities.

Airfield safety clearances applicable to Army airfields that support Air Force cargo aircraft missions will be based on an Army Class B airfield. This will be coordinated between the Army and the Air Force.

2-5.4.3 Prohibited Land Uses.

AICUZ compatible land use standards prohibit certain land uses within the clear zone and APZs (APZ I and APZ II). These land uses include storage and handling of munitions and hazardous materials, and live-fire weapons ranges. See DoDI 4165.57 and Service-specific AICUZ directives for more information.

2-5.4.4 Wake Turbulence.

The problem of wake turbulence may be expected at airfields where there is a mix of light and heavy aircraft. At these airfields, some taxiway and holding apron design modifications may help to alleviate the hazards. Although research is underway to improve detection and elimination of the wake, at the present time the most effective means of avoiding turbulent conditions is provided by air traffic control personnel monitoring and regulating both air and ground movement of aircraft. Planners can assist this effort by providing controllers with line-of-site observation to all critical aircraft operational areas and making allowances for aircraft spacing and clearances in turbulence-prone areas. Additional information on this subject is available in FAA AC 90-23.

2-5.5 Storm Water Management Facilities.

Use UFC 3-201-01 for airfield drainage design and manage stormwater in ways that will not compromise airfield safety. Design stormwater elements to minimize the attraction of hazardous wildlife by reducing open standing water such as retention ponds and stormwater wetlands to the maximum extent practicable. Some techniques that may be used to achieve these goals include:

- Increasing the separation distance between stormwater elements and the runway
- Using underground detention
- Using detention ponds with a maximum 48-hour detention period

For Army: No new above ground detention or retention ponds shall be sited within 1500' of the runway centerline as extended through the ends of the clear zones without prior approval from USACE-TSC.

2-5.6 Renewable Energy Systems.

When siting renewable power generation facilities (e.g. photovoltaic cell arrays) in close proximity to airfields, issues like airspace coordination, glare and low-altitude testing and training route interference must be considered. See UFC 3-440-01, Facility-Scale Renewable Energy Systems and UFC 3-540-08, Utility-Scale Renewable Energy Systems for additional information and requirements. For Air Force, see AFI 32-7063 for additional guidance on hazards to aircraft flight zone.

2-6 AIRSIDE AND LANDSIDE FACILITIES.

An aviation facility consists of four land use areas, further described in paragraphs 2-7 through 2-10.

a. Airside Facilities – facilities associated with the movement and parking of aircraft.

- Landing and takeoff surfaces
- Aircraft ground movement and parking areas

b. Landside Facilities – facilities not associated with the movement and parking of aircraft but are required for the facilities' mission.

- Aircraft maintenance areas
- Aviation operations support areas

2-7 LANDING AND TAKEOFF SURFACES.

2-7.1 Runways and Helipads.

Takeoff and landing surfaces are based on either a runway or helipad. The landing/takeoff surface consists of not only the runway and helipad surface, shoulders, and overruns, but also the approach slope surfaces, safety clearances, and other imaginary airspace surfaces.

2-7.2 Number of Runways.

Aviation facilities normally have only one runway. Additional runways may be necessary to accommodate operational demands, minimize adverse wind conditions, or overcome environmental impacts. A parallel runway may be provided based on operational requirements. Methodologies for calculating runway capacity in terms of annual service volume (ASV) and hourly IFR or visual flight rules (VFR) capacity are provided in FAA AC 150/5060-5. Planning efforts to analyze the need for more than one runway should be initiated when it is determined that traffic demand for the primary runway will reach 60 percent of its established capacity (FAA guidance). For USAF facilities, also see AFMAN 32-1084, Facility Requirements, Facility Analysis Category (FAC) 1111, Runways.

2-7.3 Number of Helipads.

At times at airfields or heliports, a large number of helicopters are parked on mass aprons or are in the process of takeoff and landing. When this occurs, there is usually a requirement to provide landing and takeoff facilities that permit more rapid launch and recovery operations than can otherwise be provided by a single runway or helipad. This increased efficiency can be obtained by providing one or more of the following options, but is not necessarily limited to:

- Multiple helipads, hoverpoints, or runways
- Rotary-wing runways in excess of 490 m (1600 ft) long

- Landing lane(s)

2-7.4 Runway and Helipad Location.

Runway and helipad location and orientation are paramount to airport safety, efficiency, economics, practicality, and environmental impact. The degree of concern given to each factor influencing runway or helipad location depends greatly on meteorological conditions, adjacent land use and land availability, airspace availability, runway/helipad type/instrumentation, environmental factors, terrain features/topography, and obstructions to air navigation.

2-7.4.1 Obstructions to Air Navigation.

Runways and helipads must have approaches that are free and clear of obstructions. Runways and helipads must be planned so that the ultimate development of the airfield provides unobstructed navigation. A survey of obstructions will be undertaken to identify those objects that may affect aircraft operations. Protection of airspace can be accomplished through land purchase, easement, zoning coordination, and application of appropriate military directives.

2-7.4.2 Airspace Availability.

Existing and planned instrument approach and departure procedures, Class D Airspace, and special use airspace and traffic patterns influence airfield layouts and runway and helipad locations. Construction projects for new airfields and heliports or construction projects on existing airfields have the potential to affect airspace. These projects require notification to the FAA to examine feasibility for conformance with and acceptability into the national airspace system.

2-7.4.3 Runway and Helipad Orientation.

Wind direction and velocity is a major consideration for siting runways and helipads. To be functional, efficient, and safe, a runway or helipad should be oriented in alignment with the prevailing winds, to the greatest extent practical, to provide favorable wind coverage. Wind data, obtained from local sources, for a period of not less than five years, should be used as a basis for developing the wind rose to be shown on the airfield general site plan. Appendix B, Section 4, provides guidance for the research, assessment, and application of wind data.

2-7.5 Runway and Helipad Separation.

The lateral separation of a runway from a parallel runway, parallel taxiway, or helipad/hoverpoint is based on the type of aircraft the runway serves. Runway and helipad separation criteria are presented in Chapters 3 and 4 of this manual.

2-7.6 Runway Instrumentation.

Navigational Aids (NAVAIDS) require land areas of specific size, shape, and grade to function properly and remain clear of safety areas.

2-7.6.1 NAVAIDS, Vault, and Buildings.

NAVAIDS assist the pilot in flight and during landing. The type of air NAVAIDS that are installed at an aviation facility is based on the instrumented runway studies, as previously discussed in 2-4.5. A lighting equipment vault is provided for airfields and heliport facilities with NAVAIDS, and may be required at remote or stand-alone landing sites. A (NAVAID) building will be provided for airfields with NAVAIDS. Each type of NAVAID equipment is usually housed in a separate facility. Technical advice and guidance for air NAVAIDS should be obtained from service-specific support and siting agencies.

2-8 AIRCRAFT GROUND MOVEMENT AND PARKING AREAS.

Aircraft ground movement and parking areas consist of taxiways and aircraft parking aprons.

2-8.1 Taxiways.

Taxiways provide for free ground movement to and from the runways, helipads, and maintenance, cargo/passenger, and other areas of the aviation facility. The objective of taxiway system planning is to create a smooth traffic flow. This system allows unobstructed ground visibility; a minimum number of changes in aircraft taxiing speed; and, ideally, the shortest distance between the runways or helipads and apron areas.

2-8.1.1 Taxiway System.

The taxiway system is comprised of entrance and exit taxiways; bypass, crossover taxiways; apron taxiways and taxilanes; hangar access taxiways; and partial-parallel, full-parallel, and dual-parallel taxiways. The design and layout dimensions for various taxiways are provided in Chapter 5.

2-8.1.2 Taxiway Capacity.

At airfields with high levels of activity, the capacity of the taxiway system can become the limiting operational factor. Runway capacity and access efficiency can be enhanced or improved by the installation of parallel taxiways. A full-length parallel taxiway may be provided for a single runway, with appropriate connecting lateral taxiways to permit rapid entrance and exit of traffic between the apron and the runway. At facilities with low air traffic density, a partial parallel taxiway or mid-length exit taxiway may suit local requirements; however, develop plans so that a full parallel taxiway may be constructed in the future when such a taxiway can be justified.

2-8.1.3 Runway Exit Criteria.

The number, type, and location of exit taxiways is a function of the required runway capacity. Exit taxiways are typically provided at the ends and in the center and midpoint on the runway. Additional locations may be provided as necessary to allow landing aircraft to exit the runway quickly. Chapter 5 provides additional information on exit taxiways.

2-8.1.4 Dual-Use Facility Taxiways.

For taxiways at airfields supporting both fixed-wing and rotary-wing operations, the appropriate fixed-wing criteria will be applied.

2-8.1.5 Paved Taxiway Shoulders.

Paved taxiway shoulders are provided to reduce the effects of jet blast on areas adjacent to the taxiway. Paved taxiway shoulders help reduce ingestion of foreign object debris (FOD) into jet intakes. Paved shoulders will be provided on taxiways in accordance with the requirements in Chapter 5.

2-8.2 Aircraft Parking Aprons.

Aircraft parking aprons are the paved areas required for aircraft parking, loading, unloading, and servicing. They include the necessary maneuvering area for access and exit to parking positions. Aprons will be designed to permit safe and controlled movement of aircraft under their own power. Aircraft apron dimensions and size are based on mission requirements. Additional information concerning Air Force aprons is provided in AFMAN 32-1084, FAC 1131, Aprons. For Navy, see UFC 3-000-05N and paragraph 6-2 APRON REQUIREMENTS for additional guidance.

2-8.2.1 Requirement.

Aprons are individually designed to support specific aircraft and missions at specific facilities. The size of a parking apron depends on the type and number of aircraft authorized. Chapter 6 provides additional information on apron requirements.

2-8.2.2 Location.

Aircraft parking aprons typically are located between the parallel taxiway and the hangar line. Apron location with regard to airfield layout will adhere to the operations and safety clearances provided in Chapter 6 of this manual.

2-8.2.3 Capacity.

Aircraft parking capacity for the Army is discussed in the Facility Planning System (FPS) contained in the Real Property Planning and Analysis System (RPLANS)DAPAM 415-28; in UFC 2-000-05N for the Navy; and in AFMAN 32-1084 for the Air Force.

2-8.2.4 Clearances.

Lateral clearances for parking aprons are provided from all sides of aprons to fixed and/or mobile objects. Additional information on lateral clearances for aprons is discussed in Chapter 6.

2-8.2.5 Access Taxilanes, Entrances, and Exits.

The dimensions for access taxilanes on aircraft parking aprons are provided in Chapter 6. The minimum number of exit/entrance taxiways provided for any parking apron should be two.

2-8.2.6 Aircraft Parking Schemes.

On a typical mass parking apron, aircraft should be parked in rows. The recommended tactical/fighter aircraft parking arrangement is to park aircraft at a 45-degree angle. This is the most economical parking method for achieving the clearance needed to dissipate jet blast temperatures and velocities to levels that will not endanger aircraft or personnel. (For the Navy, these are 38 degrees Celsius (100 degrees Fahrenheit) and 56 km per hour (km/h) (35 miles per hour (mph)) at break-away (intermediate power)). Typical parking arrangements and associated clearances are provided in Chapter 6.

2-8.2.7 Departure Sequencing.

Aircraft egress patterns from aircraft parking positions to the apron exit taxiways should be considered to prevent congestion at the apron exits. For example, aircraft departing from one row of parking positions should taxi to one exit taxiway, allowing other rows to simultaneously taxi to a different exit.

2-8.2.8 Apron/Other Pavement Types.

Special use aprons may exist on an aviation facility. Chapter 6 provides further information on these aprons/pavements.

2-9 AIRCRAFT MAINTENANCE AREA (OTHER THAN PAVEMENTS).

An aircraft maintenance area is required when aircraft maintenance must be performed regularly at an aviation facility. Space requirements for maintenance facilities are based on aircraft type.

2-9.1 Aircraft Maintenance Facilities.

The aircraft maintenance facility includes but is not limited to: aircraft maintenance hangars, special purpose hangars, hangar access aprons, weapons system support shops, aircraft system testing and repair shops, aircraft parts storage, corrosion control facilities, and special purpose maintenance pads. The aircraft maintenance area includes utilities, roadways, fencing, and security facilities and lighting.

2-9.2 Aviation Maintenance Buildings and Hangars.

For aviation maintenance building information for the Army, see the Facility Planning System (FPS) contained in the Real Property Planning and Analysis System (RPLANS); for the Air Force, see AFMAN 32-1084; for the Navy see UFC 2-000-05N.

2-9.2.1 Maintenance Hangars.

Maintenance hangars are required to support those aircraft maintenance, repair, and inspection activities that can be more effectively accomplished while the aircraft is under complete cover. The size requirement for maintenance hangars is determined by the number of aircraft assigned. See UFC 4-211-01 for hangars.

2-9.2.2 Security and Storage Hangars.

These hangars are limited in use and do not require the features normally found in maintenance hangars.

2-9.2.3 Avionics Maintenance Shop.

Avionics maintenance space should normally be provided within the maintenance hangar; however, a separate building for consolidated avionics repair may be provided at aviation facilities with multiple units.

2-9.2.4 Engine Repair and Engine Test Facilities.

Engine repair and test facilities are provided at air bases with aircraft engine removal, repair, and testing requirements. Siting of engine test facilities will consider the impacts of jet blast, jet blast protection, and noise suppression.

2-9.2.5 Parts Storage.

Covered storage of aircraft parts should be provided at all aviation facilities and located close enough to the maintenance area to allow easy access to end users.

2-9.3 Maintenance Aprons.

These aprons should be sized according to the dimensions discussed in Chapter 6.

2-9.4 Apron Lighting.

Apron area lighting (floodlights) is provided where aircraft movement, loading or unloading, and security are required at night, and during poor visibility. The type of lighting is based on the amount of apron space or number of aircraft positions that receive active use during nighttime operations.

2-9.5 Security.

The hangar line typically represents the boundary of the airfield operations area. Maintenance buildings should be closely collocated to discourage unauthorized access and enhance facility security.

2-10 AVIATION OPERATIONS SUPPORT AREA.

2-10.1 Aviation Operations Support Facilities.

Aviation operations support facilities include those facilities that directly support the flying mission. Operations support includes air traffic control, aircraft rescue and firefighting, fueling facilities, the airfield operations center (airfield management facility), squadron operations/aircraft maintenance units, and air mobility operations groups.

2-10.2 Location.

Aviation operations support facilities should be located along the hangar line, with the central area typically being allocated to airfield operations (airfield management facility), air traffic control, aircraft rescue and firefighting, and flight simulation. Aircraft maintenance facilities should be located on one side of the runway to allow simplified access among maintenance areas, aircraft, and support areas.

2-10.3 Orientation of Facilities.

Facilities located either parallel or perpendicular to the runway make the most efficient use of space. Diagonal and curved areas tend to divide the area and result in awkward or unusable spaces.

2-10.4 Multiple Supporting Facilities.

When multiple aviation units are located at one facility, their integrity may be retained by locating such units adjacent to each other.

2-10.5 Transient Facilities.

Provisions should be made for transient and very important person (VIP) aprons and buildings. These facilities should be located near the supporting facilities discussed in paragraph 2-10.1.

2-10.6 Other Support Facilities.

When required, other support facilities, such as aviation fuel storage and dispensing, heating plants, water storage, consolidated parts storage, and motor pool facilities, should be sited on the far side of an access road paralleling the hangar line.

2-10.6.1 Air Traffic Control Facilities.

The siting and height of the Air Traffic Control Tower (ATCT) are determined in accordance with Appendix B, Section 16. For Army and Air Force, other air traffic control facilities will be sited in accordance with Appendix B, Section 13. For Navy, other air traffic control facilities will be sited in compliance with surfaces described in Chapters 3 and 4.

2-10.6.2 Radar Approach Control Facilities.

Some airfields are equipped with radar capability. When the functional proponent determines the need for radar capability, space for radar equipment will be provided. Space for radar equipment should be provided in the air traffic control tower building and/or RAPCON. See UFC 4-133-01, Air Traffic Control and Air Operations Facilities for facility design requirements.

2-10.6.3 Aircraft Rescue and Fire Facilities.

Airfield facilities and flight operations will be supported by fire and rescue equipment. The aircraft rescue and fire facilities must be located strategically to allow aircraft firefighting vehicles to meet response time requirements to all areas of the airfield. Coordinate the airfield fire and rescue facility and special rescue equipment with the facility protection mission and master plan. It may be economically sound to develop a consolidated or expanded facility to support both airside and landside facilities. The site of the fire and rescue station must permit ready access of equipment to the aircraft operational areas and the road system serving the airfield facilities. A site centrally located, close to the midpoint of the runway, and near the Airfield Operations Building (AOB) and the ATCT is preferred.

2-10.6.4 Rescue and Ambulance Helicopters.

With the increasing use of helicopters for emergency rescue and air ambulance service, consider providing an alert helicopter parking space near the fire and rescue station. This space may be located as part of the fire and rescue station or in a designated area on an adjacent aircraft parking apron.

2-10.6.5 Hospital Helipad.

A helipad should normally be sited in close proximity to each hospital to permit helicopter access for emergency use. Subject to necessary flight clearances and other hospital site factors, the hospital helipad should permit reasonably direct access to and from the hospital emergency entrance.

2-10.6.6 Miscellaneous Buildings.

These buildings should be provided as part of an aviation facility:

- Airfield operations building (airfield management facility)

- Aviation unit operations building (Army); squadron operations building (Air Force)
- Representative weather observation stations (RWOS)
- Authorization and space allowances should be determined in accordance with directives for each Service.

2-10.7 Aircraft Fuel Storage and Dispensing.

2-10.7.1 Location.

Aircraft fuel storage and dispensing facilities will be provided at all aviation facilities. Operating fuel storage tanks will be provided wherever dispensing facilities are remote from bulk storage. Bulk fuel storage areas require locations that are accessible by tanker truck, tanker rail car, or by waterfront. Both bulk storage and operating storage areas must provide for the loading and parking of fuel vehicles to service aircraft. Where hydrant fueling systems are authorized, bulk fuel storage locations must take into account systems design requirements (e.g., the distance from the fueling apron to the storage tanks).

2-10.7.2 Safety.

Fuel storage and operating areas have requirements for minimum clearances from buildings, aircraft parking, roadways, radar, and other structures/areas, as established in Service directives. Aviation fuel storage and operating areas also require lighting, fencing, and security alarms. All liquid fuel storage facility sitings must address spill containment and leak protection/detection.

2-10.8 Service Roadways to Support Airfield Activities.

2-10.8.1 General.

Uncontrolled vehicle roads will not be planned to violate airfield imaginary surfaces and safety clearance distances. Roads should be located so that surface vehicles will not be hazards to air navigation and air navigation equipment. All roads within the movement area will be controlled by the ATCT. See Appendix B, Section 13, Para B13-2.20.2.9.

2-10.8.2 Rescue and Firefighting Roadways.

Rescue and firefighting access roads are usually needed to provide unimpeded two-way access for rescue and firefighting equipment to potential accident areas. Connecting these access roads to the extent practical with airfield operational surfaces and other airfield roads will enhance fire and rescue operations. Dedicated rescue and firefighting access roads are all-weather roads designed to support vehicles traveling at normal response speeds.

2-10.8.3 Fuel Truck Access.

Fuel truck access points to aircraft parking aprons should be located to provide minimal disruptions and hazards to active aircraft operating areas. Fuel truck access from the facility boundary to the fuel storage areas should be separate from other vehicular traffic. Fuel trucks should be parked as close to the flight line as is reasonably possible.

2-10.8.4 Explosives and Munitions Transfer to Arm/Disarm Pads.

Transfer of explosives and munitions from storage areas to arm/disarm pads should occur on dedicated transfer roads. Transfer roads should be used exclusively for explosives and munitions transfer vehicles.

2-11 NAVY/MARINE CORPS EXCEPTIONS FROM CRITERIA NOT REQUIRING NAVFAC DESIGN WAIVERS/EXEMPTIONS FROM UFC 3-260-01 OR NAVAIR AIRFIELD SAFETY WAIVERS.

Siting and design for airfield facilities and equipment must conform to appropriate design and siting criteria, and must be necessary for support of assigned mission aircraft, or multiple waivers (design and safety) may be required. (See Appendix B, Section 1, Para B1-3 for waiver types and procedures.) If the equipment renders satisfactory service at locations that do not penetrate airfield safety surfaces, such locations should be selected to enhance the overall efficiency and safety of airfield operations. This section lists certain airfield facilities that are considered exceptions to certain criteria (such as violating safety surfaces) only if they are sited in those zones in accordance with guidance in this UFC. This is due to their nature of inherently needing to be locating within certain zones for functional reasons that may create a criteria conflict. Even so, siting guidance in this UFC for these facilities must be satisfied or a design or safety waiver is still required. All structures placed or constructed within the airfield environment must be made frangible (to the maximum extent practicable) or placed below grade. Consult NAVAIR for Airfield Safety Waiver requirements for airfield facilities and equipment that are not specifically listed in this section. THE FOLLOWING FACILITIES DO NOT REQUIRE AN AIRFIELD SAFETY WAIVER or NAVFAC DESIGN WAIVER IF SITED IN ACCORDANCE WITH THIS UFC WHERE GUIDANCE IS PROVIDED:

2-11.1 Visual Air Navigational Facilities.

This term identifies, as a type of facility, all lights, signs and other devices located on, and in the vicinity of, an airfield that provide a visual reference to pilots for guidance when operating aircraft in the air and on the ground. Examples of visual air navigation facilities are Precision Approach Path Indicator (PAPI), Visual Slope Indicator (VASI), Optical Lighting Systems (OLS), runway distance remaining (RDR) signs, taxiway guidance and orientation signs, beacons, approach lighting, wind direction indicators, obstruction lights, and electric transformers in support of airfield lighting. For detailed construction and siting criteria, see UFC 3-535-01.

2-11.2 Radar/Communications Facilities.

When properly sited by Space and Naval Warfare Systems Center (SPAWARS) the exempted systems include Fixed Base Airport Surveillance Radar (ASR), Fixed Base Digital Airport Surveillance Radar (DASR), Tactical Air Navigation System (TACAN), Precision Approach Radar (PAR), Instrument Landing System (ILS), radar reflectors, and VHF/UHF radio facility (transmitter receiver site may include shelter), expeditionary equipment (TACAN, ASR, PAR) temporarily located for an event.

2-11.3 Other Facilities and Equipment.

Other facilities that are excepted from waiver requirements include Arm-Dearm Pads, Automated Surface Observing System (ASOS), Portable Landing Signal Officer (LSO), and Runway Duty Officer (RDO) facilities positioned on the primary surface during an event and permanent LSO facilities positioned adjacent to dedicated simulated Landing, Helicopter, Assault (LHA)/Landing, Helicopter, Deck (LHD) facility, Concrete bollards positioned to protect fire hydrants and extinguishers if located on the aircraft parking apron and next to the hangar. Airfield service roads located for access to NAVAIDs, aircraft arresting systems, weather sensors, and other similar areas on the airfield. Signage and traffic signals associated with the airfield service roads.

2-12 AIRFIELD UTILITY STRUCTURES.

All buried utility structures (manholes, handholes, drainage structures, etc.) constructed within runways, taxiways, towways, helipads, aprons, overruns or shoulders (paved or unpaved) will, at a minimum, be designed as provided in the following paragraphs. Regardless of location on the airfield, the top surface of foundations, manhole covers, handhole covers, and frames will be flush with the grade. Maintenance action is required if the drop-off at any edge of the structure exceeds 76 mm (3 in).

2-12.1 Load Bearing Pavements and Paved Shoulder Areas.

- For manhole covers and inlet grates and frames, design for a 45,000 kg (100,000 lb) wheel load with 1.72 MPa (250 psi) tire pressure. Higher tire pressures should be assumed if the using aircraft will have tire pressure greater than 1.72 MPa (250 psi).
- For structures with their shortest span equal to or less than 0.6 m (2 ft), design based on a single wheel load of 45,000 kg (100,000 lb) at a contact pressure of 1.72 MPa (250 psi), or a uniform live load over the entire structure of 1.72 MPa (250 psi), whichever is greater.
- For structures with their shortest span greater than 0.6 m (2 ft), design based on the maximum number of wheels that can fit onto the span, considering the most critical assigned aircraft operating at its maximum gross weight. In no case, however, should the design be based on computed stress conditions less than those created by a wheel load of 45,000 kg (100,000 lb) at a contact pressure of 1.72 MPa (250 psi).

2-12.2 Unpaved Shoulder Areas.

- For manhole covers and inlet grates and frames, design for a 45,000 kg (100,000 lb) wheel load with 1.72 MPa (250 psi) tire pressure. Higher tire pressures should be assumed if the using aircraft will have tire pressure greater than 1.72 MPa (250 psi).
- For structures with their shortest span equal to or less than 0.6 m (2 ft), design based on a single wheel load of 22,667 kg (50,000 lb) at a contact pressure of 1.72 MPa (250 psi), or a uniform live load over the entire structure of 1.72 MPa (250 psi), whichever is greater.
- For structures with their shortest span greater than 0.6 m (2 ft), design based on the maximum number of wheels that can fit onto the span, considering the most critical assigned aircraft operating at its maximum gross weight. In no case, however, should the design be based on computed stress conditions less than those created by a wheel load of 22,667 kg (50,000 lb) at a contact pressure of 1.72 MPa (250 psi).

2-12.3 Other Airfield Areas.

- Beyond the paved or unpaved shoulder areas of runways, taxiways, towways, helipads, aprons or overruns, underground structures are not designed to support aircraft wheel loads; however, they will be designed to support standard truck loads (AASHTO H20/HS20).

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CHAPTER 3
RUNWAYS (FIXED-WING) AND IMAGINARY SURFACES

3-1 CONTENTS.

This chapter presents design standards and considerations for fixed-wing runways and associated imaginary surfaces.

3-2 REQUIREMENTS.

The landing and takeoff design considerations for an airfield include mission requirements, expected type and volume of air traffic, traffic patterns such as the arrangement of multidirectional approaches and takeoffs, ultimate runway length, runway orientation required by local wind conditions, local terrain, restrictions due to airspace obstacles or the surrounding community, noise impact, and aircraft accident potential. When planning to construct a new runway or to lengthen an existing runway, in addition to local permitting requirements, file FAA Form 7480-1 in accordance with FAA Order 7400.2.

3-3 RUNWAY CLASSIFICATION.

Runways are classified as either Class A or Class B based on aircraft type as shown in Table 3-1. This table uses the same runway classification system established by the Office of the Secretary of Defense as a means of defining accident potential areas (zones) for the AICUZ program. These runway classes are not to be confused with aircraft approach categories and aircraft wingspan in other DoD or FAA documents, aircraft weight classifications, or pavement traffic areas. The aircraft listed in Table 3-1 are examples of aircraft that fall into these classifications and may not be all-inclusive.

3-3.1 Class A Runways.

Class A runways are primarily intended for small, light aircraft. These runways do not have the potential or foreseeable requirement for development for use by high-performance and large, heavy aircraft. Ordinarily, these runways are less than 2,440 m (8,000 ft) long and less than 10% of their operations involve aircraft in the Class B category; however, this is not intended to limit the number of C-130 and C-17 operations conducted on any Class A airfield.

3-3.2 Class B Runways.

Class B runways are primarily intended for high-performance and large, heavy aircraft, as shown in Table 3-1. For airfield safety clearances applicable to USAF missions on US Army airfields, see paragraph 2-5.4.2.

3-3.3 Special Tilt-Rotor Aircraft Considerations (V-22).

The V-22 is a tilt-rotor aircraft that can operate both as a fixed-wing aircraft or a rotary-wing aircraft. When the V-22 operates on a fixed-wing airfield, this chapter applies with noted V-22 exceptions. See paragraph 1.2.2.4 for general V-22 planning considerations.

Table 3-1. Runway Classification by Aircraft Type

Runway Classification by Aircraft Type				
Class A Runways		**Class B Runways**		
C-1 C-2 C-12 C-20 C-21 C-22 C-23 C-26 C-37 C-38 E-1 E-2 MQ-1	OV-10 T-3 T-6 (Navy) T-28 T-34 T-41 T-44 U-21 UC-35 UV-18 V-22 DASH-7 DASH-8	A-4 A-6 EA-6B A-10 AV-8 B-1 B-2 B-52 C-5 C-9 KC-10 KC-135 KC-46 C-17 C-27J C-32 C-40 C-130 C-135 C-137	E-3 E-4 E-6 E-8 EA-18 R/F-4 F-5 F-15 F-16 E/F/A-18 F-22 F-35	P-3 P-8 RQ-4 RQ-9 MQ-4 S-3 T-1 T-2 T-6 (Air Force) T-38 T-43 T-45 TR-1 U-2 VC-25

NOTES:

1. Only symbols for basic mission aircraft or basic mission aircraft plus type are used. Designations represent entire series. Runway classes in this table are not related to aircraft approach categories, aircraft weight, aircraft wingspan, or to pavement design classes or types.
2. These are examples of aircraft that fall into these classifications, and may not be all-inclusive.
3. Rotary aircraft are not addressed in this table.
4. For F-35B aircraft operating as STOVL, see Chapter 8.
5. For US Army rotary-wing aircraft, see Chapter 4.

3-3.4 Landing Zones (formerly called Short Fields and Training Assault Landing Zones).

Landing zones are special use fields. Design criteria for these airfields are provided in Chapter 7 of this manual.

3-4 RUNWAY SYSTEMS.

3-4.1 Single Runway.

A single runway is the least flexible and lowest capacity system. The capacity of a single runway system will vary from approximately 40 to 50 operations per hour under IFR conditions and up to 75 operations per hour under VFR conditions.

3-4.2 Parallel Runways.

Parallel runways are the most commonly used system for increased capacity. In some cases, parallel runways may be staggered, with the runway ends offset from each other and with terminal or service facilities located between the runways. When parallel runways are separated by less than the IFR separation distance shown in Item 15 of Table 3-2, the second runway will increase capacity at the airfield under VFR conditions, but due to the close distance, capacity at the airfield will not be increased under IFR conditions.

3-4.3 Crosswind Runways.

Crosswind runways may be either the open-V or the intersecting type of runway. The crosswind system is adaptable to a wider variety of wind conditions than the parallel system. When winds are calm, both runways may be used simultaneously. An open-V system has a greater capacity than an intersecting system.

Table 3-2. Runways

Table 3-2. Runways				
Item		Class A Runway	Class B Runway	
No.	Description	Requirement		Remarks
1	Length	See Table 3-3	See Remarks	For Army airfields. For Army Class B runways, runway length will be determined by the ACOMs/ASCCs/DRUs/or ARNG in conjunction with HQDA, G4 by identifying the most critical aircraft in support of USTRANSCOM global transportation requirements.
		See Remarks	See Remarks	For Air Force airfields, runway length will be determined by the MAJCOM/A3 for the most critical aircraft to be supported
		See Remarks	See Remarks	For Navy and Marine Corps airfields, see UFC 2-000-05N for computation of runway lengths.
2	Width	30 m (100 ft)	46 m (150 ft)	Army airfields and Air Force airfields, not otherwise specified.
		N/A	90 m (300 ft)	B-52 aircraft. AFI 11-202 V3 allows that B-52 aircraft may routinely operate on 60 m (200 ft) wide runways.
		23 m (75 ft)	60 m (200 ft)	Navy and Marine Corps airfields. Runway width for T-34 and T-44 will be 45 m (150 ft).
3		15 m (50 ft)	60 m (200 ft)	Army and Air Force airfields

Table 3-2. Runways				
Item		Class A Runway	Class B Runway	
No.	Description	Requirement		Remarks
	Total width of shoulder (paved and unpaved)	7.5 m (25 ft)	46 m (150 ft)	Navy and Marine Corps airfields
4	Paved shoulder width	7.5 m (25 ft)	7.5 m (25 ft)	Army and Air Force Manned Aircraft with exception for Trainer, Fighter and B-52 aircraft indicated below. For Air Force, pave shoulders to provide a combined hard surface width (runway and paved shoulders) of not less than 60 m (200 feet) with at least 0.6 m (2 ft) of paved surface beyond the edge lights.
		N/A	3 m (10 ft)	Air Force airfields designed for Trainer, Fighter and B-52 aircraft. (Pave shoulders to provide a combined hard surface width (runway and paved shoulders) of 52 m (170 feet) for fighters and trainers and 98 m (320 feet) for B-52 mission runways, with at least 0.6 m (2 ft) of paved surface beyond the edge lights.
		3 m (10 ft)	3 m (10 ft)	Navy and Marine Corps airfields
5	Longitudinal grades of runway and shoulders	Maximum 1.0%		Grades may be both positive and negative but must not exceed the limit specified. Grade restrictions are exclusive of other pavements and shoulders. Where other pavements tie into runways, comply with grading requirements for towways, taxiways, or aprons as applicable, but hold grade changes to the minimum practicable to facilitate drainage. Exception for shoulders (paved and unpaved): a 3.33% maximum is permitted where arresting systems and visual glide slope indicators (VGSIs) are installed relative to the longitudinal slope of the runway and shoulders. Grade deviations must be held to a minimum for VGSI installations but may be used when necessary to limit the overall height of the light housings above grade.
6	Longitudinal runway grade changes	No grade change is to occur less than 300 m (1,000 ft) from	No grade change is to occur less than 900 m (3,000 ft) from	Where economically feasible, the runway will have a constant centerline gradient from end to end. Where terrain dictates the need for centerline grade changes, the distance between two successive point of

Table 3-2. Runways				
Item		Class A Runway	Class B Runway	
No.	Description	Requirement		Remarks
		the runway end	the runway end	intersection (PI) will be not less than 300 m (1,000 ft) and two successive distances between PIs will not be the same.
7	Rate of longitudinal runway grade changes	Max 0.167% per 30 linear meters (100 linear feet) of runway		Army and Air Force Maximum rate of longitudinal grade change is produced by vertical curves having 180-m (600-ft) lengths for each % of algebraic difference between the two grades.
		Max 0.10% per 30 linear meters (100 linear feet) of runway		Navy and Marine Corps Maximum rate of longitudinal grade change is produced by vertical curves having 300-m (1,000-ft) lengths for each% of algebraic difference between the two grades.
		See Remarks		Exceptions: 0.4% per 30 linear meters (100 ft) for edge of runways at runway intersections
8	Longitudinal sight distance	Min 1,500 m (5,000 ft)		Any two points 2.4 m (8 ft) above the pavement must be mutually visible (visible by each other) for the distance indicated. For runways shorter than 1,500 m (5,000 ft), height above runway will be reduced proportionally.
9	Transverse grade of runway	Min 1.0% Max 1.5%		New runway pavements will be centerline crowned. Existing runway pavements with insufficient transverse gradients for rapid drainage should provide increasing gradients when overlaid or reconstructed.
				Slope pavement downwards from centerline of runway. 1.5% slope is optimum transverse grade of runway. Selected transverse grade is to remain constant for length and width of runway, except at or adjacent to runway intersections where pavement surfaces must be warped to match abutting pavements. For Navy and Marine Corps, this exception also applies to aircraft arresting system cables where the transverse slope may be reduced to 0.75% in the center section to allow achieving the

Table 3-2. Runways				
Item		Class A Runway	Class B Runway	
No.	Description	Requirement		Remarks
				proper pendant height above the runway crown. See paragraph 3-17.2.2 for modifications to transverse grade in the area of the aircraft arresting system pendant.
10	Transverse grade of paved shoulder	2% min 3% max		Paved portion of shoulder. Slope downward from runway pavement. Reversals are not allowed. Exception allowed in the tape sweep area for USAF aircraft arresting systems. At runway edge sheaves, paved shoulder slope should match runway cross slope on centerline crowned runways. Designers will warp the adjacent tape sweep area pavement surfaces to direct drainage away from the aircraft arresting system components as much as possible. Pavement within the tape sweep area of arresting systems will meet the design and grade criteria in USAF Typical Installation Drawing 67F2013A.
11	Transverse grade of unpaved shoulder	(a) 40-mm (1.5-in) drop-off at edge of paved shoulder, +/- 13 mm (0.5 in) (b) 2% min, 4% max.		Unpaved portion of shoulder Slope downward from shoulder pavement. For additional information, see Figure 3-1. Reversals not allowed.
12	Runway lateral clearance zone	152.40 m (500 ft)	152.40 m (500 ft)	Army airfields
		152.40 m (500 ft)	304.80 m (1,000 ft)	Air Force, Navy, and Marine Corps
		152.4 m (500 ft)	228.6 m (750 ft)	Navy airfields constructed prior to 1981.
		(1) The runway lateral clearance zone's lateral limits coincide with the limits of the primary surface. The ends of the lateral clearance zone coincide with the runway ends. The ground surface within this area must be clear of fixed or mobile objects as defined in the glossary, and graded to the requirements of Table 3-2, items 13 and 14. The zone distance is measured perpendicularly each direction from the centerline of the runway and begins at the runway centerline. See Table 3-7 for other height restrictions and controls. (2) Fixed obstacles are those defined in the glossary. Navigational aids and meteorological equipment may be sited within these clearances where essential for their proper functioning. For Army and Air Force, this area to be clear of all obstacles except for properly sited permissible deviations		

Table 3-2. Runways				
Item		Class A Runway	Class B Runway	
No.	Description	Requirement		Remarks
		noted in Appendix B, Section 13. For Navy and Marine Corps, certain items that are listed in Appendix B, Section 1, Paragraph B1-3.4 are exempted. (3) Mobile obstacles are those defined in the glossary. Taxiing aircraft, emergency vehicles, and authorized maintenance vehicles are exempt from this restriction. (4) For Army and Air Force airfields, parallel taxiway (exclusive of shoulder width) will be located in excess of the lateral clearance distances (primary surface). For Navy and Marine Corps airfields, the centerline of a runway and a parallel taxiway will be a minimum of 152.4 m (500 ft) apart. For Class A Airfields, one half of the parallel taxiway may be located within the runway lateral clearance zone. (5) For Class A runways, except at Navy and Marine Corps airfields, above ground drainage structures, including headwall, are not permitted within 91.26 m (300 ft) of the runway centerline. For Class B runways, except at Navy and Marine Corps airfields, above ground drainage structures, including headwalls are not permitted within 114.3 m (375 ft) of the runway centerline. At Navy and Marine Corps airfields, above ground drainage structures will be individually reviewed. Drainage slopes of up to a 10 to 1 ratio are permitted for all runway classes, but swales with more gentle slopes are preferred. (6) Distance from runway centerline to helipads is discussed in Table 4-1. (7) For Military installations overseas (other than bases located in the United States, its territories, trusts, and possessions), apply to the maximum practical extent.		
13	Longitudinal grades within runway lateral clearance zone	Max 10.0%		Exclusive of pavement, shoulders, and cover over drainage structures. Slopes are to be as gradual as practicable. Avoid abrupt changes or sudden reversals. Rough grade to the extent necessary to minimize damage to aircraft.
14	Transverse grades within runway lateral clearance zone (in direction of surface drainage)	Min of 2.0% to Max 10.0%[4] Grades may be upwards or downwards		Exclusive of pavement, shoulders, and cover over drainage structures. Slopes are to be as gradual as practicable. Avoid abrupt changes or sudden reversals. Rough grade to the extent necessary to minimize damage to aircraft.
15	Distance between centerlines of parallel runways	213.36 m (700 ft)	304.80 m (1,000 ft)	VFR without intervening parallel taxiway between the parallel runways. One of the parallel runways must be a VFR only runway.
		632.46 m (2,075 ft)		VFR with intervening parallel taxiway.

Table 3-2. Runways				
Item		Class A Runway	Class B Runway	Remarks
No.	Description	Requirement		
		762.00 m (2,500 ft)		IFR using simultaneous operation (depart-depart) (depart-arrival)
		1,310.64 m (4,300 ft)		IFR using simultaneous approaches
				For separation distance between fixed-wing runways and rotary-wing facilities, see Table 4-1.
16	Width of USAF and Army mandatory frangibility zone (MFZ)	152.4 m (500 ft)		Centered on the runway centerline. All items sited within this area must be frangible (see Appendix B, Section 13).
17	Length of USAF and Army MFZ	Runway length plus 914.4 m (3,000 ft) at each end		Centered on the runway. All items sited within this area to the ends of the graded area of the clear zone must be frangible (also see Table 3-5 and Appendix B, Section 13). Items located beyond the graded area of the clear zone must be constructed to be frangible, low impact resistant structures, or semi-frangible (see Appendix B, Section 13).

NOTES:

1. Geometric design criteria in this manual are based on aircraft-specific requirements and are not direct conversions from inch-pound (English) dimensions.
2. Airfield and heliport imaginary surfaces and safe wingtip clearance dimensions are direct conversions from inch-pound to SI units.
3. English dimensions apply to new airfield construction at US facilities. Metric units apply to airfield construction where necessary for host nation construction practices. .
4. Bed of channel may be flat. When drainage channels are required, the channel bottom cross section may be flat but the channel must be sloped to drain

3-5 RUNWAY ORIENTATION/WIND DATA.

Runway orientation is the key to a safe, efficient, and usable aviation facility. Orientation is based on an analysis of wind data, terrain, local development, operational procedures, and other pertinent data. Procedures for analysis of wind data to determine runway orientation are discussed further in Appendix B, Section 4.

3-6 ADDITIONAL CONSIDERATIONS FOR RUNWAY ORIENTATION.

In addition to meteorological and wind conditions, the factors in paragraphs 3-6.1 through 3-6.7 must be considered.

3-6.1 Obstructions.

A specific airfield site and the proposed runway orientation must be known before a detailed survey can be made of obstructions that affect aircraft operations. Runways should be so oriented that approaches necessary for the ultimate development of the airfield are free of all obstructions.

3-6.2 Restricted Airspace.

Airspace through which aircraft operations are restricted, and possibly prohibited, is shown on sectional and local aeronautical charts. Runways should be so oriented that their approach and departure patterns do not encroach on restricted areas.

3-6.3 Built-Up Areas.

Airfield sites and runway alignment will be selected and operational procedures adopted that will least impact local inhabitants. Additional guidance for facilities is found in DoDI 4165.57.

3-6.4 Neighboring Airports.

Existing aircraft traffic patterns of airfields in the area may affect runway alignment.

3-6.5 Topography.

Avoid sites that require excessive cuts and fills. Evaluate the effects of topographical features on airspace zones, grading, drainage, and possible future runway extensions.

3-6.6 Soil Conditions.

Evaluate soil conditions at potential sites to minimize settlement problems, heaving from highly expansive soils, high groundwater problems, and construction costs Evaluate the project area for wetlands and potential historical/archeological sites. Analyze the soil for contaminants and plan for remediation or protection, as necessary.

3-6.7 Noise Analysis.

Noise analyses will be conducted to determine noise impacts to on-base and local communities and to identify noise-sensitive areas.

3-7 RUNWAY DESIGNATION.

Runways are identified by the whole number nearest one-tenth (1/10) the magnetic azimuth of the runway centerline. The magnetic azimuth of the runway centerline is measured clockwise from magnetic north when viewed from the direction of approach. For example, where the magnetic azimuth is 183 degrees, the runway designation marking would be 18; and for a magnetic azimuth of 117 degrees, the runway designation marking would be 12. For a magnetic azimuth ending in the number 5, such as 185 degrees, the runway designation marking can be either 18 or 19. Supplemental letters, where required for differentiation of parallel runways, are placed between the designation numbers and the threshold or threshold marking. For parallel runways, the supplemental letter is based on the runway location, left to right, when viewed from the direction of approach: for two parallel runways—"L," "R"; for three parallel runways—"L," "C," "R." A zero (0) is marked to precede single-digit numbers on Class B runways except those subject to NAVAIR 51-50AAA-2.

3-8 RUNWAY DIMENSIONS.

The paragraphs, tables, and figures in this section present the design criteria for runway dimensions at all aviation facilities except landing zones. The criteria presented in the figures are for all DoD components (Army, Air Force, Navy, and Marine Corps), except where deviations are noted.

3-8.1 Runway Dimension Criteria, Except Runway Length.

Table 3-2 presents all dimensional criteria, except runway length, for the layout and design of runways used primarily to support fixed-wing aircraft operations.

3-8.2 Runway Length Criteria.

3-8.2.1 Army.

For Army Class A runways, the runway length will be determined in accordance with Table 3-3. Army Class B runways are used to support USTRANSCOM global transportation requirements; therefore, runway length will be determined by the ACOMs/ASCCs/DRUs/or ARNG in conjunction with HQDA, G4 by identifying the most critical aircraft in support of USTRANSCOM requirements.

3-8.2.2 Air Force.

For Air Force Class A and Class B runways, the length will be determined by the MAJCOM.

3-8.2.3 Navy and Marine Corps.

Runway length computation for Navy and Marine Corps Class A and Class B runways is presented in UFC 2-000-05N.

3-8.3 Layout.

Typical sections and profiles for Army, Air Force, Navy, and Marine Corps airfield runways and the associated airspace surfaces are shown in Figures 3-1 through 3-22.

Table 3-3. Army Class A Runway Lengths

Temperature	Elevation				
	Sea Level	**304 meters (1,000 feet)**	**610 meters (2,000 feet)**	**1,524 meters (5,000 feet)**	**1,828 meters (6,000 feet)**
15ºC (60ºF)	1,615 m (5,300 ft)	1,676 m (5,500 ft)	1,768 m (5,800 ft)	2,042 m (6,700 ft)	2,164 m (7,100 ft)
30ºC (85ºF)	1,707 m (5,600 ft)	1,798 m (5,900 ft)	1,890 m (6,200 ft)	2,286 m (7,500 ft)	2,438 m (8,000 ft)
40ºC (105ºF)	1,798 m (5,900 ft)	1,890 m (6,200 ft)	2,042 m (6,700 ft)	2,469 m (8,100 ft)	2,682 m (8,800 ft)

NOTES:
1. Based on zero runway gradient and a clean, dry runway surface for the most critical aircraft in the Army's inventory to date (RC-12N).

3-9 RUNWAY END SITING REQUIREMENTS.

This paragraph provides guidance on the preliminary design for the establishment of runway thresholds and departure ends. Final design must be based on a detailed analysis and coordination with each service Flight Standards Agency and verified with Terminal Instrument Procedures (TERPS).

3-9.1 Runway Ends.

The runway ends are the physical ends of the rectangular surface that constitutes a runway. The end of the runway is normally the beginning of the takeoff roll and the end of the landing roll out.

3-9.2 Threshold.

The threshold is ideally located at the beginning of the runway. The threshold is located to provide proper clearance for landing aircraft over existing obstacles while on approach to landing. When an object is beyond the DoD's ability to remove, relocate, or reduce the height and the object obstructs the airspace required for aircraft to land at the beginning of the runway for takeoff, the threshold may be located farther down the runway. Such a threshold is called a "displaced threshold."

3-9.2.1 Displaced Threshold.

A displaced threshold may be designated on certain runways in order to avoid obstacles in the imaginary or TERPS surfaces. When it is determined that a runway requires a displaced threshold, the responsible airfield authority will evaluate each individual situation and set the displaced threshold and airspace imaginary surfaces.

3-9.2.2 Impacts to Runway Length.

Displacement of a threshold reduces the length of runway available for landings. The portion of the runway behind a displaced threshold may be available for takeoffs and, depending on the reason for displacement, may be available for takeoffs and landings from the opposite direction.

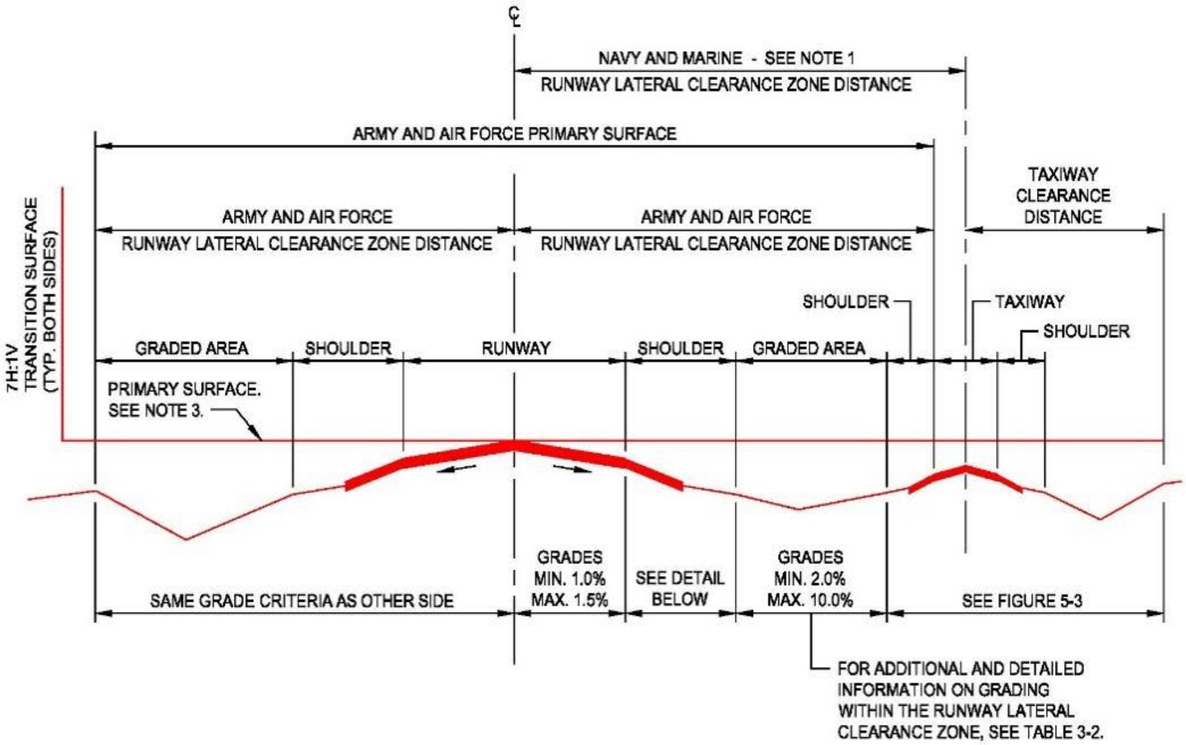
3-9.2.3 Other Impacts.

Displacement of the threshold often introduces disruptions to an otherwise orderly airport design. Approach lighting systems and NAVAIDs used for landing may need to be moved. Taxiways that remain in the new approach area (prior to the threshold) can create situations where taxiing aircraft penetrate the approach surface or the Clear Zone. Hold lines may also need to be moved to keep aircraft clear of these areas and runway capacity may be affected. While threshold displacement is often used to as a solution for constrained airspace, airfield designers need to carefully weigh the trade-offs of a displaced threshold. Displacing a threshold may also create a situation where the holdline must be placed on the parallel taxiway. This is undesirable as pilots do not normally expect to encounter a holdline on the parallel taxiway.

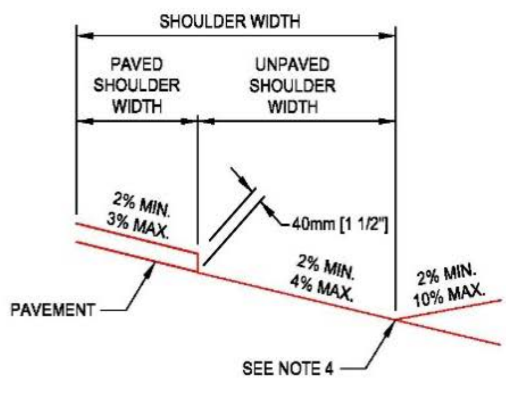
3-9.2.4 Cautions.

Threshold displacement should be undertaken only after full evaluation reveals that displacement is the best alternative. Coordination must be made with each Service Flight Standards Agency, TERPS, Engineering, and Operations.

Figure 3-1. Runway Transverse Sections and Primary Surface



RUNWAY TRANSVERSE SECTION
N.T.S.



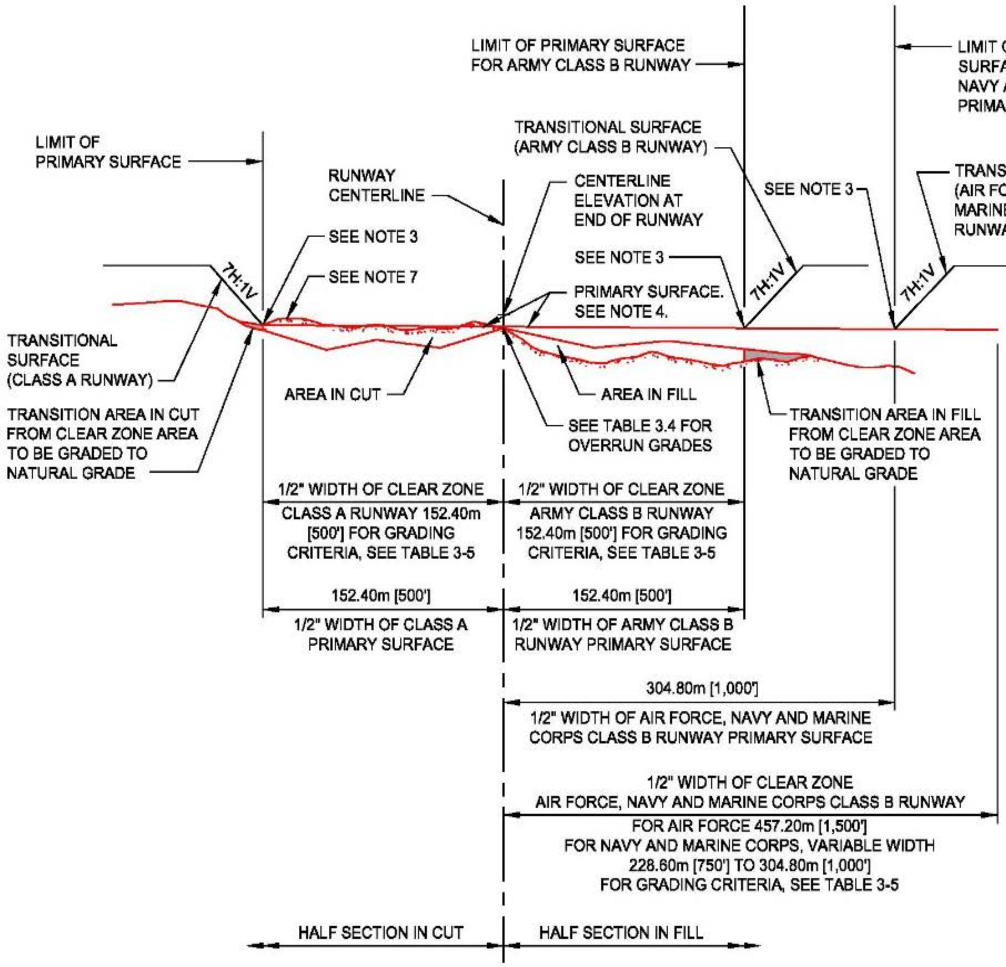
SHOULDER GRADE DETAIL
N.T.S.

NOTES

1. AT NAVY AND MARINE CORPS AIRFIELDS, THE CENTERLINES OF A RUNWAY AND A PARALLEL TAXIWAY SHALL BE A MINIMUM OF 152.4 METERS [500 FEET] APART. FOR CLASS A AIRFIELDS, ONE-HALF OF THE PARALLEL TAXIWAY MAY BE LOCATED WITHIN THE LATERAL CLEARANCE ZONE. SEE TABLE 3-2.
2. PROVIDE A 40mm [1-1/2"] DROP-OFF FROM PAVED SHOULDERS.
3. THE PRIMARY SURFACE WIDTH IS COINCIDENT WITH THE RUNWAY LATERAL CLEARANCE ZONE WIDTH. THE ELEVATION OF ANY POINT ON THE PRIMARY SURFACE IS THE SAME AS THE ELEVATION OF THE NEAREST POINT ON THE RUNWAY CENTERLINE.
4. WHEN A SLOPE REVERSAL IS REQUIRED AT THE TOE OF THE SHOULDER, THE DESIGNER MUST PROVIDE AN ADEQUATELY FLAT BOTTOM DITCH.

CLASS A AND CLASS B RUNWAYS

Figure 3-2. Clear Zone Transverse Section Detail



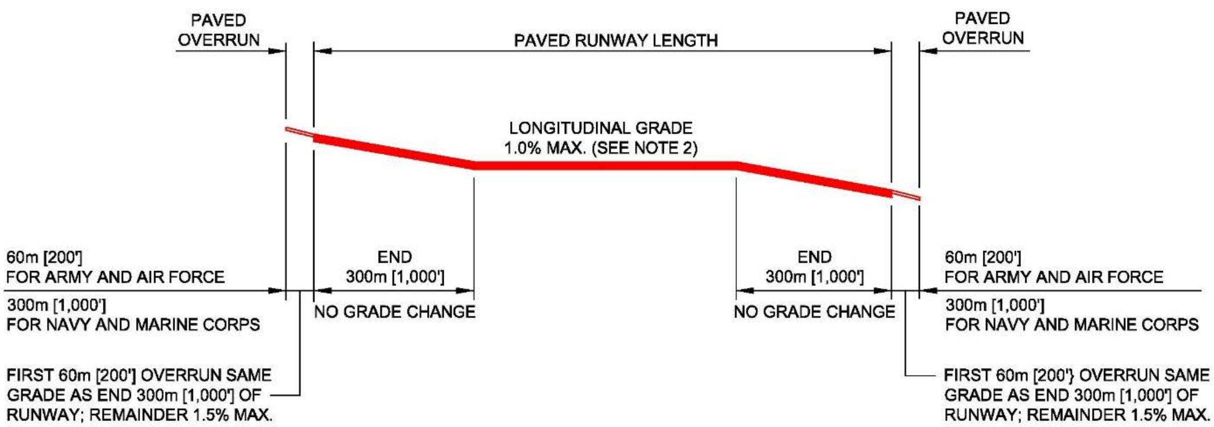
CLEAR ZONE TRANSVERSE SECTION DETAIL

N.T.S.

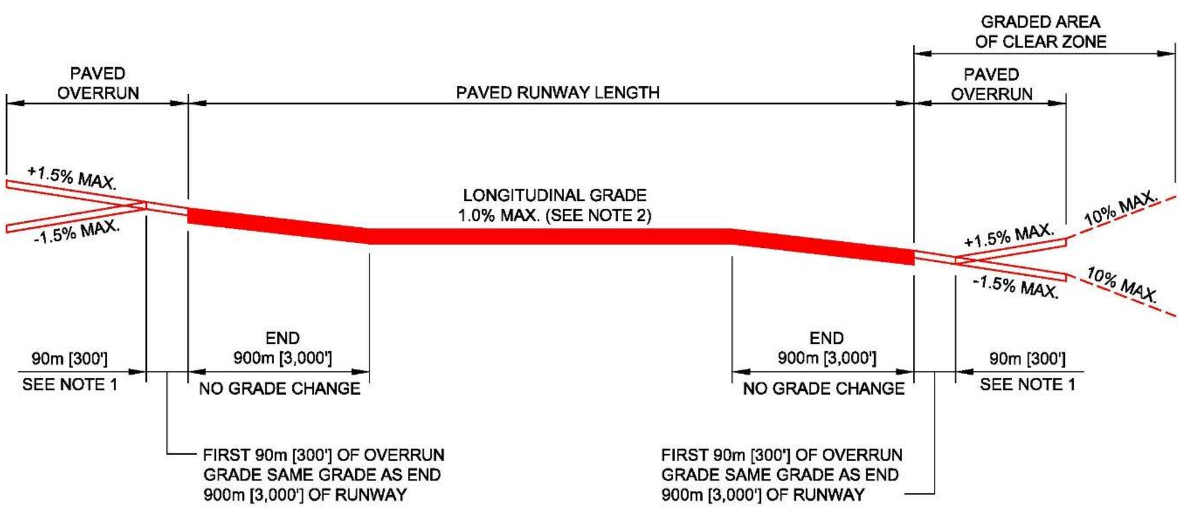
NOTES

1. TAKEN BEYOND END OF RUNWAY.
2. PRIMARY SURFACE APPLIES ONLY TO FIRST 60.96m [200'] BEYOND END OF RUNWAY.
3. THE STARTING ELEVATION FOR THE 7:1 TRANSITIONAL SURFACE IS THE ELEVATION OF THE PRIMARY SURFACE. REFER TO TABLE 3-7.
4. ELEVATION OF ANY POINT ON THE PRIMARY SURFACE IS THE SAME AS THE ELEVATION OF THE NEAREST POINT ON THE RUNWAY CROWN.
5. AT NAVY AND MARINE CORPS FACILITIES, THE PRIMARY SURFACE MAY BE 228.60m [750'].
6. DISTANCES ARE SYMETRICAL ABOUT CENTER OF RUNWAY.
7. NO PART OF THE AIRCRAFT OPERATIONS AREA WILL BE CONSIDERED AN OBSTRUCTION IF APPLICABLE GRADING CRITERIA ARE MET. GROUND SURFACES MAY PENETRATE THE PRIMARY SURFACE PROVIDED IT MEETS THE GRADING REQUIREMENTS. SEE PARAGRAPH 3.16.1.

Figure 3-3. Runway and Overrun Longitudinal Profile



CLASS A RUNWAY
N.T.S.

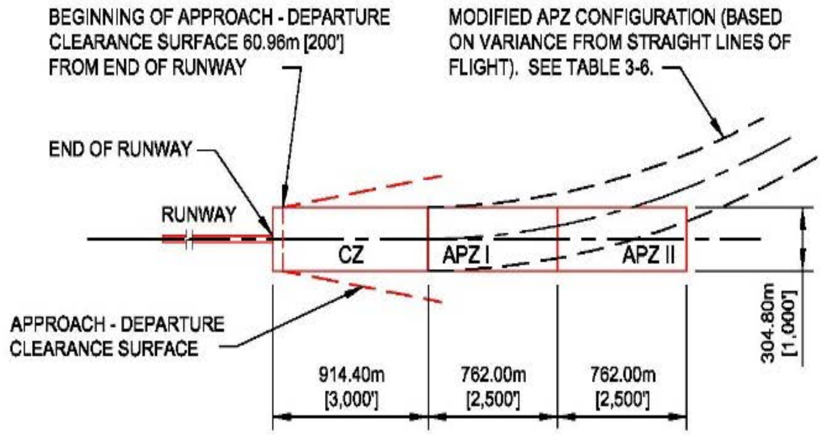


CLASS B RUNWAY
N.T.S.

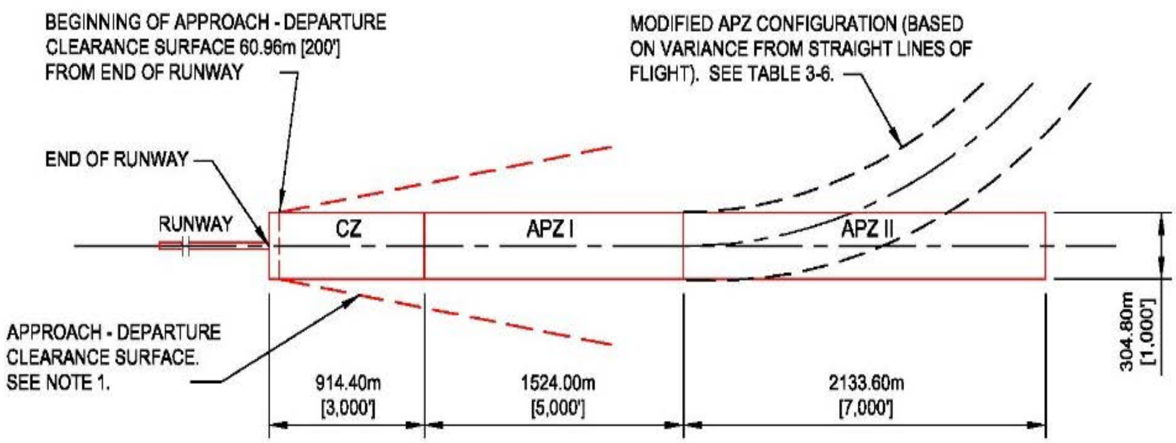
NOTES

1. TO AVOID ABRUPT CHANGES IN GRADE BETWEEN THE FIRST 90m [300'] OF THE OVERRUN AND THE REMAINDER OF THE OVERRUN, THE MAXIMUM CHANGE OF GRADE IS 2.0% PER 30m [100 L.F.].
2. GRADE MAY BE POSITIVE OR NEGATIVE BUT MUST NOT EXCEED THE LIMIT SPECIFIED.
3. SEE TABLE 3-5 FOR GRADING REQUIREMENTS BEYOND THE END OF THE OVERRUN.

Figure 3-4. Army Clear Zone and Accident Potential Zone Guidelines



ARMY CLASS A RUNWAY
N.T.S.



ARMY CLASS B RUNWAY
N.T.S.

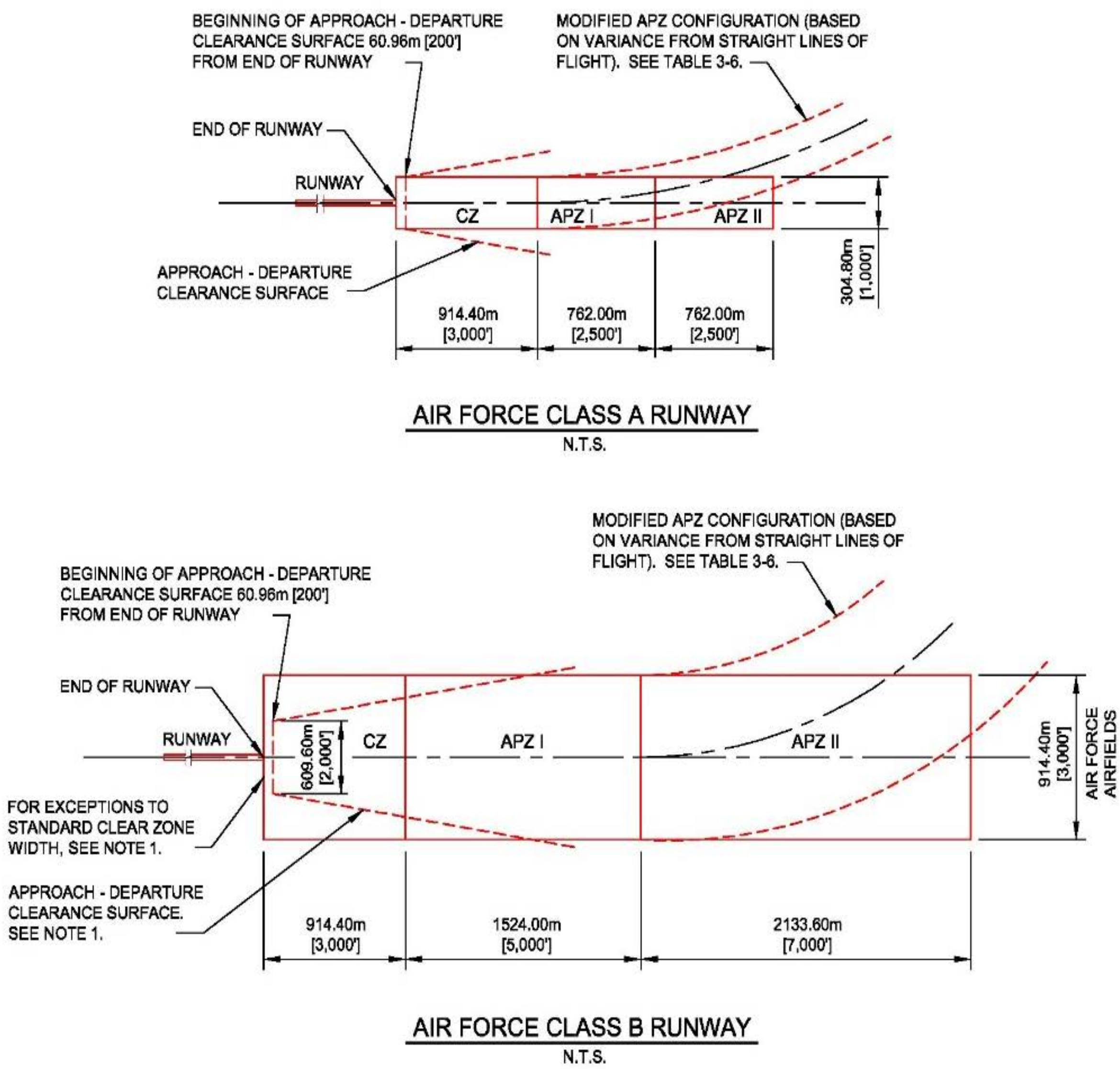
NOTES

1. THE WIDTH AND CONFIGURATION OF AN APPROACH - DEPARTURE CLEARANCE SURFACE ARE BASED ON THE CLASS OF RUNWAY, NOT THE WIDTH OF THE CLEAR ZONE.
2. FOR ADDITIONAL INFORMATION ON CLEAR ZONES, SEE TABLE 3-5.
3. FOR ADDITIONAL INFORMATION ON ACCIDENT POTENTIAL ZONES, SEE TABLE 3-6.

LEGEND

CZ	CLEAR ZONE
APZ I	ACCIDENT POTENTIAL ZONE I
APZ II	ACCIDENT POTENTIAL ZONE II

Figure 3-5. Air Force Clear Zone and APZ Guidelines



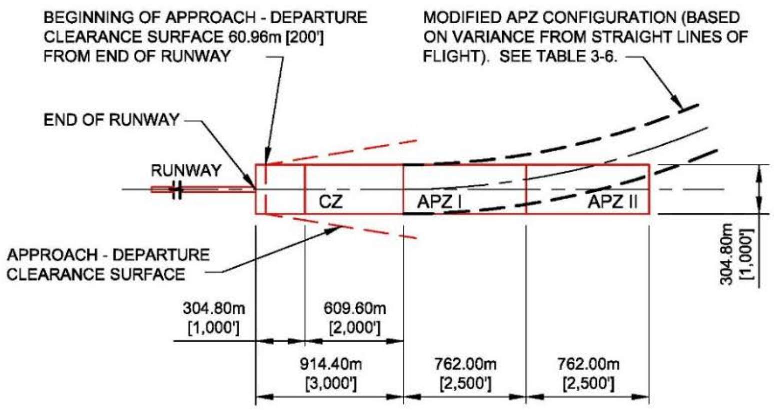
NOTES

1. STANDARD WIDTH OF CLEAR ZONE MAY BE VARIED BASED ON INDIVIDUAL SERVICE ANALYSIS OF HIGHEST ACCIDENT POTENTIAL AREA AND LAND ACQUISITION CONSTRAINTS. HOWEVER, FOR NEW AIR FORCE CONSTRUCTION, A 914.40m [3,000'] WIDE CLEAR ZONE IS REQUIRED. SEE AFI 32-7063.
2. THE WIDTH AND CONFIGURATION OF AN APPROACH - DEPARTURE CLEARANCE SURFACE ARE BASED ON THE CLASS OF RUNWAY, NOT THE WIDTH OF THE CLEAR ZONE.
3. FOR ADDITIONAL INFORMATION ON CLEAR ZONES, SEE TABLE 3-5.
4. FOR ADDITIONAL INFORMATION ON ACCIDENT POTENTIAL ZONES, SEE TABLE 3-6.

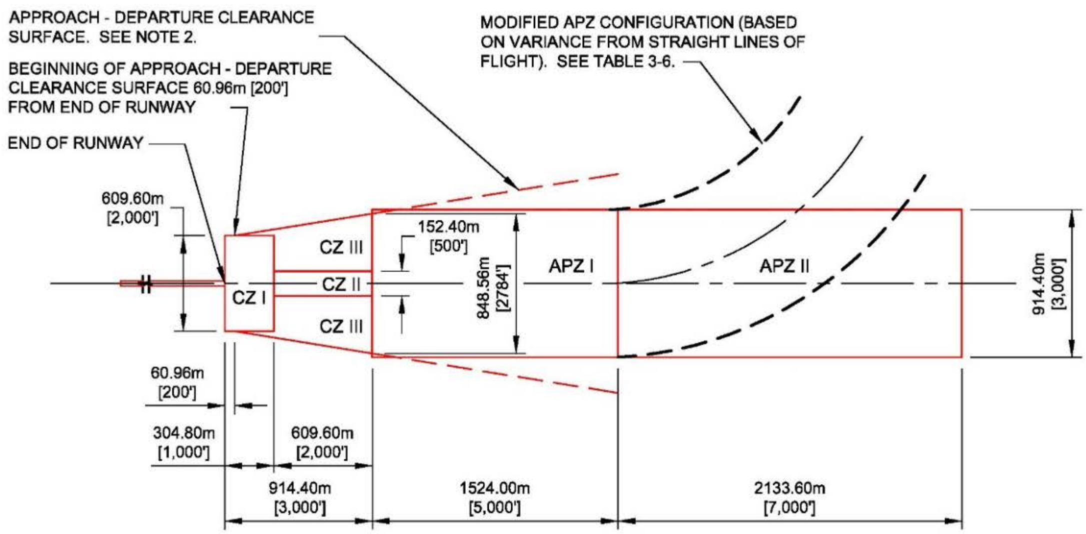
LEGEND

CZ	CLEAR ZONE
APZ I	ACCIDENT POTENTIAL ZONE I
APZ II	ACCIDENT POTENTIAL ZONE II

Figure 3-6. Navy and Marine Corps Clear Zone and APZ Guidelines



NAVY AND MARINE CORPS CLASS A RUNWAY
N.T.S.



NAVY AND MARINE CORPS CLASS B RUNWAY
N.T.S.

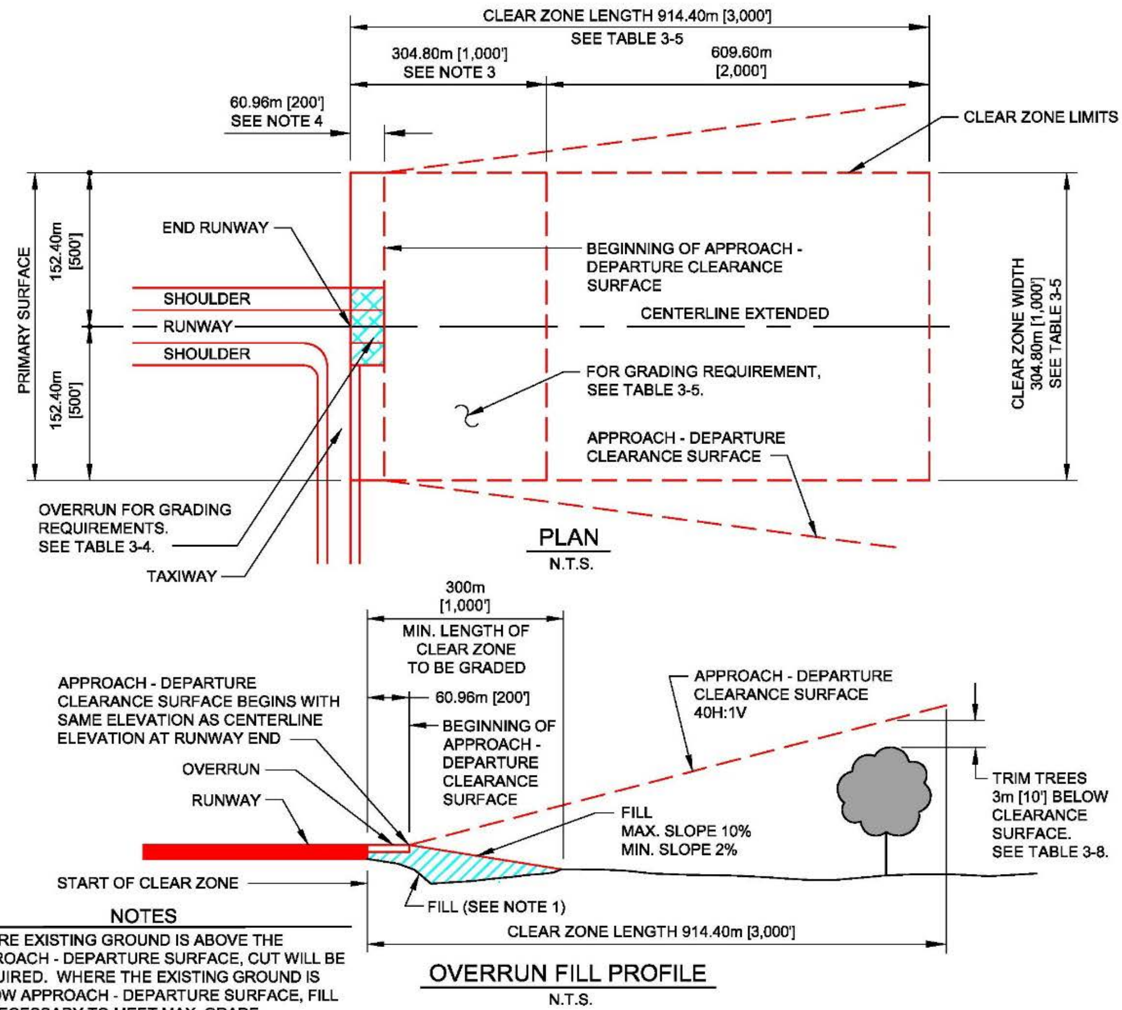
NOTES

1. MINIMUM WIDTH OF CLEAR ZONE IS BASED ON INDIVIDUAL SERVICE ANALYSIS OF HIGHEST ACCIDENT POTENTIAL AREA. FOR NAVY AND MARINE CORPS CONSTRUCTION, A 914.40m [3000'] WIDE CLEAR ZONE IS REQUIRED. SEE OPNAVINST 11010.36C/MCO11010.16 (OR LATEST VERSION).
2. THE WIDTH AND CONFIGURATION OF AN APPROACH - DEPARTURE CLEARANCE SURFACE ARE BASED ON THE CLASS OF RUNWAY, NOT THE WIDTH OF THE CLEAR ZONE.
3. FOR ADDITIONAL INFORMATION ON CLEAR ZONES, SEE TABLE 3-5.
4. FOR ADDITIONAL INFORMATION ON ACCIDENT POTENTIAL ZONES, SEE TABLE 3-6.

LEGEND

APZ I	ACCIDENT POTENTIAL ZONE I
APZ II	ACCIDENT POTENTIAL ZONE II
CZ	CLEAR ZONE
CZ I	TYPE I CLEAR ZONE
CZ II	TYPE II CLEAR ZONE
CZ III	TYPE III CLEAR ZONE

Figure 3-7. Class A VFR Runway Primary Surface End Details



NOTES

1. WHERE EXISTING GROUND IS ABOVE THE APPROACH - DEPARTURE SURFACE, CUT WILL BE REQUIRED. WHERE THE EXISTING GROUND IS BELOW APPROACH - DEPARTURE SURFACE, FILL AS NECESSARY TO MEET MAX. GRADE REQUIREMENTS.
2. FOR A TRANSVERSE SECTION OF THE CLEAR ZONE AND AREA TO BE GRADED, SEE FIGURE 3-2.
3. MINIMUM AREA OF CLEAR ZONE TO BE GRADED, SEE TABLE 3-5.
4. FOR NAVY AND MARINE CORPS, OVERRUN LENGTH IS 300m [1,000'].

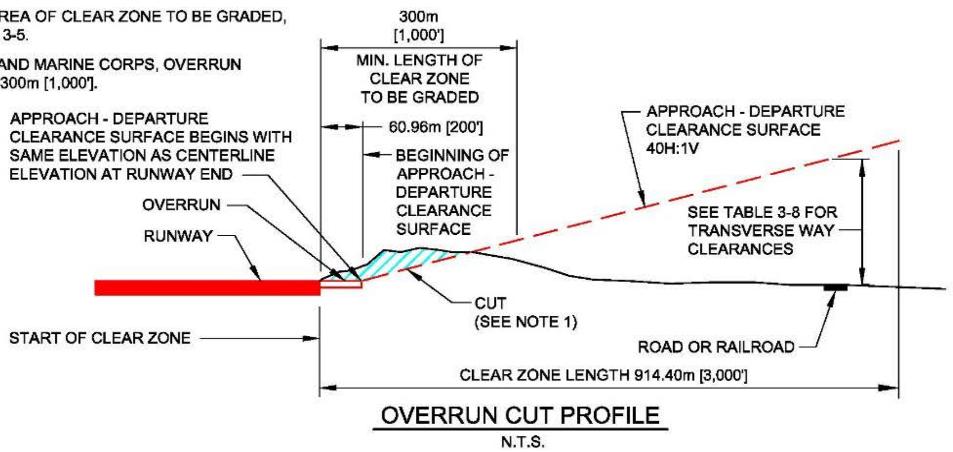
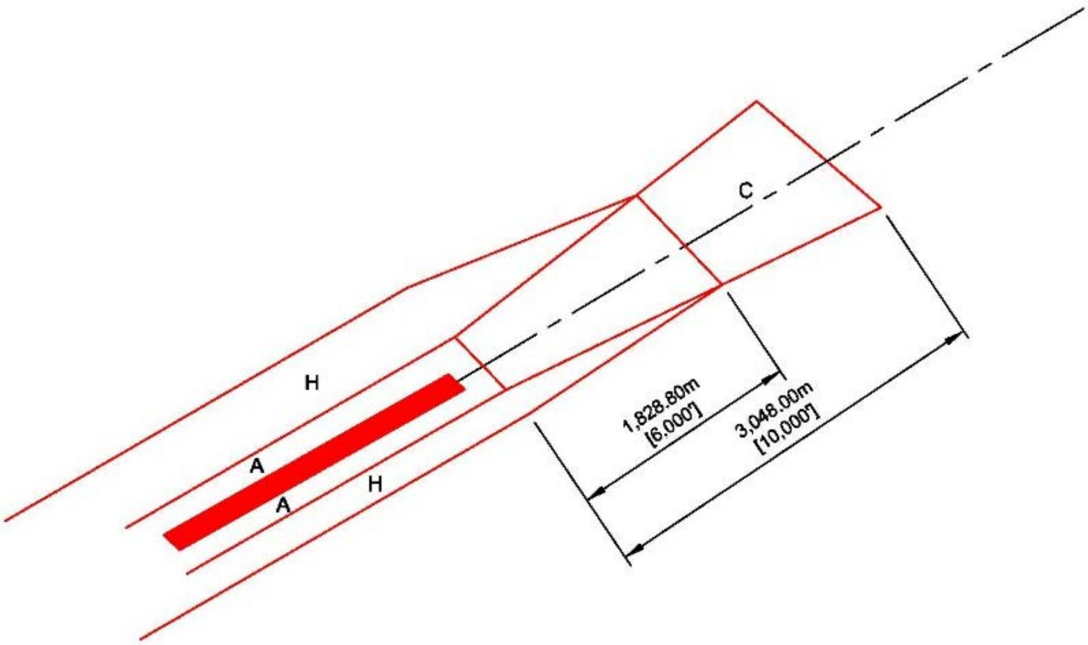


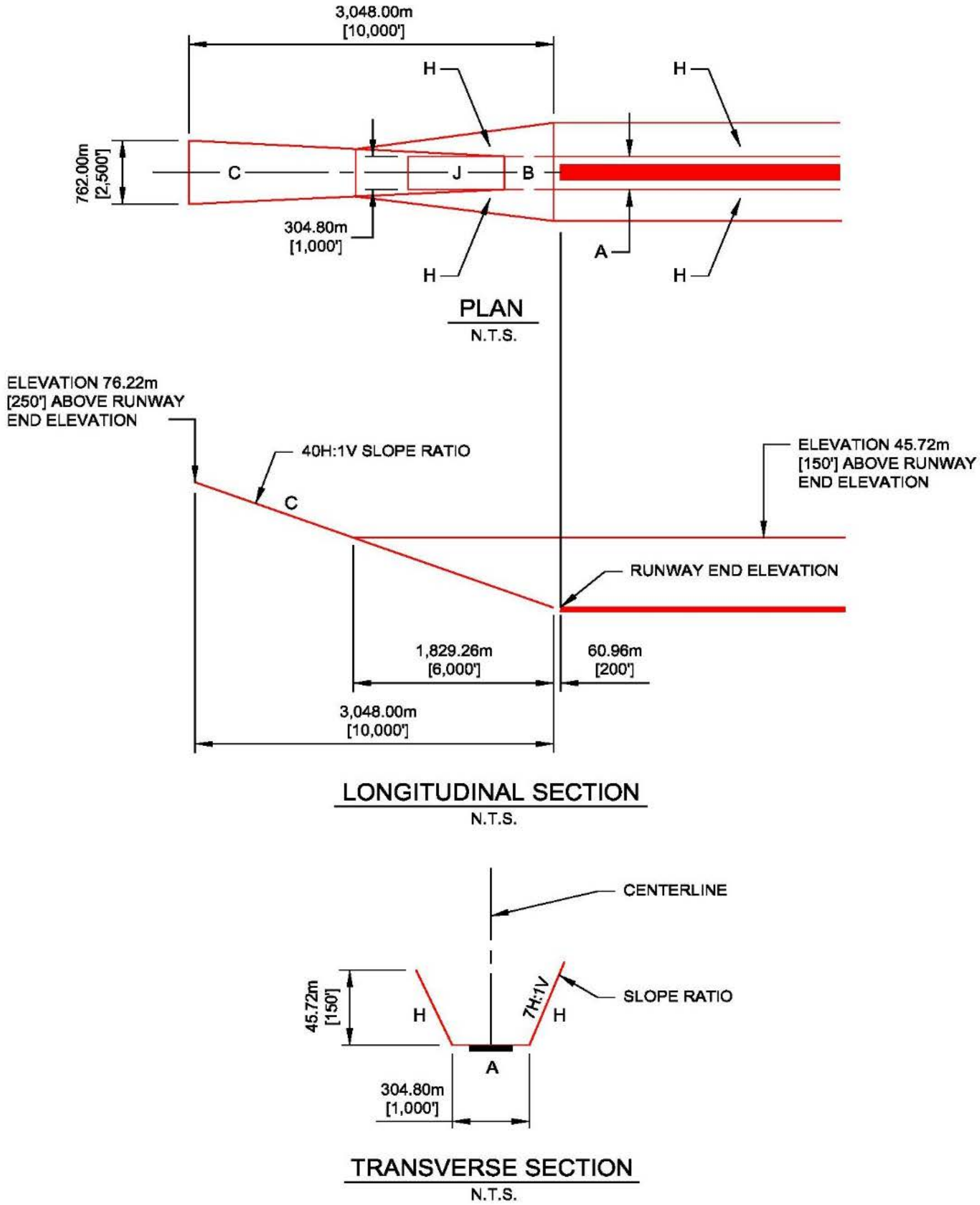
Figure 3-8. Class A VFR Runway Isometric Airspace Imaginary Surfaces



LEGEND

A PRIMARY SURFACE
B CLEAR ZONE SURFACE (NOT SHOWN)
C APPROACH - DEPARTURE CLEARANCE SURFACE (40H:1V SLOPE RATIO)
D APPROACH - DEPARTURE CLEARANCE SURFACE (HORIZONTAL) (NOT REQUIRED)
E INNER HORIZONTAL SURFACE (NOT REQUIRED)
F CONICAL SURFACE (NOT REQUIRED)
G OUTER HORIZONTAL SURFACE (NOT REQUIRED)
H TRANSITIONAL SURFACE (7H:1V SLOPE RATIO)
I NOT USED
J ACCIDENT POTENTIAL ZONE (APZ) (NOT SHOWN)

Figure 3-9. Class A VFR Runway Plan and Profile Airspace Imaginary Surfaces



NOTES

1. DATUM ELEVATION FOR:
   a. SURFACE C IS THE RUNWAY CENTERLINE ELEVATION AT THE THRESHOLD.
   b. SURFACE H VARIES AT EACH POINT ALONG THE RUNWAY CENTERLINE. SEE TABLE 3-7.
2. THE SURFACES SHOWN ON THE PLAN ARE FOR THE CASE OF A LEVEL RUNWAY.

LEGEND

A PRIMARY SURFACE
B CLEAR ZONE SURFACE
C APPROACH - DEPARTURE CLEARANCE SURFACE (SLOPE)
D APPROACH - DEPARTURE CLEARANCE SURFACE (HORIZONTAL) (NOT REQUIRED)
E INNER HORIZONTAL SURFACE (NOT REQUIRED)
F CONICAL SURFACE (NOT REQUIRED)
G OUTER HORIZONTAL SURFACE (NOT REQUIRED)
H TRANSITIONAL SURFACE
I NOT USED
J ACCIDENT POTENTIAL ZONE (APZ)

Figure 3-10. Class A IFR Runway Primary Surface End Details

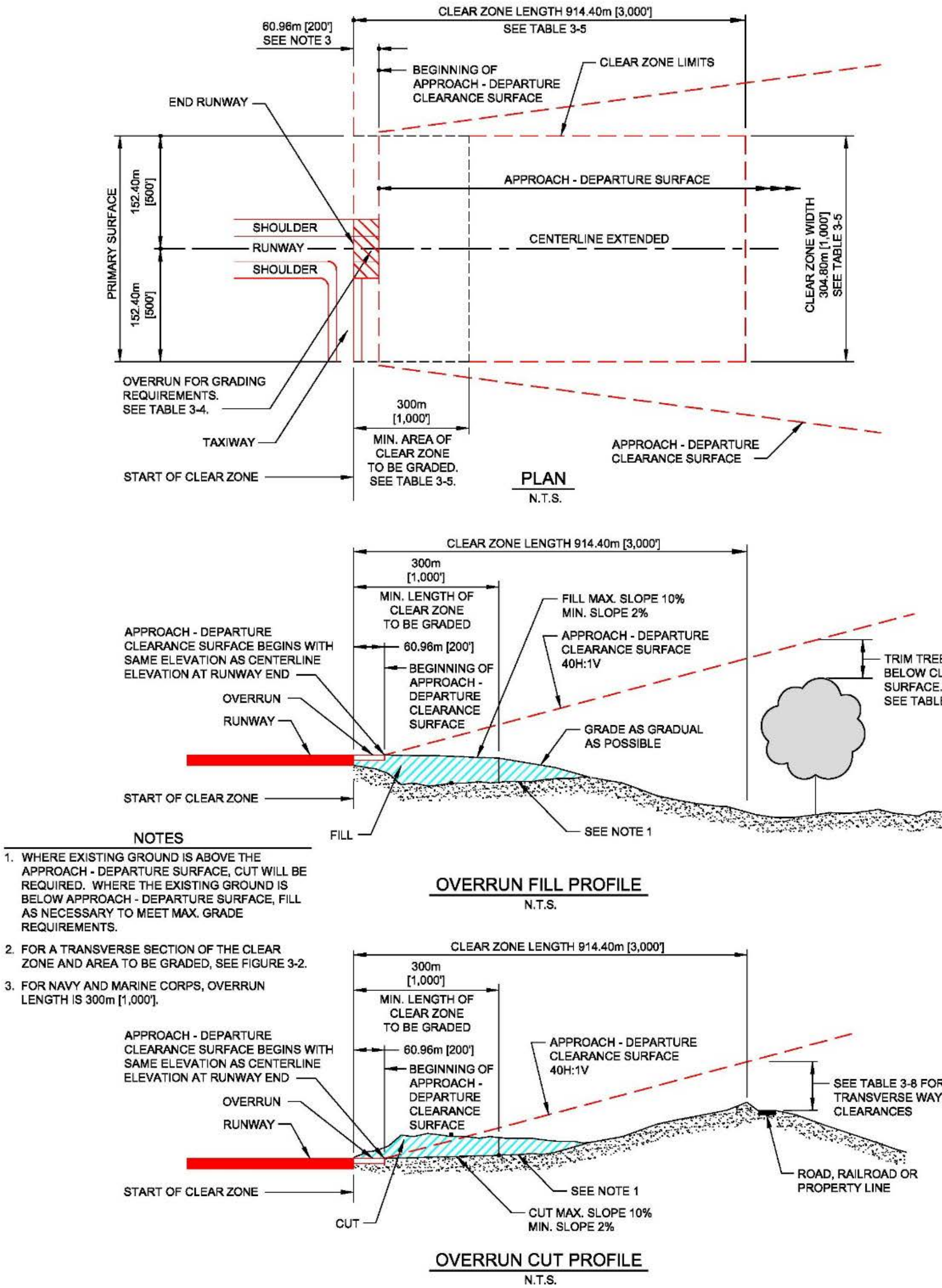
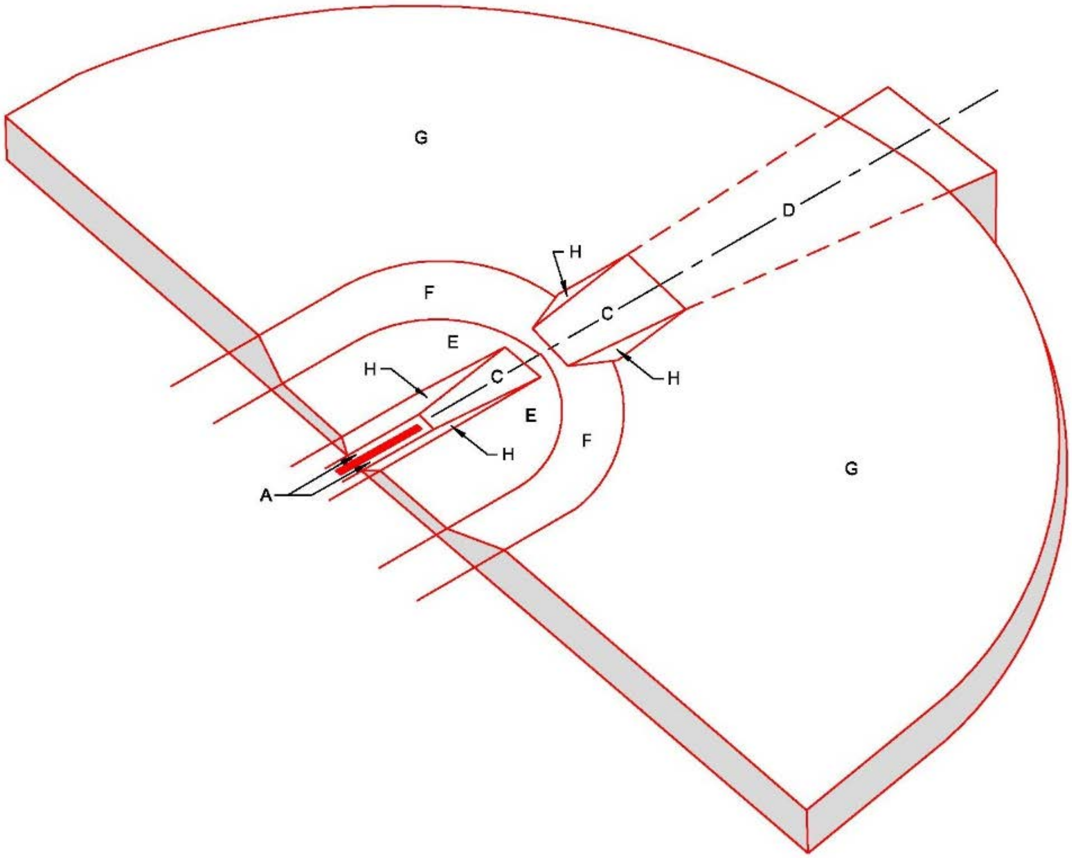


Figure 3-11. Class A IFR Runway Airspace Imaginary Surfaces

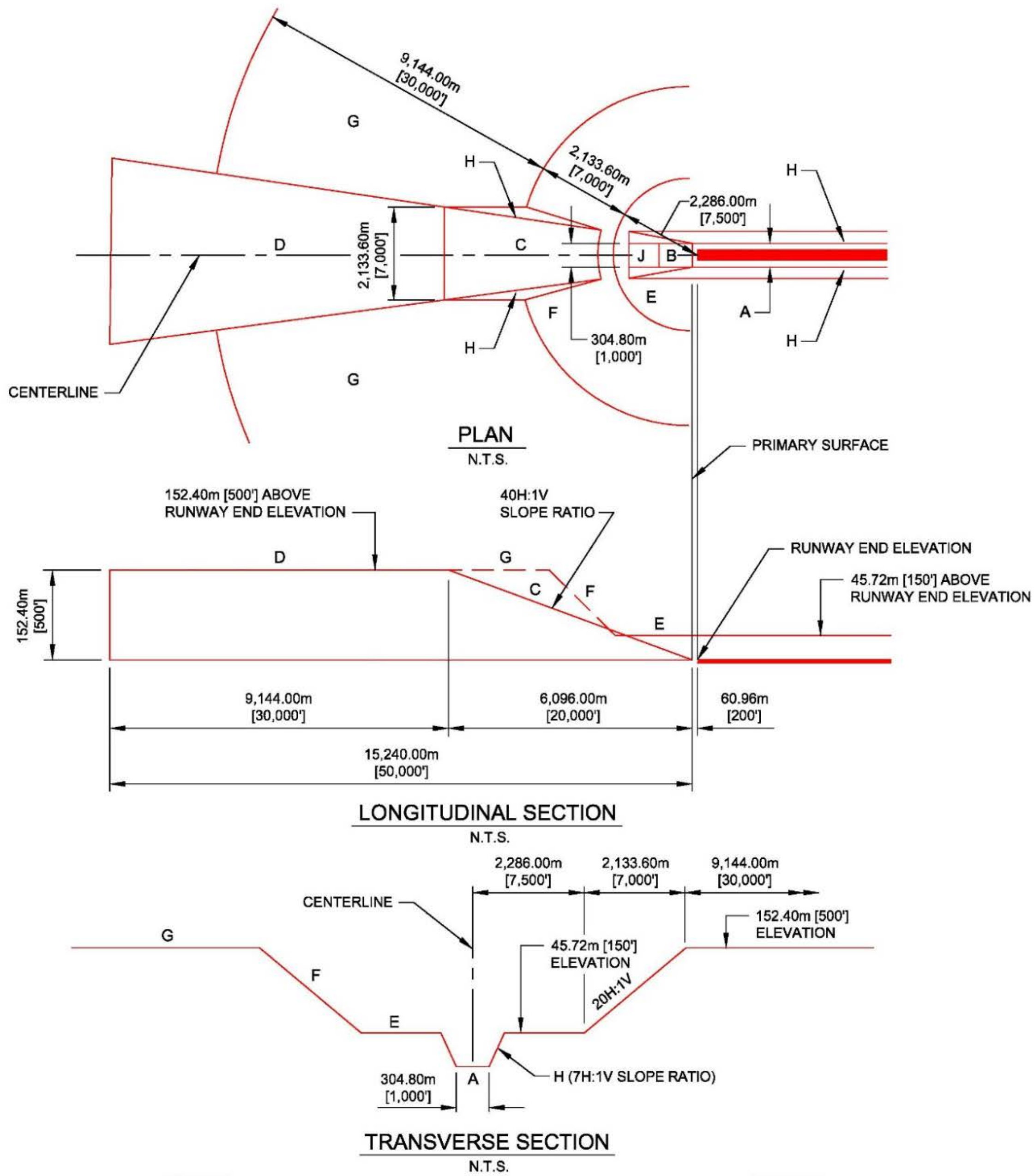


LEGEND

A PRIMARY SURFACE
B CLEAR ZONE SURFACE (NOT SHOWN)
C APPROACH - DEPARTURE CLEARANCE SURFACE (SLOPE) (40H:1V RATIO)
D APPROACH - DEPARTURE CLEARANCE SURFACE (HORIZONTAL)
E INNER HORIZONTAL SURFACE (45.72m [150'] ELEVATION)
F CONICAL SURFACE (20H:1V)
G OUTER HORIZONTAL SURFACE (152.40m [500'] ELEVATION)
H TRANSITIONAL SURFACE (7H:1V)
I NOT USED
J ACCIDENT POTENTIAL ZONE (APZ) (NOT SHOWN)

ISOMETRIC
N.T.S.

Figure 3-12. Class A IFR Runway Plan and Profile Airspace Imaginary Surfaces



NOTES

1. DATUM ELEVATION FOR:
   a. SURFACES D, E, F AND G ARE THE ESTABLISHED AIRFIELD ELEVATION.
   b. SURFACE C IS THE RUNWAY CENTERLINE ELEVATION AT THE THRESHOLD.
   c. SURFACE H VARIES AT EACH POINT ALONG THE RUNWAY CENTERLINE. SEE TABLE 3-7.
2. THE SURFACES SHOWN ON THE PLAN ARE FOR THE CASE OF A LEVEL RUNWAY.

LEGEND

A PRIMARY SURFACE
B CLEAR ZONE SURFACE
C APPROACH - DEPARTURE CLEARANCE SURFACE (SLOPE)
D APPROACH - DEPARTURE CLEARANCE SURFACE (HORIZONTAL)
E INNER HORIZONTAL SURFACE
F CONICAL SURFACE
G OUTER HORIZONTAL SURFACE
H TRANSITIONAL SURFACE
I NOT USED
J ACCIDENT POTENTIAL ZONE (APZ)

Figure 3-13. Class B Army and Air Force Runway End and Clear Zone Details

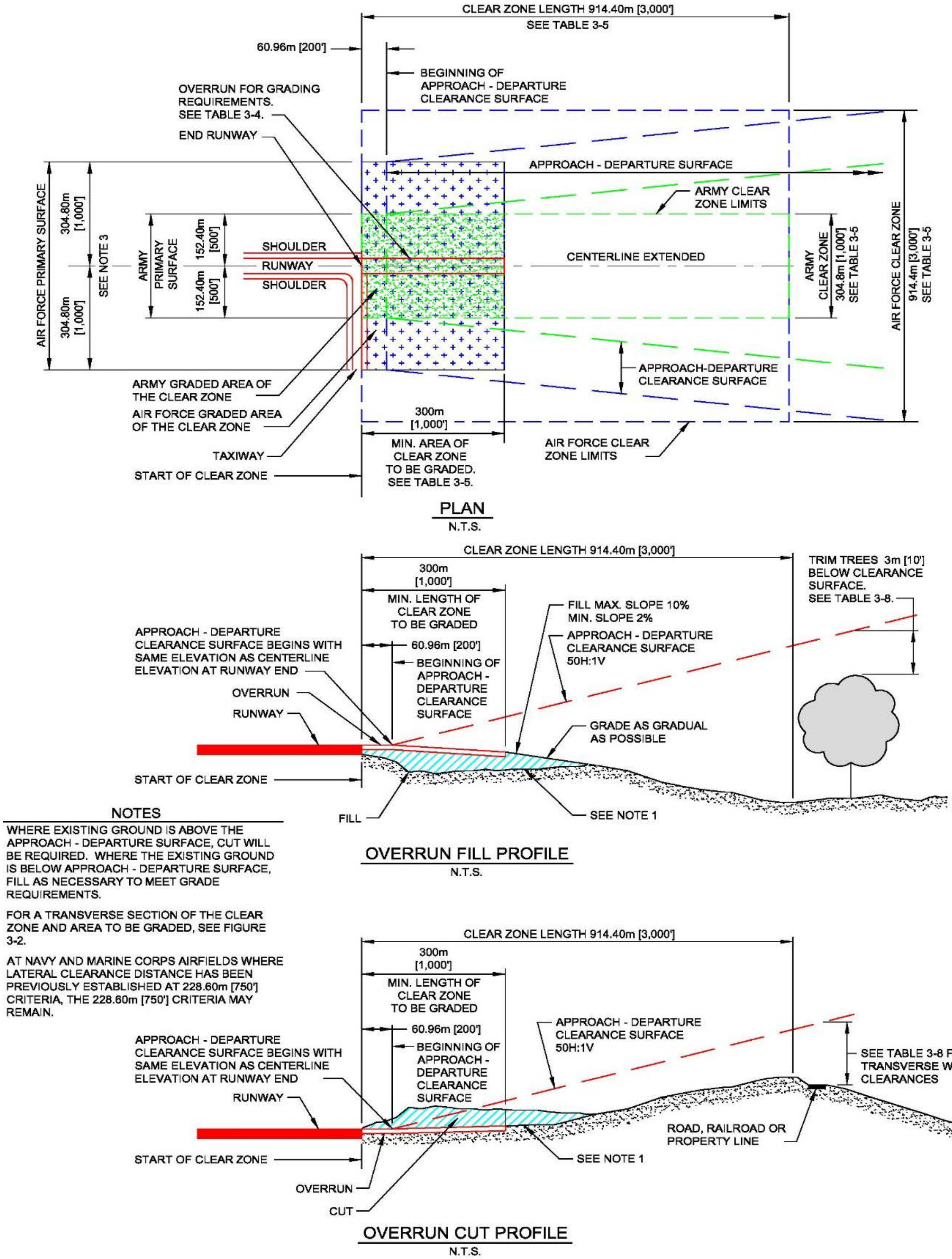


Figure 3-14. Class B Army Runway Airspace Imaginary Surfaces

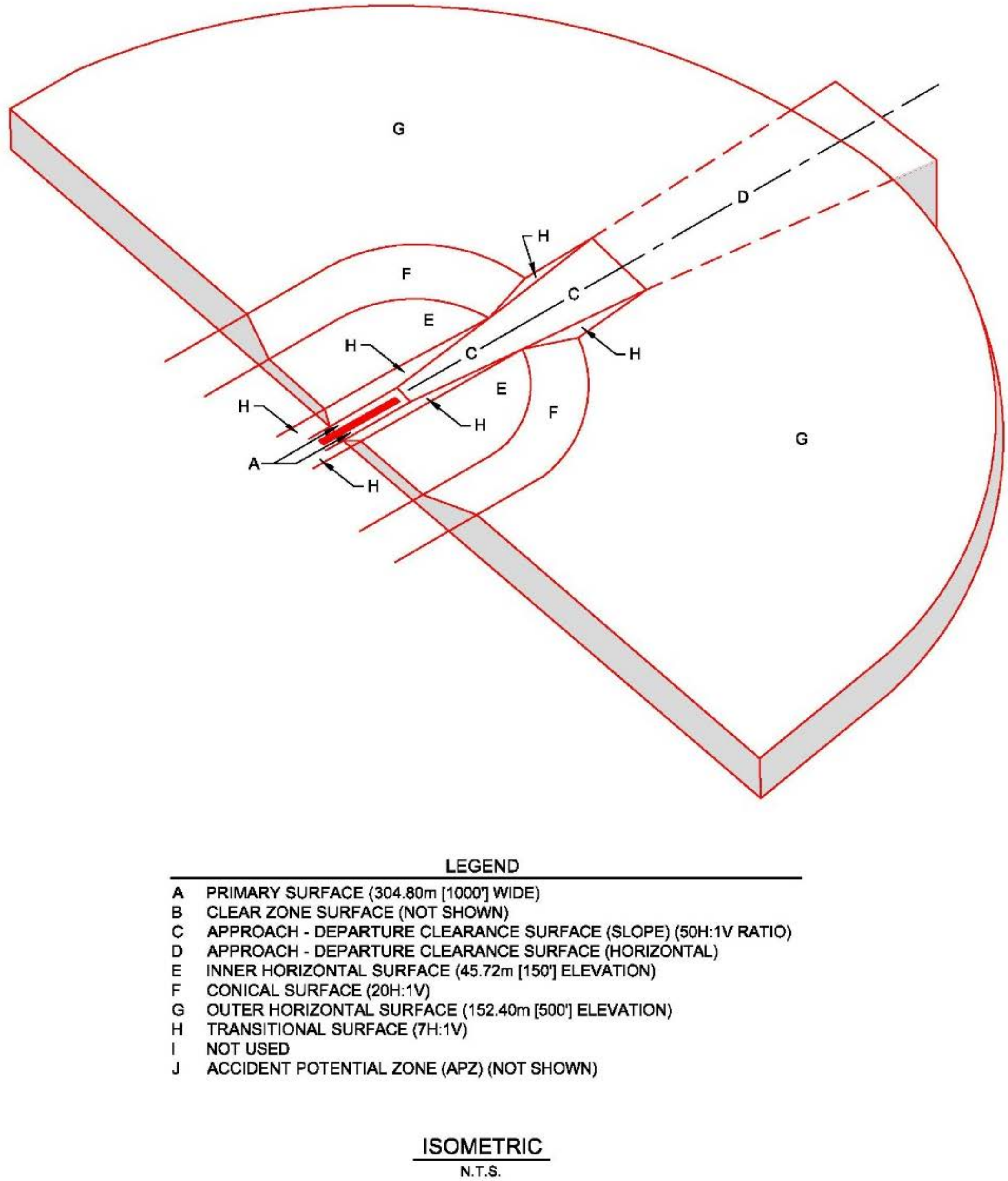
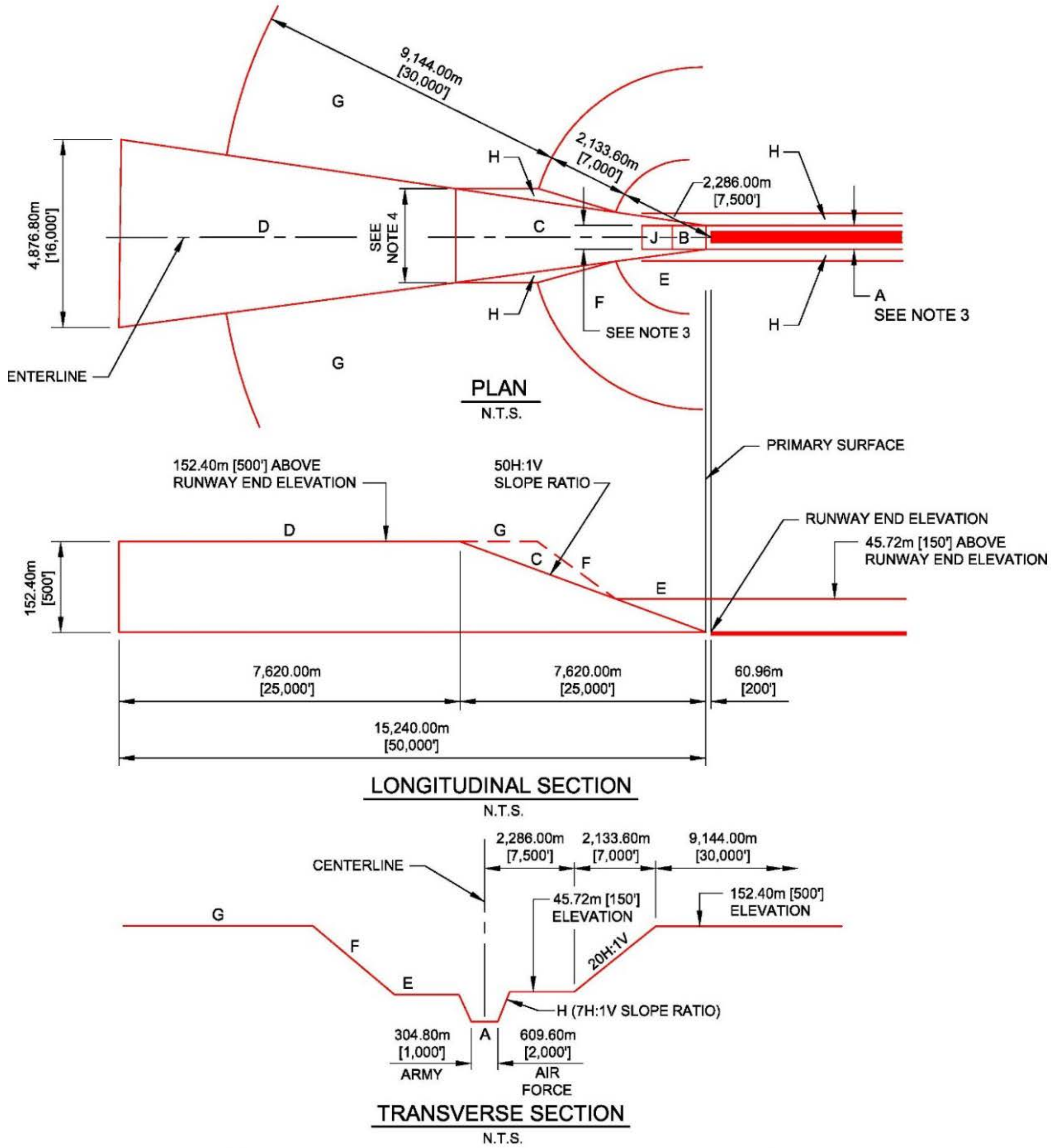


Figure 3-15. Class B Army and Air Force Runway Airspace Plan and Profile Runway Imaginary Surfaces



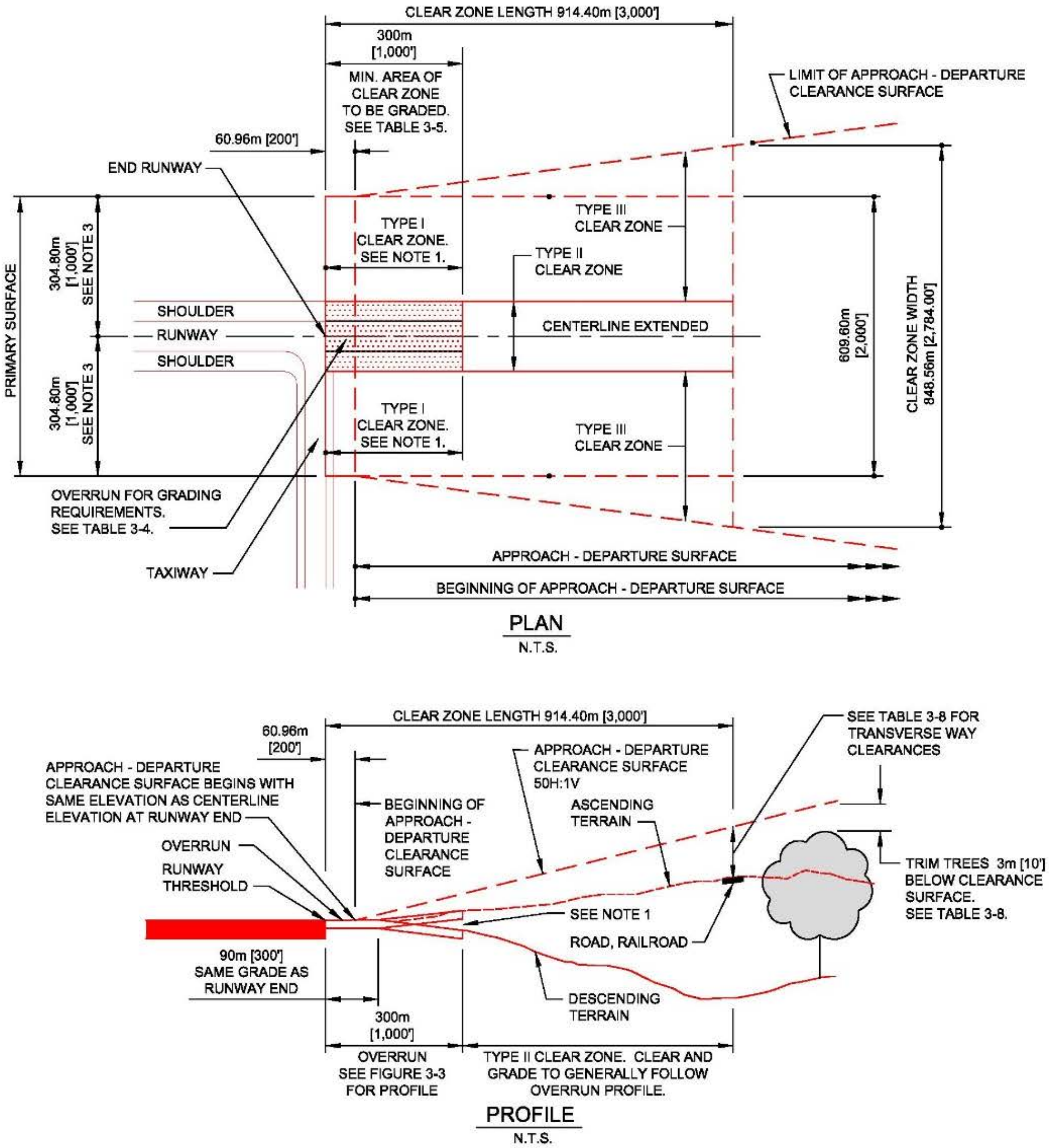
NOTES

1. DATUM ELEVATION FOR:
   a. SURFACES D, E, F AND G ARE THE ESTABLISHED AIRFIELD ELEVATION.
   b. SURFACE C IS THE RUNWAY CENTERLINE ELEVATION AT THE THRESHOLD.
   c. SURFACE H VARIES AT EACH POINT ALONG THE RUNWAY CENTERLINE. SEE TABLE 3-7.
2. THE SURFACES SHOWN ON THE PLAN ARE FOR THE CASE OF A LEVEL RUNWAY.
3. 304.80m [1000'] FOR ARMY AND 609.60m [2000'] FOR AIR FORCE.
4. 2590.80m [8500'] FOR ARMY AND 2743.20m [9000'] FOR AIR FORCE.

LEGEND

A	PRIMARY SURFACE
B	CLEAR ZONE SURFACE
C	APPROACH - DEPARTURE CLEARANCE SURFACE (SLOPE)
D	APPROACH - DEPARTURE CLEARANCE SURFACE (HORIZONTAL)
E	INNER HORIZONTAL SURFACE
F	CONICAL SURFACE
G	OUTER HORIZONTAL SURFACE
H	TRANSITIONAL SURFACE
I	NOT USED
J	ACCIDENT POTENTIAL ZONE (APZ)

Figure 3-16. Class B Navy Runway Primary Surface End Details



NOTES

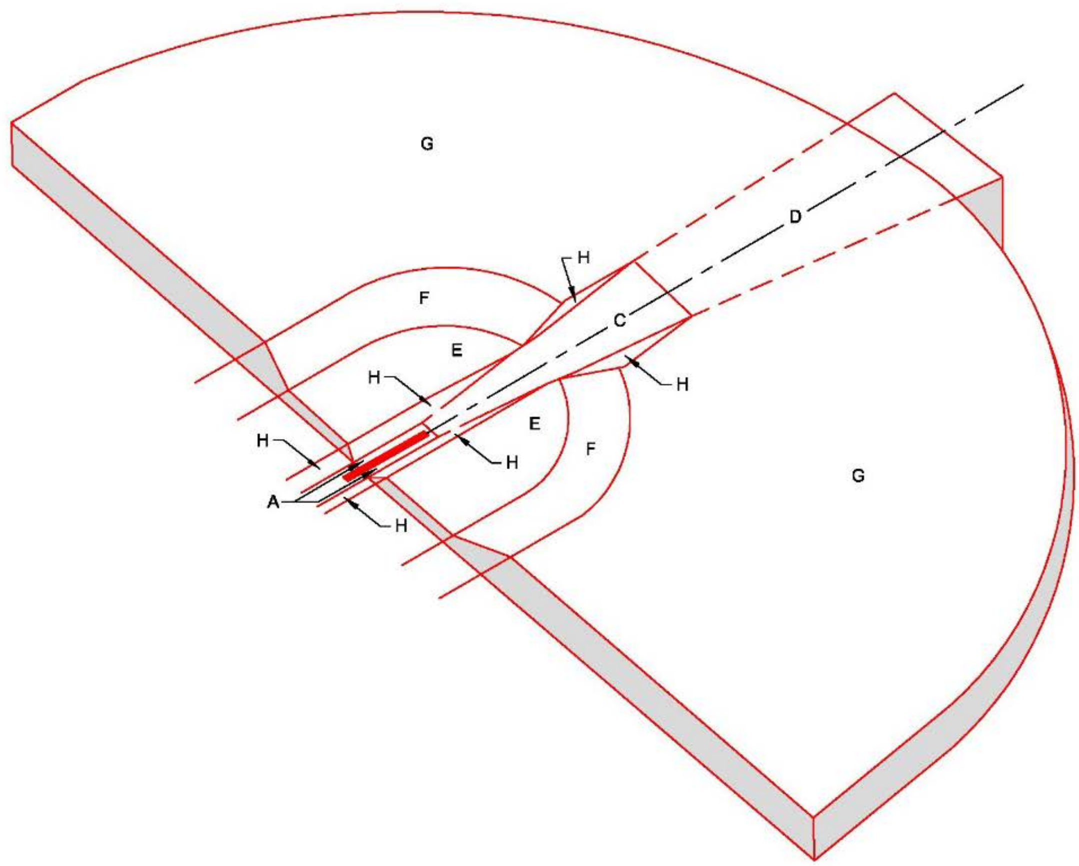
1. WHERE EXISTING GROUND IS ABOVE THE APPROACH - DEPARTURE SURFACE, CUT WILL BE REQUIRED.
2. WHERE THE EXISTING GROUND IS BELOW APPROACH - DEPARTURE SURFACE, FILL AS NECESSARY TO MEET MAX. GRADE REQUIREMENTS.

   TYPE I CLEAR ZONE IS TO BE CLEARED, GRADED AND FREE OF ABOVE GROUND OBJECTS.

   GRADES: LONGITUDINAL MAX. 10%, MAX. GRADE CHANGE ± 2.0% PER 30m [100']
   TRANSVERSE MAX. 10%, MIN. 2%

   OVERRUN: LONGITUDINAL GRADE, FIRST 90m [300'] SAME AS LAST 900m [3,000'] OF RUNWAY.
   REMAINDER 1.5% MAX.
   MAX. LONG GRADE CHANGE 2% PER 30m [100']
   TYPE II CLEAR ZONE CLEAR AND GRADE TO GENERALLY FOLLOW OVERRUN PROFILE.
   TYPE III CLEAR ZONE NOT GRADED.
3. AT AIRFIELDS WHERE LATERAL CLEARANCE DISTANCE HAS BEEN PREVIOUSLY ESTABLISHED AT 228.60m [750'] CRITERIA, THE 228.60m [750'] CRITERIA MAY REMAIN.

Figure 3-17. Class B Air Force and Navy Runway Airspace Imaginary Surfaces

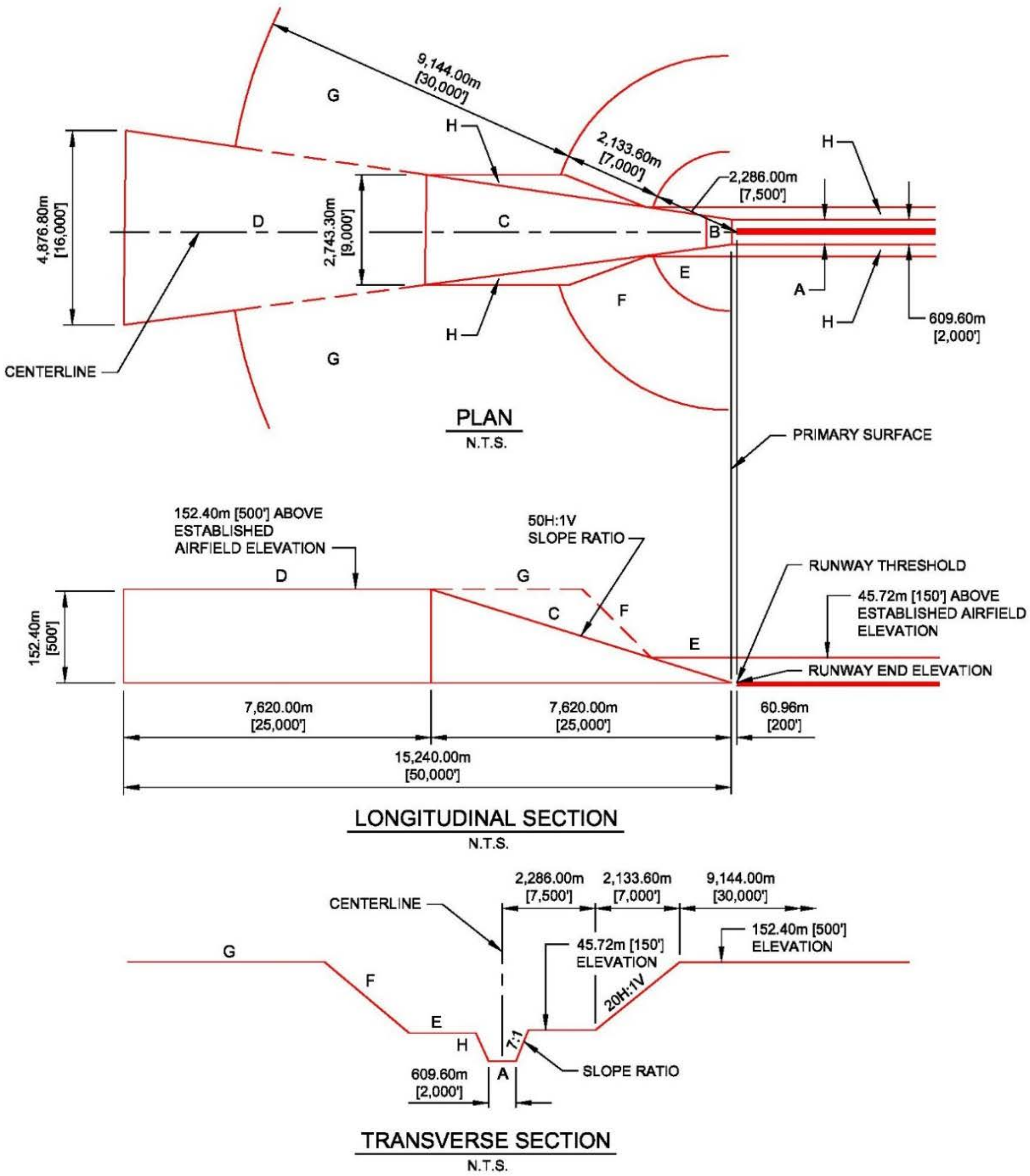


LEGEND

A PRIMARY SURFACE
B CLEAR ZONE SURFACE (NOT SHOWN)
C APPROACH - DEPARTURE CLEARANCE SURFACE (SLOPE) (50H:1V RATIO)
D APPROACH - DEPARTURE CLEARANCE SURFACE (HORIZONTAL)
E INNER HORIZONTAL SURFACE (45.72m [150'] ELEVATION)
F CONICAL SURFACE (20H:1V)
G OUTER HORIZONTAL SURFACE (152.40m [500'] ELEVATION)
H TRANSITIONAL SURFACE (7H:1V)
I NOT USED
J ACCIDENT POTENTIAL ZONE (APZ) (NOT SHOWN)

ISOMETRIC
N.T.S.

Figure 3-18. Class B Navy Runway Airspace Plan and Profile Runway Imaginary Surfaces



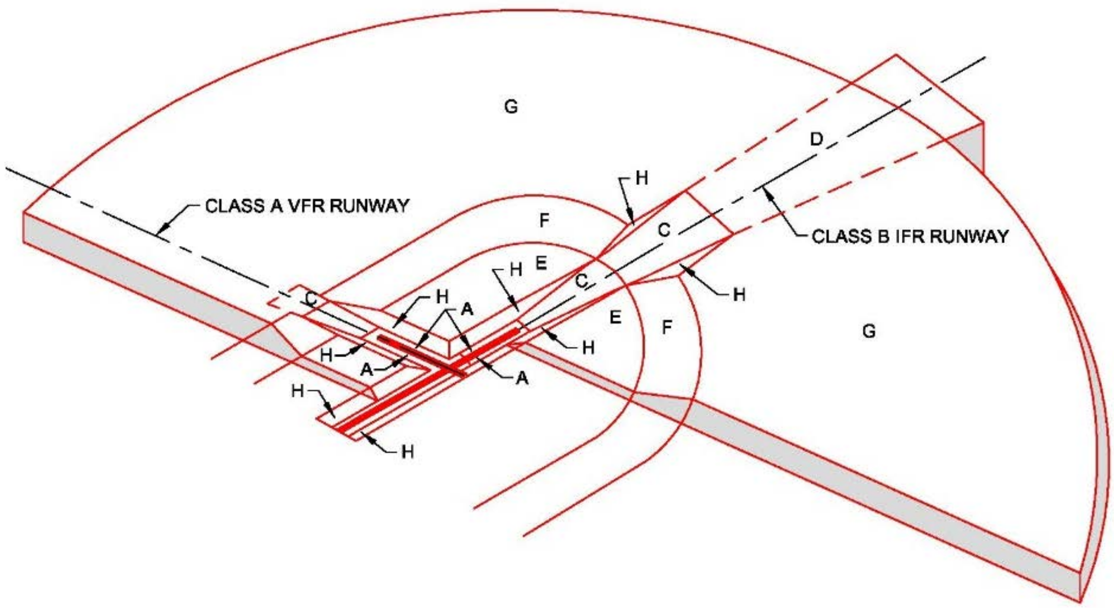
NOTES

1. DATUM ELEVATION FOR:
   a. SURFACES D, E, F AND G ARE THE ESTABLISHED AIRFIELD ELEVATION.
   b. SURFACE C IS THE RUNWAY CENTERLINE ELEVATION AT THE THRESHOLD.
   c. SURFACE H VARIES AT EACH POINT ALONG THE RUNWAY CENTERLINE. SEE TABLE 3-7.
2. THE SURFACES SHOWN ON THE PLAN ARE FOR THE CASE OF A LEVEL RUNWAY.

LEGEND

- A PRIMARY SURFACE
- B CLEAR ZONE SURFACE
- C APPROACH - DEPARTURE CLEARANCE SURFACE (SLOPE)
- D APPROACH - DEPARTURE CLEARANCE SURFACE (HORIZONTAL)
- E INNER HORIZONTAL SURFACE
- F CONICAL SURFACE
- G OUTER HORIZONTAL SURFACE
- H TRANSITIONAL SURFACE
- I NOT USED
- J ACCIDENT POTENTIAL ZONE (APZ) (NOT SHOWN)

Figure 3-19. VFR and IFR Crosswind Runways Isometric Airspace Imaginary Surfaces

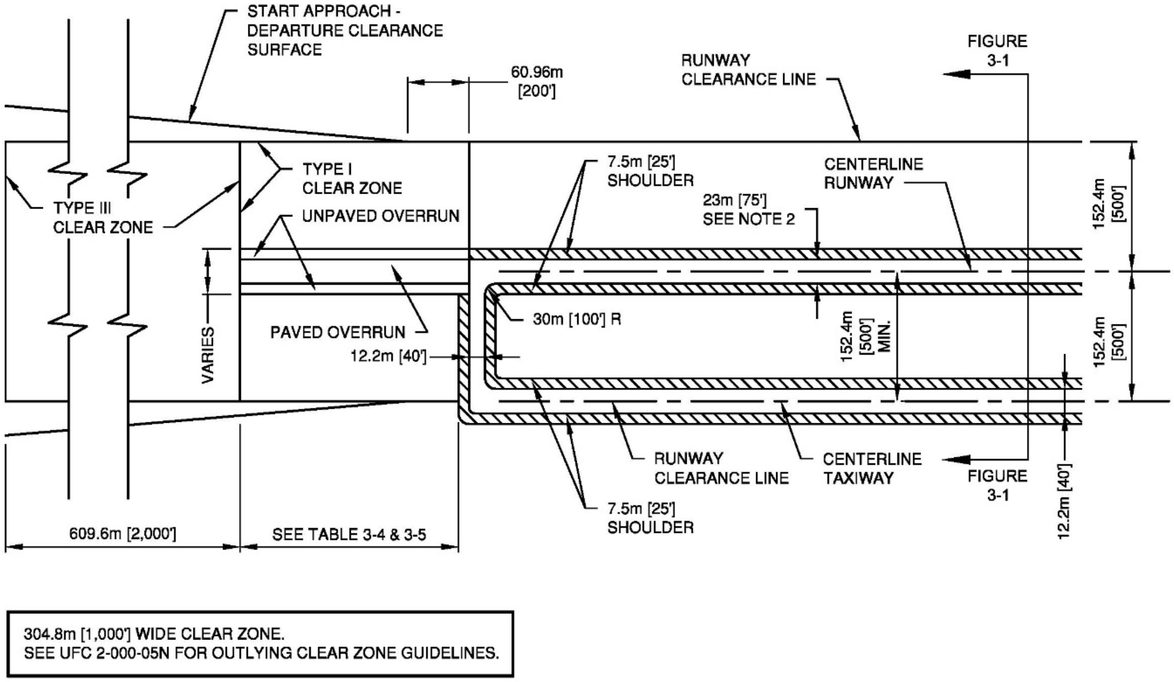


LEGEND

A	PRIMARY SURFACE
B	CLEAR ZONE SURFACE (NOT SHOWN)
C	APPROACH - DEPARTURE CLEARANCE SURFACE (SLOPE) (40:1 VFR, 50:1 IFR)
D	APPROACH - DEPARTURE CLEARANCE SURFACE (HORIZONTAL)
E	INNER HORIZONTAL SURFACE (45.72m [150'] ELEVATION)
F	CONICAL SURFACE (20H:1V)
G	OUTER HORIZONTAL SURFACE (152.40m [500'] ELEVATION)
H	TRANSITIONAL SURFACE (7H:1V)
I	NOT USED
J	ACCIDENT POTENTIAL ZONE (APZ) (NOT SHOWN)

ISOMETRIC
N.T.S.

Figure 3-20. Plan, Single Runway, Navy Class A, and Basic Training Outlying Field

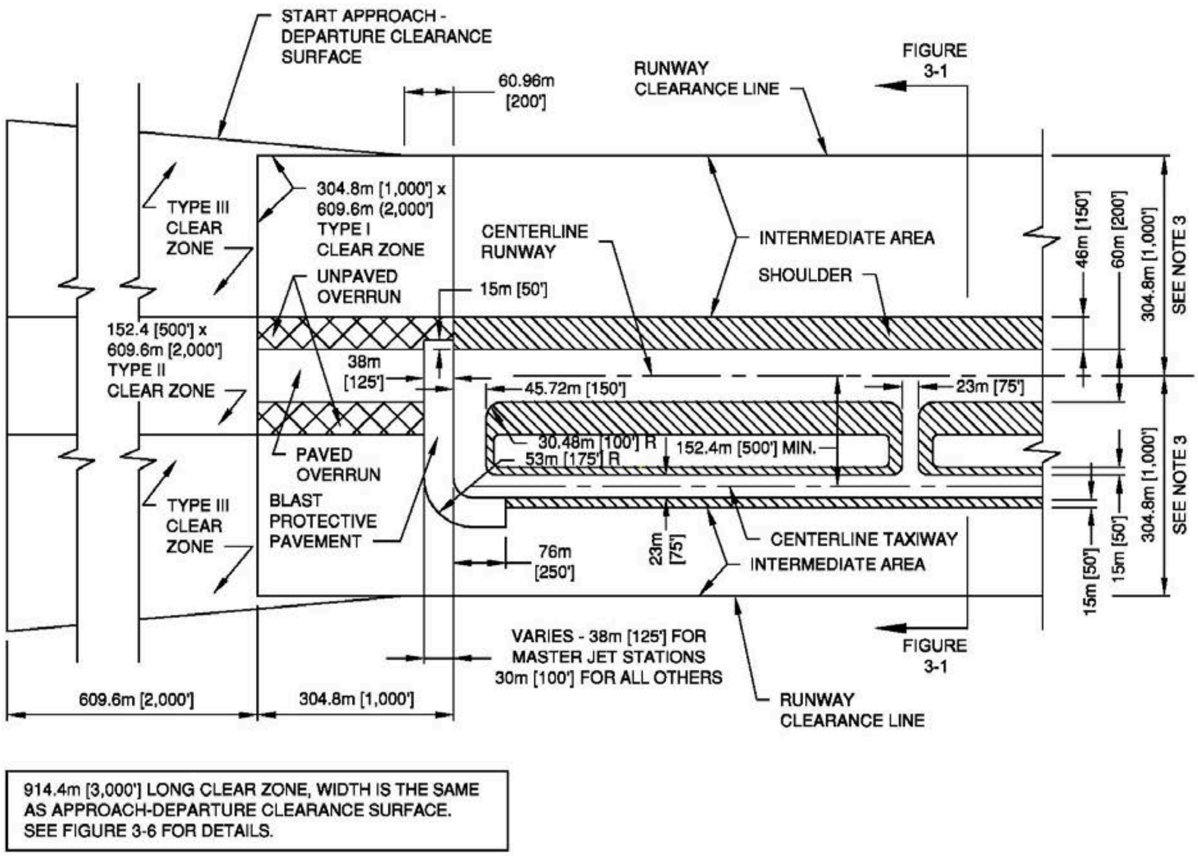


PLAN
N.T.S.

NOTES

1. SEE UFC 2-000-05N FOR SPECIFICS ON CLEAR ZONE AND APPROACH-DEPARTURE CLEARANCE SURFACES.
2. MINIMUM OF 23m [75'] WIDTH. WIDTH SHALL BE INCREASED TO 46m [150'] AT TRAINING COMMAND RUNWAYS FOR T-34 AND T-44 AIRCRAFT.
3. FOR DIMENSIONS OF SPECIFIC ELEMENTS, SEE APPROPRIATE TABLES.
4. FOR RADII OF FILLETS, REFER TO FIGURES 5-4 AND 5-5.
5. FOR NAVY AND MARINE CORPS AIRFIELDS PARALLEL TAXIWAYS MAY BE LOCATED WITHIN THE PRIMARY SURFACE A MINIMUM DISTANCE OF 152.4m [500'] FROM CENTERLINE OF RUNWAY TO CENTERLINE OF TAXIWAY.
6. FOR GRADES WITHIN THE PRIMARY SURFACE, SEE TABLE 3-2.
7. FOR OVERRUN, SEE TABLE 3-4.

Figure 3-21. Plan, Single Runway, and Navy Class B

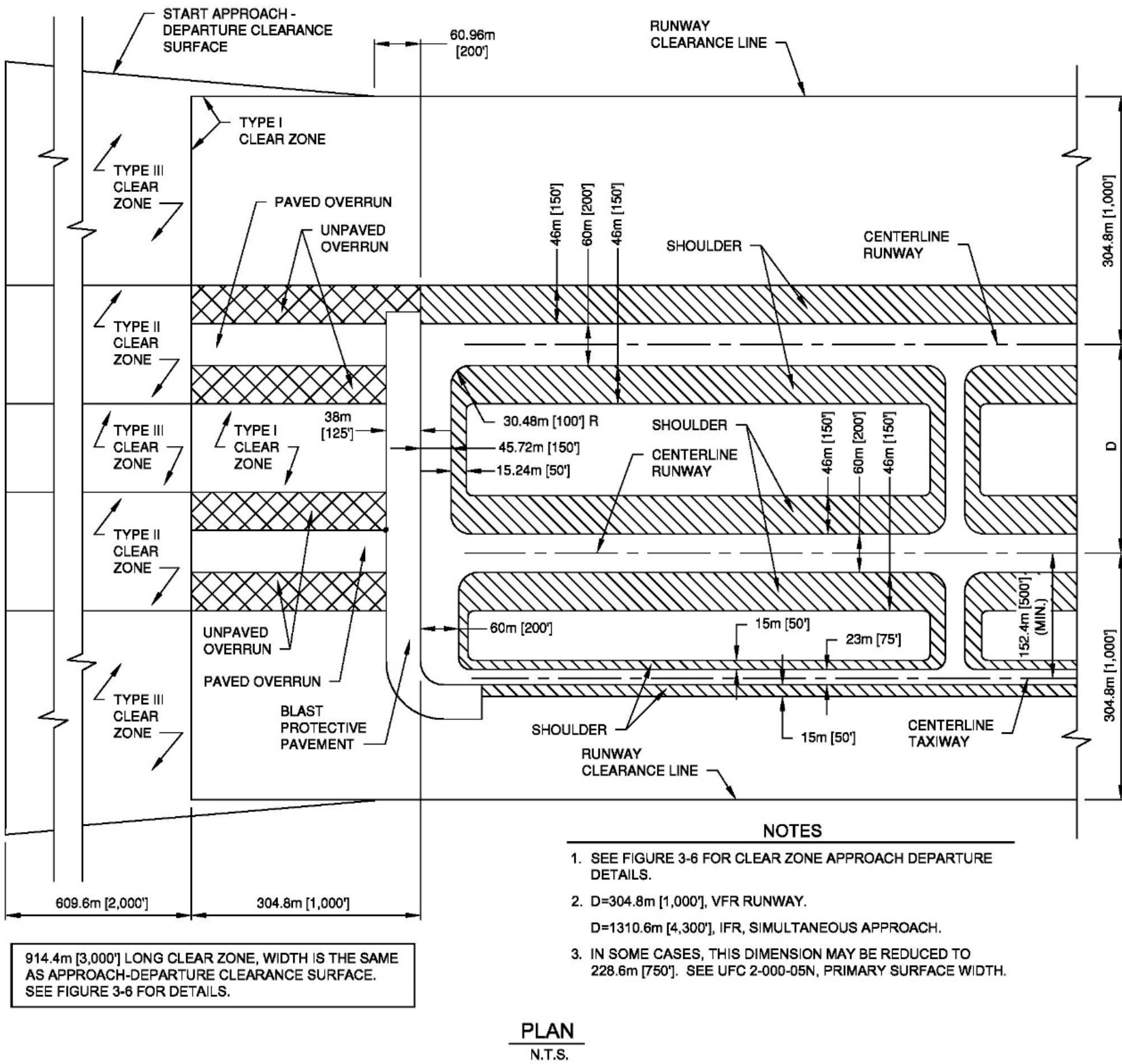


PLAN
N.T.S.

NOTES

1. SEE FIGURE 3-20 FOR SINGLE RUNWAY - CLASS A.
2. IN SOME CASES, THIS DIMENSION MAY BE REDUCED TO 228.6m [750']. SEE UFC 2-000-05N, PRIMARY SURFACE WIDTH.

Figure 3-22. Typical Layout, Navy Dual Class B Runways



3-10 SHOULDERS.

Unprotected areas adjacent to runways and overruns are susceptible to erosion caused by jet blast. Shoulders reduce the probability of serious damage to an aircraft to a minimum in the event that the aircraft runs off the runway pavement. The shoulder width, shown in Item 3 of Table 3-2, includes both paved and unpaved shoulders. Paved shoulders are required adjacent to all runways. The minimum paved shoulder width, shown in Table 3-2, allows the runway edge lights to be placed within the paved portion of the shoulder and to reduce foreign object damage (FOD) to aircraft. The unpaved shoulder will be graded to prevent water from ponding on the adjacent paved area (shoulder and runway). The drop-off next to the paved area prevents turf (which may build up over the years) from ponding water. See Paragraph 2-12 for requirements for designing buried utility structures in shoulders.

3-11 RUNWAY OVERRUNS.

Runway overruns keep the probability of serious damage to an aircraft to a minimum in the event that the aircraft runs off the runway end during a takeoff or landing, or lands short during a landing. Overruns are required for the landing and takeoff area. Table 3-4 shows the dimensional requirements for overruns. Overrun profiles are shown in Figure 3-3, and an overrun layout is shown in Figures 3-7, 3-10, 3-13, and 3-16. USAF and Army design and construction requirements are covered in UFC 3-260-02 (Chapter 10, under "Special Areas"). See Paragraph 2-12 for requirements for designing buried utility structures in overruns.

In certain situations, mission capability may be improved by increased runway length for takeoff. With responsible airfield authority approval, this can sometimes be accomplished by strengthening the paved overrun to support full aircraft traffic, thereby extending the allowable takeoff length, but not changing the approach or departure surfaces or runway thresholds. This situation will require displaced threshold markings to indicate the landing threshold and may require changes to lighting systems. See Paragraph 3-9.2 for displaced threshold guidance.

Table 3-4. Overruns

Table 3-4. Overruns				
Item		Class A Runway	Class B Runway	Remarks
No.	Description	Requirement		
1	Length	60 m (200 ft)	300 m (1,000 ft)	Army and Air Force airfields. Pave the entire length.
		300 m (1,000 ft)		Navy and Marine Corps airfields. Pave the entire length. At outlying fields for T-34 aircraft, the required overrun length is 150 m (500 ft).
2	Total width of overrun (paved and unpaved)	Sum of runway and shoulders		The outside edges of the overrun, equal in width to the runway shoulder, are graded but not paved.
3	Paved overrun width	Same as width of runway		Center on runway centerline extended
4	Longitudinal centerline grade	First 60 m (200 ft) same as last 300 m (1,000 ft) of runway. Remainder 1.5% Max.	First 90 m (300 ft) same as last 900 m (3,000 ft) of runway. Remainder: 1.5% Max	To avoid abrupt changes in grade between the first 90 m (300 ft) and remainder of overrun of a Class B runway, the maximum change of grade is 2.0% per 30 linear m (100 linear ft).
5	Transverse grade	Min 2.0% Max 3.0% 40 mm (1.5 in) drop-off at edge of paved overrun +/- 13 mm (0.5 in)		From centerline of overrun. Transition from the runway and runway shoulder grades to the overrun grades to be made within the first 45 m (150 ft) of overrun.

Note: Geometric design criteria in this manual are based on aircraft-specific requirements and are not direct conversions from inch-pound (English) dimensions. Inch-pound units are included only to permit reference to the previous standard.

3-12 RUNWAY CLEAR ZONES.

Runway clear zones are areas on the ground, located at the ends of each runway. They possess a high potential for accidents, and their use is restricted to be compatible with aircraft operations. Runway clear zones are required for the runway and should be owned or protected under a long-term lease. Table 3-5 shows the dimensional requirements for runway clear zones. Layout of the clear zones is shown in Figures 3-4, 3-5, 3-6, 3-7, 3-9, 3-10, 3-12, 3-13, 3-15, 3-16, 3-18, 3-20, 3-21, and 3-22. See Chapter 2, Para 2-12 for criteria for designing buried utility structures (manholes, handholes, drainage structures) in the Clear Zone.

3-12.1 Land Use in Clear Zones.

The purpose of the clear zone is to protect the safety of flight and safety of people on the ground. The entire clear zone area is a land use control area intended to protect people both flight safety and property on the ground. DoDI 4165.57 and individual Service component directives govern land use within this area.

3-12.2 Clear Zone Mandatory Frangibility Zone (MFZ).

For the USAF and Army, a MFZ extends through the land use control area to the end of the clear zone if on property owned or controlled by the USAF or Army, or to the base boundary if an avigation easement does not exist. Items that must be sited there due to their function must be made frangible, semi-frangible or low impact resistant to the maximum extent possible (see Appendix B, Section 13). Items that cannot be made frangible (such as highway guard rails) but must be located within this area for urgent and compelling reasons must be waived by the MAJCOM or USAASA in accordance with Appendix B, Section 1, before they are constructed. This is to ensure that all alternatives are considered before non-frangible structures are sited within this area. for additional information. Interaction with property owners whose land falls within the MFZ is encouraged. Owners should be encouraged to make items in these areas frangible where practicable. For Air Force, see AFI 32-7063 for additional information.

Table 3-5. Clear Zones

Table 3-5. Clear Zones[1]				
Item		Class A Runway	Class B Runway	Remarks
No.	Description	Requirement		
1	Length	914.40 m (3,000 ft)	914.40 m (3,000 ft)	Measured along the extended runway centerline beginning at the runway end[2]. Although desirable, clearing and grading of the entire area is not required. For acceptable land uses in the clear zone, see AFI 32-7063 and AFH 32-7084 for USAF, and, OPNAVINST 11010.36C/MCO 11010.16 (or latest version), for Navy and Marine Corps. For grading requirements, see items 4 and 5.
2	Width at start of clear zone (adjacent to the runway)	304.80 m (1,000 ft)	304.80 m (1,000 ft)	Army airfields. Exception to these widths is permissible based on Army analysis of highest accident potential area for specific runway use and acquisition constraints.
			914.80 m (3,000 ft)	Air Force airfields. Though desirable, clearing and grading of the entire area is not required. For acceptable land uses in the clear zone, see AFI 32-7063 and AFH 32-7084 for USAF.
			609.60 m (2,000 ft)	Navy and Marine Corps: (See OPNAVINST 11010.36C/MCO 11010.16 (or latest version) for historical guidance where this dimension is 457 m

Table 3-5. Clear Zones[1]

Item No.	Item Description	Class A Runway Requirement	Class B Runway Requirement	Remarks
				(1,500 ft) for airfields built before 1981. For grading requirements, see items 4 and 5.
		See Remarks		Width of the clear zone is centered on and measured at right angles to the extended runway centerline. Refer to Figures 3-4, 3-5, and 3-6.
3	Width at end of clear zone	304.80 m (1,000 ft)	304.80 m (1,000 ft)	Army airfields. Exception to these widths is permissible based on Army analysis of highest accident potential area for specific runway use and acquisition constraints.
			914.40 m (3,000 ft)	Air Force airfields
		304.80 m (1,000 ft)	848.56 m (2,784 ft)	Navy and Marine Corps: See OPNAVINST 11010.36C/MCO 11010.16 (or latest version) for historical guidance for airfields built before 1981. The clear zone has the same dimensions as the approach-departure surface, as shown in Table 3-7. The first 60.96 m (200 ft) of the clear zone is a uniform 609.60 m (2,000 ft) in width, and which point the variable width begins.
			704.7 m (2,312 ft)	Navy and Marine Corps runways constructed prior to 1981 with 457.2m (1500 ft) primary surface.
		See Remarks		Width of the clear zone is centered on and measured at right angles to the extended runway centerline. Refer to Figures 3-4 (US Army), 3-5 (USAF), and 3-6 (US Navy and Marine Corps).
4	Longitudinal grade of area to be graded	Max 10.0%		For Army and Air Force, the area to be graded is 300 m (1,000 ft) in length by the established width of the primary surface. Grades are exclusive of the overrun, but are to be shaped into the overrun grade. The maximum longitudinal grade change cannot exceed $\pm$ 2.0% per 30 m (100 ft). Grade restrictions are also exclusive of other pavements and shoulders. Where other pavements cross the graded area, comply with grading requirements for the specific pavement design (towways, taxiways, or aprons as applicable), but hold grade changes to the minimum practicable to facilitate drainage. For Navy and Marine Corps, the area to be graded will be based on the type of clear zone, as shown in Figures 3-16, 3-20, 3-21, and 3-22. For all Services, the graded area is to be cleared and grubbed of stumps and free of abrupt surface
5	Transverse grade of area to be graded (in direction of surface drainage prior to channelization)	Min 2.0% Max 10.0%		(see remarks for item 4)

Table 3-5. Clear Zones[1]				
Item		**Class A Runway**	**Class B Runway**	
No.	**Description**	**Requirement**		**Remarks**
				irregularities, ditches, and ponding areas. No aboveground structures (see note 3), objects, or roadways (except air traffic control controlled service roads to arresting gear or NAVAIDs) are permitted in the area to be graded, but gentle swales, subsurface drainage, covered culverts and underground structures are permissible. The transition from the graded area to the remainder of the clear zone is to be as gradual as feasible. For policy regarding permissible facilities, geographical features, and land use in the clear zone, refer to guidance furnished by each individual Service, and DoD AICUZ guidelines for clear zones and accident potential zones. (See Appendix B, Section 3.)
6	Width of USAF and Army MFZ	152.4 m (500 ft)		Centered on the extended runway centerline. **\1** All items sited in the clear zone must be frangible (see B13 for exceptions such as fencing). **/1/** Man-made items located beyond the Graded Area of the clear zone but within the MFZ must be constructed to be frangible, low impact-resistant structures, or semi-frangible to the maximum extent possible (see Appendix B, Section 13).
7	Length of USAF and Army MFZ	914.4 m (3000 ft)		

NOTES:

1. Applicable to aviation facilities installations of the military departments in the United States, its territories, trusts, and possessions. For military facilities overseas, other than in locations designated, apply to the maximum practical extent.
2. For the definition of runway end refer to the glossary.
3. Essential NAVAID structure exceptions are discussed in Appendix B, Section 13.
4. Airfield and heliport imaginary surfaces and safe wingtip clearance dimensions are direct conversions from inch-pound to SI units.

3-12.3 US Navy Clear Zones.

Clear zones possess a high potential for accidents, and are subject to severe land use restrictions. For compatible land use assessment purposes, the clear zone is considered as one contiguous geometric area. Land use in the clear zone is governed by DoDI 4165.57 and OPNAVINST 11010.36C/MCO 11010.16 (or latest version). For the purpose of clear zone design, associated graded areas and approach-departure clearance requirements, the Navy defines three clear zone types as follows:

3-12.3.1 Type I Clear Zone.

This zone is immediately adjacent to the end of the runway. It will be cleared, graded, and free of above-ground objects (except airfield lighting) and is to receive special ground treatment or pavement in the area designated as the runway overrun. This clear zone is required at both ends of all runways.

3-12.3.2 Type II Clear Zone.

This zone is used only for Class B runways and is an extension of the Type I clear zone except that the width is reduced. The Type II clear zone will be graded and cleared of all above-ground objects except airfield lighting.

3-12.3.3 Type III Clear Zone.

This zone is laterally adjacent to the Type II clear zone for Class B runways and is used in lieu of the Type II clear zone at Class A runways and basic training outlying fields used by the T-34 aircraft. Objects in this zone will not penetrate the approach-departure clearance surface. Trees, shrubs, bushes, or any other natural growth will be topped 3 m (10 ft) below the approach-departure clearance surface or to a lesser height if necessary to ensure the visibility of airfield lighting. Traverse ways (e.g., roads, railroads, canals) are permitted provided that they would not penetrate airfield imaginary surfaces after the height of the traverse way has been increased by the distances specified in UFC 2-000-05N.

3-13 ACCIDENT POTENTIAL ZONES (APZ).

APZs are areas on the ground located beyond the clear zone of each runway. They possess a potential for accidents, and land use in APZs is governed in accordance with DoDI 4165.57 and Service-specific AICUZ directives. Table 3-6 shows the dimensional requirements for runway APZs. Layout of APZs is shown in Figure 3-4 for the Army, Figure 3-5 for the Air Force, and Figure 3-6 for the Navy. Navy planners will use OPNAVINST 11010.36C/MCO 11010.16 (or latest version) to determine specific AICUZ requirements. For the Air Force, land use guidelines within the clear zone (beyond the graded area) and APZ I and APZ II are provided in AFI 32-7063 and AFH 32-7084.

3-14 AIRSPACE IMAGINARY SURFACES.

The area surrounding a runway that must be kept clear of objects that might damage an aircraft is bounded by imaginary surfaces that are defined in this manual. An object, either man-made or natural, that projects above an imaginary surface is an obstruction. Imaginary surfaces for fixed-wing airfields are shown in Figures 3-6 through 3-22 and are defined in the glossary. The applicable dimensions and slopes are provided in Table 3-7. These imaginary surfaces include:

- Primary surface
- Approach-departure surface
- Inner horizontal surface
- Conical surface
- Outer horizontal surface
- Transitional surface

- The graded portion of the clear zone

Table 3-6. Accident Potential Zones (APZs)

Table 3-6. Accident Potential Zones (APZs)				
Item		Class A Runway	Class B Runway	
No.	Description	Requirement		Remarks
1	APZ I length	762.00 m (2,500 ft)	1,524.00 m (5,000 ft)	APZ I starts at the end of the clear zone, and is centered and measured on the extended centerline.
2	APZ I width	304.80 m (1,000 ft)	304.80 m (1,000 ft)	Army airfields
			914.400 m (3,000 ft)	Air Force, Navy, and Marine Corps airfields
3	APZ II length	762.00 m (2,500 ft)	2,133.60 m (7,000 ft)	Standard APZ II starts at the end of the APZ I and is centered and measured on the extended runway centerline.
4	APZ II width	304.80 m (1,000 ft)	304.80 m (1,000 ft)	Army airfields
			914.40 m (3,000 ft)	Air Force, Navy, and Marine Corps airfields

NOTES:

1. Applicable to aviation facilities of the military departments in the United States, its territories, trusts, and possessions. For military facilities overseas, other than in locations designated, follow the guidance of the individual Service component.
2. For guidance on land use within the APZs, see land use compatibility guidelines in DoD AICUZ guidelines (Appendix B, Section 3). For USAF, see AFI 32-7063 and AFH 32-7084. For Navy and Marine Corps, see OPNAVINST 11010.36C/MCO 11010.16 (or latest version).
3. Airfield and heliport imaginary surfaces and safe wingtip clearance dimensions are shown as a direct conversion from inch-pound to SI units.

Table 3-7. Airspace Imaginary Surface

Table 3-7. Airspace Imaginary Surfaces						
Item			Class A Runway Requirement		Class B Runway Requirement	
No.	Description	Legend	VFR	IFR	VFR and IFR	Remarks
1	Primary surface width	A	304.80 m (1,000 ft)	304.80 m (1,000 ft)		
					304.80 m (1,000 ft)	Army airfields
					609.60 m (2,000 ft)	Air Force, Navy, and Marine Corps airfields
			See Remarks			Centered on the runway centerline. At US Navy and Marine Corps airfields where the lateral clearance was established according to the previous 228.60 m (750 ft) from centerline criterion, the 457.2-m (1500-ft) distance may remain. For USAF, the primary surface width was expanded 10 Nov 64. Facilities constructed under the previous standard are exempt. See Chapter 1 and Appendix B, Section 17. Parallel taxiways located within the primary surface under previous standards may remain but should be evaluated for continued use in the current location when major repairs are necessary. For Navy and Marine Corps, this surface was expanded on 12 May 1981.
2	Primary surface length	A	Runway Length + 60.96 m (200 ft) at each end			Primary surface extends 60.96 m (200 ft) beyond each end of the runway.
3	Primary surface elevation	A	The elevation of any point on the primary surface is the same as the elevation of the nearest point on the runway centerline.			
4	Clear zone surface (graded area)	B	See Table 3-5			Graded area only. For land use in the clear zone, apply AICUZ standards. For USAF, see AFI 32-7063 and AFH 32-7084; for US Army, see Appendix B, Section 3. For Navy and Marine Corps, see

<table>
<tr><th colspan="9">Table 3-7. Airspace Imaginary Surfaces</th></tr>
<tr><th colspan="2">Item</th><th rowspan="2">Legend</th><th colspan="2">Class A Runway Requirement</th><th>Class B Runway Requirement</th><th rowspan="2">Remarks</th></tr>
<tr><th>No.</th><th>Description</th><th>VFR</th><th>IFR</th><th>VFR and IFR</th></tr>
<tr><td></td><td></td><td></td><td colspan="3"></td><td>OPNAVINST 11010.36C/MCO 11010.16 (or latest version).</td></tr>
<tr><td>5</td><td>Start of approach-departure surface</td><td>C</td><td colspan="3">60.96 m
(200 ft)</td><td>Measured from runway threshold.</td></tr>
<tr><td>6</td><td>Length of sloped portion of approach-departure surface</td><td>C</td><td>3,048.00 m
(10,000 ft)</td><td>6,096.00 m
(20,000 ft)</td><td>7,620.00 m
(25,000 ft)</td><td>Measured horizontally.</td></tr>
<tr><td>7</td><td>Slope of approach-departure surface</td><td>C</td><td>40:1</td><td>40:1</td><td>50:1</td><td>Slope ratio is horizontal: vertical. Example: 40:1 is 40 m (ft) horizontal to 1 m (ft) vertical.
For clearances over highway and railroads, see Table 3-8.</td></tr>
<tr><td rowspan="3">8</td><td rowspan="3">Width of approach-departure surface at start of sloped portion</td><td rowspan="3">C</td><td>304.80 m
(1,000 ft)</td><td>304.80 m
(1,000 ft)</td><td>304.80 m
(1,000 ft)</td><td>Army airfields.</td></tr>
<tr><td></td><td></td><td>609.60 m
(2,000 ft)</td><td>Air Force, Navy, and Marine Corps airfields.</td></tr>
<tr><td colspan="3">See Remarks</td><td>Centered on the extended runway centerline, and is the same width as the Primary Surface.
For Navy and Marine Corps airfields where the lateral clearance distance has been established according to the previous 228.60 m (750 ft) from centerline criterion, the 457.20-m (1,500-ft) distance at the start of the approach-departure clearance surface may remain.</td></tr>
<tr><td rowspan="3">9</td><td rowspan="3">Width of approach-departure surface at end of sloped portion</td><td rowspan="3">C</td><td rowspan="2">762.00 m
(2,500 ft)</td><td rowspan="2">2,133.60 m
(7,000 ft)</td><td>2,590.80 m
(8,500 ft)
See Note 4</td><td>Army Airfields</td></tr>
<tr><td>2,743.20 m
(9,000 ft)
See Note 4</td><td>Air Force Airfields</td></tr>
<tr><td colspan="3">See Remarks</td><td>Centered on the extended runway centerline.</td></tr>
</table>

Table 3-7. Airspace Imaginary Surfaces						
Item			Class A Runway Requirement		Class B Runway Requirement	
No.	Description	Legend	VFR	IFR	VFR and IFR	Remarks
10	Elevation of approach-departure surface at start of sloped portion	C	See Remarks			Same as the runway centerline elevation at the threshold.
11	Elevation of approach-departure surface at end of sloped portion	C	76.20 m (250 ft)	152.40 m (500 ft)	152.40 m (500 ft)	Above the established airfield elevation.
12	Start of horizontal portion of approach-departure surface	D	N/A	6,096.00 m (20,000 ft) See Note 4	7,620.00 m (25,000 ft) See Note 4	Measured from the end of the primary surface. The end of the primary surface (start of the approach-departure surface) is 60.96 m (200 ft) from the end of the runway.
13	Length of horizontal portion of approach-departure surface	D	N/A	9,144.00 m (30,000 ft)	7,620.00 m (25,000 ft)	Measured horizontally along the ground.
14	Width of approach-departure surface at start of horizontal portion	D	N/A	2,133.60 m (7,000 ft) See Note 4	2,743.20 m (9,000 ft) See Note 4	Centered along the runway centerline extended.
15	Width of approach-departure surface at end of horizontal portion	D	N/A	4,876.80 m (16,000 ft)	4,876.80 m (16,000 ft)	Centered along the runway centerline extended.
16	Elevation of horizontal portion of approach-departure surface	D	N/A	152.40 m (500 ft)	152.40 m (500 ft)	Above the established airfield elevation.

Table 3-7. Airspace Imaginary Surfaces						
Item			Class A Runway Requirement		Class B Runway Requirement	
No.	Description	Legend	VFR	IFR	VFR and IFR	Remarks
17	Radius of inner horizontal surface	E	N/A	2,286.00 m (7,500 ft)		An imaginary surface constructed by scribing an arc with a radius of 2,286 m (7,500 ft) about the centerline at each end of each runway and inter-connecting these arcs with tangents.
18	Width between outer edges of inner horizontal surface	E	N/A	4,572.00 m (15,000 ft)		
19	Elevation of inner horizontal surface	E	N/A	45.72 m (150 ft)		Above the established airfield elevation. See Attachment 1 for the definitions of “airfield elevation” and “inner horizontal surface.” For Navy, also see UFC 2-000-05N.
20	Horizontal width of conical surface	F	N/A	2,133.60 m (7,000 ft)		Extends horizontally outward from the outer boundary of the inner horizontal surface.
21	Slope of conical surface	F	N/A	20:1		Slope ratio is horizontal:vertical. Example: 20:1 is 20 m (ft) horizontal to 1 m (ft) vertical
22	Elevation of conical surface at start of slope	F	N/A	45.72 m (150 ft)		Above the established airfield elevation.
23	Elevation of conical surface at end of slope	F	N/A	152.40 m (500 ft)		Above the established airfield elevation.
24	Distance to outer edge of conical surface	G	N/A	4,419.60 m (14,500 ft)		
25	Width of outer horizontal surface	G	N/A	9,144.00 m (30,000 ft)		Extending horizontally outward from the outer periphery of the conical surface.
26	Elevation of outer horizontal surface	G	N/A	152.40 m (500 ft)		Above the established airfield elevation.

Table 3-7. Airspace Imaginary Surfaces						
Item		Legend	Class A Runway Requirement		Class B Runway Requirement	Remarks
No.	Description		VFR	IFR	VFR and IFR	
27	Distance to outer edge of outer horizontal surface	G	N/A	13,563.60 m (44,500 ft)		An imaginary surface formed by scribing an arc with a radius of 13,563.6 m (44,500 ft) about the centerline at each end of each runway, and interconnecting the arcs with tangents.
28	Start of transitional surface	H	152.40 m (500 ft)		152.40 m (500 ft)	At Army airfields
			152.40 m (500 ft)		304.8 m (1,000 ft)	Air Force, Navy, and Marine Corps
29	End of transitional surface	H	See Remarks			The transitional surface ends at the inner horizontal surface, conical surface, outer horizontal surface, or at an elevation of 45.72 m (150 ft).
30	Slope of transitional surfaces	H	7:1			Slope ratio is horizontal:vertical. 7:1 is 7 m (ft) horizontal to 1 m (ft) vertical. Vertical height of vegetation and other fixed or mobile obstacles and/or structures will not penetrate the transitional surface. Taxiing aircraft are exempt from this requirement. For Navy and Marine Corps airfields, taxiway pavements are exempt from this requirement. For the USAF, the Air Traffic Control Tower is exempt from this requirement if the height will not affect TERPS criteria. See paragraph B16-2.7 and B16-4.3 of Appendix B, Section 16.

NOTES:

1. Approach-departure surfaces are based on instrument approach-departure procedures. Verify instrument approach-departure procedures with Army Aeronautical Service Agency, Air Force Flight Standard Agency, or Navy Flight Information Group (NAFIG), as appropriate, prior to using this table.
2. N/A = not applicable
3. Airfield and heliport imaginary surfaces and safe wingtip clearance dimensions are shown as a direct conversion from inch-pound to SI units.
4. Differences in elevation between the runway thresholds and the Established Airfield Elevation will have some effect on the extended length and width of the sloped portion of the ADCS and the start of the horizontal portion of the ADCS. Careful evaluation of these surfaces is required.

3-15 AIRSPACE FOR AIRFIELDS WITH TWO OR MORE RUNWAYS.

Typical airspace requirements for an airfield with multiple runways, such as a VFR and an IFR runway, are shown in Figure 3-19.

3-16 OBSTRUCTIONS TO AIR NAVIGATION.

An existing object (including a mobile object) is, and a future object would be, an obstruction to air navigation if it is higher than any of the heights or surfaces listed in FAR Part 77 and the surfaces described in this manual.

3-16.1 Aircraft Operating Area (AOA).

No part of the airfield (runway/taxiway aprons) where aircraft operate under their own power will be considered an obstruction if the applicable grading criteria are met. (See the glossary for the definition of "aircraft operating area," as used in this manual.)

3-16.2 Determining Obstructions.

For airfields located in the US and trust territories, an obstruction to air navigation is determined in accordance with this UFC and the standards contained in 14 Code of Federal Regulations (CFR) Part 77, Paragraph 77.23, "Standards for Determining Obstruction. For airfields located elsewhere, an obstruction is determined in accordance with either the host county's standards, or the individual Service's standards, whichever are more stringent.

3-16.3 Trees.

All trees within the runway, taxiway and apron lateral clearance distances and within the graded area of the clear zone need to be removed. Trees that project into the imaginary surfaces must be removed or lowered to a distance below the imaginary surface, as specified in Table 3-8. Trees are permitted near an airfield provided that they do not cause Bird Aircraft Strike Hazards (BASH), penetrate the imaginary surfaces, the taxiway clearance distance, the apron clearance distance, or instrument procedure obstacle identification surfaces (OIS) as described in TERPS regulations.

Table 3-8. Imaginary Surfaces Minimum Clearances over Highway, Railroad, Waterway, and Trees

Table 3-8. Imaginary Surfaces Minimum Clearances			
Item			**Class A and Class B Runways**
No.	**Description**	**Traverse Way/Objects**	**Dimensions**
1	Minimum vertical clearance between established imaginary surfaces and traverse ways/objects (measured from the highest and nearest elevation of the traverse ways/objects)	Interstate highway that is part of the National System of Military and Interstate Highways	5.18 m (17 ft)
2		Other public highways not covered in Item 1	4.57 m (15 ft)
3		Private or military road	3.05 m (10 ft) minimum or height of highest mobile object that would usually traverse them, whichever is greater
4		Railroad	7.01 m (23 ft)
5		Waterway or traverse way, not previously covered	A distance equal to the height of the highest mobile object that usually would traverse them
6		Trees*	3 m (10 ft)

* Trees must be removed or topped the distance shown below the applicable imaginary surface.

3-17 AIRCRAFT ARRESTING SYSTEMS.

Aircraft arresting systems consist of engaging devices and energy absorbers. Engaging devices are net barriers, disc-supported pendants (hook cables), and cable support systems that allow the pendant to be raised to the battery position or retracted below the runway surface. Energy-absorbing devices are ships' anchor chains, textile brake arresting systems, rotary friction brakes, such as the BAK-9 and BAK-12, or rotary hydraulic systems such as the BAK-13 and E-28. The systems designated "Barrier, Arresting Kit" (BAK) are numbered in the sequence of procurement of the system design. There is no connection between the Air Force designations of these systems and their function. The equipment is government-furnished equipment, as discussed in **\1** AFMAN 32-1040. **/1/** Other designations such as E-5, E-28, and M-31 are US Navy designations. These USAF systems are currently in use: MA-1A, E-5, BAK-12, BAK-14, 61QSII (BAK-15), mobile aircraft arresting system (MAAS), textile brake, and Type H hook cable retraction system.

3-17.1 Navy and Marine Corps Requirements.

Navy and Marine Corps unique requirements are identified where appropriate. In general, the Navy and Marine Corps use aircraft arresting gear design criteria consistent with requirements identified here.

3-17.2 Installation Design and Repair Considerations.

For the USAF, further information on planning, installing, and repairing an arresting system or arresting system complex is provided in **\1** AFMAN 32-1040 **/1/** and FC 3-260-18F. During the planning, installation, or repair process, consider the items in paragraphs 3-17.2.1 through 3-17.2.3.

3-17.2.1 Configuration and Location.

The configuration and location of arresting system installations will be determined in accordance with FC 3-260-18F. Design will conform to the criteria in section 3 of the appropriate 35E8 series technical order and the typical installation drawings. Both may be obtained from:

AFLCMC/WNZEC
ATTN: Aircraft Arresting Systems Engineer
235 Byron St
Robins AFB GA 31098-1813
or the AFLCMC/WNZ Workflow Box at:
642CBSG.Workflow@us.af.mil

3-17.2.2 Runway Pavement.

The 60 m (200 ft) of pavement on both the approach and departure sides of the arresting system pendant is a critical area. Protruding objects and undulating surfaces are detrimental to successful tailhook engagements and are not allowable. The maximum permissible longitudinal surface deviation in this area is plus or minus 3 mm (0.125 in) in 3.6 m (12 ft). Saw-cut grooves in runway pavement to improve surface drainage and surface friction characteristics in accordance with UFC 3-260-02 are not considered protruding objects or undulations; however, the pavement will not be grooved within the first 3 m (10 ft) on either side of the arresting system cables. For USAF facilities, changes in pavement type or an interface between rigid and flexible pavements are not permitted within the center 22.86 m (75 ft) of the runway for 60 m (200 ft) in either direction from the arresting system cables. Sacrificial panels installed beneath arresting system cables in accordance with **\1** AFMAN 32-1040 **/1/** are not considered a change in pavement type or an interface between rigid and flexible pavements. The prohibition on changes in surface pavement type is not applicable to emergency aircraft arresting systems located in overruns. Portland cement concrete (PCC) foundations designed in accordance with USAF Typical Installation Drawing 67F2013A are required for aircraft arresting system cable tie-downs and are also exempt from the prohibition on changes in surface pavement type. Navy aircraft arresting gear pavement protection will be designed in accordance with NAVFAC Standard Design Drawing numbers 4568319 through 4568322. The 2 m (6.56 ft) of pavement on both the approach and departure sides of the pendant are the critical areas for the Navy and Marine Corps. For Navy and Marine Corps runways, use a runway transverse slope of 0.75% for the center 2 slabs (for PCC) or twice the paving machine width (for asphalt concrete) but less than the center 6 m (20 feet), and 1% to 1.5% for the remainder of the runway section for at least 90 m (300 feet) in either longitudinal direction from the arresting gear cable.

3-17.2.3 Repair of Bituminous Pavements.

Rigid inlays will not be used as a surface repair material beneath the cable in a flexible runway system. This type of repair causes high hook skip potential when the flexible pavement consolidates, exposing the leading edge of the rigid pavement. Rigid pavement must be used, however, as a foundation for sacrificial pads installed beneath aircraft arresting system cables. No part of the foundation for the panels will be used as a surface pavement in a flexible runway pavement.

3-17.3 Joint-Use Airfields.

Arresting systems installed on joint-use civil/military airfields to support military aircraft are sited in accordance with FAA AC 150/5220-9 at https://www.faa.gov/airports/resources/advisory_circulars/.

3-17.3.1 Agreement to Install.

When planning the installation of an arresting system at a joint-use facility, the installation commander must first notify the airport manager/authority of the need. If the agreement is mutual, the installation commander submits the plan with sketches or drawings to the Air Force Liaison Officer in the appropriate FAA regional office. Disagreement between the responsible officials must be referred to the next higher level for resolution.

3-17.3.2 Disagreements.

If a lease agreement is involved and does not allow placement of additional structures on the leased premises, the issue will be elevated to the MAJCOM for resolution.

3-17.3.3 Operating Agency.

When an arresting system is installed at a joint-use civil airfield for the primary use of US military aircraft, the FAA acts for, and on behalf of, the DoD Service component in operating this equipment.

3-17.3.4 Third-Party Claims.

Third-party claims presented for damage, injury, or death resulting from the FAA operation of the system for military aircraft or from DoD maintenance of the system is the responsibility of the DoD and must be processed under the appropriate DoD component's regulatory guidance.

3-17.3.5 DoD and FAA Agreements.

Separate agreements between the DoD and the FAA are not required concerning liability for damage arising from the intentional operation of the system by FAA personnel for civil aircraft because such claims are the responsibility of the FAA.

3-17.3.6 Operational Agreement.

The MAJCOM is responsible for negotiating the operational agreement with the FAA for a joint-use civil airport; however, authority may be delegated to the installation commander. The agreement will describe FAA functions and responsibilities concerning the remote control operation of arresting systems by FAA air traffic controllers.

3-17.4 Military Rights Agreements for Non-CONUS Locations.

These systems are installed under the military rights agreement with the host government. If a separate agreement is specifically required for installation of a system, the installation commander coordinates with the local US diplomatic representative and negotiates the agreement with the host nation.

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CHAPTER 4
ROTARY-WING RUNWAYS, HELIPADS, LANDING LANES, AND HOVERPOINTS

4-1 CONTENTS.

This chapter presents design standards and requirements for rotary-wing (helicopter) landing facilities: runways, helipads, helicopter landing lanes, and hoverpoints.

4-2 LANDING AND TAKEOFF LAYOUT REQUIREMENTS.

The landing design requirements for rotary-wing landing facilities, which include rotary-wing runways, helipads, landing lanes, slide areas (autorotation lanes), and hoverpoints, are similar to the requirements for fixed-wing runways as discussed in Chapter 3.

4-3 ROTARY-WING RUNWAY.

The rotary-wing runway allows for a helicopter to quickly land and roll to a stop, compared to the hovering stop used during a vertical helipad approach.

4-3.1 Orientation and Designation.

Consider the strength, direction, and frequency of the local winds when orienting a runway to minimize crosswinds. Follow the methods in Chapter 2 for rotary-wing runway orientation. Follow the guidance in Chapter 3, Paragraph 3-7 for determining rotary-wing runway designation. Runways are identified by the whole number, nearest one-tenth (1/10), of the magnetic azimuth of the runway centerline when viewed from the direction of approach.

4-3.2 Dimensions.

Table 4-1 presents dimensional criteria for the layout and design of rotary-wing runways.

4-3.3 Layout.

The layout for rotary-wing runways, including clear zones, are illustrated in Figure 4-1 for VFR runways and Figures 4-2 and 4-3 for IFR runways.

4-3.4 Special Tilt-Rotor Aircraft Considerations (V-22).

The V-22 is a tilt-rotor aircraft that can operate both as a fixed-wing aircraft or a rotary-wing aircraft. When the V-22 operates on rotary-wing facilities, this chapter applies with noted V-22 exceptions. See paragraph 1-2.2.4 for general V-22 planning considerations.

Table 4-1. Rotary-Wing Runways

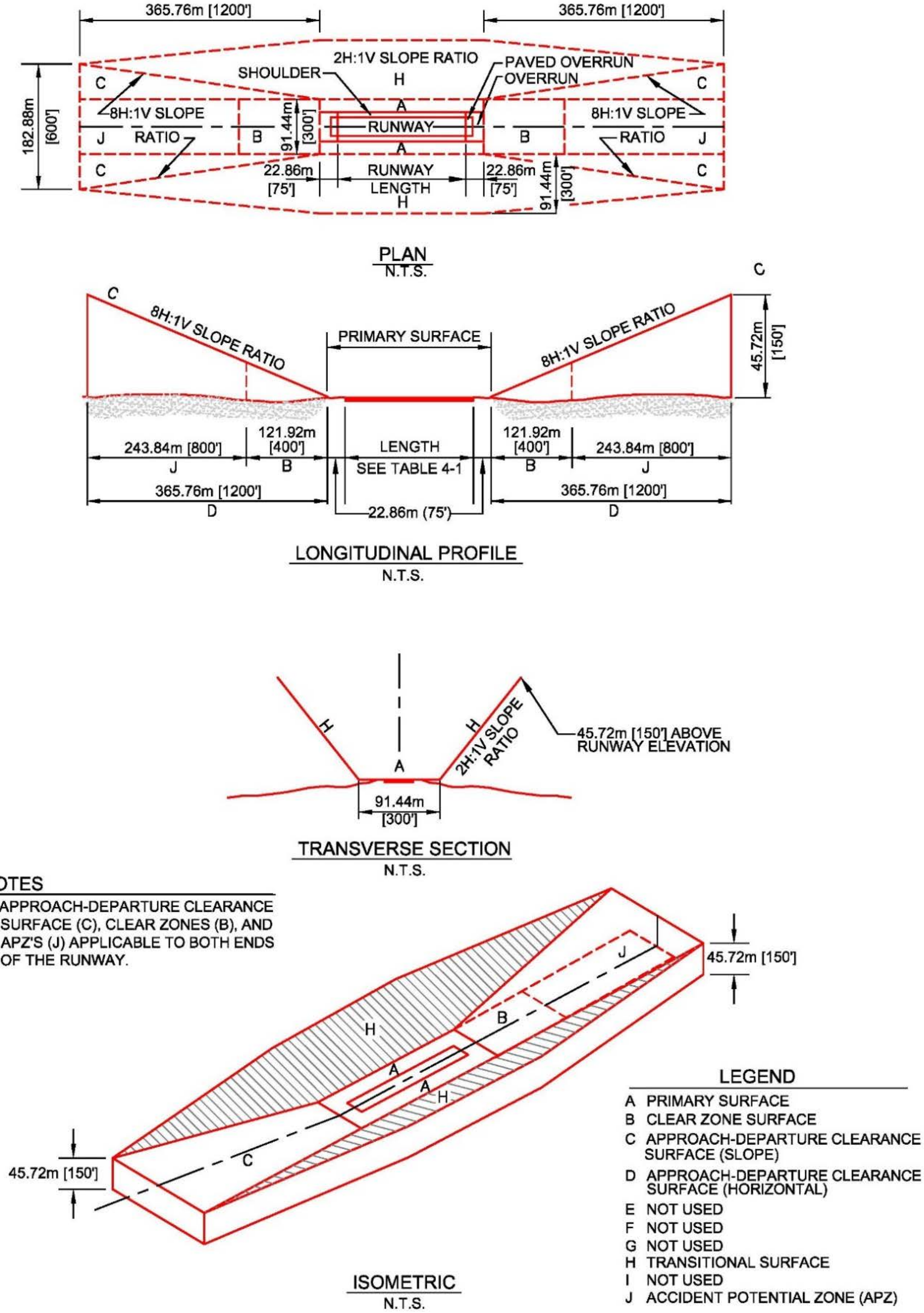
Table 4-1. Rotary-Wing Runways			
Item			
No.	Description	Requirement	Remarks
1	Basic length	490 m (1,600 ft)	For Army and Air Force facilities, use basic length up to 1,220 m (4,000 ft) in elevation above mean sea level (AMSL). Increase basic length to 610 m (2,000 ft) when above 1,220 m (4,000 ft) in elevation above MSL. For Navy and Marine Corps facilities, basic length to be corrected for elevation and temperature. Increase 10% for each 300 m (1,000 ft) in elevation above 600 m (2,000 ft) MSL and add 4.0% for each 5 degrees C (10 degrees F), above 15 degrees C (59 degrees F) for the average daily maximum temperature for the hottest month. For a special mission or proficiency training such as autorotation operations, the length may be increased up to 300 m (1,000 ft); in that case, make no additive corrections.
		137.2 m (450 ft)	For facilities constructed prior to May 1999.
2	Width	23 m (75 ft)	For Navy and Marine Corps facilities, increase width to 30 m (100 ft) on runways which regularly accommodate H-53 and V-22.
3	Longitudinal grade	Max. 1.0%	Maximum longitudinal grade change is 0.167% per 30 linear meters (100 linear feet) of runway. Exceptions: 0.4% per 30 linear meters (100 linear feet) for edge of runways at runway intersections.
4	Transverse grade	Min. 1.0% Max. 1.5%	From centerline of runway. Runway may be crowned or cross-sloped.
5	Paved shoulders		See Table 4-4.
6	Runway lateral clearance zone (corresponds to half the width of primary surface area)	45.72 m (150 ft)	VFR operations
		114.30 m (375 ft)	IFR operations
		See Remarks	Measured perpendicularly from centerline of runway. This area is to be clear of fixed and mobile obstacles. In addition to the lateral clearance criterion, the vertical height restriction on structures and parked aircraft as a result of the transitional slope must be taken into account. (1) Fixed obstacles include man-made or natural features constituting possible hazards to moving aircraft. Navigational aids and meteorological equipment are possible exceptions. For Army and Air Force, siting exceptions for navigational aids and meteorological facilities are provided in Appendix B, Section 13, of this manual. For Navy and Marine Corps, siting exceptions for navigational aids and meteorological facilities are found in paragraph 2-11. (2) Mobile obstacles include parked aircraft, parked and moving vehicles, railroad cars and similar equipment. (3) Taxiing aircraft are exempt from this restriction. However, parallel taxiways (exclusive of shoulder width) must be located in excess of the lateral clearance distance.
7	Grades within the primary	Min. 2.0% Max. 5.0%	Exclusive of pavement and shoulders.

Table 4-1. Rotary-Wing Runways

Item No.	Item Description	Requirement	Remarks
	surface area in any direction		
8	Overrun		See Table 4-5.
9	Distance from the centerline of a fixed-wing runway to the centerline of a parallel rotary-wing runway, helipad, or landing lane	Min. 213.36 m (700 ft)	Simultaneous VFR operations for Class A runway and Army Class B runway
		Min. 304.80 m (1,000 ft)	Simultaneous VFR operations for Class B Runway for Air Force, Navy and Marine Corps.
		Min. 213.36 m (700 ft)	Non-simultaneous VFR and IFR operations. Distance may be reduced to 60.96 m (200 ft); however, waiver is required. Ensure waiver includes evaluation of effects of wake-turbulence and jet blast. In locating the helipad, the helipad must be sited beyond the runway hold line.
		Min. 762.00 m (2,500 ft)	IFR using simultaneous operations (depart-depart) (depart-approach).
		Min. 1,310.64 m (4,300 ft)	IFR using simultaneous approaches.
10	Distance between centerlines of: (a) parallel rotary-wing runways, helipads, or any combination thereof; (b) landing lane and parallel rotary-wing runway or helipad	Min. 213.36 m (700 ft)	VFR without intervening parallel taxiway between centerlines. For US Army, distance may be reduced to 60.96 m (200 ft) between parallel helipads for non-simultaneous operations. For V-22, may be reduced to 121.9 m (400 ft) offset, centerline to centerline, for non-simultaneous operations In locating the helipad, consideration must be given to hold position marking.
		Min. 762.00 m (2,500 ft)	IFR using simultaneous operations (depart-depart) (depart-approach).
		Min. 1,310.64 m (4,300 ft)	IFR using simultaneous approaches.

NOTES:
1. Metric units apply to new airfield construction and, where practical, modification to existing airfields and heliports, as discussed in paragraph 1-3.4.
2. The criteria in this manual are based on aircraft specific requirements and are not direct conversions from inch-pound (English) dimensions. Inch-pound units are included only as a reference to the previous standard.
3. Airfield and heliport imaginary surfaces and safe wingtip clearance dimensions are shown as a direct conversion from inch-pound to SI units.

Figure 4-1. Helicopter VFR Runway



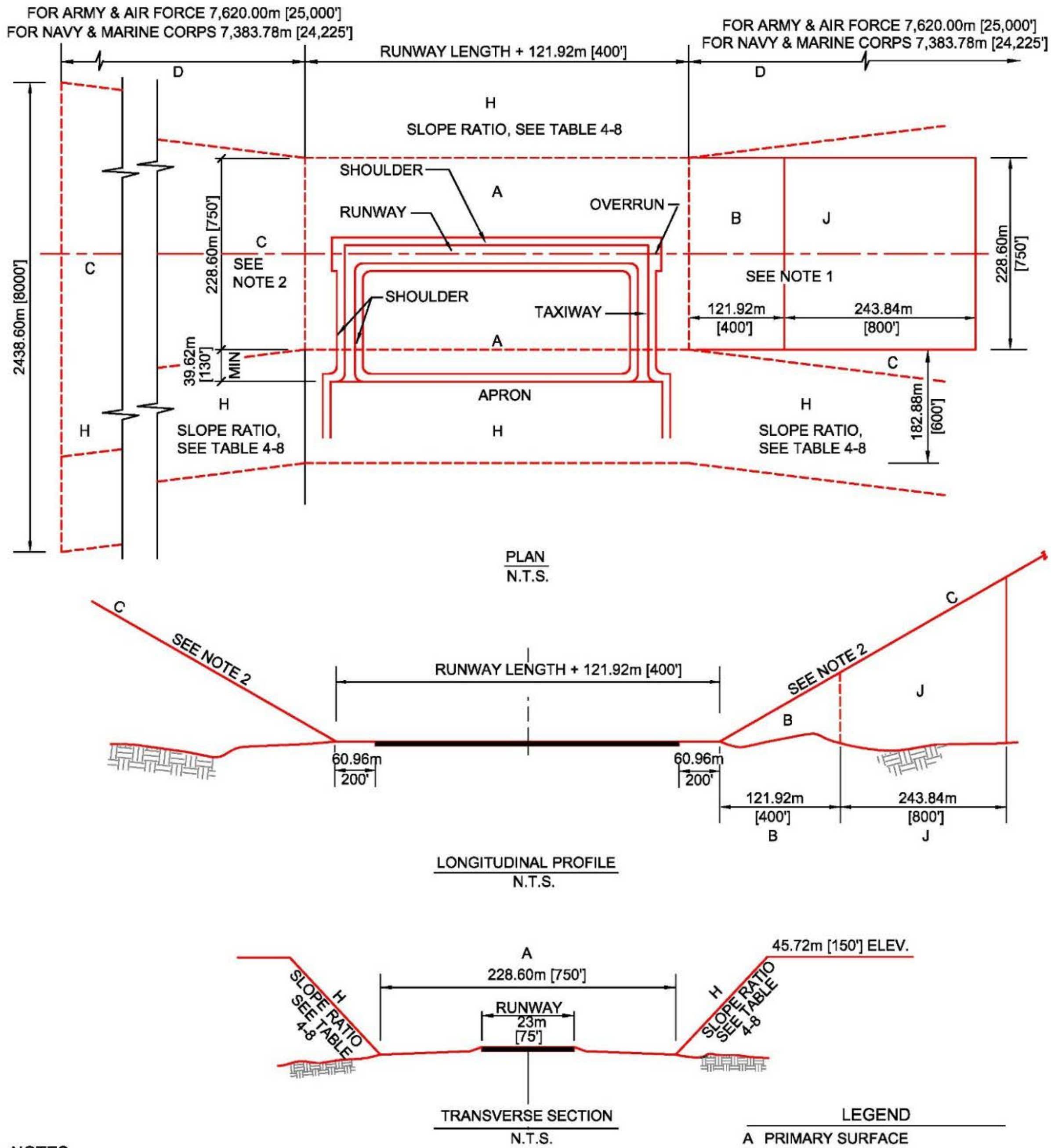
NOTES

1. APPROACH-DEPARTURE CLEARANCE SURFACE (C), CLEAR ZONES (B), AND APZ'S (J) APPLICABLE TO BOTH ENDS OF THE RUNWAY.

LEGEND

A PRIMARY SURFACE
B CLEAR ZONE SURFACE
C APPROACH-DEPARTURE CLEARANCE SURFACE (SLOPE)
D APPROACH-DEPARTURE CLEARANCE SURFACE (HORIZONTAL)
E NOT USED
F NOT USED
G NOT USED
H TRANSITIONAL SURFACE
I NOT USED
J ACCIDENT POTENTIAL ZONE (APZ)

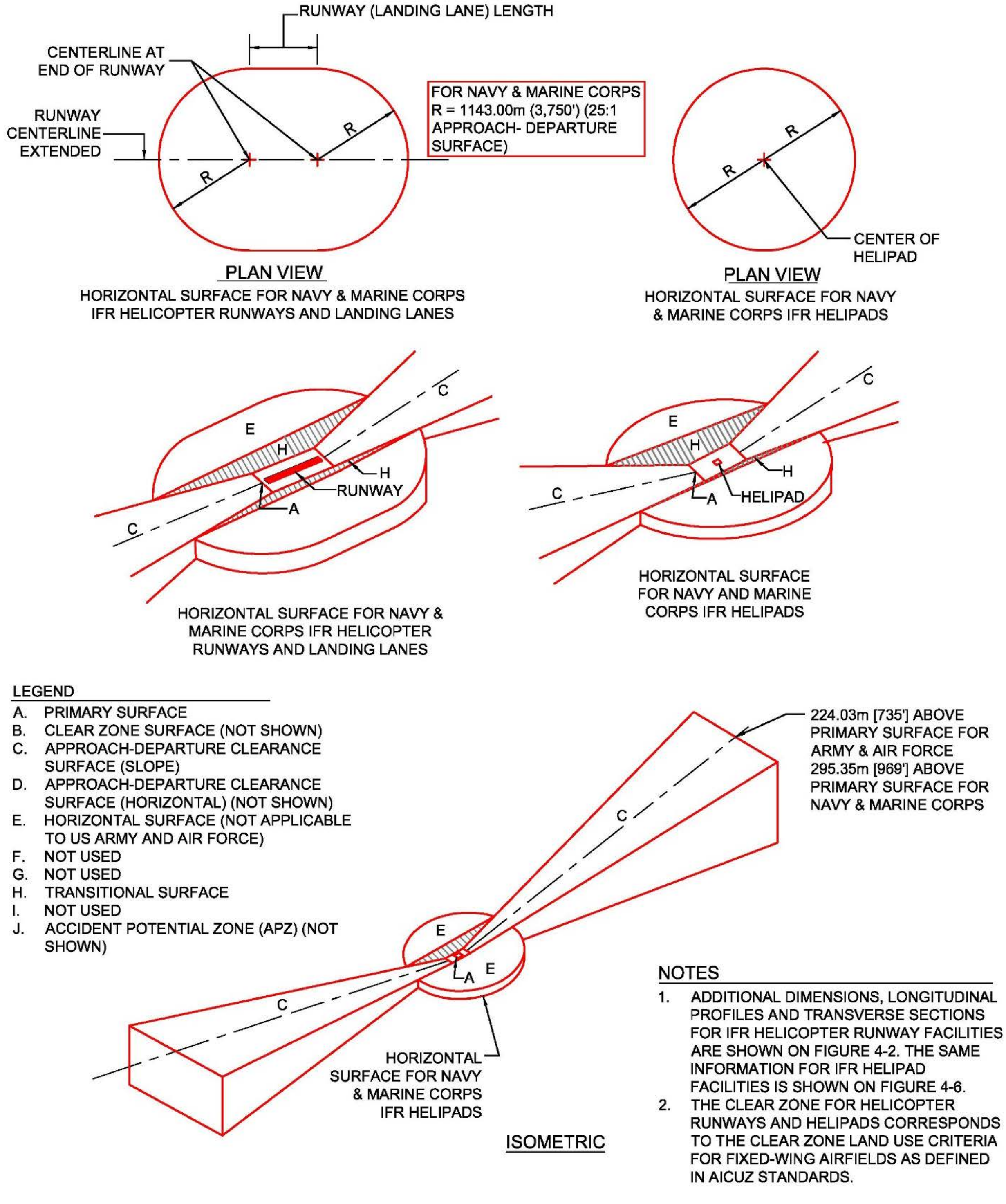
Figure 4-2. Helicopter IFR Runway



NOTES
1. CLEAR ZONE AND APZ TYPICAL AT BOTH ENDS OF RUNWAY.
2. APPROACH-DEPARTURE CLEARANCE SURFACE SLOPE RATIO IS 34H:1V FOR ARMY AND AIR FORCE AND 25H:1V FOR NAVY AND MARINE CORPS

LEGEND
- A PRIMARY SURFACE
- B CLEAR ZONE SURFACE
- C APPROACH-DEPARTURE CLEARANCE SURFACE (SLOPE)
- D APPROACH-DEPARTURE CLEARANCE SURFACE (HORIZONTAL)
- E NOT SHOWN
- F NOT USED
- G NOT USED
- H TRANSITIONAL SURFACE
- I NOT USED
- J ACCIDENT POTENTIAL ZONE (APZ 1)

Figure 4-3. IFR Airspace Imaginary Surfaces: IFR Helicopter Runway and Helipad



LEGEND

A. PRIMARY SURFACE
B. CLEAR ZONE SURFACE (NOT SHOWN)
C. APPROACH-DEPARTURE CLEARANCE SURFACE (SLOPE)
D. APPROACH-DEPARTURE CLEARANCE SURFACE (HORIZONTAL) (NOT SHOWN)
E. HORIZONTAL SURFACE (NOT APPLICABLE TO US ARMY AND AIR FORCE)
F. NOT USED
G. NOT USED
H. TRANSITIONAL SURFACE
I. NOT USED
J. ACCIDENT POTENTIAL ZONE (APZ) (NOT SHOWN)

NOTES

1. ADDITIONAL DIMENSIONS, LONGITUDINAL PROFILES AND TRANSVERSE SECTIONS FOR IFR HELICOPTER RUNWAY FACILITIES ARE SHOWN ON FIGURE 4-2. THE SAME INFORMATION FOR IFR HELIPAD FACILITIES IS SHOWN ON FIGURE 4-6.
2. THE CLEAR ZONE FOR HELICOPTER RUNWAYS AND HELIPADS CORRESPONDS TO THE CLEAR ZONE LAND USE CRITERIA FOR FIXED-WING AIRFIELDS AS DEFINED IN AICUZ STANDARDS.

4-4 HELIPADS.

Helipads allow for a helicopter hovering, landing, and takeoff. Except at facilities where helicopter runways are provided, helipads are the landing and takeoff locations for helicopters. The Army and Air Force provide for four types of helipads: standard VFR helipad, limited use helipad, IFR helipad and elevated helipad. The Navy and Marine Corps provide only one type of helipad: standard size helipad. Use High Temperature Concrete and neoprene joint sealants in locations where stationary V-22 nacelle exhaust exposure is ten minutes or greater. See Chapter 8 for additional materials information. The type of helipad depends on these operational requirements:

4-4.1 Standard VFR Helipad.

VFR design standards are used when no requirement exists or will exist in the future for an IFR helipad. Criteria for this type of helipad permit the accommodation of most helipad lighting systems.

4-4.2 Limited Use Helipad.

This is a VFR rotary-wing facility for use only by observation, attack, medical evacuation and utility (OH, AH, HH, and UH) helicopters. These type of helipads support only occasional operations at special locations such as hospitals, headquarters facilities, missile sites, and other similar locations. Limited use helipads may be located on airfields where one or more helipads are required to separate OH, AH, HH and UH traffic from other helicopter traffic or fixed-wing traffic.

4-4.3 IFR Helipad.

IFR design standards are used when an instrument approach capability is essential to the mission and no other instrument landing facilities, either fixed-wing or rotary-wing, are located within an acceptable commuting distance to the site.

4-4.4 Elevated Helipad.

This is a facility that has a helipad elevated above ground level on a building roof top or another structure built specifically for the pad (a ground level helipad with the pad on a mound is not an elevated helipad). For Army, elevated helipads require approval of USAASA. For Navy and Marine Corps facilities, contact the agency aviation office with safety waiver approval authority.

4-4.5 Helipad Location.

A helipad location should be selected with regard to mission requirements, overall facility development, approach-departure surfaces, and local wind conditions.

4-4.5.1 Near Runways.

When a helipad is to be located near fixed- and rotary-wing runways, its location should be based on the type of operations in accordance with the criteria in Table 4-1.

4-4.5.2 Standby Parking Pads.

Where it is necessary to have one or more helicopters on standby, an area adjacent to the helipad but clear of the landing approach and transitional surfaces should be designated for standby parking. This area will be designed as a parking apron in conformance with the criteria in Chapter 6.

4-4.6 Dimensional Criteria.

Table 4-2 presents dimensional criteria for the layout and design of helipads and hoverpoints.

Table 4-2. Rotary-Wing Helipads and Hoverpoints

Table 4-2. Rotary-Wing Helipads and Hoverpoints			
Item		Requirement	Remarks
No.	Description		
1	Size	30 m x 30 m (100 ft x 100 ft) min.	Standard VFR and IFR helipad – Army, Air Force and Navy including all V-22
		15 m x 15 m (50 ft x 50 ft) min.	Limited use VFR helipad – Army and Air Force
			Elevated Army and Air Force Helipads
		17 m x 17 m (55 ft x55 ft)	UH-60 or smaller helicopters
		30 m x 30 m (100 ft x 100 ft)	CH-47 and larger helicopters
		9 m (30 ft) diameter	Hoverpoints
2	Grade	Min. 1.0% Max. 1.5%	Grade helipad in one direction. Hoverpoints should be domed to a 150-mm (6-in) height at the center.
3	Paved shoulders		See Table 4-4.
4	Size of primary surface (center primary surface on helipad)	91.44 m x 91.44 m (300 ft x 300 ft)	Air Force and Army standard VFR helipad, including all V-22 IFR
		45.72 m x 45.72 (150 ft x 150 ft) min.	Air Force and Army limited use VFR helipad Navy and Marine Corps Standard VFR helipad Hoverpoints
		472.44 m x 228.60 m (1,550 ft x 750 ft)	Standard IFR. Long dimension in direction of helicopter approach.
		228.60 m x 228.60 m (750 ft x 750 ft)	Army and Air Force IFR same direction ingress/egress.

Table 4-2. Rotary-Wing Helipads and Hoverpoints			
Item No.	Item Description	Requirement	Remarks
			Elevated Army and Air Force Helipads
		59.44 m x 59.44 m (195 ft x195 ft)	UH-60 or smaller helicopters
		91.44 m x 91.44 m (300 ft x 300 ft)	CH-47 and larger helicopters
5	Grades within the primary surface area in any direction	Min. of 2.0% prior to channelization.* Max. 5.0%	Exclusive of pavement and shoulders. For IFR helipads, the grading requirements apply to a 91.44 m X 91.44 m (300 ft X 300 ft) area centered on the helipad. The balance of the area is to be clear of obstructions and rough graded to the extent necessary to reduce damage to aircraft in event of an emergency landing. For VFR helipads, the grade requirements apply to the entire primary surface. For elevated helipads, no obstacles may penetrate the elevation of the primary surface.
6	Length of clear zone**/protection zone	121.92 m (400 ft)	Hoverpoints, VFR, and standard IFR helipads. Begins at the end of the primary surface.
		251.46 m (825 ft)	Army and Air Force IFR same direction ingress/egress.
		335.28 m (1,100 ft)	V-22 IFR helipad.
7	Width of clear zone**/protection zone		Corresponds to the width of the primary surface. Center clear zone width on extended center of the pad.
		45.72 m (150 ft)	Air Force and Army VFR limited use helipads and hoverpoints. Navy and Marine Corps Standard VFR. See OPNAVINST 11010.16 (or latest version) for additional guidance.
		91.44 m (300 ft)	Air Force and Army standard VFR helipad and VFR helipad same direction ingress/egress.
		228.60 m (750 ft)	Standard IFR and V-22 IFR helipad

Table 4-2. Rotary-Wing Helipads and Hoverpoints			
Item		Requirement	Remarks
No.	Description		
			Elevated Army and Air Force Helipads
		59.44m (195 ft) at start of Protection Zone expanding to 89.92m (295 ft) at end of Protection Zone	UH-60 or smaller helicopters
		91.44m (300 ft) at start of Protection Zone expanding to 121.92m (400 ft) at end of Protection Zone	CH-47 and larger helicopters
8	Grades of clear zone** any direction	5.0% max	Area to be free of obstructions. Rough grade and turf when required.
9	APZ I length***	243.84 m (800 ft)	Elevated helipads, Hoverpoints, VFR, and standard IFR helipads, including V-22 IFR helipads
		121.92 m (400 ft)	Army and Air Force IFR same direction ingress/egress
10	APZ I width***	45.72 m (150 ft)	Army and Air Force VFR limited use and hoverpoints; Navy and Marine Corps standard VFR
		91.44 m (300 ft)	Army and Air Force standard VFR
		228.60 m (750 ft)	Standard IFR and V-22 IFR helipad
		 89.92 m (295 ft) 121.92 m (400 ft)	Elevated Army and Air Force Helipads UH-60 or smaller helicopters CH-47 or larger helicopters
11	Distance between centerline of helipad and fixed- or rotary-wing runways		See Table 4-1.

* Bed of channel may be flat.
** The clear zone area for helipads corresponds to the clear zone land use criteria for fixed-wing airfields as defined in DoD AICUZ standards. The remainder of the approach-departure zone corresponds to APZ I land use criteria similarly defined. APZ II criteria is not applicable for rotary-wing aircraft.
*** There are no grading requirements for APZ I.

NOTES:

1. Metric units apply to new airfield construction and, where practical, modification to existing airfields and heliports, as discussed in paragraph 1-3.4.
2. The criteria in this manual are based on aircraft specific requirements and are not direct conversions from inch-pound (English) dimensions. Inch-pound units are included only as a reference to the previous standard.
3. Airfield and heliport imaginary surfaces and safe wingtip clearance dimensions are shown as a direct conversion from inch-pound to SI units.

4-4.7 Layout Criteria.

Layouts for standard, limited use, and IFR helipads, including clear zones, are illustrated in Figures 4-8 through 4-10.

4-5 SAME DIRECTION INGRESS/EGRESS.

Helipads with same direction ingress/egress allow a helicopter pad to be located in a confined area where approach-departures are made from only one direction. The approach may be either VFR or IFR. For the USAF and Army, single direction ingress/egress VFR limited use helipads are configured as shown in Figure 4-12 using the criteria given in Tables 4-2 and 4-7.

4-5.1 Dimensions Criteria.

Table 4-2 presents dimensional criteria for VFR and IFR same direction ingress/egress helipads.

4-5.2 Layout Criteria.

Layout for VFR, VFR limited use, and IFR same direction ingress/egress helipads are illustrated in Figures 4-11, 4-12 and 4-13.

4-6 HOVERPOINTS.

4-6.1 General.

A hoverpoint is a prepared and marked surface used as a reference or control point for air traffic control purposes by arriving or departing helicopters.

4-6.2 Dimensions.

Table 4-2 presents dimensional criteria for the layout and design of hoverpoints. Layout. Hoverpoint design standards are illustrated in Figure 4-14.

4-7 ELEVATED HELIPADS – ARMY AND AIR FORCE ONLY.

4-7.1 General.

Elevating helipads 6 feet (1.8 m) or more above the level of the roof will generally minimize the turbulent effect of air flowing over the roof edge. While elevating the platform helps reduce or eliminate the air turbulence effects, a safety net may be required. Helipads should be constructed of metal or concrete. Surfaces should have a broomed pavement or other roughened finish that provides a skid-resistant surface for helicopters and non-slippery footing for people. The primary surface should be contained on the structure.

4-7.2 Rooftop and Other Elevated Helipads.

Elevated helipads and any supporting helipad structure should be capable of supporting the dynamic loads of the design helicopter in accordance with UFC 3-301-01, Structural Engineering. For UH-60 and smaller rotor diameter use 22,000 LB as the minimum aircraft weight for structural design. For CH-47, use 50,000 LB as the minimum aircraft weight for structural design. Use heavier design weight if mission aircraft is heavier than the minimum.

4-7.3 Dimensions.

Table 4-2 presents dimensional criteria for the layout and design of elevated helipads.

Figure 4-4. Elevated Helipad Layout Criteria for UH-60 or Smaller Rotor Diameter Helicopters (8H:1V)

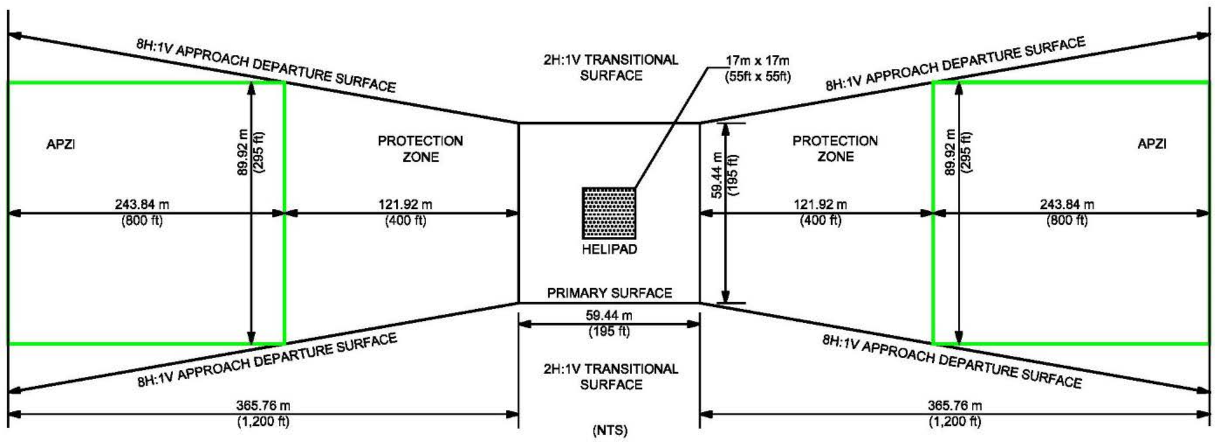


Figure 4-5. Elevated Helipad Layout Criteria for CH-47 and Larger Helicopters (8H:1V)

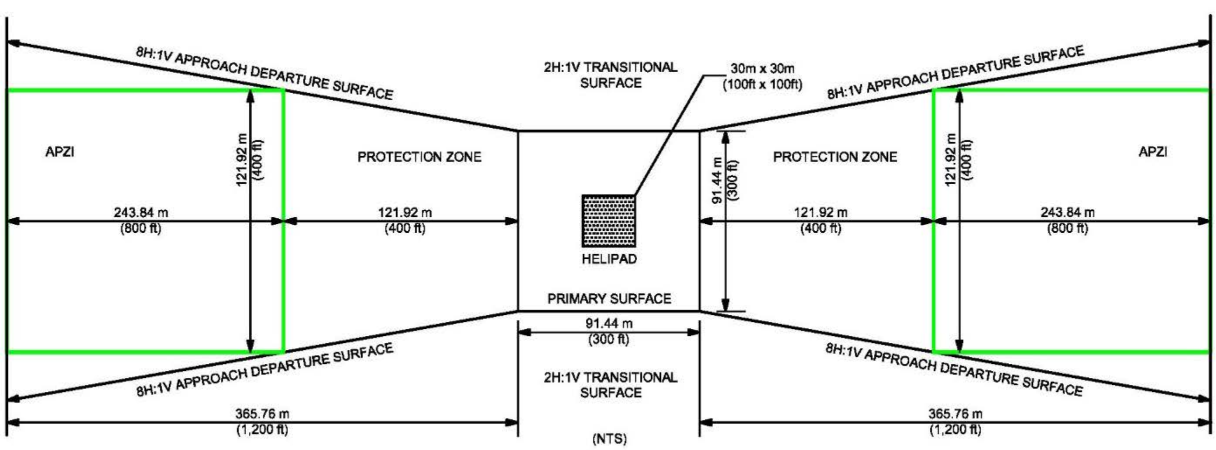


Figure 4-6. Elevated Hospital Helipad Layout Criteria for UH-60 or Smaller Rotor Diameter Helicopters (16.4H:1V)

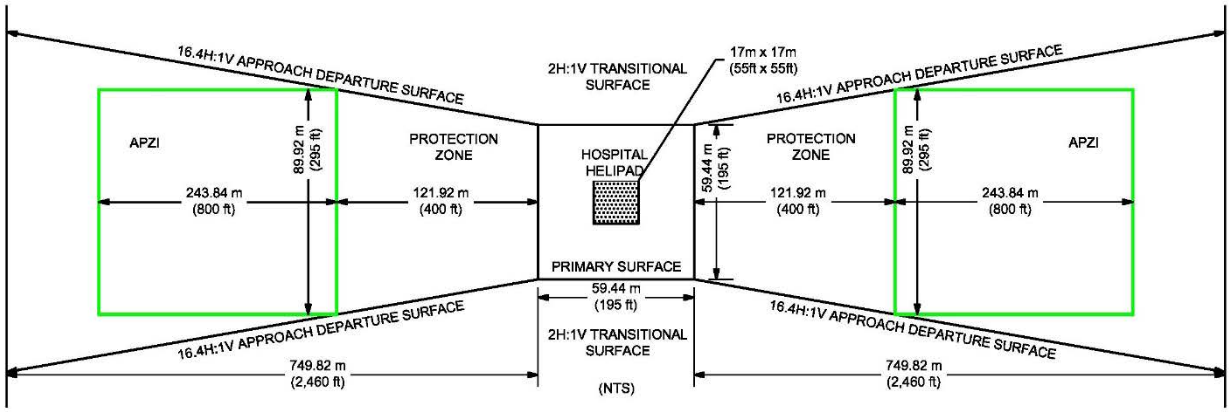
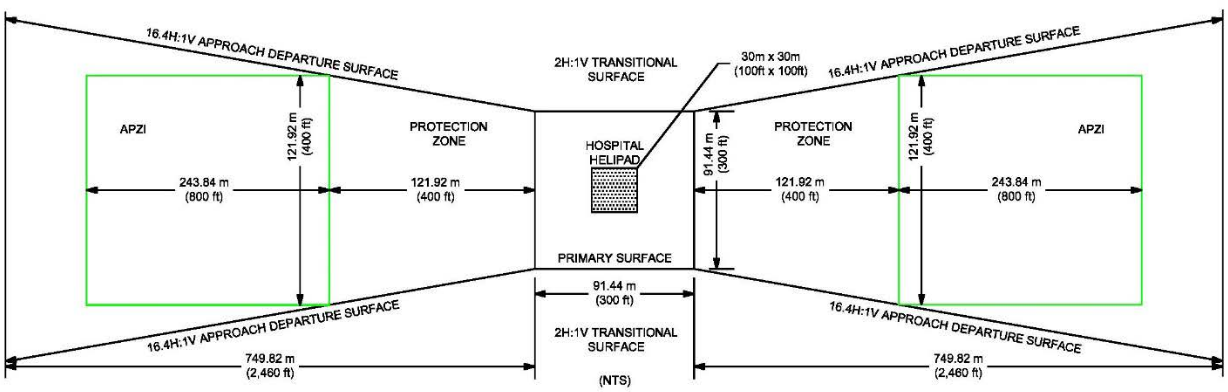


Figure 4-7. Elevated Hospital Helipad Layout Criteria for CH-47 and Larger Helicopters (16.4H:1V)



4-7.4 Safety Net.

When the helipad is on a platform elevated more than 30 inches (76 cm) above its surroundings, a safety net, not less than 5 feet (1.5 m) wide, should be provided. A railing or fence should not be used since it would be a safety hazard during helicopter operations. The safety net should have a load carrying capability of 25 lb/ft^2 (122 kg/m^2). The net should not project above the level of the helipad. Both the inside and outside edges of the safety net should be fastened to a solid structure.

4-7.5 Access to Elevated Helipads.

OSHA requires two separate access points for an elevated structure such as an elevated helipad. Hospital heliports should provide access to and from the helipad via a ramp in order to provide for quick and easy transportation of a patient on a gurney. Ramps should be built in accordance with state and local requirements. The width of the ramp, and any turns in the ramp, should be wide enough to accommodate a gurney with a person walking on each side. Straight segments of the ramp should be not less than 6 feet (1.8 m) wide. Additional width may be required in the turns. The ramp surface should provide a slip-resistant surface. The slope of the ramp should be no steeper than 12:1 (12 unit horizontal in 1 units vertical). Inside the primary surface any handrails should not extend above the elevation of the helipad. Where a handrail complying with Appendix A of 49 CFR 37, Section 4.8, is not provided, other means should be provided to protect personnel from fall hazards.

4-7.6 Fixed Objects within a Primary Surface.

No fixed object shall be permitted within a primary surface or protection zone, except for frangibly mounted objects that, due to their function, must be located there.

4-7.7 Obstructions.

Elevator penthouses, cooling towers, exhaust vents, fresh-air vents, and other raised features can impact helipad operations. Helicopter exhausts can impact building air quality if the helipad is too close to fresh-air vents. These issues shall be resolved during facility design. In addition, control mechanisms should be established to ensure that obstruction hazards are not installed after the helipad is operational. Those objects whose functions require them to be located within these areas should be less than a height of 8 inches (20 cm), be frangible, and must not penetrate the approach/departure surfaces or transitional surfaces.

4-7.8 Protection Zone.

The protection zone takes the place of a clear zone for elevated helipads. It is an imaginary planar surface that starts at the elevation of the helipad and extends out 400'. The area underlying the protection zone has to be owned or controlled by the installation. All incompatible objects or facilities should be removed from this area. Incompatible facilities include, occupied structures, main entrances, other areas where people congregate, and facilities that might create smoke or steam that would obscure visibility."

4-8 ROTARY-WING LANDING LANES.

Except when used as an autorotation lane, these lanes permit efficient simultaneous use by a number of helicopters in a designated traffic pattern.

4-8.1 Requirements for a Landing Lane.

Occasionally at airfields or heliports, helicopters are parked densely on mass aprons. When this occurs, there is usually a requirement to provide landing and takeoff facilities that permit more numerous rapid launch and recovery operations than otherwise could be provided by a single runway or helipad. Increased efficiency can be attained by providing one or more of, but not necessarily limited to, these options:

- Multiple helipads or hoverpoints
- A rotary-wing runway of length in excess of the criteria in Table 4-1
- Helicopter landing lanes

4-8.2 Landing Lane Location.

Landing lanes are typically located in front of the paved apron on which the helicopters park, as shown in Figure 4-15.

4-8.3 Touchdown Points.

The location at which the helicopters are to touchdown on the landing lane are designated with 1.2m (4') x 1.8m (6') rectangular panel markings placed at equal intervals on the landing lane centerline not less than 400 feet apart.

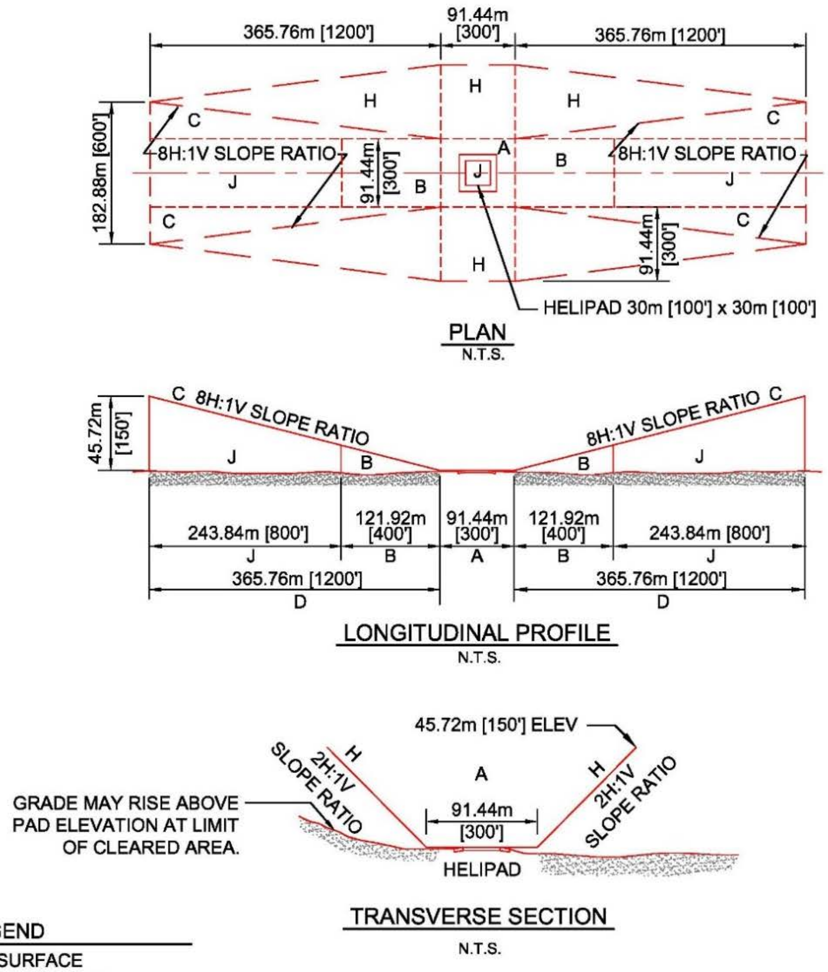
4-8.4 Dimensions.

Table 4-3 presents dimensional criteria for the layout and design of rotary-wing landing lanes.

4-8.5 Layout.

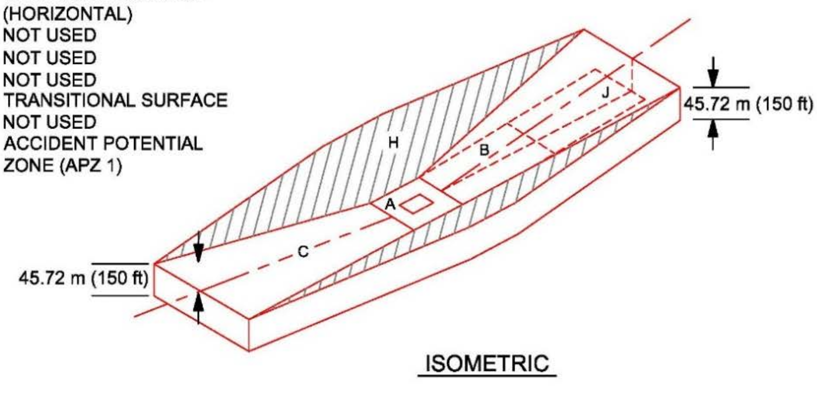
A layout for rotary-wing landing lanes is illustrated in Figure 4-15.

Figure 4-8. Standard VFR Helipad for Army and Air Force



LEGEND

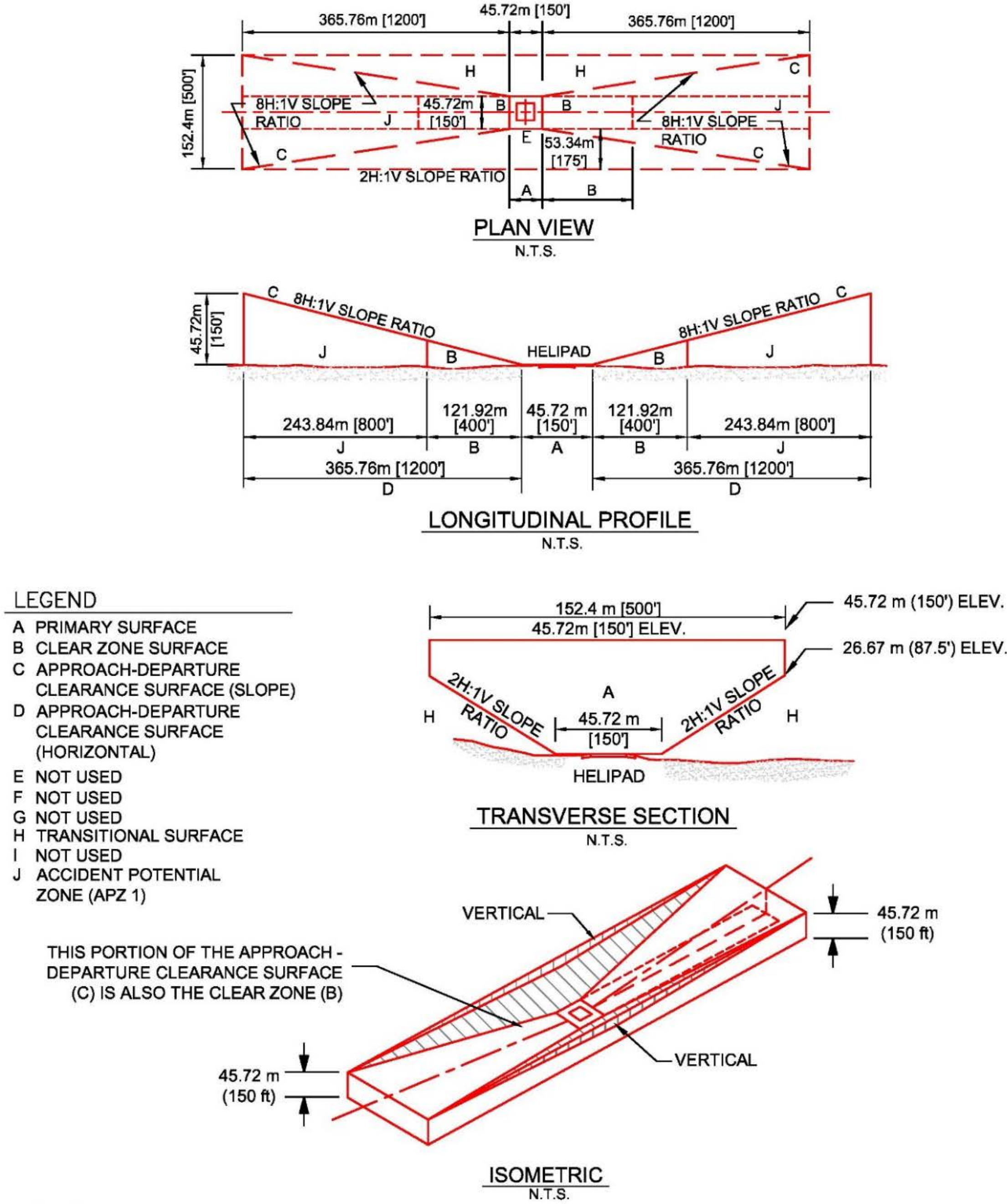
A PRIMARY SURFACE
B CLEAR ZONE SURFACE
C APPROACH-DEPARTURE CLEARANCE SURFACE (SLOPE)
D APPROACH-DEPARTURE CLEARANCE SURFACE (HORIZONTAL)
E NOT USED
F NOT USED
G NOT USED
H TRANSITIONAL SURFACE
I NOT USED
J ACCIDENT POTENTIAL ZONE (APZ 1)



NOTES

1. APPROACH-DEPARTURE CLEARANCE SURFACE (C), CLEAR ZONES (B), AND APZS (J) APPLICABLE TO BOTH ENDS OF RUNWAY.
2. FOR ARMY HOSPITAL HELIPADS:
   A. THE SLOPE OF THE APPROACH-
   B. DEPARTURE CLEARANCE SURFACE SHALL BE 16.4:1 WHEN A CHAPI IS USED.
   C. THE LENGTH OF THE APPROACH-
   D. DEPARTURE CLEARANCE SURFACE SHALL BE 749.82M(2460') WHEN A CHAPI IS USED.
   E. THE WIDTH OF SLOPED PORTION OF APPROACH- DEPARTURE SURFACE AT END OF SLOPED PORTION SHALL BE 278.90M (915') WHEN A CHAPI IS USED.

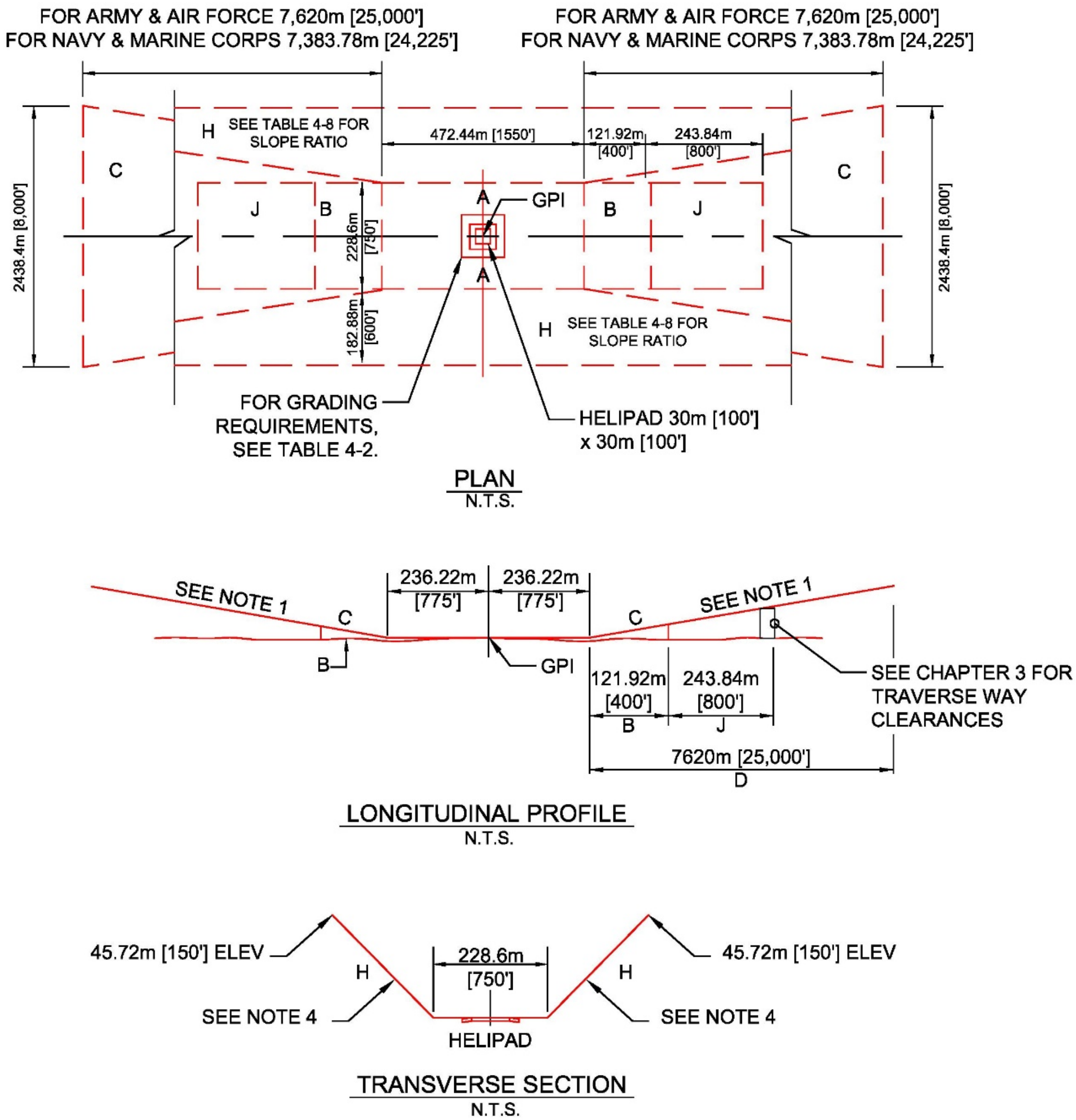
Figure 4-9 Standard VFR Helipad for Navy and Marine Corps and Limited Use VFR Helipad for Army and Air Force



NOTES

1. CLEAR ZONE AND APZ TYPICAL IN BOTH APPROACH ZONES.
2. APPROACH-DEPARTURE CLEARANCE SURFACE (C), CLEAR ZONES (B), AND APZs (J) APPLICABLE TO BOTH ENDS OF THE HELIPAD.
3. FOR ARMY HOSPITAL HELIPADS:
   - 3.1. THE SLOPE OF THE APPROACH-DEPARTURE CLEARANCE SURFACE SHALL BE 16.4:1 WHEN A CHAPI IS USED.
   - 3.2. THE LENGTH OF THE APPROACH-DEPARTURE CLEARANCE SURFACE SHALL BE 749.82 m (2460') WHEN A CHAPI IS USED.
   - 3.3. THE WIDTH OF SLOPED PORTION OF APPROACH-DEPARTURE SURFACE AT END OF SLOPED PORTION SHALL BE 256.18 m (870') WHEN A CHAPI IS USED.

Figure 4-10. Standard IFR Helipad



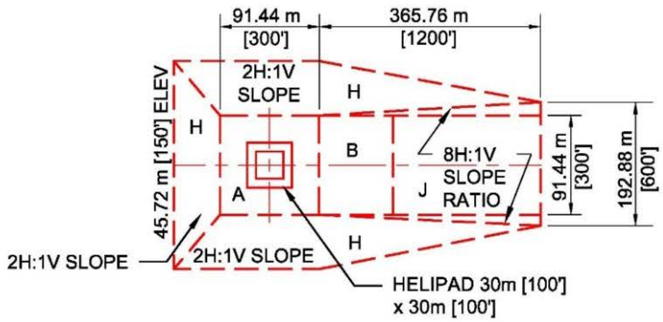
LEGEND:

A. PRIMARY SURFACE.
B. CLEAR ZONE SURFACE.
C. APPROACH-DEPARTURE CLEARANCE SURFACE (SLOPE) SEE NOTE 1.
D. APPROACH-DEPARTURE CLEARANCE SURFACE (HORIZONTAL).
E. INNER HORIZONTAL SURFACE (NOT SHOWN).
F. NOT USED
G. NOT USED
H. TRANSITIONAL SURFACE
I. NOT USED
J. ACCIDENT POTENTIAL ZONE (APZ 1).

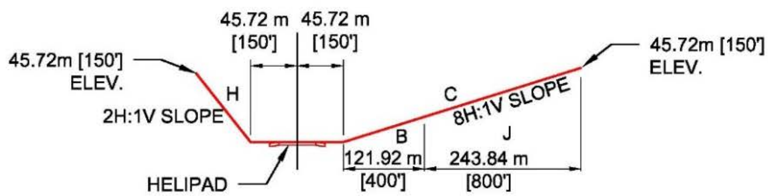
NOTES:

1. APPROACH-DEPARTURE CLEARANCE SURFACE SLOPE RATIO IS 34H:1V FOR ARMY AND AIR FORCE, AND 25H:1V FOR NAVY AND MARINE CORPS.
2. CLEAR ZONE AND APZ TYPICAL AT BOTH ENDS OF RUNWAY.
3. FOR ISOMETRIC, SEE FIGURE 4-3.
4. TRANSITIONAL SURFACE SLOPE RATIO IS 4H:1V.

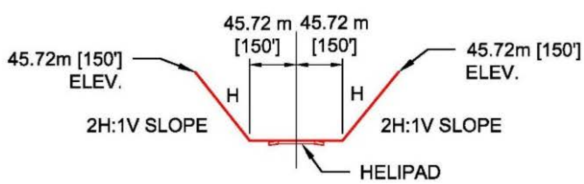
Figure 4-11. Army, Air Force, Navy, and Marine Corps VFR Helipad with Same Direction Ingress/Egress



PLAN
N.T.S.



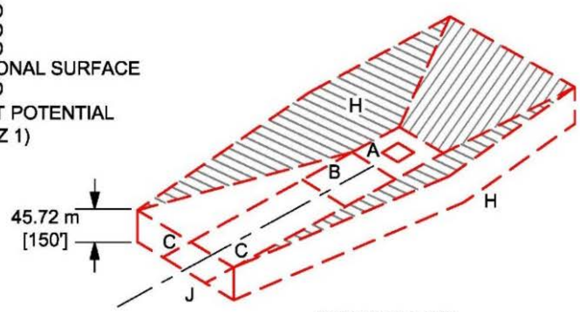
LONGITUDINAL PROFILE
N.T.S.



TRANSVERSE SECTION
N.T.S.

LEGEND

A PRIMARY SURFACE
B CLEAR ZONE SURFACE
C APPROACH-DEPARTURE CLEARANCE SURFACE (SLOPE)
D NOT USED
E NOT USED
F NOT USED
G NOT USED
H TRANSITIONAL SURFACE
I NOT USED
J ACCIDENT POTENTIAL ZONE (APZ 1)



ISOMETRIC
N.T.S.

NOTES

1. FOR ARMY HOSPITAL HELIPADS:
   A. THE SLOPE OF THE APPROACH-DEPARTURE CLEARANCE SURFACE SHALL BE 16.4:1 WHEN A CHAPI IS USED.
   B. THE LENGTH OF THE APPROACH-DEPARTURE CLEARANCE SURFACE SHALL BE 749.82 m (2460') WHEN A CHAPI IS USED.
   C. THE WIDTH OF SLOPED PORTION OF APPROACH-DEPARTURE SURFACE AT END OF SLOPED PORTION SHALL BE 2786.90 m (915') WHEN A CHAPI IS USED.

Figure 4-12. Army and Air Force VFR Limited Use Helipad with Same Direction Ingress/Egress

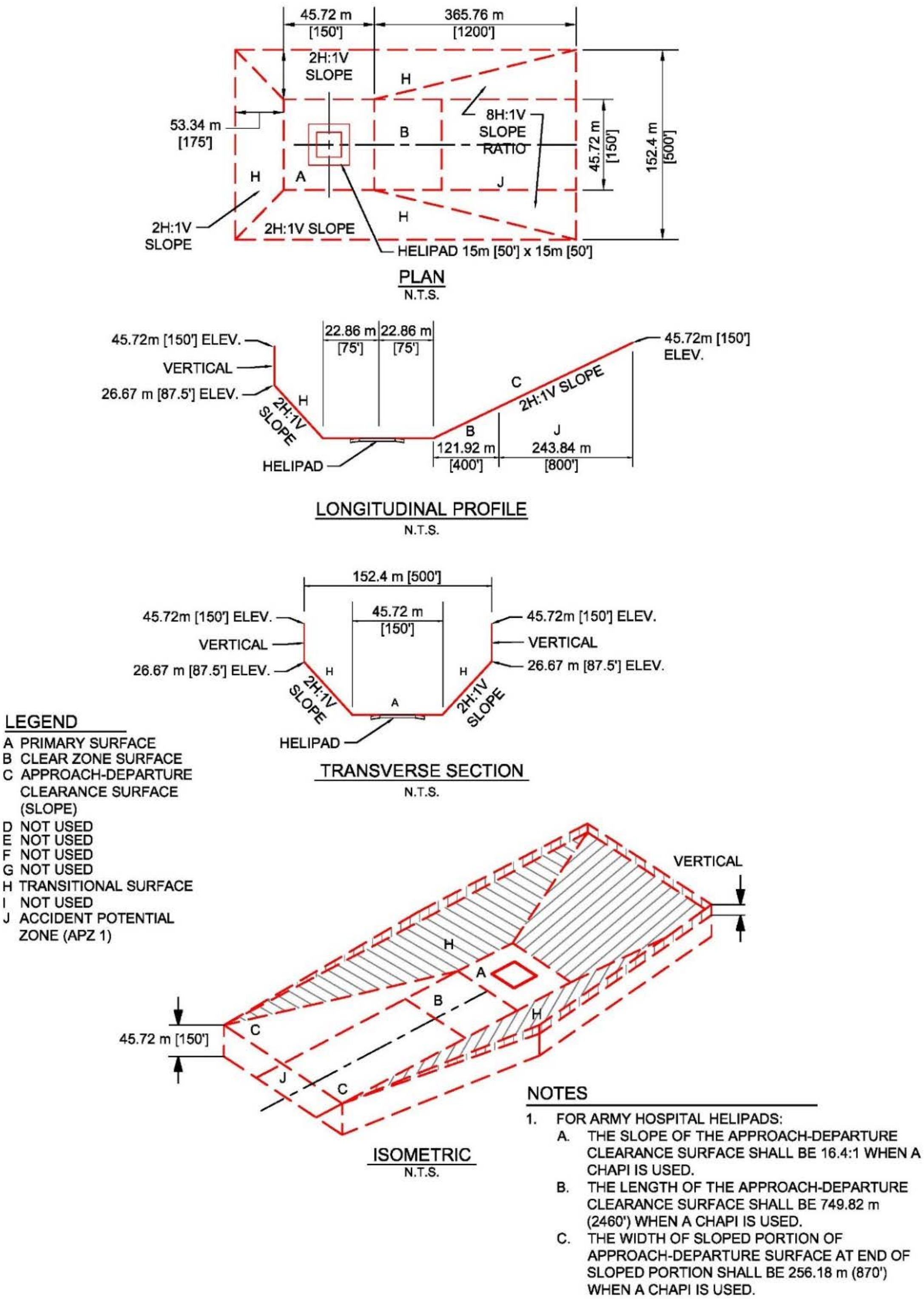


Figure 4-13. Army and Air Force IFR Helipad with Same Direction Ingress/Egress

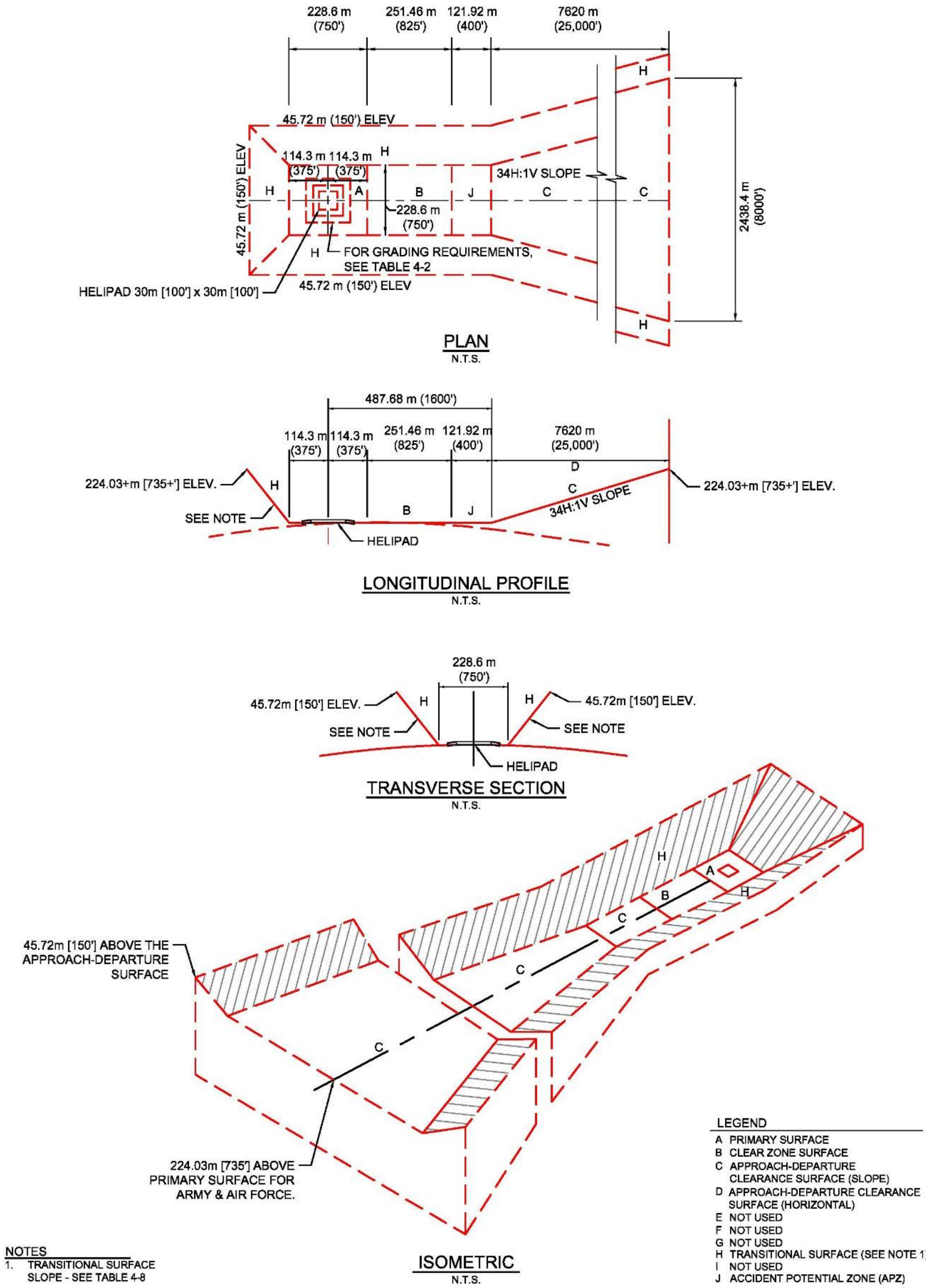


Figure 4-14. Helicopter Hoverpoint

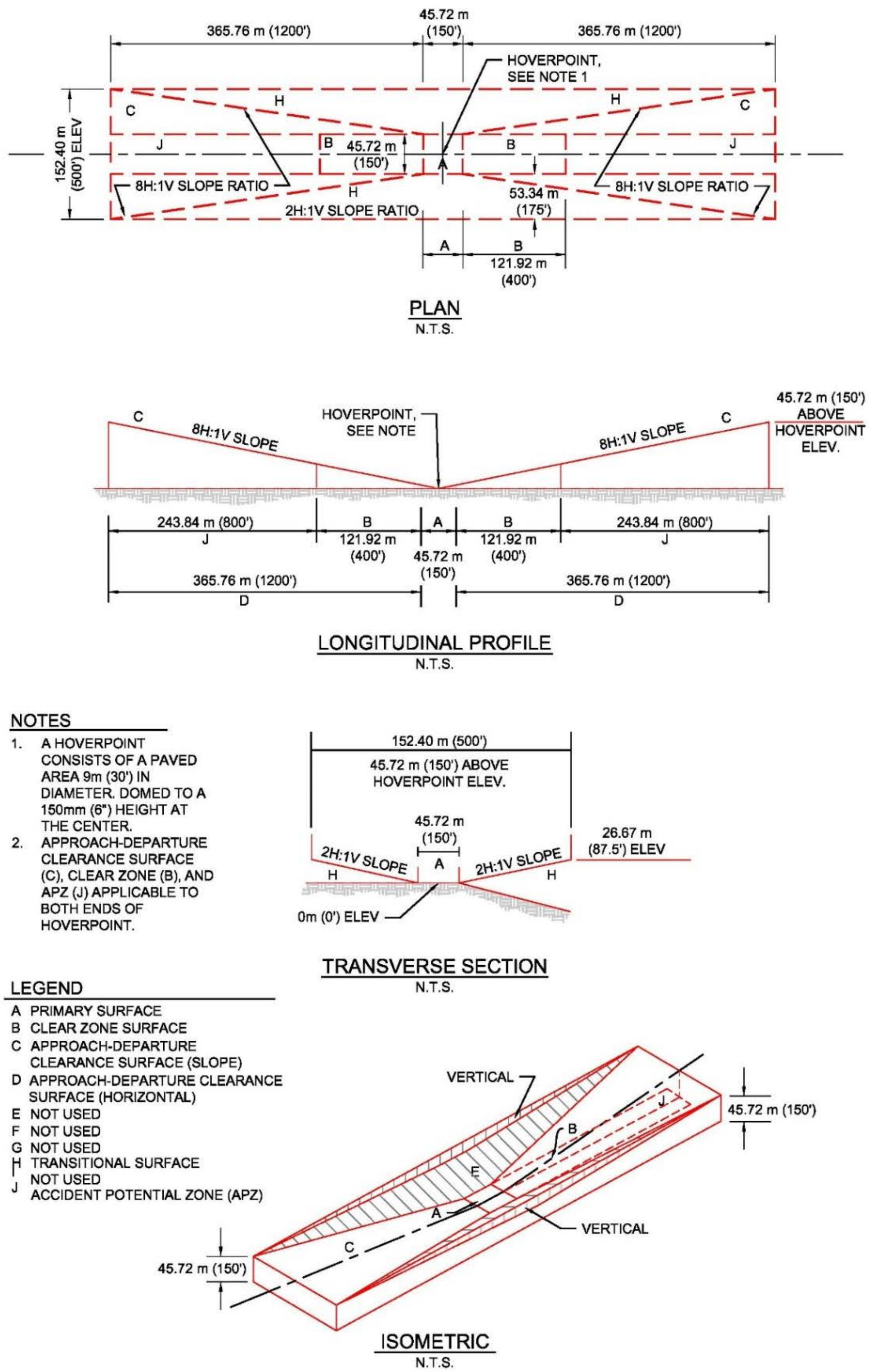


Table 4-3. Rotary-Wing Landing Lanes

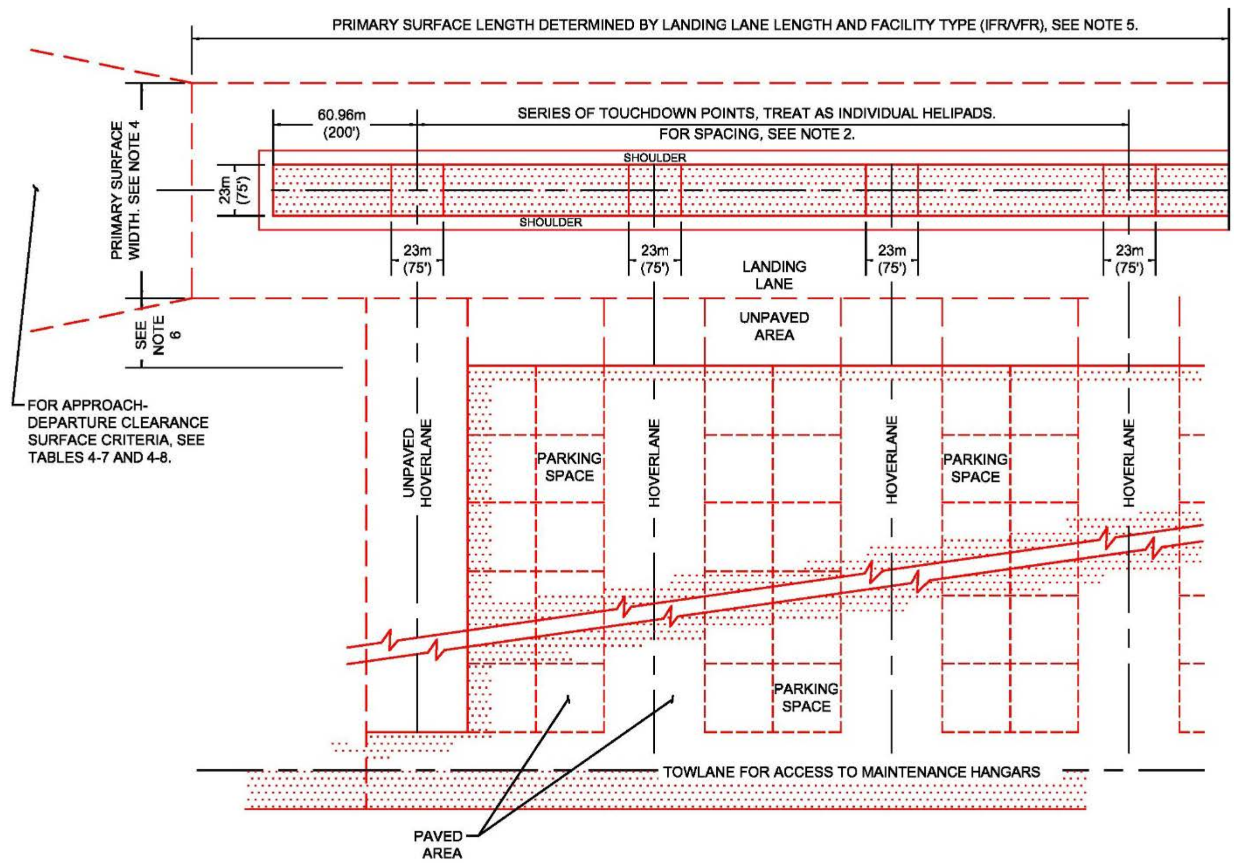
Table 4-3. Rotary-Wing Landing Lanes			
Item			
No.	Description	Requirement	Remarks
1	Length	480 m (1,600 ft) to 600 m (2,000 ft)	Landing lane length based on the number of touchdown points. Evenly space touchdown points along the landing lane. Minimum length is for four touchdown points spaced 120 m (400 ft) apart. The first and last pad centers are 60.96 m (200 feet) inward from the ends of the landing lanes.
2	Width	23 m (75 ft)	For Navy and Marine Corps facilities, increase width to 30 m (100 ft) on landing lanes that will regularly accommodate H-53 and V-22 aircraft
3	Distance between touchdown points on landing lane, center to center	120 m, min (400 ft, min)	Provide a number of equally spaced "touchdown" or holding points with adequate separation.
4	Longitudinal grade	Max. 1.0%	Maximum longitudinal grade change is 0.167% per 30 linear meters (100 linear feet). Exceptions: 0.4% per 30 linear meters (100 linear feet) is allowable for edge of landing lanes at intersections
5	Transverse grade	Min. 1.0% Max. 1.5%	From centerline of landing lane. Landing lanes may be crowned or uncrowned
6	Paved shoulders		See Table 4-4.
7	Distance between centerlines of rotary-wing landing lanes	60.96 m (200 ft)	For operations with an active operational air traffic control tower.
		91.44 m (300 ft)	For operations without an active operational air traffic control tower.
8	Landing lane lateral clearance zone (corresponds to half the width of primary surface area)	45.72 m (150 ft)	VFR facilities. Measured perpendicularly from centerline of runway to fixed or mobile obstacles. See Table 4-1, item 6, for obstacles definition.
		114.3 m (375 ft)	IFR facilities. Measured perpendicularly from centerline of runway to fixed or mobile obstacles. See Table 4-1, item 6, for obstacles definition.
9	Grades within the primary surface area in any direction	Min 2.0% Max 5.0%	Exclusive of pavement and shoulders.
10	Overrun	See Remarks	See Table 4-5
11	Clear zone*	See Remarks	See Table 4-6.
12	APZ I*	See Remarks	See Table 4-6.
13	Distance between centerlines of a fixed-wing runway and landing lane	See Table 4-1, item 9	
		213.36 m min (700 ft min)	

* The clear zone area for landing lanes corresponds to the clear zone land use criteria for fixed-wing airfields as defined in DoD AICUZ standards. The remainder of the approach-departure zone corresponds to APZ I land use criteria similarly defined. APZ II criteria are not applicable for rotary-wing aircraft.

NOTES:

1. Metric units apply to new airfield construction and, where practical, modification to existing airfields and heliports, as discussed in paragraph 1-3.4.
2. The criteria in this manual are based on aircraft specific requirements and are not direct conversions from inch-pound (English) dimensions. Inch-pound units are included only as a reference to the previous standard.
3. Airfield and heliport imaginary surfaces and safe wingtip clearance dimensions are shown as a direct conversion from inch-pound to SI units.

Figure 4-15. Rotary-Wing Landing Lane



NOTES

1. WIDTH OF HOVER LANES AND PARKING SPACES ARE DETERMINED BY THE TYPE OF HELICOPTER USED AND THE CLEARANCES REQUIRED.
2. THE DISTANCE BETWEEN THE TOUCHDOWN POINTS IS DETERMINED BY THE DISTANCE BETWEEN HOVERLANE CENTERLINES AND IS USUALLY NOT LESS THAN 120m (400') CENTER-TO-CENTER.
3. SIZE AND LAYOUT OF THE PARKING APRON VARIES WITH THE TYPE OF HELICOPTER USED AND THE MISSION REQUIREMENTS.
4. PRIMARY SURFACE WIDTH IS 91.44m (300') FOR VFR FACILITIES AND 228.60m (750') FOR IFR FACILITIES.
5. PRIMARY SURFACE LENGTH IS THE LANDING LANE LENGTH PLUS 45.72m (150') FOR ARMY AND AIR FORCE VFR LANDING LANES AND 60.96m (200') FOR NAVY AND MARINE CORPS VFR LANDING LANES. FOR ARMY, AIR FORCE, NAVY AND MARINE CORPS IFR LANDING LANES, THE PRIMARY SURFACE LENGTH IS THE LANDING LANE LENGTH PLUS 121.92m (400').
6. MINIMUM DISTANCE BETWEEN THE PRIMARY SURFACE AND THE APRON IS DETERMINED BY THE TRANSITIONAL SURFACE CLEARANCE TO PARKED AIRCRAFT. TRANSITIONAL SURFACE SLOPES ARE SHOWN IN TABLES 4-7 AND 4-8.

LEGEND

PAVEMENT

4-9 AIR FORCE HELICOPTER SLIDE AREAS (OR “SKID PADS”).

VFR helicopter runway criteria described in Table 4-1 and shown in Figures 4-1 and 4-8 (in terms of length, width, grade, and imaginary surfaces) are suitable for slide areas. The forces associated with helicopters landing at a small (but significant) rate of descent, and between 10 and 30 knots of forward velocity, require that slide area surfaces have both good drainage and some resistance to rutting; however, these landing surfaces need not be paved. Refer to UFC 3-260-02 for helicopter slide area structural criteria.

4-10 SHOULDERS FOR ROTARY-WING FACILITIES.

Unprotected areas adjacent to runways and overruns are susceptible to erosion caused by rotor wash. The shoulder width for rotary-wing runways, helipads, and landing lanes, shown in Table 4-4, includes both paved and unpaved shoulders. Paved shoulders are required adjacent to all helicopter operational surfaces, including runways, helipads, landing lanes, and hoverpoints. The unpaved shoulder must be graded to prevent water from ponding on the adjacent paved area. The drop-off next to the paved area prevents turf, which may build up over the years, from ponding water. Rotary-wing facility shoulders are illustrated in Figures 4-1 through 4-11. See paragraph 2-12 for requirements for designing buried utility structures in shoulders.

Table 4-4. Shoulders for Rotary-Wing Facilities

Table 4-4. Shoulders for Rotary-Wing Facilities			
Item		Requirement	Remarks
No.	Description		
1	Total width of shoulders (paved and unpaved) adjacent to all operational pavements	7.5 m (25 ft)	May be increased when necessary to accommodate dual operations with fixed-wing aircraft
2	Paved shoulder width	7.5 m (25 ft)	Air Force, Army, Navy and Marine Corps Exception: For Navy and Marine Corps helipads, use 3.75 m (12.5 ft) paved shoulders. Note: For V-22 and CH-53 taxiways, increase paved shoulder width to ensure 30 m (100 ft) total width (taxiway and shoulder) of paved surface.
3	Longitudinal grade	Variable	Conform to the longitudinal grade of the abutting primary pavement
4	Transverse grade	2.0% min 4.0% max	Slope downward from edge of pavement
5	Grade (adjacent to paved shoulder)	(a) 40-mm (1.5-in) drop-off at edge of paved shoulder +/- 13 mm (0.5 in) (b) minimum 2%, maximum 5% within the primary surface	Primary surface and clear zone criteria apply beyond this point.

NOTES:
1. Metric units apply to new airfield construction and, where practical, modification to existing airfields and heliports, as discussed in paragraph 1-3.4.
2. The criteria in this manual are based on aircraft specific requirements and are not direct conversions from inch-pound (English) dimensions. Inch-pound units are included only as a reference to the previous standard.
3. Airfield and heliport imaginary surfaces and safe wingtip clearance dimensions are shown as a direct conversion from inch-pound to SI units.

4-11 OVERRUNS FOR ROTARY-WING RUNWAYS AND LANDING LANES.

Overruns are required at the end of all rotary-wing runways and landing lanes. Table 4-5 shows the dimensional requirements for overruns for rotary-wing runways and landing lanes. The pavement in the overrun is considered a paved shoulder. Rotary-wing overruns for runways and landing lanes are illustrated in Figures 4-1, 4-2, and 4-15. See paragraph 2-12 for requirements for designing buried utility structures in overruns.

Table 4-5. Overruns for Rotary-Wing Runways and Landing Lanes

Table 4-5. Overruns for Rotary-Wing Runways and Landing Lanes			
Item			
No.	**Description**	**Requirement**	**Remarks**
1	Total length (paved and unpaved)	23 m (75 ft)	
2	Paved length of overrun	7.5 m (25 ft) 0 m (0 ft)	Air Force and Army only Navy
3	Width	38 m (125 ft)	Width of runway plus shoulders A minimum width of 45 m (150 ft) for airfields that regularly accommodate H-53 and V-22 aircraft (30-m (100-ft) runway and 7.5-m (25-ft) shoulders)
4	Longitudinal centerline grade	Same as last 150 m (500 ft) of runway. Remainder Max. 1.0%	To avoid abrupt changes in longitudinal grade between the runway and overrun, the maximum change of grade is 2.0% per 30 linear m (100 linear ft)
5	Transverse grade (paved and unpaved)	Min. 2.0% Max. 3.0%	Warp to meet runway and shoulder grades.

NOTES:

1. Metric units apply to new airfield construction and, where practical, modification to existing airfields and heliports, as discussed in paragraph 1-3.4.
2. The criteria in this manual are based on aircraft specific requirements and are not direct conversions from inch-pound (English) dimensions. Inch-pound units are included only as a reference to the previous standard.
3. Airfield and heliport imaginary surfaces and safe wingtip clearance dimensions are shown as a direct conversion from inch-pound to SI units.

4-12 CLEAR ZONE AND ACCIDENT POTENTIAL ZONE (APZ).

The clear zone and APZ are areas on the ground, located under the rotary-wing approach-departure surface. The clear zone and APZ are required for rotary-wing runways, helipads, landing lanes, and hoverpoints.

4-12.1 Clear Zone Land Use.

The clear zone for rotary-wing facilities must be free of obstructions, both natural and man-made, and rough-graded to minimize damage to an aircraft that runs off or lands short of the end of the landing surface. In addition, the clear zone permits recovery of aircraft that are aborted during takeoff. The clear zone should be either owned or protected under a long-term lease. Land use for the clear zone area for rotary-wing facilities corresponds to the clear zone land use criteria for fixed-wing airfields as defined for DoD AICUZ and Service-specific standards and as discussed in Chapter 3.

4-12.2 Accident Potential Zone (APZ).

Land use for the APZ area at rotary-wing facilities corresponds to the APZ land use criteria for fixed-wing airfields as defined in DoD AICUZ and Service-specific standards and as discussed in Chapter 3. Ownership of the APZ is desirable but not required. If ownership is not possible, land use should be controlled through long-term lease agreements or local zoning ordinances.

4-12.3 Dimensions.

Table 4-6 shows the dimensional requirements for the clear zone and APZ. These dimensions apply to rotary-wing runways, helipads, landing lanes, and hoverpoints, depending on whether they support VFR or IFR operations. Layout of the clear zone and APZ are shown in Figures 4-1, 4-2, and 4-8 through 4-15.

4-13 IMAGINARY SURFACES FOR ROTARY-WING RUNWAYS, HELIPADS, LANDING LANES, AND HOVERPOINTS.

Rotary-wing runways, helipads, landing lanes, and hoverpoints have imaginary surfaces similar to the imaginary surfaces for fixed-wing facilities. The imaginary surfaces are defined planes in space that establish clearance requirements for helicopter operations. An object, either man-made or natural, that projects through an imaginary surface plane is an obstruction to air navigation. Layout of the rotary-wing airspace imaginary surfaces is provided in Tables 4-7 and 4-8 and Figures 4-1 through 4-15. Rotary-wing airspace imaginary surfaces are defined in the glossary and listed here:
Primary surface

- Approach-departure clearance surface (VFR)
- Approach-departure clearance surface (VFR limited use helipads)
- Approach-departure clearance surface (IFR)
- Horizontal surface (IFR)
- Transitional surfaces

Table 4-6. Rotary-Wing Runway and Landing Lane Clear Zone and APZ

Table 4-6. Rotary-Wing Runway and Landing Lane Clear Zone and APZ1,2			
Item			
No.	**Description**	**Requirement**	**Remarks**
1	Clear zone length	121.92 m (400 ft)	Clear zone begins at the end of the primary surface.
2	Clear zone width (center width on extended runway/landing lane centerline) (corresponds to the width of the primary surface)	91.44 m (300 ft)	VFR rotary-wing runways and landing lanes See note 2.
		228.60 m (750 ft)	IFR rotary-wing runways and landing lanes See note 2.
3	Grades in clear zone in any direction	2.0% Min. 5.0% Max.	Clear zone only Area to be free of obstructions. Rough-grade and turf when required.
4	APZ I length	243.84 m (800 ft)	See notes 2 and 3.
5	APZ I width	91.44 m (300 ft)	VFR rotary-wing runways and landing lanes See notes 2 and 3.
		228.60 m (750 ft)	IFR rotary-wing runways and landing lanes See notes 2 and 3.

NOTES:

1. The clear zone area for rotary-wing runways and landing lanes corresponds to the clear zone land use criteria for fixed-wing airfields as defined in DoD and Service-specific AICUZ standards and as discussed in Chapter 3 . The remainder of the approach-departure zone corresponds to APZ I land use criteria similarly defined. APZ II criteria is not applicable for rotary-wing aircraft.
2. No grading requirements for APZ I.
3. Metric units apply to new airfield construction and, where practical, modification to existing airfields and heliports, as discussed in paragraph 1-3.4.
4. The criteria in this manual are based on aircraft specific requirements and are not direct conversions from inch-pound (English) dimensions. Inch-pound units are included only as a reference to the previous standard.
5. Airfield and heliport imaginary surfaces and safe wingtip clearance dimensions are shown as a direct conversion from inch-pound to SI units.

Table 4-7. Rotary-Wing Imaginary Surface for VFR Approaches

Item		Legend in Figures	Helicopter Runway and Landing Lane	Helipad		Elevated Helipad	Remarks
No.	Description			Air Force and Army VFR Standard	Air Force and Army VFR Limited Use; Navy and Marine Corps Standard Helipad and Hoverpoints[1,2]	Air Force and Army	
1	Primary surface width	A	91.44 m (300 ft)	91.44 m (300 ft)	45.72 m (150 ft)	59.4 m (195ft) for UH60 and smaller helicopters 91.44 m (300 ft) for CH47 and larger helicopters	Centered on the ground point of intercept (GPI).
2	Primary surface length	A	Runway or landing lane length plus 22.86 m (75 ft) at each end	91.44 m (300 ft) centered on facility	45.72 m (150 ft) centered on facility	59.4 m (195 ft) for UH60 and smaller helicopters 91.44 m (300 ft) for CH47 and larger helicopters	Runway or landing lane length plus 30.48 m (100 ft) at each end for Navy and Marine Corps facilities.
3	Primary surface elevation	A	The elevation of any point on the primary surface is the same as the elevation of the nearest point on the runway centerline or at the established elevation of the landing surface.			The elevation of any point on the primary surface is the same as the established elevation of the landing surface	
4	Clear zone surface	B	See Table 4-6	See Table 4-2	See Table 4-2	See Table 4-2	
5	Start of approach-departure surface	C	22.86 m (75 ft) from end of runway or landing lane	45.72 m (150 ft) from GPI	22.86 m (75 ft) from GPI	29.7 m (97.5 ft) from GPI for UH60 and smaller helicopters	

						45.72 m (150 ft) from GPI for CH47 and larger helicopters	
6	Length of sloped portion of approach-departure surface	C	365.76 m (1,200 ft)	365.76 m (1,200 ft)*	365.76 m (1,200 ft)*	365.76 m (1,200 ft)*	Measured horizontally. *(For Army Hospital Helipads – The length shall be 749.82m (2460') when a CHAPI is used).
7	Slope of approach-departure surface	C	8:1	8:1**	8:1**	8:1**	See remarks below.
			Slope ratio is horizontal to vertical. 8:1 is 8 m (ft) horizontal to 1 m (ft) vertical. **(For Army Hospital Helipads – The slope shall be 16.4:1 when a Chase Helicopter Approach Path Indicator (CHAPI) is used).				
8	Width of sloped portion of approach-departure surface at start of sloped portion	C	91.44 m (300 ft)	91.44 m (300 ft)	45.72 m (150 ft)	59.4 m (195 ft) for UH60 and smaller helicopters 83.3 m (275 ft) for CH47 and larger helicopters	Centered on the extended center-line, and is the same width as the primary surface.
9	Width of sloped portion of approach-departure surface at end of sloped portion	C	182.88 m (600 ft)	182.88 m (600 ft) *** 278.90m (915 ft)	152.4 m (500 ft) *** 265.18m (870 ft)	Small 150.88 m (495 ft) Large 182.88 m (600 ft) *** Small – 246.89 m (810 ft) *** Large – 278.90 m (915 ft)	Centered on the extended center-line. *** (For Army Hospital Helipads when a CHAPI is used).
10	Elevation of approach-departure surface at start of sloped portion	C	0 m (0 ft)	0 m (0 ft)	0 m (0 ft)	0 m (0 ft)	Above the established elevation of the landing surface.
11	Elevation of approach-departure surface at end	C	45.72 m (150 ft)	45.72 m (150 ft)	45.72 m (150 ft)	45.7 m (150 ft)	Above the established elevation of the landing surface.

	of sloped portion						
12	Length of approach-departure zone	D	365.76 m (1,200 ft)	365.76 m (1,200 ft)*	365.76 m (1,200 ft)*	365.76 m (1,200 ft)*	See remarks below.
			Measured horizontally from the end of the primary surface and is the same length as the approach-departure clearance surface length *(For Army Hospital Helipads – The length shall be 749.82m (2460') when a CHAPI is used).				
13	Start of approach-departure zone	D	22.86 m (75 ft) from end of runway	45.72 m (150 ft) from center of helipad	22.86 m (75 ft) from center of helipad	29.7 m (97.5 ft) from center of helipad for UH60 and smaller helicopters 45.72 m (150 ft) from center of helipad for CH47 and larger helicopters	Starts at the end of the primary surface.
14	Transitional surface slope	H	2H:1V See remark 1	2H:1V See remark 1	2H:1V See remark 2	2H:1V See remark 2	See remarks below.
			(1) The transitional surface starts at the lateral edges of the primary surface and the approach-departure clearance surface. It continues outward and upward at the prescribed slope to an elevation of 45.72 m (150 ft) above the established airfield elevation. (2) The transitional surface starts at the lateral edges of the primary surface and the approach-departure clearance surface. It continues outward and upward at the prescribed slope to a point 250 ft from extended helipad/hoverpoint centerline. It then rises vertically to an elevation of 45.7 m (150 ft) above the established airfield elevation. (3) See Figures 4-8 and 4-14 for the shape of transitional surfaces.				
15	Horizontal surface	G	Not required	Not required	Not required	Not required	

NOTES:
1. The Navy and Marine Corps do not have criteria for same direction ingress/egress.
2. Metric units apply to new airfield construction and, where practical, modification to existing airfields and heliports, as discussed in paragraph 1-3.4.
3. Elevated helipads apply only to Army.

Table 4-8. Rotary-Wing Imaginary Surfaces for IFR Approaches

Table 4-8. Rotary-Wing Imaginary Surfaces for IFR Approaches						
Item		Legend in Figures	Helicopter Runway and Landing Lanes	Helipad		Remarks
No.	Description			Standard	Same Direction Ingress/Egress	
1	Primary surface width	A	228.60 m (750 ft)	228.60 m (750 ft)	228.60 m (750 ft)	Centered on helipad
2	Primary surface length	A	The runway or landing lane length plus 60.96 m (200 ft) at each end.	472.44 m (1,550 ft) centered on GPI	228.6 m (750 ft) centered on GPI	
3	Primary surface elevation	A	The elevation of any point on the primary surface is the same as the elevation of the nearest point on the runway or landing lane centerline or established elevation of the helipad.			
4	Clear zone surface	B	See Table 4-6	See Table 4-2	See Table 4-2	
5	Start of approach-departure surface	C	Begins 60.96 m (200 ft) feet beyond the end of runway, coincident with end of primary surface	236.22 m (775 ft) from GPI	487.68 m (1,600 ft) from GPI	Army and Air Force facilities
			236.22 m (775 ft) from GPI.	236.22 m (775 ft) from GPI.	N/A	Navy and Marine Corps facilities
			See Remarks	See Remarks	See Remarks	Starts at the end of the primary surface
6	Length of sloped portion of approach-departure surface	D	7,620.00 m (25,000 ft)	7,620.00 m (25,000 ft)	7,620.00 m (25,000 ft)	Army and Air Force facilities
			7,383.78 m (24,225 ft)	7,383.78 m (24,225 ft)	N/A	Navy and Marine Corps facilities
			See Remarks	See Remarks	See Remarks	Measured horizontally
7	Slope of approach-departure surface	C	34:1	34:1	34:1	Army and Air Force Facilities
						Navy and Marine Corps do not have criteria for unidirectional ingress/egress.
			25:1	25:1	N/A	Navy and Marine Corps facilities
			See Remarks	See Remarks	See Remarks	Slope ratio is horizontal to vertical. 34:1 is 34 m (ft) horizontal to 1 m (ft) vertical.

Table 4-8. Rotary-Wing Imaginary Surfaces for IFR Approaches						
Item		Legend in Figures	Helicopter Runway and Landing Lanes	Helipad		Remarks
No.	Description			Standard	Same Direction Ingress/Egress	
8	Width of approach-departure surface at start of sloped portion	C	228.60 m (750 ft)	228.60 m (750 ft)	228.60 m (750 ft)	Army and Air Force facilities
			228.60 m (750 ft)	228.60 m (750 ft)	N/A	Navy and Marine Corps facilities
			See Remarks	See Remarks	See Remarks	Centered on the extended centerline and is the same width as the primary surface
9	Width of approach-departure surface at end of sloped portion	C	2,438.60 m (8,000 ft)	2,438.60 m (8,000 ft)	2,438.60 m (8,000 ft)	Army and Air Force facilities
			2,438.60 m (8,000 ft)	2,438.60 m (8,000 ft)	N/A	Navy and Marine Corps facilities
			See Remarks	See Remarks	See Remarks	Centered on the extended centerline
10	Elevation of approach-departure surface at start of sloped portion	C	0 m (0 ft)	0 m (0 ft)	0 m (0 ft)	Army and Air Force facilities
			0 m (0 ft)	0 m (0 ft)	N/A	Navy and Marine Corps facilities
			See Remarks	See Remarks	See Remarks	Above the established elevations of the landing surface
						Navy and Marine Corps do not have criteria for unidirectional ingress/egress.
11	Elevation of approach-departure clearance surface at end of sloped portion	C	224.03 m (735 ft)			Air Force and Army
			295.35 m (969 ft)		N/A	Navy and Marine Corps
			See Remarks			Above the established elevation of the landing surface
12	Transitional surface slope	H	4:1	4:1	4:1	Army
			4:1	4:1	4:1	Air Force
			4:1	4:1	N/A	Navy and Marine Corps
			The transitional surface starts at the lateral edges of the primary surface and the approach-departure clearance surface. It continues outward and upward at the prescribed slope to 45.72 m (150 ft) above the established airfield elevation.			
13	Horizontal surface radius	E	1,143 m (3,750 ft) for 25:1 approach-departure surfaces	N/A	N/A	Navy and Marine Corps airfields only. An imaginary surface located 45.72 m (150 ft) above the established heliport elevation, formed by

Table 4-8. Rotary-Wing Imaginary Surfaces for IFR Approaches						
Item		Legend in Figures	Helicopter Runway and Landing Lanes	Helipad		Remarks
No.	Description			Standard	Same Direction Ingress/Egress	
						scribing an arc about the end of each runway or landing lane, and interconnecting these arcs with tangents
			1,554.48 m (5,100 ft) for 34:1 approach-departure surfaces	N/A	N/A	Navy and Marine Corps airfields only
			N/A	1,402.08 m (4,600 ft)	1,402.08 m (4,600 ft)	Navy and Marine Corps airfields only. Circular in shape, located 45.72 m (150 ft) above the established heliport or helipad elevation, defined by scribing an arc with a 1,402.08 m (4,600 ft) radius about the center point of the helipad
14	Elevation of horizontal surface	H	45.72 m (150 ft)	45.72 m (150 ft)	45.72 m (150 ft)	Navy and Marine Corps airfields only

NOTES:
1. Metric units apply to new airfield construction and, where practical, modification to existing airfields and heliports, as discussed in paragraph 1-3.4.
2. The criteria in this manual are based on aircraft specific requirements and are not direct conversions from inch-pound (English) dimensions. Inch-pound units are included only as a reference to the previous standard.
3. Airfield and heliport imaginary surfaces and safe wingtip clearance dimensions are shown as a direct conversion from inch-pound to SI units.
4. N/A = not applicable

4-14 OBSTRUCTIONS AND AIRFIELD AIRSPACE CRITERIA.

If the imaginary surface around a rotary-wing runway, helipad, elevated helipad, landing lane, or hoverpoint is penetrated by man-made or natural objects as defined in 14 CFR Part 77, Paragraph 77.23 “Standards for Determining Obstruction”, the penetrating object is an obstruction.

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CHAPTER 5
TAXIWAYS

5-1 CONTENTS.

This chapter presents design standards and considerations for fixed- and rotary-wing taxiways.

5-2 TAXIWAY REQUIREMENTS.

Taxiways provide for ground movement of fixed- and rotary-wing aircraft. Taxiways connect the runways, helipads and other landing/takeoff surfaces of the airfield with the parking and maintenance areas and provide access to hangars, docks, and various parking aprons and pads.

5-3 TAXIWAY SYSTEMS.

5-3.1 Basic.

The basic airfield layout consists of a taxiway connecting the center of the runway, helipads and other landing/takeoff surfaces with the parking apron. This system limits the number of aircraft operations at an airfield. Departing aircraft must taxi on the runway to reach the runway threshold. When aircraft are taxiing on the runway, no other aircraft is allowed to use the runway. If runway operations are minimal or capacity is low, the basic airfield layout with one taxiway may be an acceptable layout.

5-3.2 Parallel Taxiway.

A taxiway parallel for the length of the runway, with connectors to the end of the runway and parking apron, is the most efficient taxiway system. Aircraft movement is not hindered by taxiing operations on the runway, and the connectors permit rapid entrance and exit of traffic.

5-3.3 High-Speed Taxiway Turnoff.

High-speed taxiway turnoffs are located intermediate of the ends of the runway to increase the capacity of the runway. The high-speed taxiway turnoff enhances airport capacity by allowing aircraft to exit the runways at a faster speed than turnoff taxiways allow.

5-3.4 Additional Types of Taxiways.

Besides the types of taxiways already discussed in this section, there are other taxiways at an airfield. Taxiways are often referred to based on their function. Common airfield taxiways and their designations are shown in Figure 5-1.

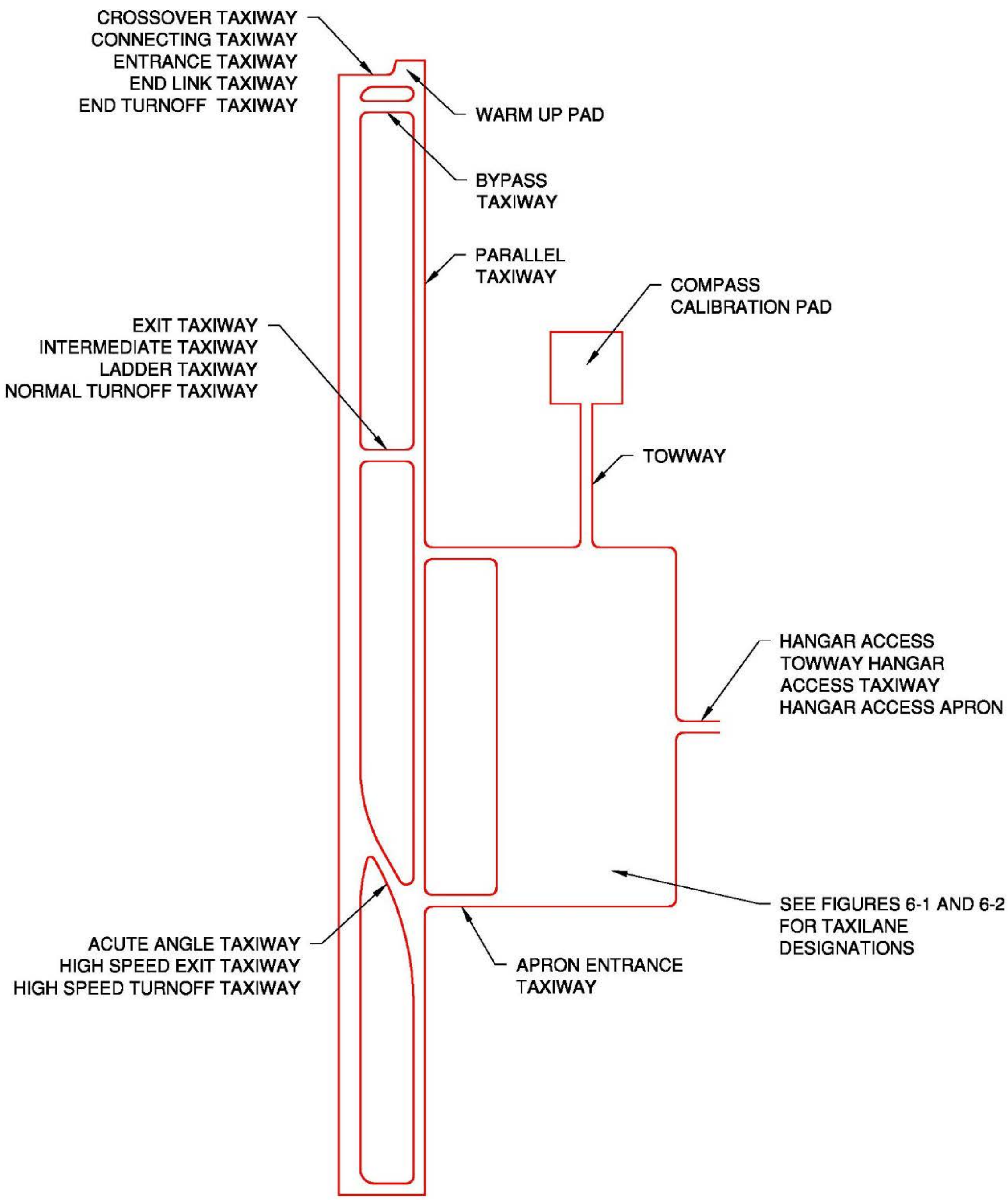
5-3.5 Taxilanes.

A taxi route through an apron is referred to as a “taxilane.” Taxilanes are discussed further in Chapter 6 for the Army and Air Force and UFC 2-000-05N for the Navy and Marine Corps.

5-3.6 USAF Taxitraks.

A taxi route connecting a dispersed parking platform (e.g., a fighter loop) to a taxiway or runway is referred to as a “taxitrak.” Dispersed parking platform and taxitrak use are limited to fighter aircraft only. Use of taxitraks by tactical transport aircraft is permitted provided minimum clearances as set by MAJCOM guidance are met. Table 5-7 presents the criteria for taxitraks.

Figure 5-1. Common Taxiway Designations



PLAN
N.T.S.

NOTES

1. TAXIWAY LAYOUT IS FOR GUIDANCE ONLY.

5-4 TAXIWAY LAYOUT.

These considerations should be addressed when planning and locating taxiways at an airfield:

5-4.1 Efficiency.

Runway efficiency is enhanced by planning for a parallel taxiway.

5-4.2 Direct Access.

Taxiways should provide as direct an access as possible from the runway, helipads and other landing/takeoff surfaces to the apron. Connecting taxiways should be provided to join the runway, helipads and other landing/takeoff surfaces exit points to the apron.

5-4.3 Simple Taxiing Routes.

A sufficient number of taxiways should be provided to prevent complicated taxiing routes. Turning from one taxiway onto another often creates confusion and may require additional airfield signs and communication with the air traffic control tower.

5-4.4 Delay Prevention.

A sufficient number of taxiways should be provided to prevent capacity delays that may result when one taxiway must service more than one runway.

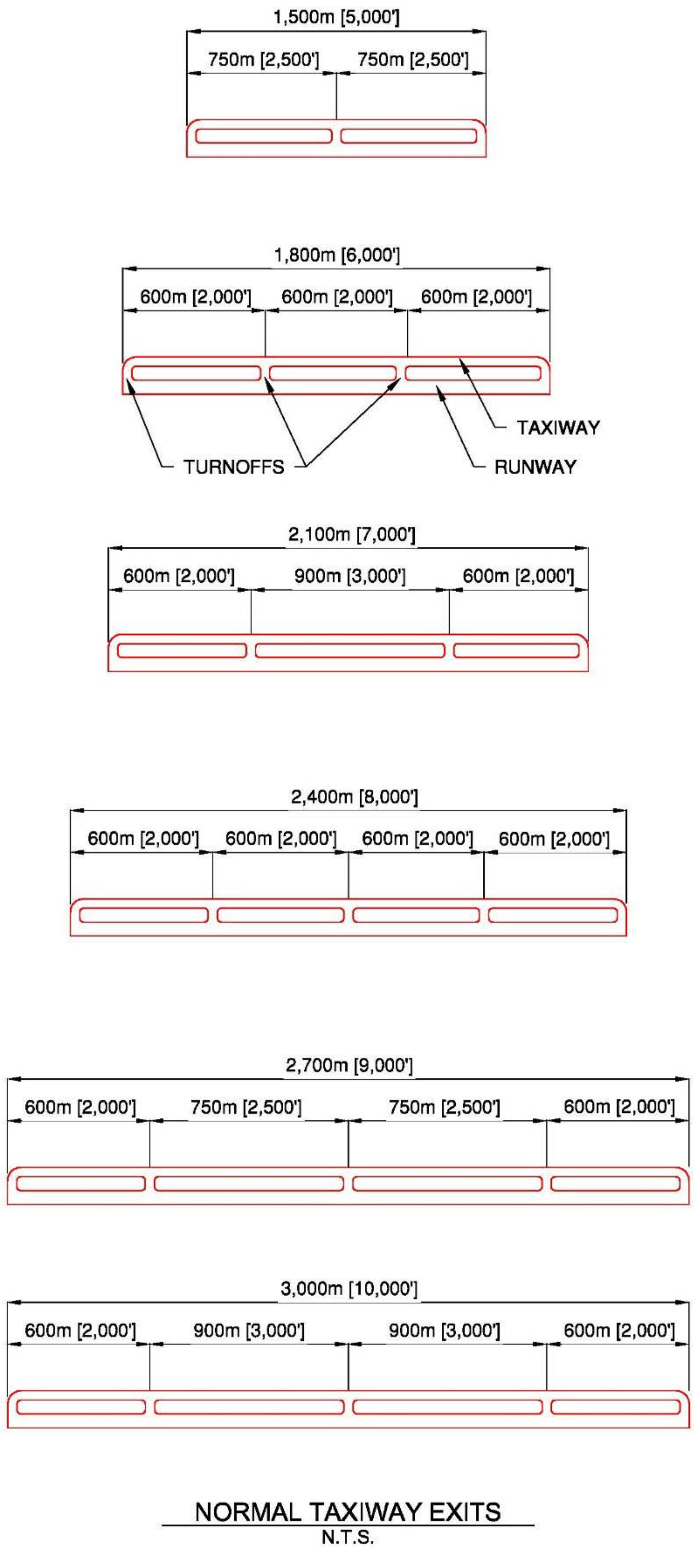
5-4.5 Runway Exit Criteria.

The number, type, and location of exits is a function of runway length, as shown in Figure 5-2 and as discussed in Chapter 2.

5-4.6 Taxiway Designation.

Use letters of the alphabet for designating taxiways. Optimally, designation of the taxiways should start at one end of the airport and continue to the opposite end, e.g., east to west or north to south (see UFC 3-535-01). Designate all separate, distinct taxiway segments. Do not use the letters I, O, or X for taxiway designations.

Figure 5-2. Spacing Requirements: Normal Taxiway Exits



5-5 FIXED-WING TAXIWAY DIMENSIONS.

The dimensions of a taxiway are based on the class of runway that the taxiway serves.

5-5.1 Criteria.

Table 5-1 presents the criteria for fixed-wing taxiway design, including clearances, slopes, and grading dimensions.

5-5.2 Transverse Cross-Section.

A typical transverse cross-section of a taxiway is shown in Figure 5-3.

Table 5-1. Fixed-Wing Taxiways

Table 5-1. Fixed-Wing Taxiways				
Item		**Class A Runway**	**Class B Runway**	
No.	**Description**	**Requirement**		**Remarks**
1	Width	15 m (50 ft)	23 m (75 ft)	Army and Air Force airfields
		12 m (40 ft)	23 m (75 ft)	Navy and Marine Corps airfields
		See Remarks		May be modified for particular mission requirements (special taxiways such as high-speed and end turn-off)
2	Total width of shoulders (paved and unpaved)	7.5 m (25 ft)	15 m (50 ft)	
3	Paved shoulder width	7.5 m (25 ft)	7.5 m (25 ft)	Army and Air Force airfields except as noted below
		N/A	3 m (10 ft)	Air Force taxiways devoted exclusively for fighter and trainer aircraft A paved shoulder up to 7.5 m (25 ft) is allowed on the outside of taxiway turns of 90 degrees or more.
		N/A	15 m (50 ft)	Airfields for B-52 aircraft. Also see note 3.
		As Required	As Required	Navy and Marine Corps airfields – where V-22 operations occur, provide total paved width (taxiway and shoulder) of 30 m (100 ft). Where rotary operations occur on fixed wing taxiways, follow paragraph 5-7.2. Air Force airfields devoted exclusively to trainer aircraft operations. Local Commanders must complete a risk

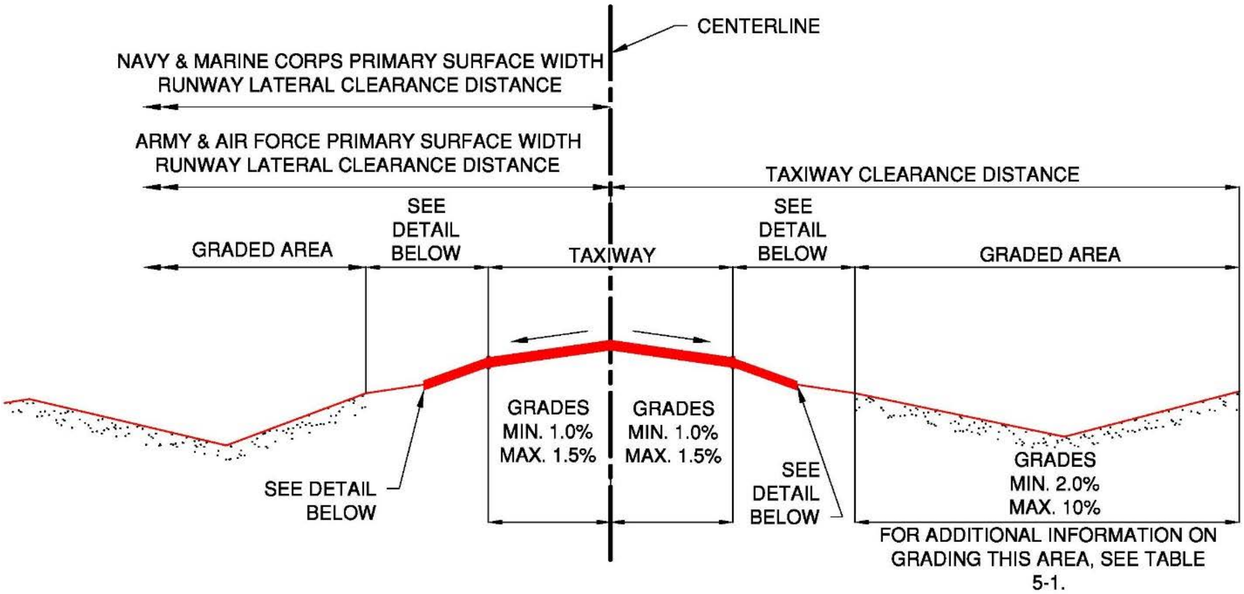
Table 5-1. Fixed-Wing Taxiways				
Item		Class A Runway	Class B Runway	
No.	Description	Requirement		Remarks
				assessment if not opting to install shoulders.
4	Longitudinal grade of taxiway and shoulders	Max 3.0%		Army, Navy, and Marine Corps airfields. For Navy and Marine Corps airfields, a maximum of 2.0% is recommended when jet aircraft are required to accelerate from a standing position.
		Max 1.5%		Air Force airfields. A gradient exception of 5.0% is permitted for a distance of not more than 120 m (400 ft) unless within 180 m (600 ft) of a runway entrance. There, a 3.0% maximum applies.
		See Remarks		Grades may be positive or negative but must not exceed the limits specified.
5	Rate of longitudinal taxiway grade change	Max 1.0% per 30 m (100 ft)		The minimum distance between two successive points of intersection (PI) is 150 m (500 ft). Changes are to be accomplished by means of vertical curves. For the Air Force and Army, up to a 0.4% change in grade is allowed without a vertical curve. A vertical curve is not necessary where a taxiway crosses a runway or taxiway crown.
6	Longitudinal sight distance	Min 600 m (2,000 ft) between eye level at 2.14 m (7 ft) and an object 3.05 m (10 ft) above taxiway pavement		Army, Navy, and Marine Corps airfield taxiways
		Min 300 m (1,000 ft). Any two points 3 m (10 ft) above the pavement must be mutually visible for the distance indicated.		Air Force airfield taxiways
7	Transverse grade of taxiway	Min 1.0% Max 1.5%		New taxiway pavements will be centerline crowned. Slope pavement downward from the centerline of the taxiway. When existing taxiway pavements have insufficient transverse gradients for rapid drainage, provide for increased gradients when the pavements are overlaid or reconstructed.

Table 5-1. Fixed-Wing Taxiways				
Item		Class A Runway	Class B Runway	Remarks
No.	Description	Requirement		
				The transverse gradients requirements are not applicable at or adjacent to intersections where pavements must be warped to match abutting pavements.
8	Transverse grade of paved shoulders	Min 2.0% Max 4.0%		Army, Navy, Marine Corps, and Air Force airfields not otherwise specified
		N/A	Min 1.5% Max 2.0%	Air Force taxiways designed for B-52 aircraft
9	Transverse grade of unpaved shoulders	(a) 40 mm (1.5 in) drop-off at edge of pavement +/- 13 mm (0.5 in) (b) 2.0% min, 4.0% max		For additional information, see Figure 5-3. Unpaved shoulders shall be graded to provide positive surface drainage away from paved surfaces.
10	Clearance from taxiway centerline to fixed or mobile obstacles (taxiway clearance line)	Min 45.72 m (150 ft)		Army, Navy, and Marine Corps airfields
		Min 45.72 m (150 ft)	Min 60.96 m (200 ft)	Air Force airfields
		See Remarks		See Table 3-2, item 12, for obstacle definition.
11	Distance between taxiway centerline and parallel taxiway/taxilane centerline	53 m (175 ft)	57 m (187.5 ft) or wingspan + 15.3 m (wingspan + 50 ft), whichever is greater	Army airfields
		53 m (175 ft)	72.4 m (237.5 ft) or wingspan + 15.3 m (wingspan + 50 ft), whichever is greater	Air Force and Navy airfields
12	Grade of area between taxiway shoulder and taxiway clearance line	Min of 2.0% prior to channelization Max 10.0%[2]		Army, Air Force, Navy, and Marine Corps airfields, except as noted below. For additional information, see Figure 5-3. Unpaved areas shall be graded to provide positive surface drainage away from paved surfaces. For cases where the entire shoulder is paved (Class A airfields and taxiways designed for B-52 aircraft), provide a 40 mm (1.5-in) drop-off at pavement edge, +/- 13 mm (0.5 in).

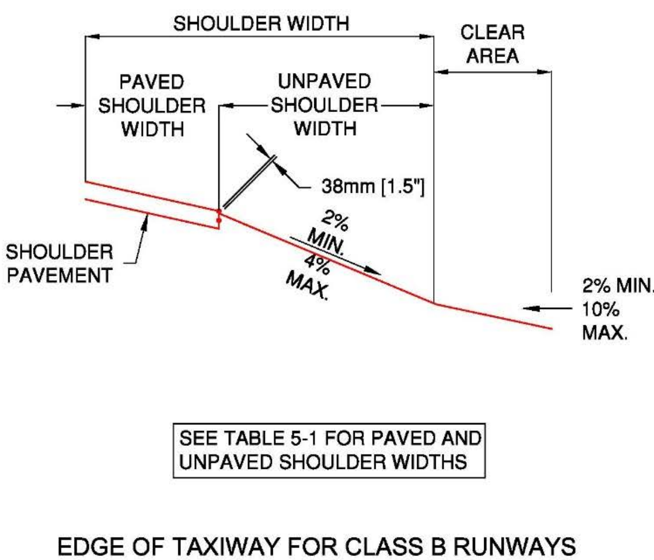
NOTES:

1. N/A = not applicable
2. Bed of channel may be flat. When drainage channels are required, the channel bottom cross section may be flat but the channel must be sloped to drain.
3. A 15-m (50-ft) paved shoulder is allowed for C-5, E-4, and 747 aircraft where vegetation cannot be established. Transverse grade of paved shoulder is 2% minimum to 4% maximum.
4. Metric units apply to new airfield construction and, where practical, modification to existing airfields and heliports, as discussed in paragraph 1-3.4.
5. The criteria in this manual are based on aircraft specific requirements and are not direct conversions from inch-pound (English) dimensions. Inch-pound units are included only as a reference to the previous standard.
6. Airfield and heliport imaginary surfaces and safe wingtip clearance dimensions are shown as a direct conversion from inch-pound to SI units.

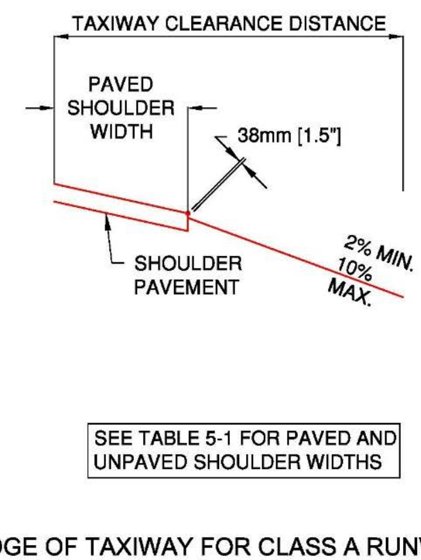
Figure 5-3. Taxiway and Primary Surface Transverse Sections



TAXIWAY TRANSVERSE SECTION
N.T.S.



EDGE OF TAXIWAY FOR CLASS B RUNWAYS EXCEPT AS NOTED IN TABLE 5-1
N.T.S.



EDGE OF TAXIWAY FOR CLASS A RUNWAYS AND CLASS B RUNWAYS FOR B-52 AIRCRAFT
N.T.S.

5-6 ROTARY-WING TAXIWAY DIMENSIONS.

Rotary-wing taxiways are either paved or unpaved. Wheel-gear configured rotary-wing aircraft require a paved surface on which to taxi. Skid-gear configured rotary-wing aircraft taxi by hovering along a paved or unpaved taxiway. Table 5-2 presents the criteria for rotary-wing taxiway design, including taxiway widths, clearances, slopes, and grading dimensions.

Table 5-2. Rotary-Wing Taxiways

Table 5-2. Rotary-Wing Taxiways			
Item			
No.	Description	Requirement	Remarks
1	Width	15 m (50 ft)	Army and Air Force facilities
		12 m (40 ft)	Navy and Marine Corps facilities
		See Remarks	Basic width applicable to taxiways that support helicopter operations only. When dual use taxiways support fixed-wing aircraft operations, use the appropriate fixed-wing criteria.
2	Longitudinal grade	Max 2.0%	
3	Rate of longitudinal grade change	Max 2.0% per 30 m (100 ft)	Longitudinal grade changes are to be accomplished using vertical curves. For the Air Force and Army, up to a 0.4% change in grade is allowed without a vertical curve. A vertical curve is not necessary where a taxiway crosses a runway or taxiway crown.
3	Transverse grade	Min 1.0% Max 1.5%	New taxiways are to be centerline crowned.
4	Paved shoulders		See Table 5-3.
5	Clearance from centerline to fixed and mobile obstacles (taxiway clearance line)	Min 30.48 m (100 ft)	Basic helicopters clearance. Increase as appropriate for dual use taxiways. See Table 3-2, item 12, for definitions of fixed and mobile obstacles.
6	Grades within the clear area	Max 5.0%	The clear area is the area between the taxiway shoulder and the taxiway clearance line.
7	Intersection fillet radius	See Table 5-4 and Table 5-5	Use the appropriate fillet depending on the width of the rotary-wing taxiway.

NOTES:
1. Metric units apply to new airfield construction and, where practical, modification to existing airfields and heliports, as discussed in paragraph 1-3.4.
2. The criteria in this manual are based on aircraft specific requirements and are not direct conversions from inch-pound (English) dimensions. Inch-pound units are included only as a reference to the previous standard.
3. Airfield and heliport imaginary surfaces and safe wingtip clearance dimensions are shown as a direct conversion from inch-pound to SI units.

5-7 TAXIWAYS AT DUAL USE (FIXED- AND ROTARY-WING) AIRFIELDS.

5-7.1 Criteria.

For taxiways at airfields supporting both fixed- and rotary-wing aircraft operations, the appropriate fixed-wing criteria will be applied, except as noted for shoulders or for STOVL aircraft requirements.

5-7.2 Taxiway Shoulders.

A paved shoulder will be provided at dual use airfields. Shoulder widths may be increased beyond the requirement in Table 5-3 when necessary to accommodate dual operations with fixed-wing aircraft.

Table 5-3. Rotary-Wing Taxiway Shoulders

Table 5-3. Rotary-Wing Taxiway Shoulders			
Item			
No.	Description	Requirement	Remarks
1	Total width of shoulder (paved and unpaved)	7.5 m (25 ft)	May be increased when necessary to accommodate dual operations with fixed-wing aircraft
2	Paved shoulder width adjacent to all rotary-wing taxiways	7.5 m (25 ft)	May be increased when necessary to accommodate dual operations with fixed-wing aircraft. See Note 4 where fire hydrants are installed along apron shoulders. Navy and Marine Corps CH-53 & V-22: Increase shoulder width to provide minimum 30 m (100 ft) total paved width (taxiways and shoulders.
3	Longitudinal grade	Variable	Conform to the longitudinal grade of the abutting primary pavement.
4	Transverse grade	2.0% min 4.0% max	Slope downward from the edge of the pavement.
5	Grades within clear area (adjacent to paved shoulder)	(a) 40 mm (1.5 in) drop-off at edge of paved shoulder. (b) 2% min 5% max	Slope downward from the edge of the shoulder. For additional grading criteria in primary surface and clear areas, see Chapter 3 for fixed-wing facilities and Chapter 4 for rotary-wing facilities.

NOTES:

1. Metric units apply to new airfield construction and, where practical, modification to existing airfields and heliports, as discussed in paragraph 1-3.4.

2. The criteria in this manual are based on aircraft specific requirements and are not direct conversions from inch-pound (English) dimensions. Inch-pound units are included only as a reference to the previous standard.
3. Airfield and heliport imaginary surfaces and safe wingtip clearance dimensions are shown as a direct conversion from inch-pound to SI units.
4. Hydrants are to be “30-35 ft” outside the “Apron” edge. Provide paved access lane to fire hydrants where needed.

5-8 TAXIWAY INTERSECTION CRITERIA.

To prevent the main gear of an aircraft from coming dangerously close to the outside edge of the taxiway during a turn, fillets and lead-ins to fillets are provided at taxiway intersections. When an aircraft turns at an intersection, the nose gear of the aircraft usually follows the painted centerline marking. The main gears, located to the rear of the nose gear, do not remain a constant distance from the centerline stripe during the turn due to the physical design of the aircraft. The main gears pivot on a shorter radius than does the nose gear during a turn. Intersections should be designed to ensure that the main gear wheels stay a minimum of 3 m (10 ft) from the pavement edge. Intersection geometry can be determined using wheel-tracking simulation tools, or using the criteria described in paragraphs 5-8.1 and 5-8.2.

For rotary-wing taxiway intersections, use Table 5-4 and Table 5-5 with the appropriate taxiway width to determine the fillet dimensions.

For additional support see CE Dash Airfield geometrics page for report "Developing Aircraft Turning Templates" at https://cs2.eis.af.mil/sites/10159/SitePages/Service%20Page.aspx?Service=Airfield Geometry .

5-8.1 Fillet-Only Dimensions.

Fillets are required at runway-taxiway and taxiway-taxiway intersections. Fillets at runway-taxiway intersections are arcs installed in accordance with Table 5-4 and Figure 5-4. Fillets at taxiway-taxiway intersections are installed in accordance with Table 5-5 and Figure 5-5. Centerline and fillet radii used for these figures and tables are based on a 45.72-m (150-ft) centerline turning radius for runway/taxiway intersections and a 38.1-m (125-ft) centerline turning radius for taxiway/taxiway intersections using the geometry of the C-5 aircraft and a taxiway width of 22.86 m (75 ft). Larger centerline turning radii, other aircraft (e.g. Boeing 747-800 or Airbus A380), or narrower taxiways may require larger fillets; therefore, the designer must consider the most demanding situation and ensure the 3 m (10 ft) edge safety margin is provided. Use of these specific criteria are not mandatory.

Table 5-4. Runway/Taxiway Intersection Fillet Radii

Table 5-4. Runway/Taxiway Intersection Fillet Radii				
Runway Width	**Taxiway Width**	**Fillet Radius**	**Fillet Radius**	**Fillet Radius**
W	**T**	**R1**	**R2**	**R3**
More than 22.86 m (75 ft) but less than 45.72 m (150 ft)	22.86 m (75 ft)	45.72 m (150 ft)	38.1 m (125 ft)	76.2 m (250 ft)
45.72 m (150 ft) or more	22.86 m (75 ft)	38.1 m (125 ft)	38.1 m (125 ft)	76.2 m (250 ft)
More than 22.86 m (75 ft) but less than 45.72 m (150 ft)	15.24 m (50 ft)	18.29 m (60 ft)	18.29 m (60 ft)	18.29 m (60 ft)
45.72 m (150 ft) or more	15.24 m (50 ft)	15.24 m (50 ft)	15.24 m (50 ft)	15.24 m (50 ft)
More than 22.86 m (75 ft) but less than 45.72 m (150 ft)	12.19 m (40 ft)	15.24 m (50 ft)	15.24 m (50 ft)	15.24 m (50 ft)
45.72 m (150 ft) or more	12.19 m (40 ft)	15.24 m (50 ft)	15.24 m (50 ft)	15.24 m (50 ft)

Table 5-5. Taxiway/Taxiway Intersection and Taxiway Turns Fillet Radii

Table 5-5. Taxiway/Taxiway Intersection and Taxiway Turns Fillet Radii			
Taxiway Width	**Fillet Radius**	**Fillet Radius**	**Fillet Radius**
W	**R4**	**R5**	**R6**
22.86 m (75 ft)	45.72 m (150 ft)	38.1 m (125 ft)	76.2 m (250 ft)
15.24 m (50 ft)	18.29 m (60 ft)	12.19 m (40 ft)	27.43 m (90 ft)
12.19 m (40 ft)	18.29 m (60 ft)	12.19 m (40 ft)	27.43 m (90 ft)

Figure 5-4. Runway/Taxiway Intersection Fillets

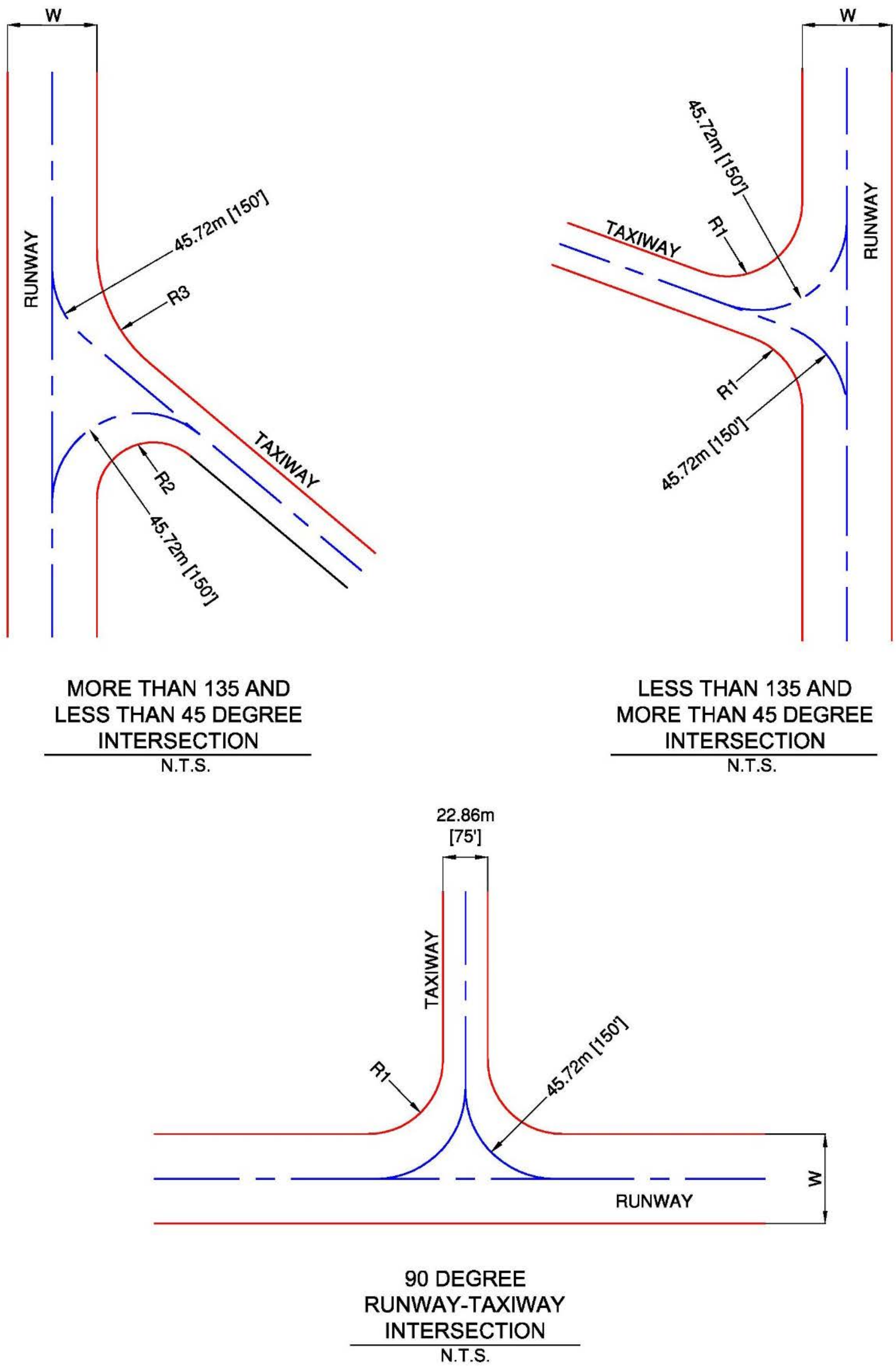
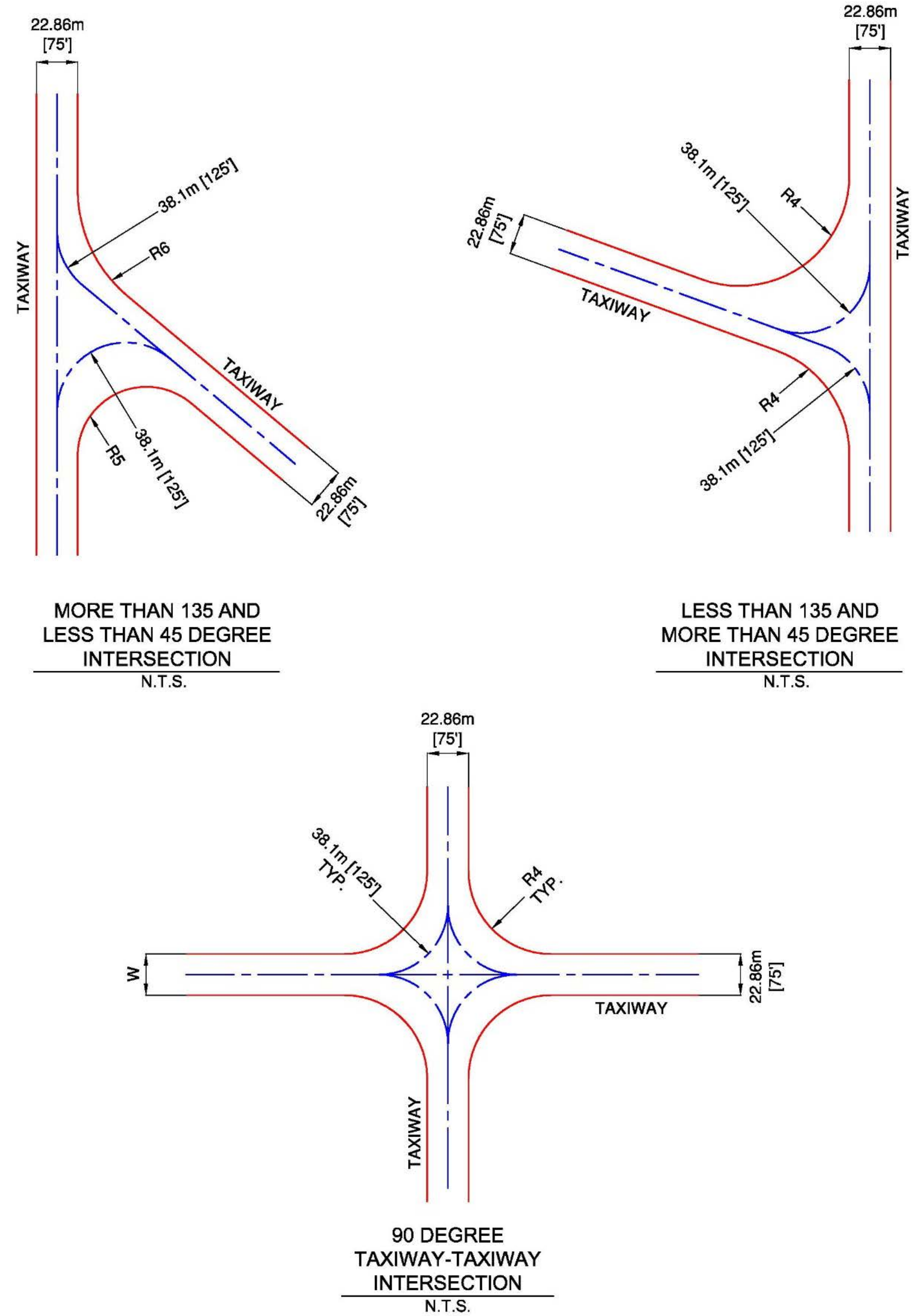


Figure 5-5. Taxiway/Taxiway Intersection Fillets



5-9 HIGH-SPEED RUNWAY EXITS.

If peak operations are expected to exceed 30 takeoffs and landings per hour, aircraft may be required to exit runways at greater than normal taxi speeds to maintain airfield capacity. In these cases, an acute-angle exit taxiway may be required. Air Force designers should contact their MAJCOM pavements engineer or Headquarters Air Force Civil Engineer Center for assistance. Army designers should contact the U.S. Army Corps of Engineers Transportation Systems Center (USACE-TSC). Navy and Marine Corps designers may use the criteria for transport aircraft provided in FAA AC 150/5300-13.

5-10 APRON ACCESS TAXIWAYS.

Apron access taxiways are provided for aircraft access onto an apron. The number of apron access taxiways should allow sufficient capacity for departing aircraft. The apron access taxiways should be located to enhance the aircraft's departing sequence and route.

5-10.1 Parking Aprons.

The minimum number of apron access taxiways for any parking apron will be two. For the USAF, the minimum may be one if a single access taxiway will not inhibit planned operations.

5-10.2 Fighter Aircraft Aprons.

Three apron access taxiways should be provided for aprons with over 24 parked fighter aircraft. Four entrance taxiways should be provided for aprons with over 48 parked fighter aircraft.

5-11 SHOULDERS.

Shoulders are provided along a taxiway to allow aircraft to recover if they leave the paved taxiway. Paved shoulders prevent erosion caused by jet blast, support an occasional aircraft that wanders off the taxiway, support vehicular traffic, and reduce maintenance of unpaved shoulder areas.

5-11.1 Fixed-Wing Taxiways.

The shoulder for fixed-wing taxiways may be either paved or unpaved, depending on the agency, class of runway, and type of aircraft. Criteria for fixed-wing taxiway shoulders, including widths and grading requirements to prevent the ponding of storm water, are presented in Table 5-1. See Paragraph 2-12 for requirements for designing buried utility structures in shoulders.

5-11.2 Rotary-Wing Taxiways.

Paved shoulders are required adjacent to rotary-wing taxiways to prevent blowing dust and debris due to rotor-wash. The criteria for a rotary-wing taxiway shoulder layout, including shoulder width, cross slopes, and grading requirements, are presented in Table 5-3.

5-12 TOWWAYS.

A towway is used to tow aircraft from one location to another or from an apron to a hangar.

5-12.1 Dimensions.

Table 5-6 presents the criteria for towway layout and design, including clearances, slopes, and grading dimensions. When designing for access to a hangar, flare the pavement to the width of the hangar door from a distance beyond the hangar sufficient to allow maintenance personnel to turn the aircraft around.

5-12.2 Layout.

A typical transverse cross-section of a towway is shown in Figure 5-6.

5-12.3 Existing Roadway.

When existing roads or other pavements are modified for use as towways, provide for necessary safety clearances, pavement strengthening (if required), and all other specific requirements set forth in Table 5-6 and Figure 5-6.

5-13 HANGAR ACCESS.

The pavement that allows access from the apron to the hangar is referred to as a “hangar access apron” and is discussed in more detail in Chapter 6.

Table 5-6. Towways

Table 5-6. Towways				
Item		Class A Runway	Class B Runway	
No.	Description	Requirement		Remarks
1	Width	(outside gear width of towed mission aircraft) +3 m (10 ft)		Army and Air Force facilities 1.5 m (5 ft) on each side of gear
		11 m (36 ft)		Navy and Marine Corps facilities for carrier aircraft
		12 m (40 ft)		Navy and Marine Corps facilities for patrol and transport aircraft

Table 5-6. Towways				
Item		Class A Runway	Class B Runway	
No.	Description	Requirement		Remarks
		10.7 m (35 ft)		Navy and Marine Corps facilities for rotary-wing aircraft
2	Total width of shoulders (paved and unpaved)	7.5 m (25 ft)		
3	Paved shoulder width	Not Required		If provided: 2.0% min. and 4.0% max.
4	Longitudinal grade of towway	Max 3.0%		Grades may be both positive and negative but must not exceed the limit specified.
5	Rate of longitudinal grade change per 30 m (100 ft)	Max 1.0%		The minimum distance between two successive PI is 150 m (500 ft). Changes are to be accomplished by means of vertical curves. For the Air Force and Army, up to a 0.4% change in grade is allowed without a vertical curve. A vertical curve is not necessary where a taxiway crosses a runway or taxiway crown.
6	Longitudinal sight distance	N/A (See note 1.)		
7	Transverse grade	Min 2.0% Max 3.0%		Pavement crowned at towway centerline Slope pavement downward from centerline of towway.
8	Towway turning radius	46 m (150 ft) radius		Criteria presented here are for straight sections of towway. Pavement width and horizontal clearance lines may need to be increased at horizontal curve locations, based on aircraft alignment on the horizontal curve.
9	Fillet radius at intersections	30 m (100 ft) radius		
10	Transverse grade of unpaved shoulder	(a) 40 mm (1.5 in) drop-off at edge of pavement, +/- 13 mm (0.5 in). (b) 2.0% min, 4.0% max.		
11	Horizontal clearance from towway centerline to fixed or mobile obstacles	The greater of: (½ the wing span width of the towed mission aircraft + 7.6 m [25 ft]); or the minimum of 18.25 m (60 ft)		Army and Air Force facilities for fixed-wing aircraft
		15 m (50 ft)		Navy and Marine Corps facilities for carrier aircraft

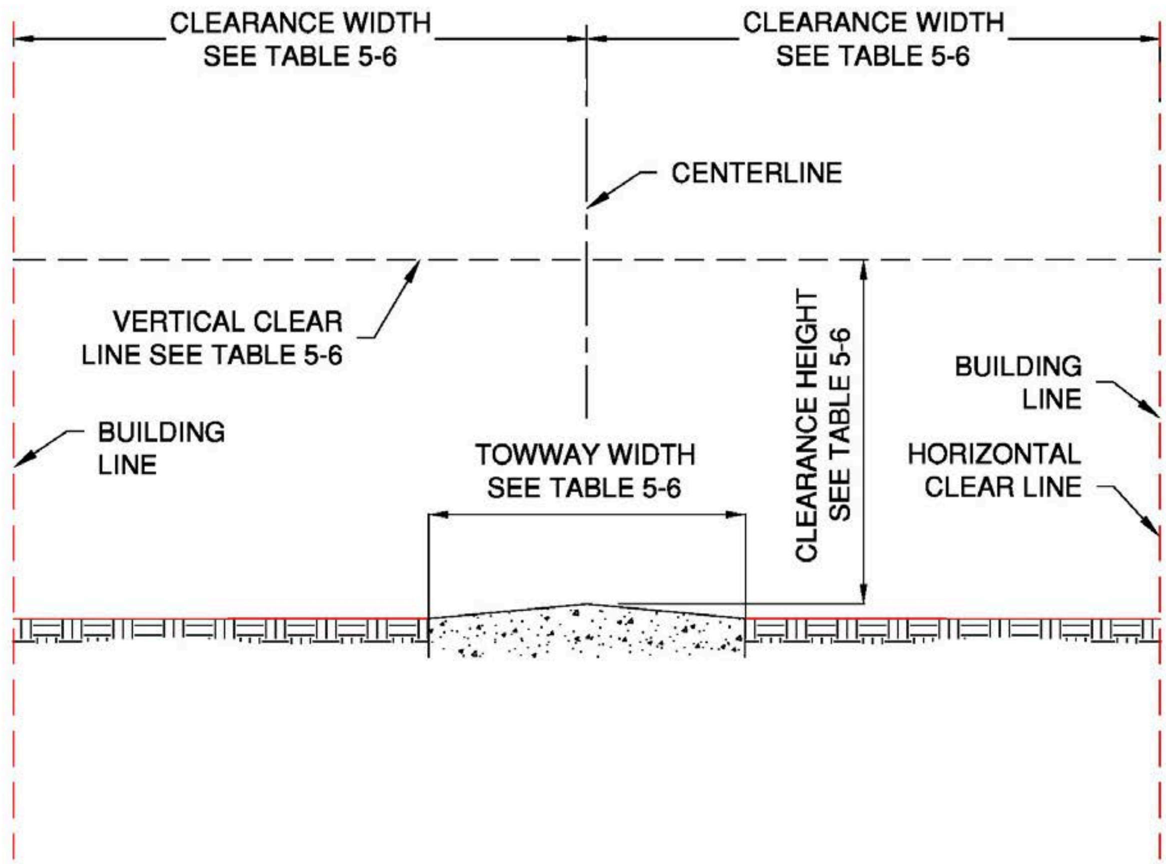
Table 5-6. Towways

Item		Class A Runway	Class B Runway	Remarks
No.	**Description**	**Requirement**		
		23 m (75 ft)		Navy and Marine Corps facilities for patrol and transport aircraft
		14 m (45 ft)		Army, Navy, and Marine Corps facilities for rotary-wing aircraft
12	Vertical clearance from towway pavement surface to fixed or mobile obstacles	(Height of towed mission aircraft) + 3 m (10 ft)		Army and Air Force facilities
		7.5 m (25 ft)		Navy and Marine Corps facilities for carrier aircraft
		14 m (45 ft)		Navy and Marine Corps facilities for patrol and transport aircraft
		9 m (30 ft)		Navy and Marine Corps facilities for rotary-wing aircraft
13	Grade (area between towway shoulder and towway clearance line)	Min of 2.0% prior to channelization Max 10%. (See note 2.)		

NOTES:

1. N/A = not applicable
2. Bed of channel may be flat.
3. Metric units apply to new airfield construction and, where practical, modification to existing airfields and heliports, as discussed in paragraph 1-3.4.
4. The criteria in this manual are based on aircraft specific requirements and are not direct conversions from inch-pound (English) dimensions. Inch-pound units are included only as a reference to the previous standard.
5. Airfield and heliport imaginary surfaces and safe wingtip clearance dimensions are shown as a direct conversion from inch-pound to SI units.

Figure 5-6. Towway Criteria



TYPICAL CROSS SECTION
(SHOWING SAFETY CLEARANCES)
N.T.S.

Table 5-7. Taxitraks

Table 5-7. Taxitraks			
Item			
No.	Description	Requirement	Remarks
1	Total width of shoulder (paved and unpaved)	15 m (50 ft)	
2	Paved shoulder width adjacent to all operational pavements	7.5 m (25 ft)	Match Runway criteria by airfield. Air Force taxiways devoted exclusively for fighter and trainer aircraft may reduce to 3m (10 ft)
3	Clearance from centerline to fixed and mobile obstacles	Min 45.72 m (150 ft)	See Table 3-2, item 12, for obstacle definition.
4	Longitudinal grade	-3.0% min 3.0% max	
5	Transverse grade	1.5% min 2.0% max	Slope downward from the centerline.
6	Transverse grade - Shoulder	1.5% min 3.0% max	Slope downward from the edge of the pavement.
7	Horizontal Curves	76 m (250 ft)	

NOTES:

1. Metric units apply to new airfield construction and, where practical, modification to existing airfields and heliports, as discussed in paragraph 1-3.4.
2. The criteria in this manual are based on aircraft specific requirements and are not direct conversions from inch-pound (English) dimensions. Inch-pound units are included only as a reference to the previous standard.

CHAPTER 6
APRONS AND OTHER PAVEMENTS

6-1 CONTENTS.

This chapter presents design standards for fixed- and rotary-wing aircraft parking aprons, access aprons, maintenance pads, and wash racks. It provides minimum wingtip clearance requirements, grades, and lateral clearance standards, as well as typical aircraft parking arrangements. The general principles of this chapter apply to the Navy and Marine Corps. Specific data for Navy and Marine Corps aprons is contained in the referenced publications. See Figures 6-43 and 6-44 and Tables 6-7 through 6-10 for Navy and Marine Corps aircraft parking apron criteria (taken from UFC 2-000-5N).

6-2 APRON REQUIREMENTS.

Aprons must provide sufficient space for parking fixed- and rotary-wing aircraft. They should be sized to allow safe movement of aircraft under their own power. During design, consider the effects of jet blast turbulence and temperature. Programming requirements for Air Force aviation facilities are provided in AFMAN 32-1084. Requirements for Navy and Marine Corps aviation facilities are contained in UFC 2-000-05N and UFC 3-260-02. The general principles of this chapter apply to the Navy and the Marine Corps. Specific data on Navy/Marine Corps aprons is contained in the referenced publications. Use High Temperature Concrete and neoprene joint sealants in locations where stationary V-22 nacelle exhaust exposure is ten minutes or greater. This will likely include but is not limited to fuel pits, warm-up areas, and aprons. Rinse facilities supporting V-22s must also include High Temperature Concrete due to heat and vapor flux.

6-3 TYPES OF APRONS AND OTHER PAVEMENTS.

Listed here are types of aprons and other aviation facilities:

- Aircraft parking apron
- Transient parking apron
- Mobilization apron
- Aircraft maintenance apron
- Hangar access apron
- Warm-up pad (holding apron)
- Unsuppressed power check pads
- Arm/dearm pad
- Compass calibration pad
- Hazardous cargo pad

- Alert pad
- Aircraft wash rack

6-4 AIRCRAFT CHARACTERISTICS.

Dimensional characteristics of various military, civil, and commercial fixed- and rotary-wing aircraft are available in TSC Report 13-2 (Aircraft Characteristics for Military Aircraft) and in TSC Report 13-3 (Aircraft Characteristics for Selective Commercial Aircraft).

6-5 PARKING APRON FOR FIXED-WING AIRCRAFT.

Fixed-wing parking at an aviation facility may consist of separate aprons for parking operational aircraft, transient aircraft, and transport aircraft, or an apron for consolidated parking.

6-5.1 Location.

Parking aprons should be located near and contiguous to maintenance and hangar facilities. Do not locate them within runway and taxiway lateral clearance distances. A typical parking apron is illustrated in Figure 6-1.

6-5.2 Size.

As a general rule, there are no standard sizes for aircraft aprons. Aprons are individually designed to support aircraft and missions at specific facilities. The actual dimensions of an apron are based on the number of authorized aircraft, the maneuvering space, and the type of activity that the apron serves. Air Force allowances are provided in AFMAN 32-1084. Army facility authorizations are discussed in RPLANS and applicable programming directives. The ideal apron size affords the maximum parking capacity with a minimum amount of paving. Generally, this is achieved by reducing the area dedicated for use as taxilanes by parking aircraft perpendicular to the long axis of the apron.

6-5.3 Army Parking Apron Layout.

6-5.3.1 Variety of Aircraft.

Where there are a large variety of fixed-wing aircraft types, fixed-wing aircraft mass parking apron dimensions will be based on the C-12J (Huron). The C-12J parking space width is 17 m (55 ft), and the parking space length is 18.25 m (60 ft).

6-5.3.2 Specific Aircraft.

If the assigned aircraft are predominantly one type, the mass parking apron will be based on the specific dimensions of that aircraft.

6-5.3.3 Layout.

Figure 6-2 illustrates a parking apron. These dimensions can be tailored for specific aircraft, including the C-12J.

6-5.4 Air Force Parking Apron Layout.

Parking apron dimensions for Air Force facilities will be based on the specific aircraft assigned to the facility and the criteria presented in AFMAN 32-1084. A typical mass parking apron should be arranged in rows as shown in Figure 6-2.

6-5.5 Layout for Combined Army and Air Force Parking Aprons.

Parking apron dimensions for combined Army and Air Force facilities will be based on the largest aircraft assigned to the facility.

6-5.6 Tactical/Fighter Parking Apron Layout.

The recommended tactical/fighter aircraft parking arrangement is to park aircraft at a 45-degree angle as discussed in AFMAN 32-1084. Arranging these aircraft at a 45-degree angle may be the most economical method for achieving the clearance needed to dissipate jet blast temperatures and velocities to levels that will not endanger aircraft or personnel (Figure 6-3). Jet blast relationships for tactical and fighter aircraft are discussed in TSC Report 13-2.

Figure 6-1. Apron Nomenclature and Criteria

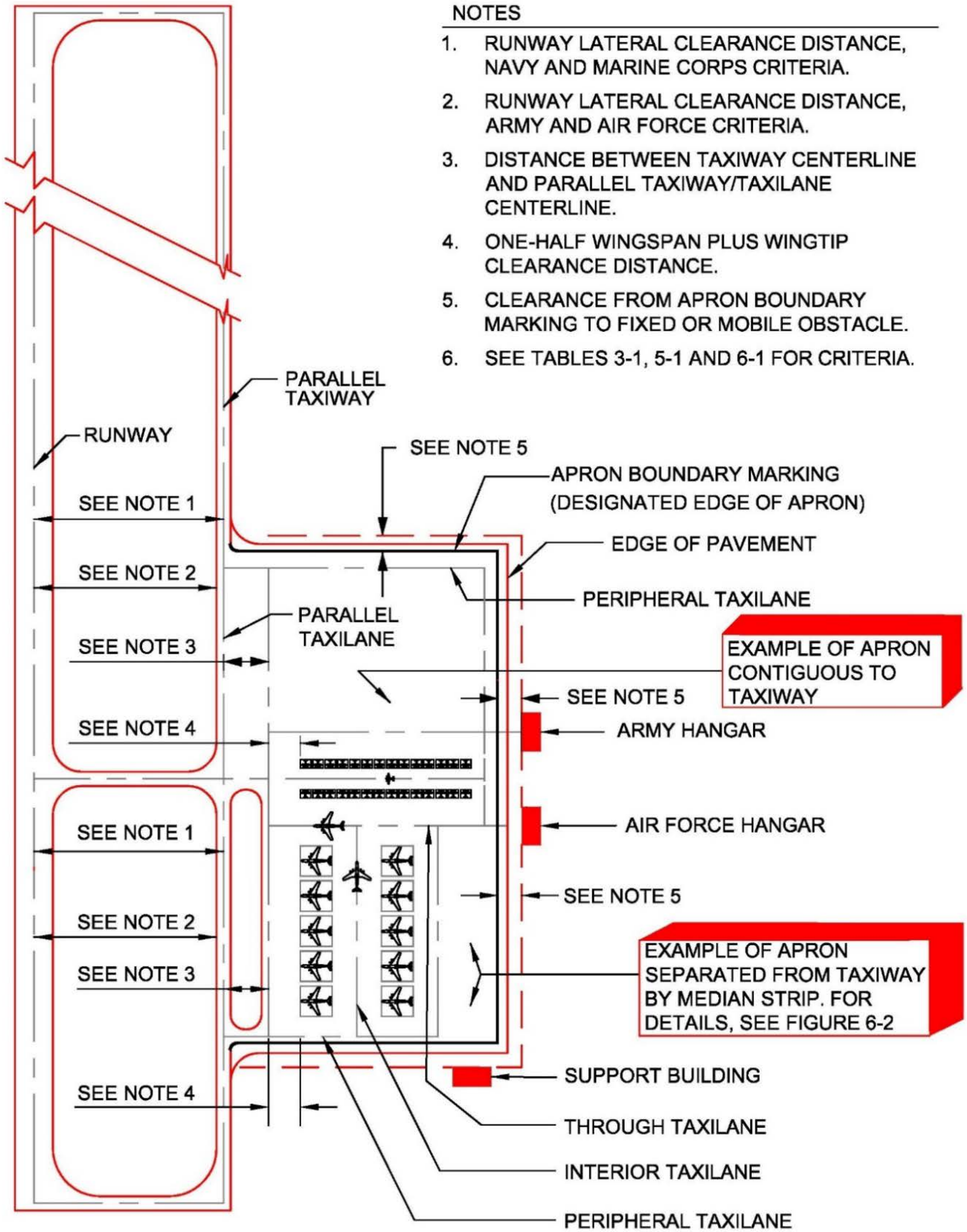
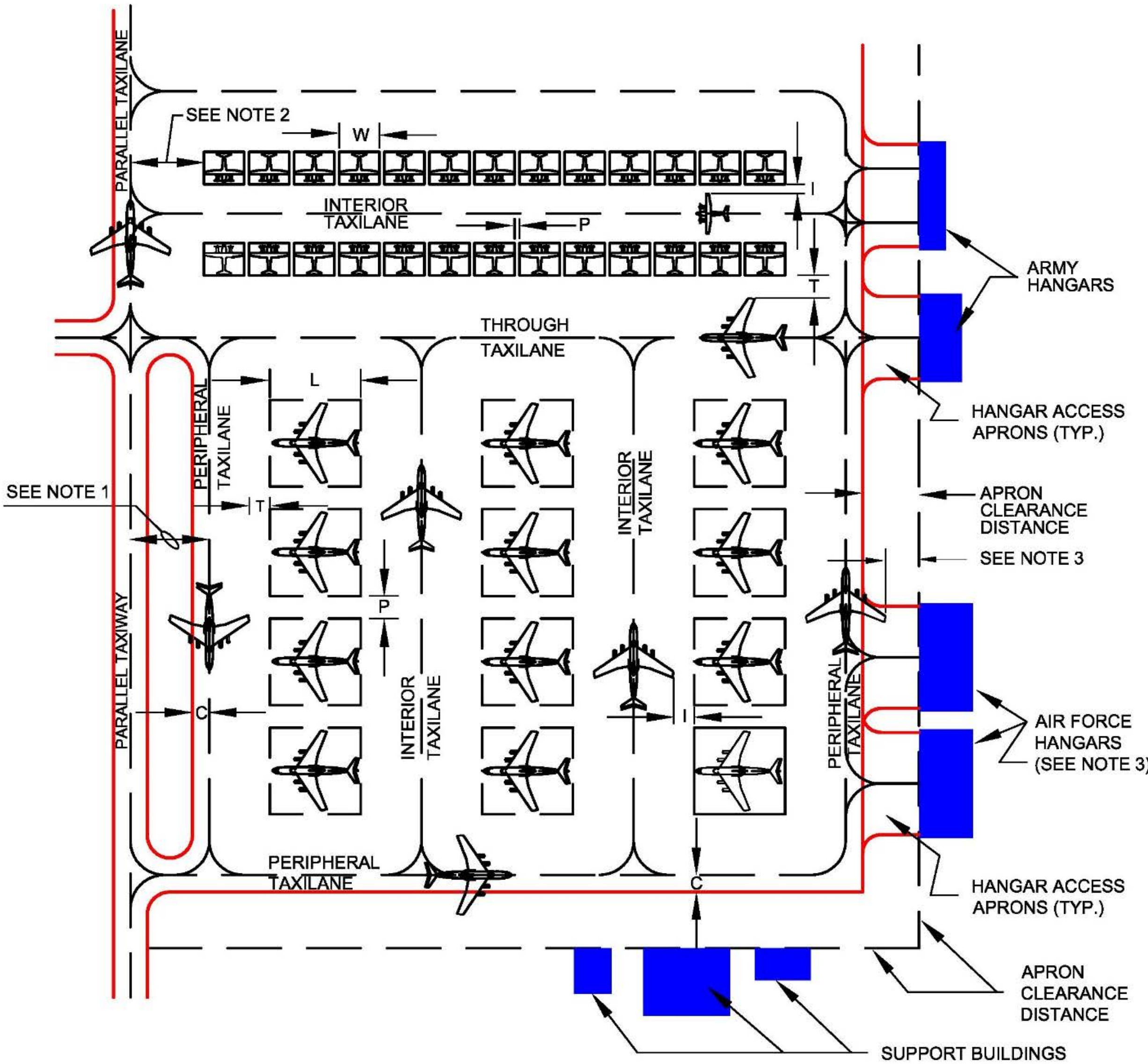


Figure 6-2. Army and Air Force Parking Plan



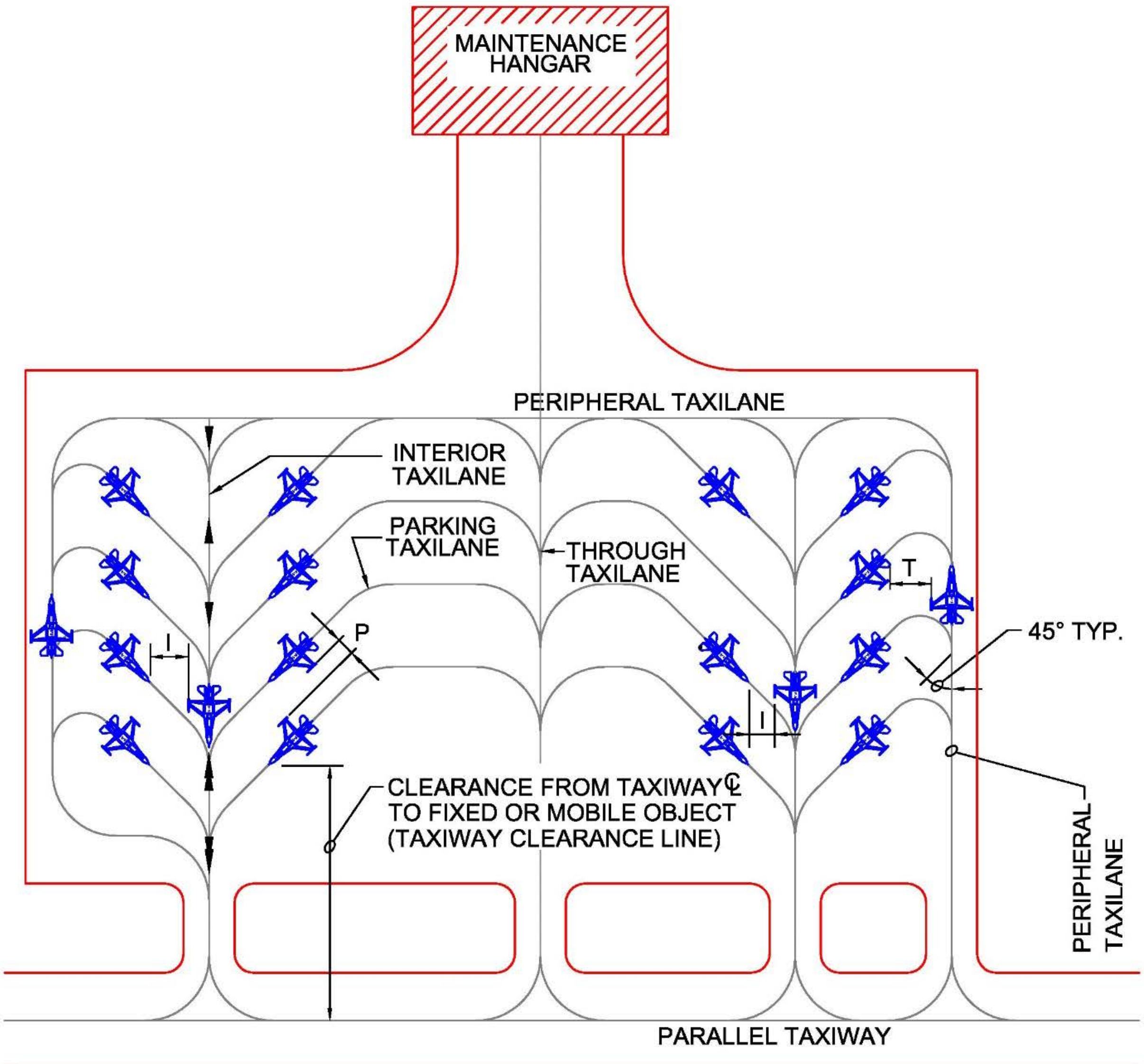
LEGEND

W -- AIRCRAFT WIDTH
L --AIRCRAFT LENGTH
I -- WINGTIP CLEARANCE FOR INTERIOR TAXILANE (MIN. TAXI CLEARANCE)
T -- WINGTIP CLEARANCE FOR THROUGH AND PRIMARY PERIPHERAL TAXILANES
P -- WINGTIP CLEARANCE FOR PARKED AIRCRAFT
C -- DISTANCE FROM PERIPHERALTAXILANE CENTERLINE TO APRON EDGE

NOTES:

1. TAXIWAY CLEARANCE DISTANCE AT FACILITIES WITH PARALLEL TAXIWAYS; SEE TABLE 5-1, ITEM 11.
2. SEE TABLE 6-1 FOR DIMENSIONAL DEFINITIONS.
3. FOR AIR FORCE: INSURE MINIMUM WINGTIP CLEARANCE IS PROVIDED TO HANGARS OR OTHER PERMISSIBLE DEVIATIONS (SEE TABLE 6-1 ITEMS 5, 6 AND 15, AND APPENDIX B, SECTION 13).

Figure 6-3. Apron with Diagonal Parking



NOTES

1. SEE TABLE 6-1 FOR DIMENSIONAL CRITERIA.
2. THIS PARKING ARRANGEMENT IS SHOWN FOR INFORMATION ONLY AND NOT NECESSARILY AN IDEAL PARKING ARRANGEMENT.

6-5.7 Refueling Considerations.

\1 Layout of aircraft parking locations and taxilanes should consider aircraft taxiing routes when an aircraft is refueled. Refueling operations should not prevent an aircraft from leaving the parking apron. Two routes in and out of the apron may be required. During refueling, active ignition sources such as sparks from ground support equipment or jet engines (aircraft) are prohibited from a zone around the aircraft. The Army and Air Force refer to this zone as the fuel servicing safety zone (FSSZ). The Navy and Marine Corps refer to this zone as the refueling safety zone (RSZ). An example of the RSZ around a fixed-wing aircraft is shown in Figure 6-4. The safety zone is the area within 15 m (50 ft) of a pressurized fuel carrying servicing component (e.g., servicing hose, fuel nozzle, single-point receptacle (SPR), hydrant hose car, ramp hydrant connection point) and 7.6 m (25 ft) around aircraft fuel vent outlets. The FSSZ is established and maintained during pressurization and movement of fuel. For additional information, see Air Force technical order (T.O.) 00-25-172*.* For additional Navy information, see MIL-HDBK-274. **/1/**

6-5.8 Parking Dimensions.

Table 6-1 presents the minimum geometric criteria for fixed-wing apron design. When designing new aprons for AMC bases hosting C-5 and C-17 aircraft, provide 15.3 m (50 ft) of wingtip separation. EXCEPTION: When you are rehabilitating an existing apron, provide the maximum wingtip separation the existing apron size will allow up to 15.3 m (50 ft), but not less than 7.7 m (25 ft). This additional separation is both desirable and permitted. At non-AMC bases, the maximum separation that can reasonably be provided for these aircraft is desirable.

6-5.8.1 Jet Blast Considerations.

The clearances listed in Table 6-1 do not consider the effects of temperature and velocity due to jet blast. The effects of jet blast and the minimum standoff distance to the edge of the pavement are described in Appendix B, Section 7.

6-5.8.2 Cargo Loading Considerations.

Consider the effects of jet blast on aircraft loading operations and cargo storage locations when you design a layout for parking cargo aircraft.

6-5.9 Tie-downs and Mooring Points.

Tie-downs or mooring points are required. See Appendix B, Section 11, for grounding requirements.

Figure 6-4. Truck Refueling Safety Zone Example

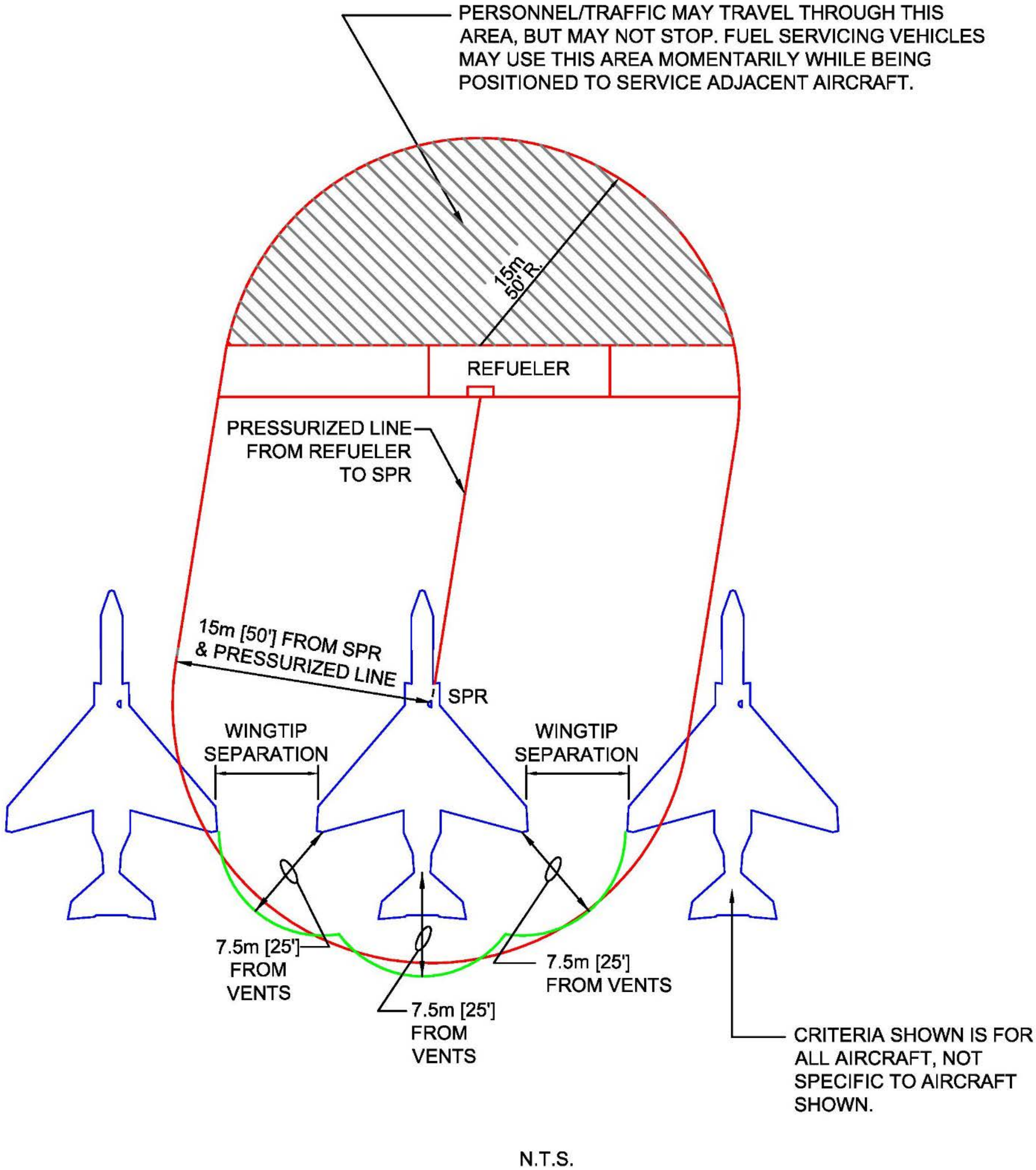


Table 6-1. Fixed-Wing Aprons

Table 6-1. Fixed-Wing Aprons				
Item		Class A Runway	Class B Runway	Remarks
No.	Description	Requirement		
1	Size and configuration	Variable For Army and Air Force requirements, see the criteria listed below and AFMAN 32-1084. For Navy and Marine Corps requirements, see UFC 2-000-05N .		As a general rule there are no standard sizes for aprons. They are individually designed to support specific aircraft uses. The dimensions are determined by the number and type of aircraft involved, the function of the apron, the maneuvering characteristics of the aircraft, the jet blast of the aircraft, and the degree of unit integrity to be maintained. Other determinants are the physical characteristics of the site, the relationship of the apron area to other airfield facilities, and the objective of the comprehensive plan.
2	Parking space width ("W")	Design aircraft wingspan		Army and Air Force airfields. For V-22 parking dimensions, see Figure 6-44.
3	Parking space length ("L")	Design aircraft length		Army and Air Force airfields. For V-22 parking dimensions, see Figure 6-44.
4	Wingtip clearance of parked aircraft ("P")	3.1 m (10 ft)		Army and Air Force airfields, aircraft with wingspans up to 33.5 m (110 ft) For V-22 wingtip clearances, see Figure 6-44.
		6.1 m (20 ft)		Army and Air Force airfields, aircraft with wingspans of 33.5 m (110 ft) or more except as noted below See note 1 for USAF.
		7.7 m (25 ft)		Army and Air Force airfields, transient aprons, C-5 and C-17 aircraft (also see paragraph 6-5.8) See note 1 for USAF.
		15.3 m (50 ft)		Army and Air Force airfields, KC-10, KC-46 and KC-135 aircraft to accommodate refueling and defueling operations. See note 1 for USAF.

Table 6-1. Fixed-Wing Aprons				
Item		Class A Runway	Class B Runway	Remarks
No.	Description	Requirement		
5	Wingtip clearance of aircraft on interior or secondary peripheral taxilanes ("I")	6.1 m (20 ft)		Army and Air Force airfields, aircraft with wingspans up to 33.5 m (110 ft), except transient aprons. For V-22 wingtip clearances, see Figure 6-44. Taxilanes that provide access to individual parking spots or hangars are considered secondary taxi routes. See note 1 for USAF.
		7.7 m (25 ft)		Army and Air Force airfields, transient aprons. Taxilanes that serve multiple types of aircraft or serve to provide circulation beyond access to individual parking spots or hangars are considered primary facilities. See note 1 for USAF. For V-22 wingtip clearances, see Figure 6-44.
		9.2 m (30 ft)		Army and Air Force airfields, aircraft with wingspans of 33.5 m (110 ft) or more, except transient aprons Taxilanes that serve multiple types of aircraft or serve to provide circulation beyond access to individual parking spots or hangars are considered primary facilities. See note 1 for USAF.
6	Wingtip clearance of aircraft on through or primary peripheral taxilanes ("T")	9.2 m (30 ft)		Army and Air Force airfields, aircraft with wingspans up to 33.5 m (110 ft). For V-22 wingtip clearances, see Figure 6-44. Taxilanes that serve multiple types of aircraft or serve to provide circulation beyond access to individual parking spots or hangars are considered primary facilities. See note 1 for USAF.
		Min 15.3 m (50 ft)		Army and Air Force airfields, aircraft with wingspans of 33.5 m (110 ft) or more Taxilanes that serve multiple types of aircraft or serve to provide circulation beyond access to individual parking spots or hangars are considered primary facilities. See note 1 for USAF.

Table 6-1. Fixed-Wing Aprons

Item No.	Item Description	Class A Runway Requirement	Class B Runway Requirement	Remarks
7	Distance from peripheral taxilane centerline to the outside edge of the apron boundary marking ("C")	7.7 m (25 ft)		Army and Air Force airfields Designed for aircraft with wingspan up to 33.5 m (110 ft). For V-22 wingtip clearances, see Figure 6-44.
		11.5 m (37.5 ft)		Army and Air Force airfields Designed for aircraft with wingspan of 33.5 m (110 ft) and greater
8	Clear distance around aircraft during fueling (see paragraph 6-5.7.)	7.7 m (25 ft)		Around aircraft fuel vent outlets (see T.O. 00-25-172).
		15.3 m (50 ft)		From a pressurized fuel carrying servicing component (see T.O. 00-25-172).
		See Remarks		Consider refueling operations when locating taxilanes.
9	Grades in the direction of drainage	Min 0.5% Max 1.5%		Avoid surface drainage patterns with numerous or abrupt grade changes that can produce excessive flexing of aircraft and structural damage. Lateral and transverse slopes must be combined to derive maximum slope in the direction of drainage. (i.e., the square root of the transverse slope squared plus longitudinal slope squared is equal to the slope in the direction of drainage.) For the Air Force, no grade changes are allowed for individual parking positions within the aircraft block dimensions (not including clearance distances) of the design aircraft. Exceptions are allowed for fuel hydrant pits.
10	Width of shoulders (total width including paved and unpaved)	7.5 m (25 ft)	15 m (50 ft)	Army and Air Force airfields
11	Paved width of shoulders	7.5 m (25 ft)	7.5 m (25 ft)	Army and Air Force airfields not otherwise specified. For apron shoulders where fire hydrants must be installed, see Note 5 and Appendix B, Section 13, for the minimum set back from the taxilane centerline.

Table 6-1. Fixed-Wing Aprons				
Item		Class A Runway	Class B Runway	Remarks
No.	Description	Requirement		
		N/A	15 m (50 ft)	Army and Air Force airfields that accommodate B-52, C-5, E-4, and 747 aircraft. For apron shoulders where fire hydrants must be installed, see Note 5 and Appendix B, Section 13, for the minimum set back from the taxilane centerline.
12	Longitudinal grade of shoulders	Variable		Conform to longitudinal grade of the abutting primary pavement.
13	Transverse grade of paved shoulder	Min 2.0% Max 4.0%		Army airfields and Air Force airfields not otherwise specified
		N/A	Min 1.5% Max 2.0%	Air Force airfields that accommodate B-52 aircraft
14	Transverse grade of unpaved shoulders	N/A	(a) 40 mm (1.5 in) drop-off at edge of paved shoulder, +/- 13 mm (0.5 in). (b) 2.0% min, 4.0% max.	Unpaved shoulders shall be graded to provide positive surface drainage away from paved surfaces.
15	Clearance from apron boundary marking to fixed or mobile obstacles	Variable		Compute this distance by multiplying 0.5 x the wingspan of the most demanding aircraft that will use the apron and add the appropriate wingtip clearance required by item 5 or 6. Then subtract the distance from the taxilane centerline to the outside edge of the apron boundary marking (item 7) to find the required clear distance. This distance is to be clear of all fixed and mobile obstacles except as specifically noted in Appendix B, Section 13, even if there is no peripheral taxilane along the edge of apron. This clear distance is required for safety purposes. **NOTES:** 1. Light poles are not allowed within this distance without waiver. 2. Implement operational controls to ensure that aircraft larger than the design aircraft do not use the apron without wing-walkers. Publish this information in the airfield operating instruction.

Table 6-1. Fixed-Wing Aprons				
Item		Class A Runway	Class B Runway	Remarks
No.	Description	Requirement		
				3. Submit a revised summary of airfield restrictions to allow update to the AMC Airfield Suitability and Restrictions Report. Mail the revision to: HQ AMC/A3AS 402 Scott Drive Unit 3A1 Scott AFB IL 62225-5302
16	Grades in cleared area beyond shoulders to fixed or mobile obstacles	(a) 40 mm (1.5 in) drop-off at edge of paved shoulder, +/- 13 mm (0.5 in). (b) Min 2% Max 10% .	Min 2% Max 10.0%	40 mm (1.5–in) drop-off (+/- 13 mm (0.5 in)) at edge of pavement when the entire shoulder is paved. When a slope reversal is required within this area, a flat bottom ditch that is graded to drain adequately shall be provided.

NOTES:
1. Air Force wingtip clearances may be reduced to those allowed by AFI 11-218 with a waiver. A waiver will be granted only if no other viable options exist.
2. Metric units apply to new airfield construction and, where practical, to modifications to existing airfields and heliports, as discussed in paragraph 1-3.4.
3. The criteria in this manual are based on aircraft specific requirements and are not direct conversions from inch-pound (English) dimensions. Inch-pound units are included only as a reference to the previous standard.
4. Airfield and heliport imaginary surfaces and safe wingtip clearance dimensions are shown as a direct conversion from inch-pound to SI units.
5. For apron edges where fire hydrants must be installed, widen paved shoulders to within 3 m (10 ft) of the hydrants to allow paved access for firefighting vehicles.
6. N/A = not applicable

6-6 TAXIING CHARACTERISTICS ON APRONS FOR FIXED-WING AIRCRAFT.

6-6.1 Apron Taxilanes.

Taxi routes across parking aprons, referred to as taxilanes, are marked on the apron for safe passage of the aircraft. Typical taxilane locations are illustrated in Figures 6-1, 6-2 and 6-3. Minimum wingtip clearances between parked and taxiing aircraft are shown in Table 6-1 (see Figure 6-2). AFI 11-218 provides authorization for operating aircraft at reduced clearances under certain circumstances. If a decision is made to reduce clearances based on this authorization, a waiver must be obtained in accordance with Appendix B, Section 1. Waivers should be pursued only when all avenues for compliance have been exhausted.

6-6.2 Turning Capabilities (Aircraft Turning and Maneuvering Characteristics).

TSC Report 13-2 (Aircraft Characteristics for Airfield Pavement Design and Evaluation Air Force and Army Aircraft) and TSC Report 13-3 (Aircraft Characteristics for Airfield Pavement Design and Evaluation Selective Commercial Aircraft) provide sources for obtaining various turning diagrams for US Army, Air Force, and numerous civil and commercial fixed-wing aircraft.

6-6.3 Departure Sequencing.

Egress patterns from aircraft parking positions to taxiways should be established to prevent congestion at the apron exits. For parking apron access taxiway requirements, see Chapter 5, section 5-10.

6-6.4 Minimum Standoff Distances from Edge Pavements.

See Appendix B, Section 7, for information on minimum standoff distances from edge pavements.

6-7 PARKING APRON FOR ROTARY-WING AIRCRAFT.

Mass parking of rotary-wing aircraft will require an apron designated for rotary-wing aircraft. Parking for transient rotary-wing aircraft and at aviation facilities where only a few rotary-wing aircraft are assigned, may be located on aprons for fixed-wing aircraft. At aviation facilities with assigned rotary-wing aircraft, a transport apron for fixed-wing aircraft is desirable.

6-7.1 Location.

Parking aprons for rotary-wing aircraft should be located similar to parking aprons for fixed-wing aircraft. Rotary-wing aprons must not be located within the lateral clearance distances discussed in Chapters 3 and 4 of this UFC. Generally, company and/or squadron units should be parked together in rows for organizational integrity in locations adjacent to their assigned hangars. Parking aprons for small helicopters (OH, UH, and AH) should be separate from parking areas used by cargo helicopters due to the critical operating characteristics of the larger aircraft.

6-7.2 Apron Size.

As with fixed-wing aircraft aprons, there is no standard size for rotary-wing aircraft aprons. The actual dimensions are based on the number of authorized aircraft, the maneuvering space, and the type of activity that the apron serves.

6-7.3 Maneuverability.

The layout of the rotary-wing parking spacing should allow aircraft access to these locations.

6-7.3.1 Approach.

Rotary-wing aircraft approach the parking spaces with either a front approach or a sideways (except USN/USMC) approach.

6-7.3.2 Undercarriage.

Rotary-wing aircraft are equipped with either a skid gear or wheel gear. Once on the ground, skid gear-equipped helicopters cannot be easily moved. Wheeled rotary-wing aircraft can be moved after they are on the ground.

6-7.4 Army Parking Apron Layout.

Rotary-wing aircraft are parked in one of two configurations, referred to as Type 1 or Type 2.

6-7.4.1 Type 1.

In this configuration, rotary-wing aircraft are parked in a single lane, which is perpendicular to the taxilane. In this configuration, the parking arrangement resembles that of fixed-wing aircraft. This parking arrangement is preferred for wheeled aircraft.

6-7.4.1.1 Parking Space, All Aircraft Except CH-47 and CH-53.

In the Type 1 configuration, the parking space dimensions for all rotary-wing aircraft except the CH-47 and CH-53 is a width of 25 m (80 ft) and a length of 30 m (100 ft). This is illustrated in Figure 6-5.

6-7.4.1.2 Parking Space, CH-47.

In the Type 1 configuration, the parking space dimensions for the CH-47 rotary-wing aircraft is a width of 30 m (100 ft) and a length of 46 m (150 ft). This is illustrated in Figure 6-6.

6-7.4.1.3 Parking Space, CH-53.

In the Type 1 configuration, the parking space dimensions for the CH-53 rotary-wing aircraft are a width of 37 m (120’) and a length of 50 m (165 ft). This is illustrated in Figure 6-7.

6-7.4.2 Type 2.

In this configuration, rotary-wing aircraft are parked in a double lane, which is parallel to the taxilane. This parking arrangement is preferred for skid-gear aircraft.

6-7.4.2.1 Parking Space, Skid-Gear Aircraft.

The parking space dimensions for all skid-gear rotary-wing aircraft in the Type 2 configuration is a width of 25 m (80 ft) and a length of 30 m (100 ft). This is illustrated in Figure 6-9.

6-7.4.2.2 Parking Space, Wheeled.

The parking space dimensions for all wheeled rotary-wing aircraft in the Type 2 configuration is a width of 30 m (100 ft) and a length of 50 m (160 ft). This is illustrated in Figure 6-10.

6-7.4.3 Barricades and Shelters.

Where barricades are provided between parking spaces or pull-through shelters are used, include an additional 8 m (26 ft) gap between parking spaces. This is illustrated in Figure 6-8.

6-7.5 Air Force Parking Apron Layout.

Rotary-wing aircraft at Air Force facilities are parked in a layout similar to that of fixed-wing aircraft. Parking space, taxilane, and clearance dimensions for Air Force facilities will be based on the rotor diameter of the specific aircraft assigned to the facility. For the Air Force, the wingtip clearance criteria provided in AFMAN 32-1084, Table 2.7, is preferred. However, USAF activities may use the Army criteria presented in this UFC for all rotary-wing aircraft except CH-53 and CH-54.

6-7.6 Refueling Considerations.

As discussed in paragraph 6-5.7, layout of aircraft parking locations and taxilanes should consider aircraft taxiing routes when an aircraft is refueled. There are two primary aircraft fueling systems used:

- Aircraft Direct-Refueling System
- Mobile Aircraft Refuelers

6-7.6.1 Aircraft Direct-Refueling System.

Aircraft direct fueling stations provide outlets located in the apron where aircraft can be fueled from closed circuit fuel system utilizing multi-arm pantographs or hydrant servicing vehicles (HSV). For design criteria, see UFC 3-460-01. Aircraft direct-refueling systems are designed primarily for “hot” refueling of aircraft.

6-7.6.1.1 Hot Refueling Criteria and Requirements.

Hot refueling is performed with engines running, it provides minimum aircraft turnaround times and reduces fueling personnel and equipment support requirements. However, it presents hazards not normally encountered during normal fueling operations. Hot refueling is performed while the fuel lines are under pressure. For the Air Force, hot refueling requires the approval of MAJCOM and will not be permitted unless individual aircraft technical order guidance, appropriate checklists and individual fueling systems are available. For additional information, see Air Force T.O. 00-25-172.

6-7.6.2 Mobile Aircraft Refuelers.

Mobile Aircraft Refuelers are tanker trucks of various capacities and configurations and are used primarily for normal (cold) fueling operations with occasional hot-refueling operations at stations where installation of a direct refueling system is not justified. If continuous or extensive hot fueling is being performed with mobile refuelers, the use of an anchored pantograph should be considered.

6-7.6.3 Safety Zone.

The safety zone for rotary-wing aircraft is the area 3 m (10 ft) greater than the area bounded by the blades and tail of the aircraft as shown on Figure 6-11 and Figure 6-12 for mobile aircraft refuelers and for aircraft direct-refueling system (pit). As shown for direct-refueling systems, the pit should be located outside of the aircraft safety zone, at a minimum, for safe operation. For additional information, see Air Force T.O. 00-25-172 and Navy UFC 2-000-05N.

6-7.6.4 Tie-downs and Mooring Points.

Tie-downs or mooring points are required. See Appendix B, Section 11, for grounding requirements.

6-7.7 Parking Dimensions.

Table 6-2 presents the criteria for rotary-wing apron design for Army airfields. Included in this table are parking space widths, grade requirements, and clearances. Criteria for rotary-wing apron design for the Air Force are presented in AFMAN 32-1084; for the Navy, they are in UFC 2-000-5N .

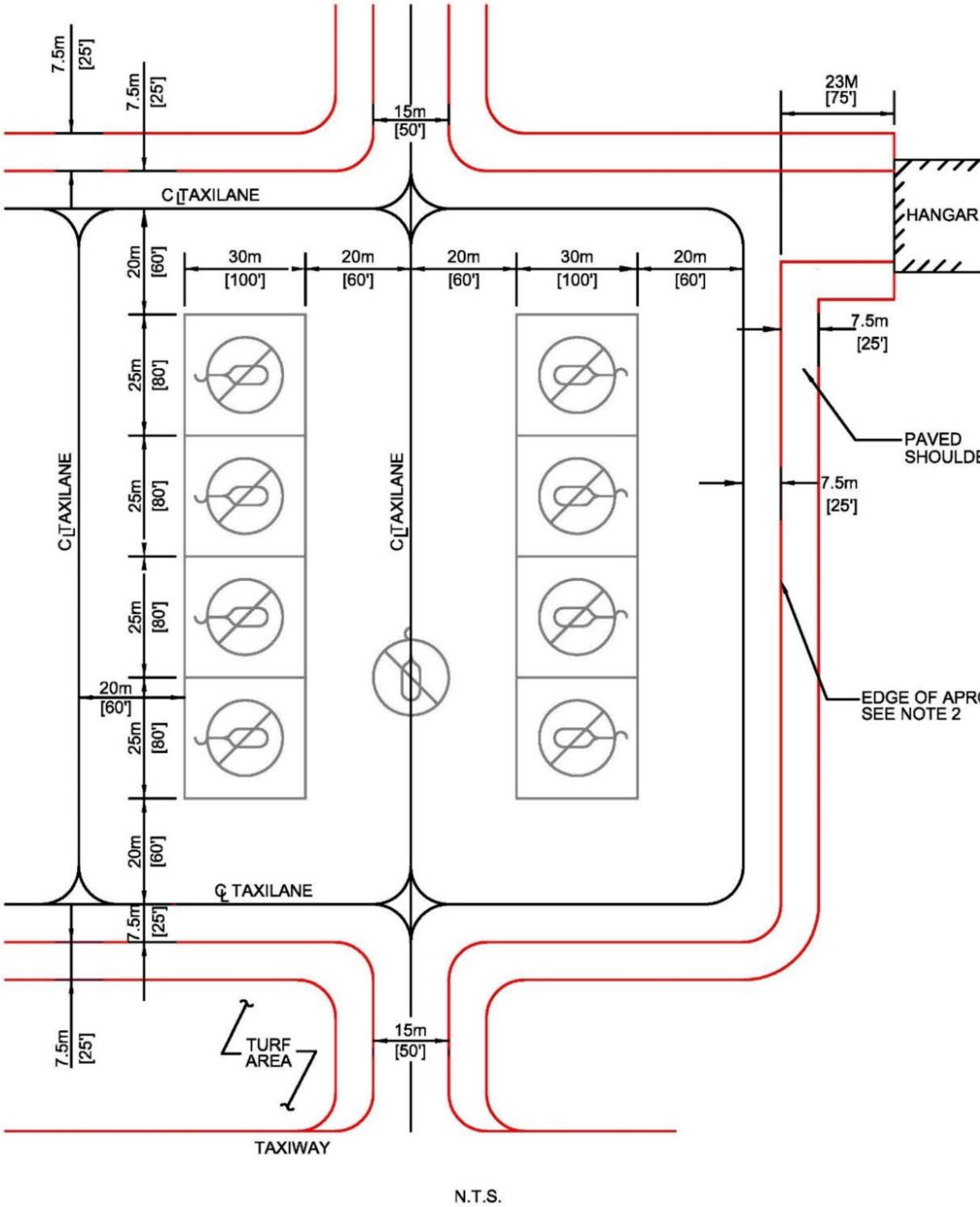
6-7.7.1 Distances between Parking Spaces.

The parking space dimensions, discussed in Table 6-2, include separation distances between parked aircraft. When laying out the rotary-wing parking spaces, the spaces should abut next to each other. Separation between rotors and the aircraft bodies is also included in the parking space dimensions.

6-7.7.2 Rotor Blade Clearances.

The taxilane and hoverlane dimensions in Table 6-2 provide adequate rotor blade clearances for the size of helicopter noted.

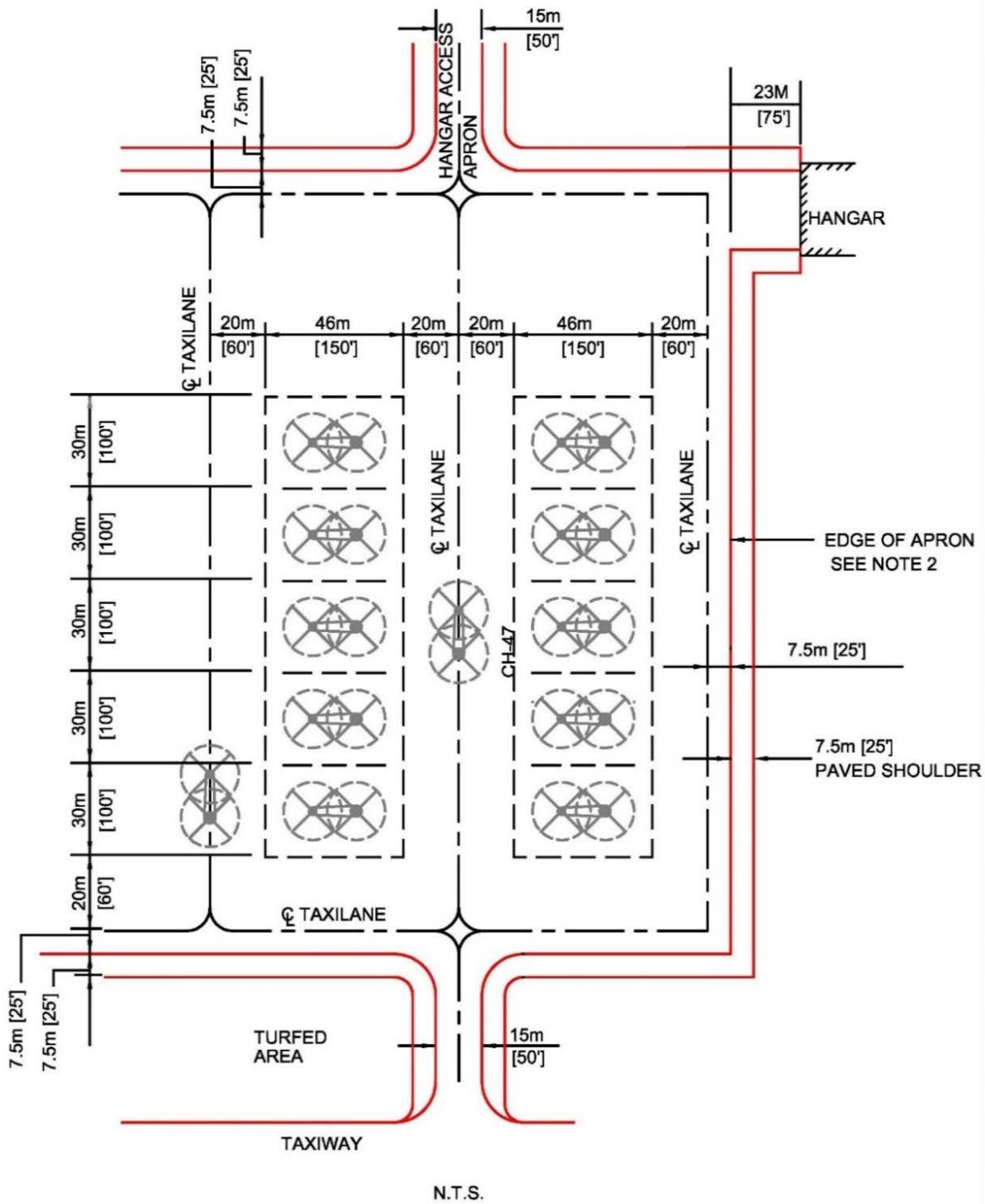
Figure 6-5. Type 1 Parking for All Rotary-Wing Aircraft Except CH-47



NOTES:

1. THE DASHED LINES FORMING BOXES AROUND THE PARKING POSITIONS SHOW THE LIMITS OF THE SAFETY ZONE AROUND THE PARKED AIRCRAFT. AIRCRAFT ARE TO BE PARKED IN THE CENTER OF THE BOX TO PROVIDE THE PROPER TAXILANE CLEARANCES.
2. EDGE OF APRON IS DEFINED AS EDGE OF A PARKED AIRCRAFT BLOCK OR EDGE OF A PERIMETER TAXIWAY.

Figure 6-6. Type 1 Parking for CH-47



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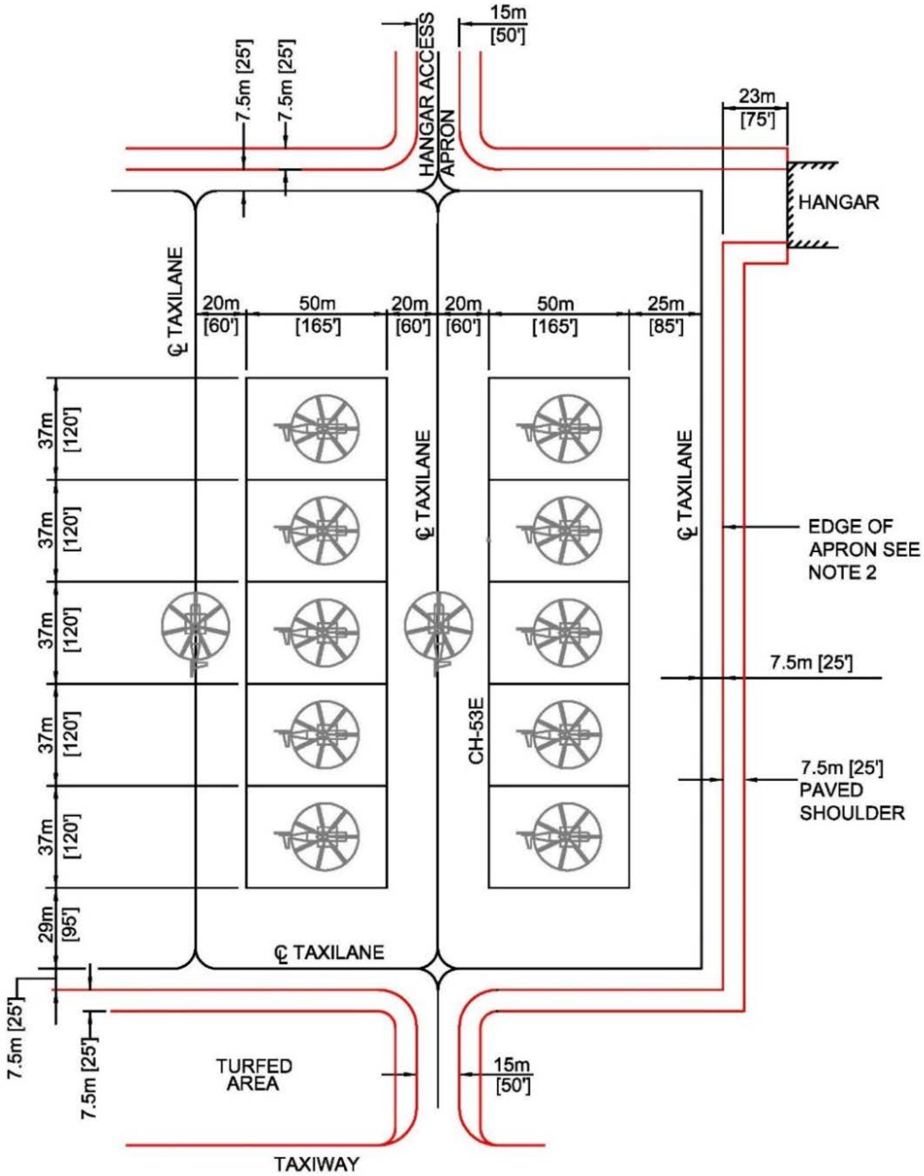
1. THE DASHED LINES FORMING BOXES AROUND THE PARKING POSITIONS SHOW THE LIMITS OF THE SAFETY ZONE AROUND THE PARKED AIRCRAFT. AIRCRAFT ARE TO BE PARKED IN THE CENTER OF THE BOX TO PROVIDE PROPER TAXILANE CLEARANCES.

2. EDGE OF APRON IS DEFINED AS EDGE OF A PARKED AIRCRAFT BLOCK OR EDGE OF A PERIMETER TAXIWAY.

Figure 6-7. Army Type 1 Parking for CH-53

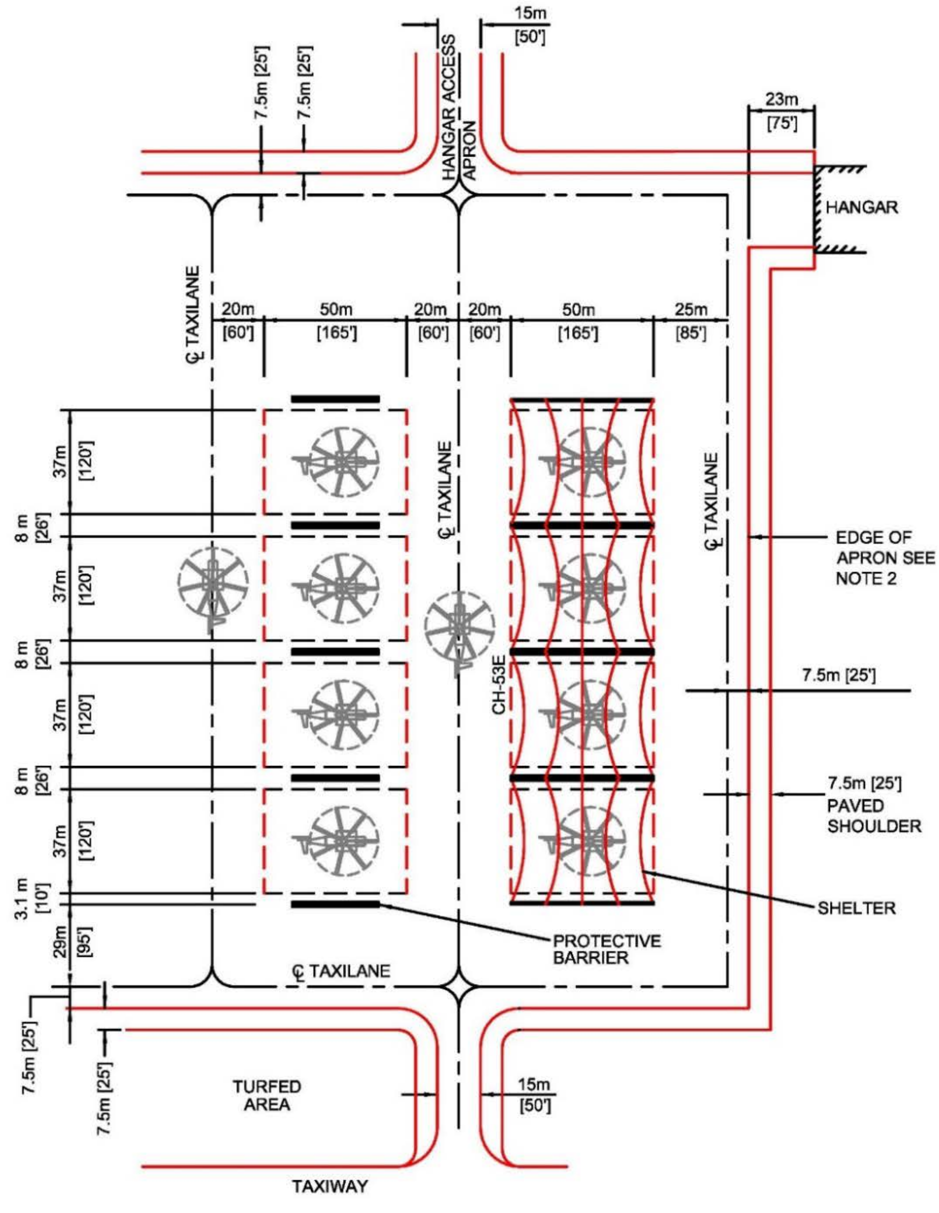


PLAN VIEW
N.T.S.

NOTES

1. THE DASHED LINES FORMING BOXES AROUND THE PARKING POSITIONS SHOW THE LIMITS OF THE SAFETY ZONE AROUND THE PARKED AIRCRAFT. AIRCRAFT ARE TO BE PARKED IN THE CENTER OF THE BOX TO PROVIDE PROPER TAXILANE CLEARANCES.
2. EDGE OF APRON IS DEFINED AS EDGE OF A PARKED AIRCRAFT BLOCK OR EDGE OF A PERIMETER TAXIWAY.

Figure 6-8. Army Type 1 Parking for CH-53 with Protective Barriers or Shelters

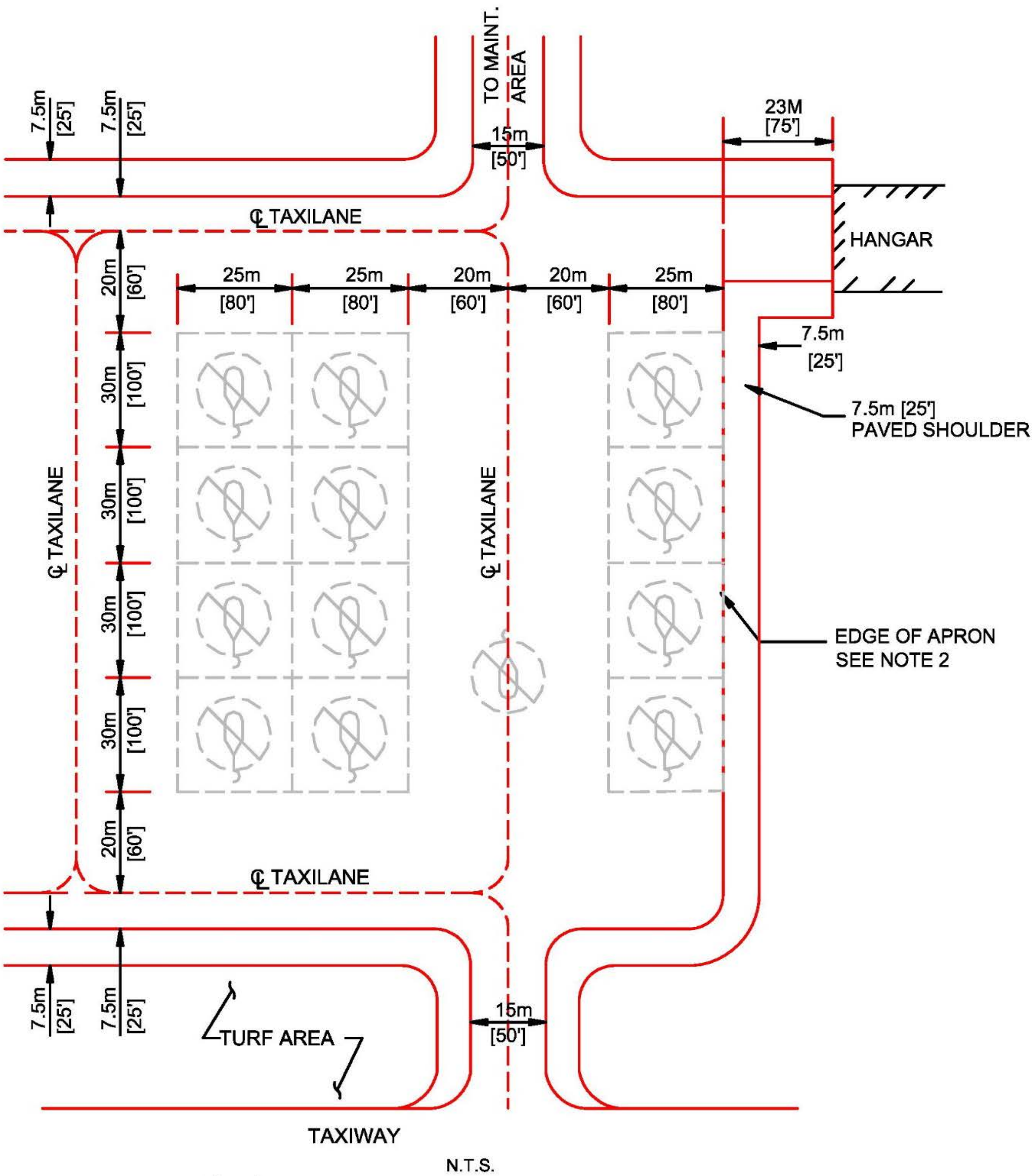


PLAN VIEW
N.T.S.

NOTES

1. THE DASHED LINES FORMING BOXES AROUND THE PARKING POSITIONS SHOW THE LIMITS OF THE SAFETY ZONE AROUND THE PARKED AIRCRAFT. AIRCRAFT ARE TO BE PARKED IN THE CENTER OF THE BOX TO PROVIDE PROPER TAXILANE CLEARANCES.
2. EDGE OF APRON IS DEFINED AS EDGE OF A PARKED AIRCRAFT BLOCK OR EDGE OF A PERIMETER TAXIWAY.

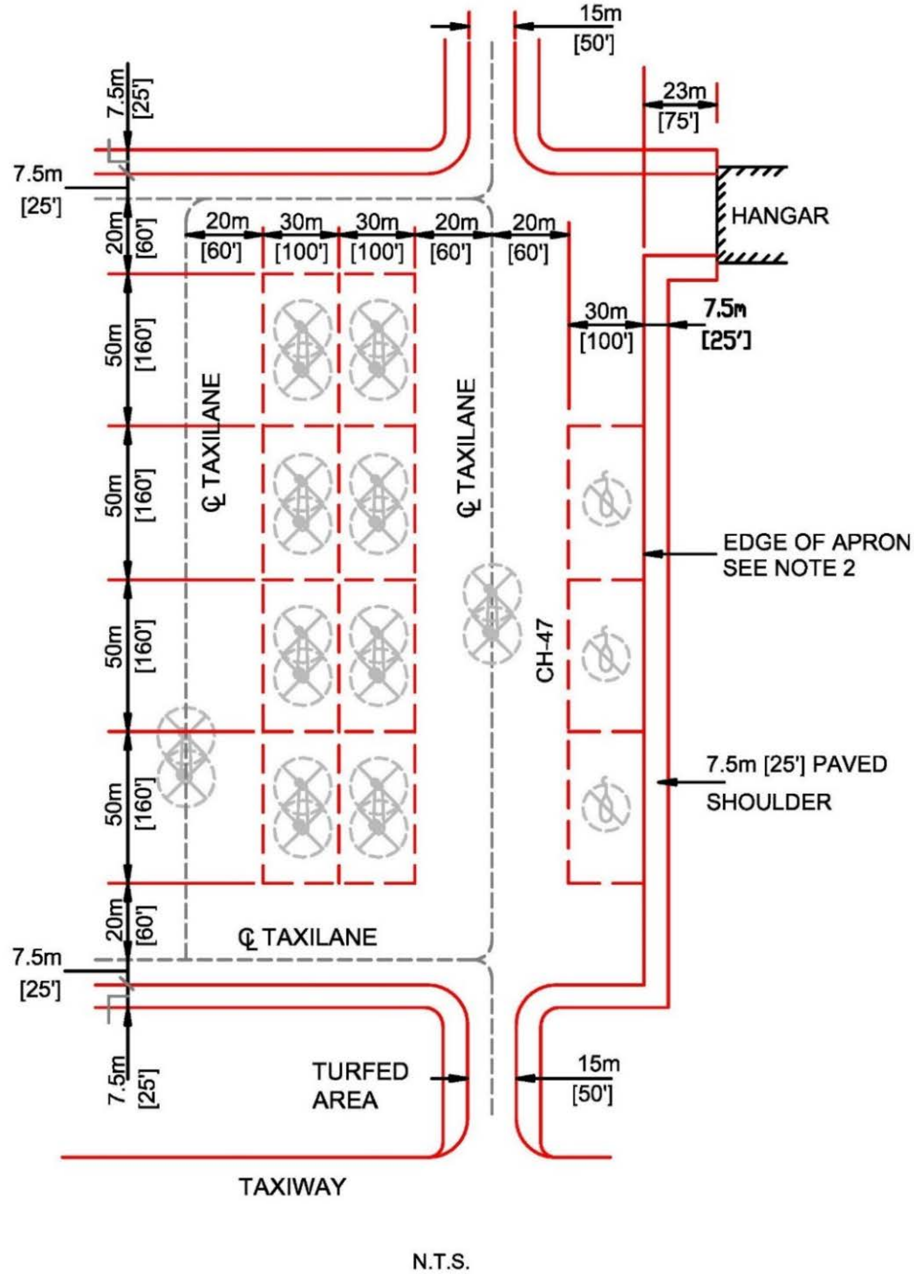
Figure 6-9. Type 2 Parking for Skid Rotary-Wing Aircraft



NOTES

1. THE DASHED LINES FORMING BOXES AROUND THE PARKING POSITIONS SHOW THE LIMITS OF THE SAFETY ZONE AROUND THE PARKED AIRCRAFT. AIRCRAFT ARE TO BE PARKED IN THE CENTER OF THE BOX TO PROVIDE PROPER TAXILANE CLEARANCES.
2. EDGE OF APRON IS DEFINED AS EDGE OF A PARKED AIRCRAFT BLOCK OR EDGE OF A PERIMETER TAXIWAY.

Figure 6-10. Type 2 Parking for Wheeled Rotary-Wing Aircraft



NOTES

1. THE DASHED LINES FORMING BOXES AROUND THE PARKING POSITIONS SHOW THE LIMITS OF THE SAFETY ZONE AROUND THE PARKED AIRCRAFT. AIRCRAFT ARE TO BE PARKED IN THE CENTER OF THE BOX TO PROVIDE PROPER TAXILANE CLEARANCES.
2. EDGE OF APRON IS DEFINED AS EDGE OF A PARKED AIRCRAFT BLOCK OR EDGE OF A PERIMETER TAXIWAY.
3. PARKING AREAS FOR CH-47 AIRCRAFT AND AH-64/UH-60 SHOULD BE SEPARATED BY A TAXILANE.

Figure 6-11. Refueling Safety Zone Example for Rotary-Wing Aircraft for Normal (Cold) Refueling Operations

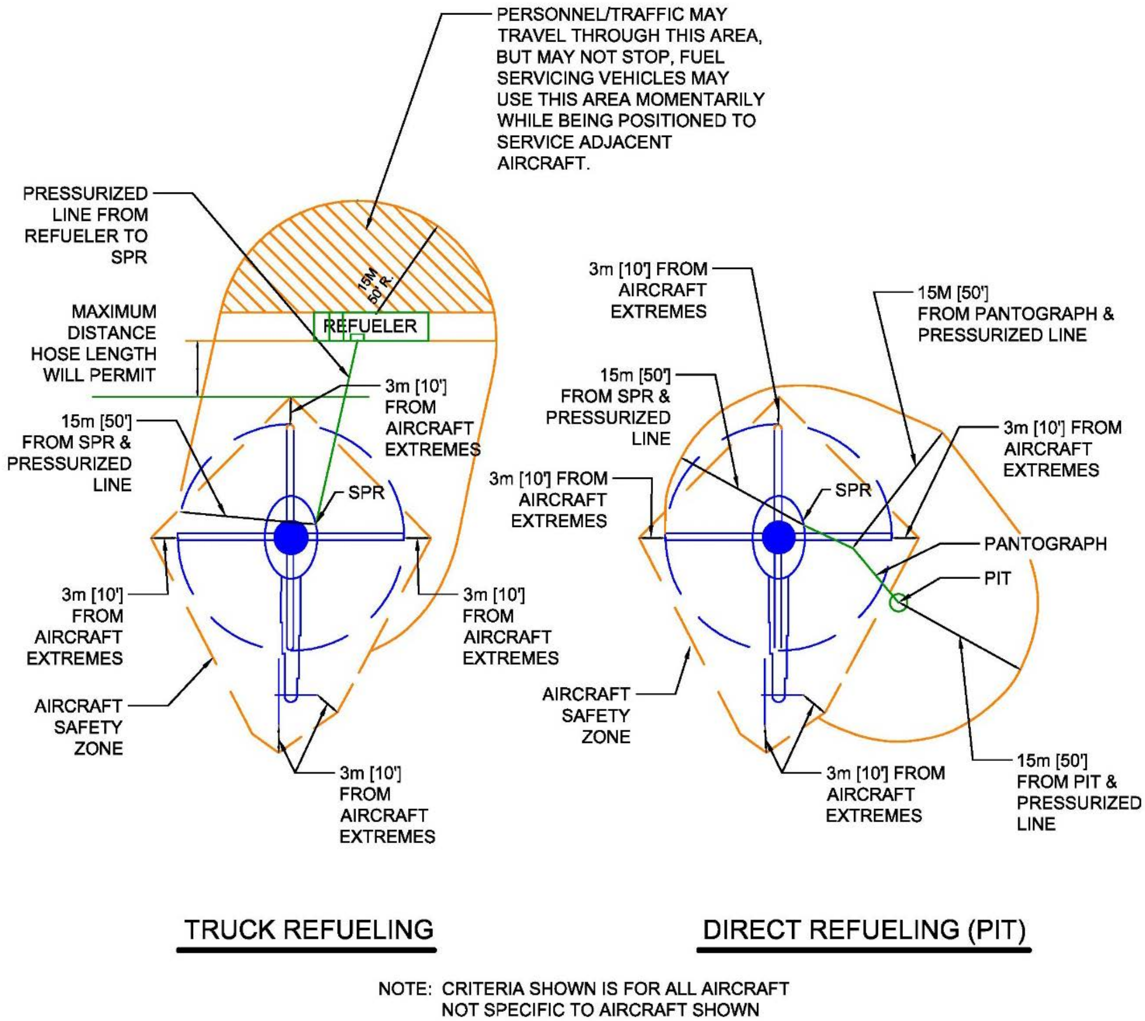
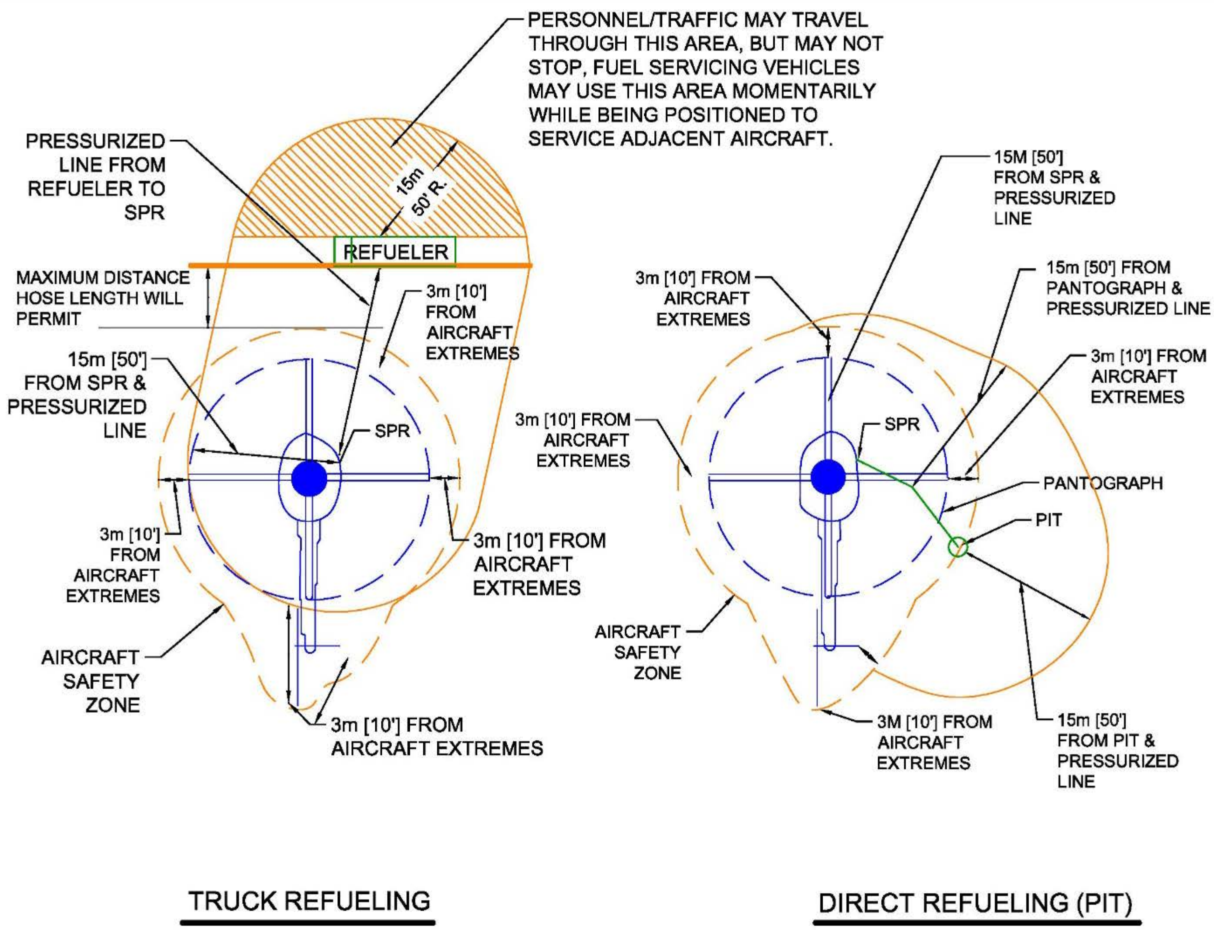


Figure 6-12. Refueling Safety Zone Example for Rotary-Wing Aircraft for Hot Refueling



NOTE: CRITERIA SHOWN IS FOR ALL AIRCRAFT. NOT SPECIFIC TO AIRCRAFT SHOWN.

Table 6-2. Rotary-Wing Aprons for Army Airfields

Table 6-2. Rotary-Wing Aprons for Army Airfields			
Item			
No.	Description	Requirement	Remarks
1	Size and configuration	Variable For Air Force space requirements, see AFMAN 32-1084. For Navy and Marine Corps space requirements, see UFC 2-000-05N.	Aprons are determined by the types and quantities of helicopters to be accommodated. Other determinants are the physical characteristics of the site and the objective of the master plan.
2	Type 1 parking space width	25 m (80 ft)	Army helicopters not otherwise specified
		30 m (100 ft)	Army CH-47 helicopters
		37 m (120 ft)	Army CH-53 helicopters
			Helicopters parked in single lanes and perpendicular to the taxilane Park helicopter in center of parking space.
3	Type 1 parking space length	30 m (100 ft)	Army helicopters not otherwise specified
		46 m (150 ft)	Army CH-47 helicopters
		50 m (165 ft)	Army CH-53 helicopters
			Helicopters parked in a single lane and perpendicular to the taxilane Park helicopter in center of parking space.
4	Type 2 parking space width	25 m (80 ft)	Army helicopters, skid configuration
		30 m (100 ft)	Army helicopters, wheeled configuration
			Helicopter parked in double lanes and parallel to the taxilane Park helicopter in center of parking space.
5	Type 2 parking space length	30 m (100 ft)	Army helicopters with skid configuration
		50 m (160 ft)	Army helicopters with wheeled configuration

Table 6-2. Rotary-Wing Aprons for Army Airfields

Item No.	Item Description	Requirement	Remarks
			Helicopter parked in double lanes and parallel to the taxilane Park helicopter in center of parking space.
6	Distance between the edge of the parking space and the taxilane centerline	20 m (60 ft)	All Army helicopters
7	Grades in the direction of drainage	Min 0.5% Max 1.5%	Engineering analysis occasionally may indicate a need to vary these limits; however, arbitrary deviation is not intended. Avoid surface drainage with numerous or abrupt grade changes that can cause adverse flexing in the rotor blades.
8	Interior taxilane/hoverlane width (between rows of aircraft)	40 m (120 ft)	From edge of parking space to edge of parking space
9	Peripheral taxilane/hoverlane width	26 m (85 ft)	From edge of parking space to edge of apron
10	Distance between the peripheral taxilane centerline and the edge of apron	7.5 m (25 ft)	From taxilane centerline to edge of apron
11	Clear distance around refueling aircraft	3 m (10 ft)	Outside of an area formed by lines connecting the tips of the blades and tail
12	Shoulders		See Table 5-3.
13	Clearance from the edge of the apron to fixed and mobile obstacles (clear area)	23 m (75 ft)	Measured from rear and side of apron. Distance to other aircraft operational pavements may require a greater clearance except as noted in Appendix B, Section 13.
		30m (100 ft)	For aprons regularly servicing H-53 helicopters
		23 m (75 ft)	When aircraft are towed on and off washracks the rotor clearance can be reduced to 25’.

NOTES:

1. Metric units apply to new airfield construction and, where practical, modification to existing airfields and heliports, as discussed in paragraph 1-3.4.
2. The criteria in this manual are based on aircraft specific requirements and are not direct conversions from inch-pound (English) dimensions. Inch-pound units are included only as a reference to the previous standard.
3. Airfield and heliport imaginary surfaces and safe wingtip clearance dimensions are shown as a direct conversion from inch-pound to SI units.

6-8 WARM-UP PADS.

A warm-up pad, also referred to as a holding apron, is a paved area adjacent to a taxiway at or near the end of a runway. The intent of a warm-up pad is to provide a holding location, off the taxiway, for aircraft that must hold due to indeterminate delays. A warm-up pad allows other departing aircraft unencumbered access to the runway. Pads must be sized to provide a minimum of 7.62 m (25 ft) of blast-resistant pavement behind the tail of an aircraft to prevent damage from jet blast.

6-8.1 Navy and Marine Corps.

Warm-up pads are not usually required at Navy facilities. Typically, the end crossover taxiway is widened to 46 m (150 ft), which provides room to accommodate aircraft warming up or waiting for other reasons.

6-8.2 Location.

6-8.2.1 At End Turnoff Taxiway.

The most advantageous position for a warm-up pad is adjacent to the end turnoff taxiway, between the runway and parallel taxiway, as shown in Figure 6-13; however, other design considerations such as NAVAIDS may make this location undesirable. Do not site new warm-up pads, other aprons, hot cargo spots, or taxiways to these facilities in a way that will allow penetration of the approach-departure clearance surface.

6-8.2.2 Along Parallel Taxiway.

If airspace and NAVAIDS prevent locating the warm-up pad adjacent to the end turnoff taxiway, the warm-up pad should be located at the end of and adjacent to the parallel taxiway, as shown in Figure 6-14.

6-8.3 Siting Considerations.

6-8.3.1 End of Runway.

Locate a warm-up pad as close to the runway as possible.

6-8.3.2 Approach-Departure Clearance Surface.

As discussed in Chapter 3, an obstruction to air navigation occurs when the imaginary surfaces are penetrated. Do not site new warm-up pads, other aprons, hot cargo spots, or taxiways to these facilities in a way that will allow penetration of the approach-departure clearance surface. Such aircraft penetrations may require revisions to TERPS procedures. Properly sited warm-up positions are illustrated in Figures 6-15 and 6-16.

6-8.3.3 Navigational Aids (NAVAIDS).

Warm-up pads must be located so that they do not interfere with the operation of NAVAIDS, including instrument landing system (ILS) equipment and precision approach radar (PAR) facilities. To eliminate interference of the ILS signal by holding aircraft, holding aircraft on or off a warm-up pad must be outside the critical areas. The critical area for ILS equipment is illustrated in Figures 6-17, 6-18, and 6-19. Additional discussion of ILS critical areas is provided in TM 5-823-4, AFI 13-203, and UFC 3-260-04.

6-8.4 Warm-Up Pad Size.

The size of the warm-up pad will be such to allow accommodating two of the largest aircraft assigned to the facility simultaneously, wingtip clearances required by the clear distance information presented in Table 6-1, and to provide a minimum of 7.62 m (25 ft) of blast-resistant pavement behind the tail of an aircraft to prevent damage from jet blast.

6-8.5 Taxi-In/Taxi-Out Capabilities.

The parking locations will have taxi-in/taxi-out capabilities to allow aircraft to taxi to their warm-up position under their own power as shown in Figure 6-20.

Figure 6-13. Warm-Up Pad at End of Parallel Taxiway

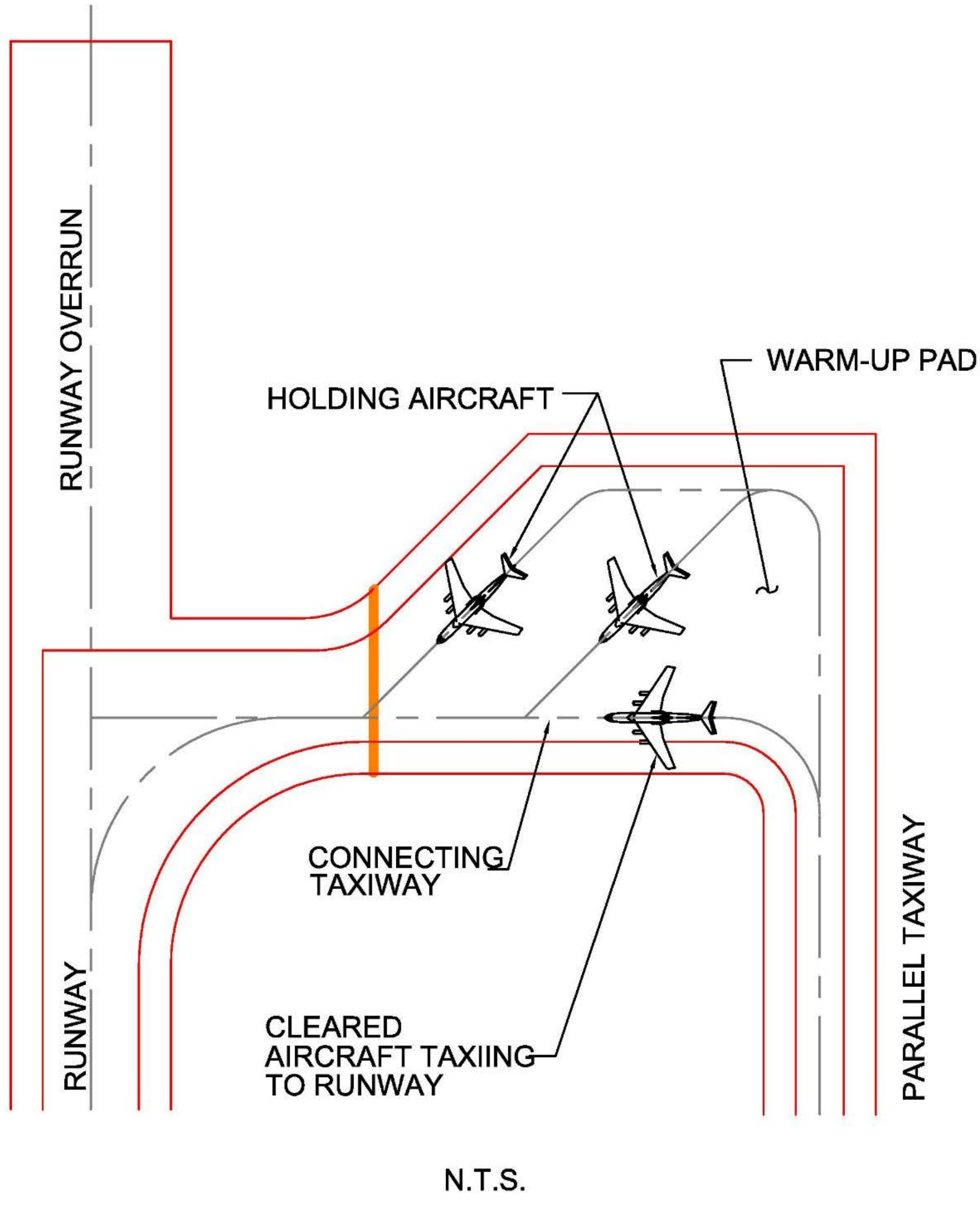
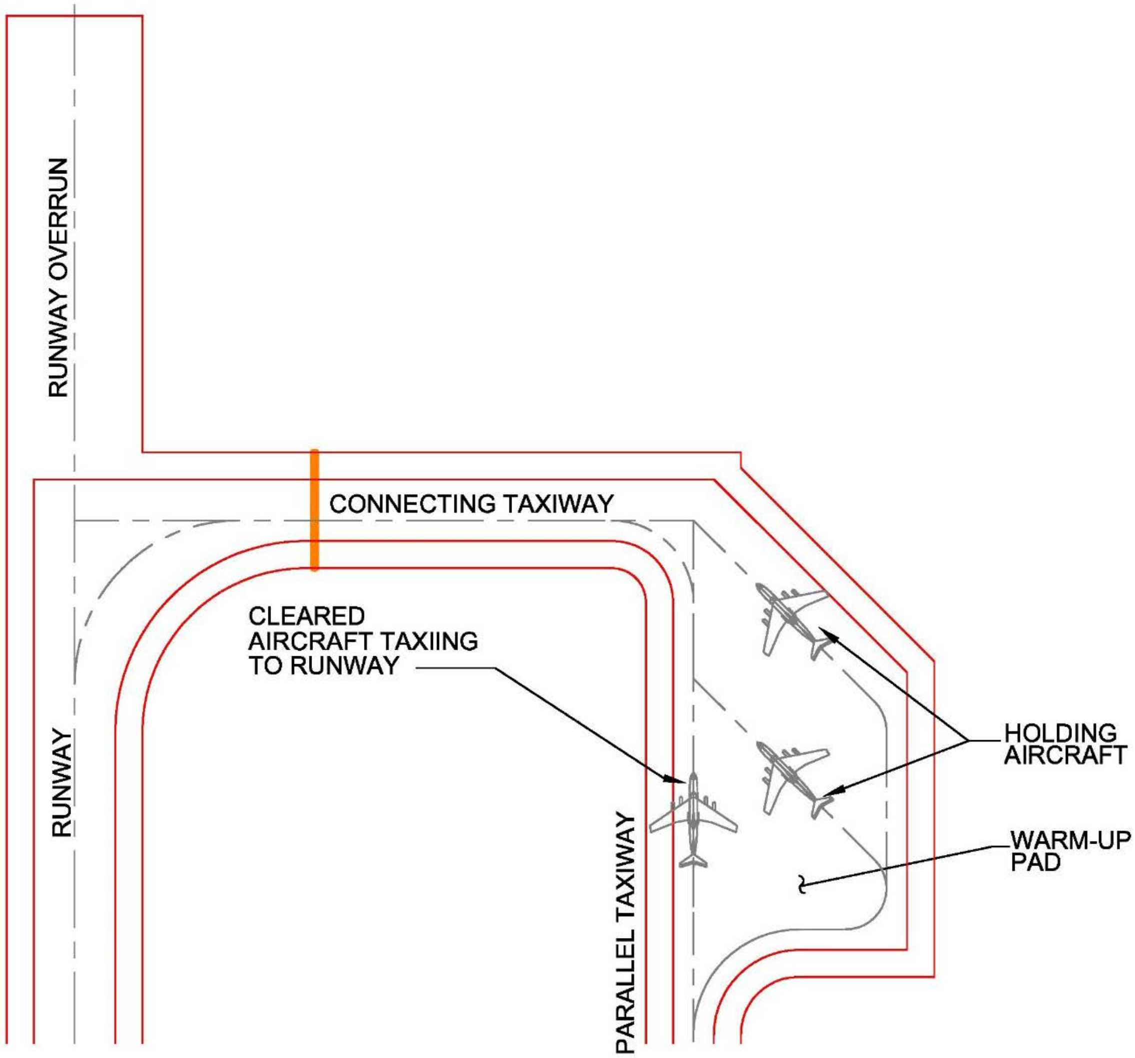


Figure 6-14. Warm-Up Pad Next to Parallel Taxiway



N.T.S.

Figure 6-15. Warm-Up Pad Located in Clear Zone

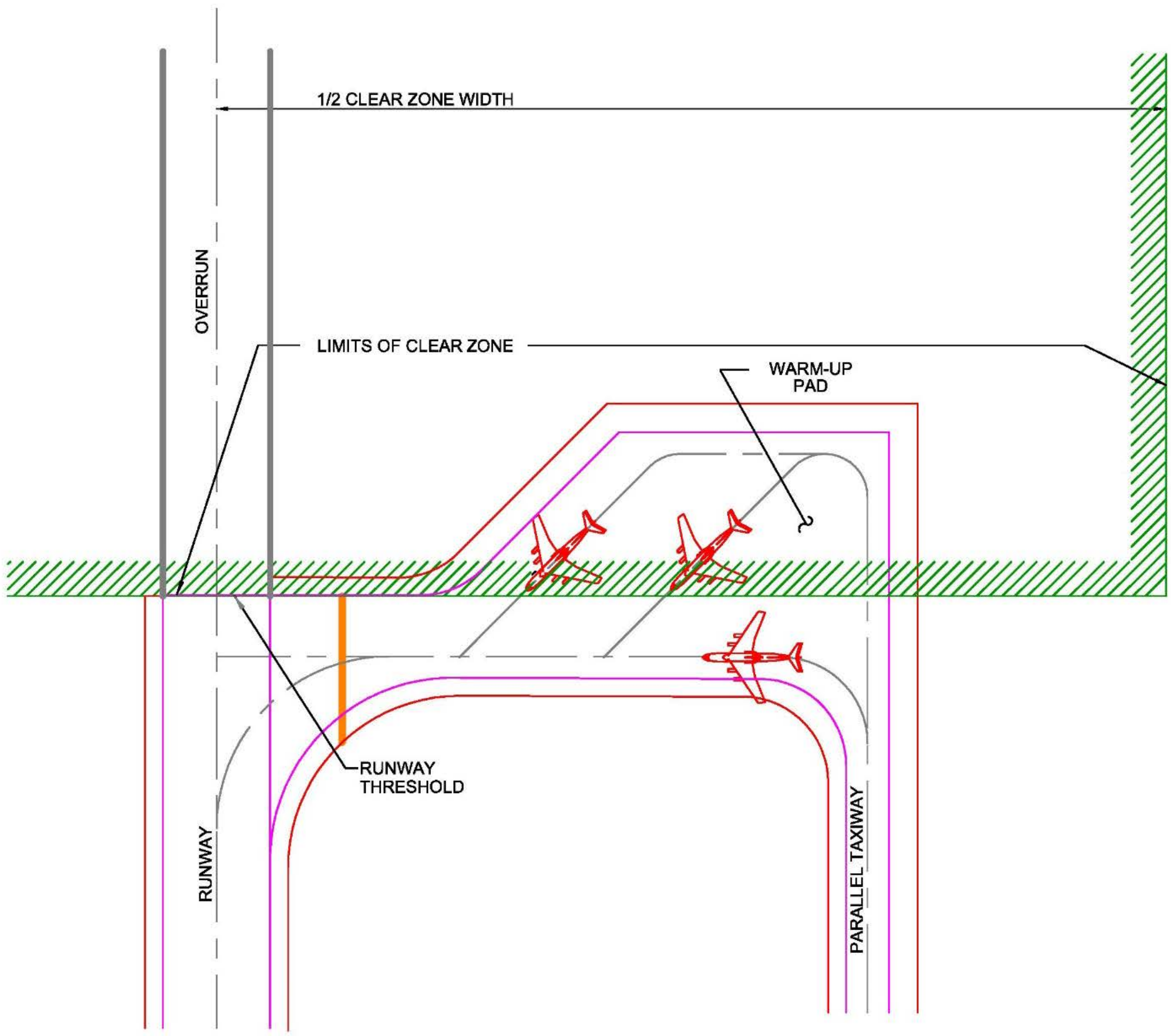
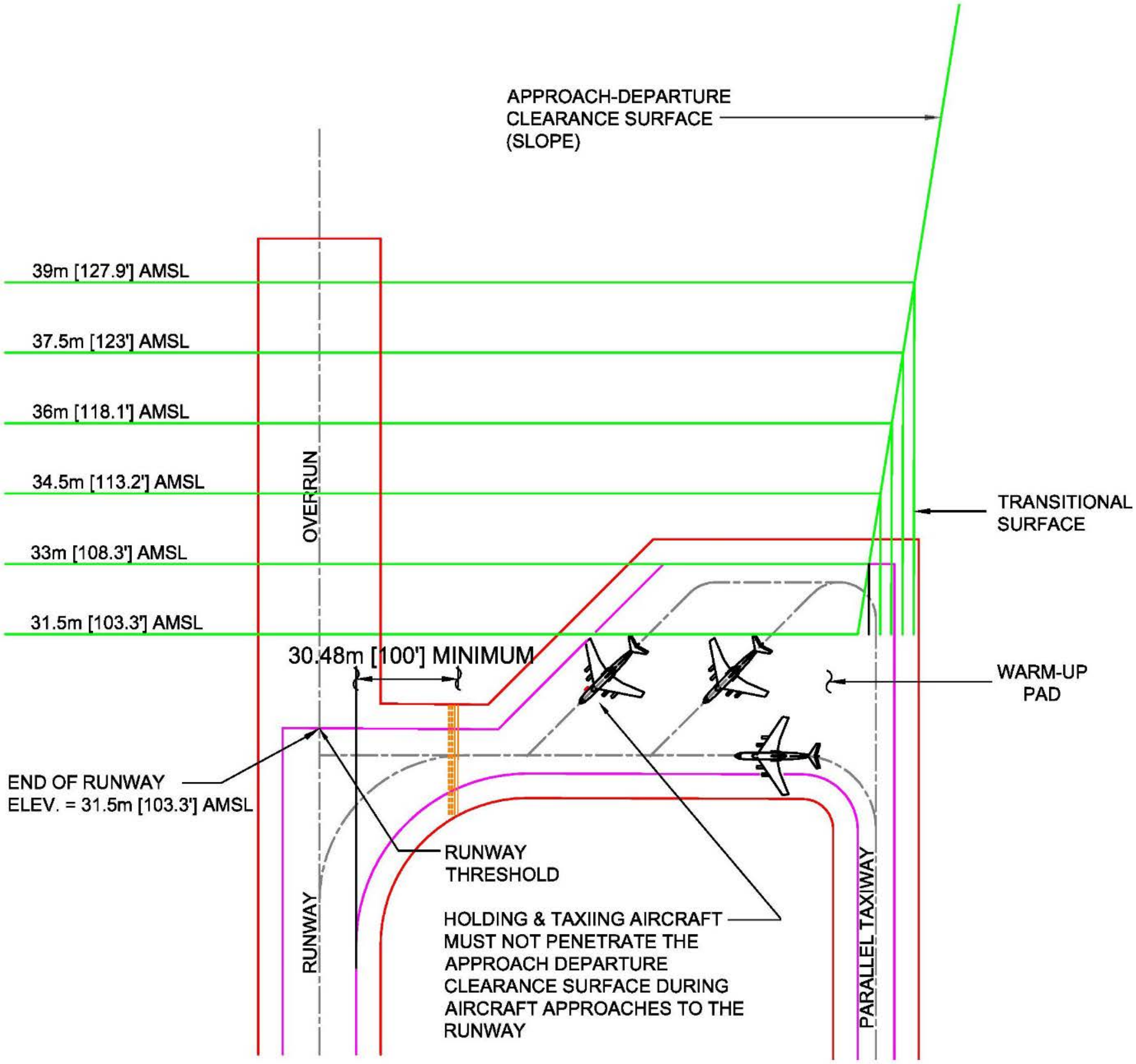


Figure 6-16. Warm-Up Pad Located in Approach-Departure Clearance Surface



N.T.S.

Figure 6-17. Warm-Up Pad/Localizer Critical Area

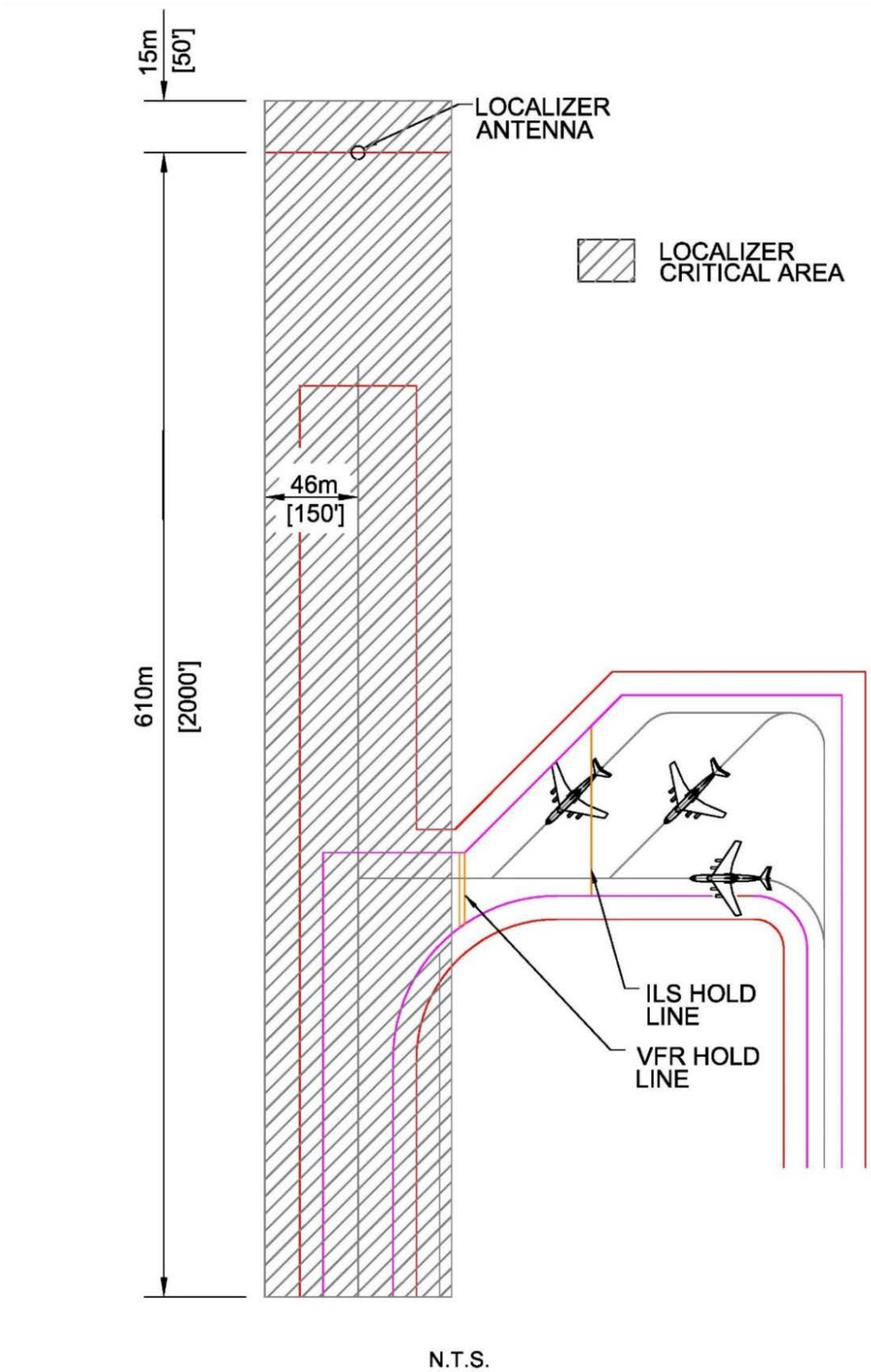


Figure 6-18. Warm-Up Pad/Glide Slope Critical Area

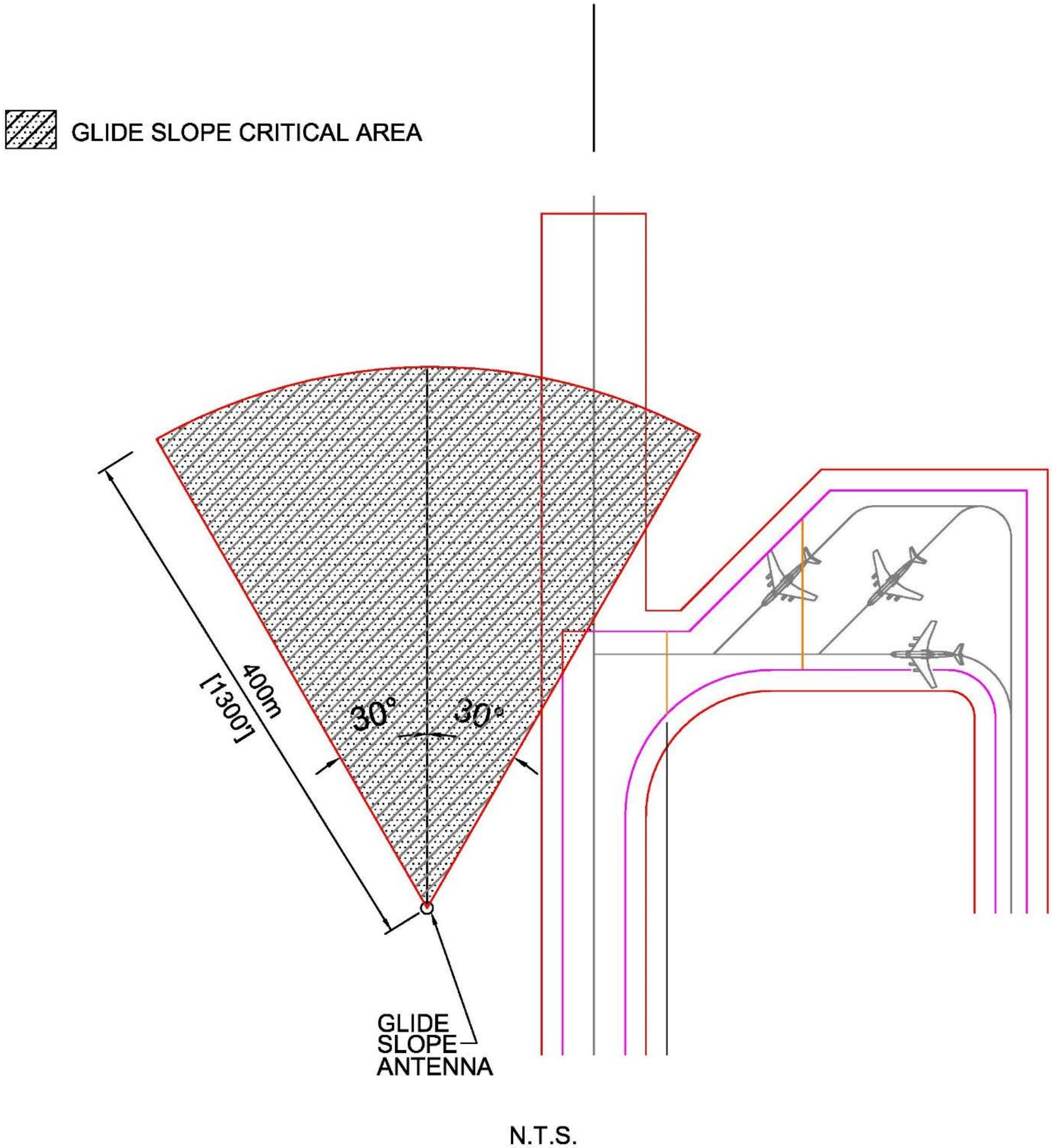
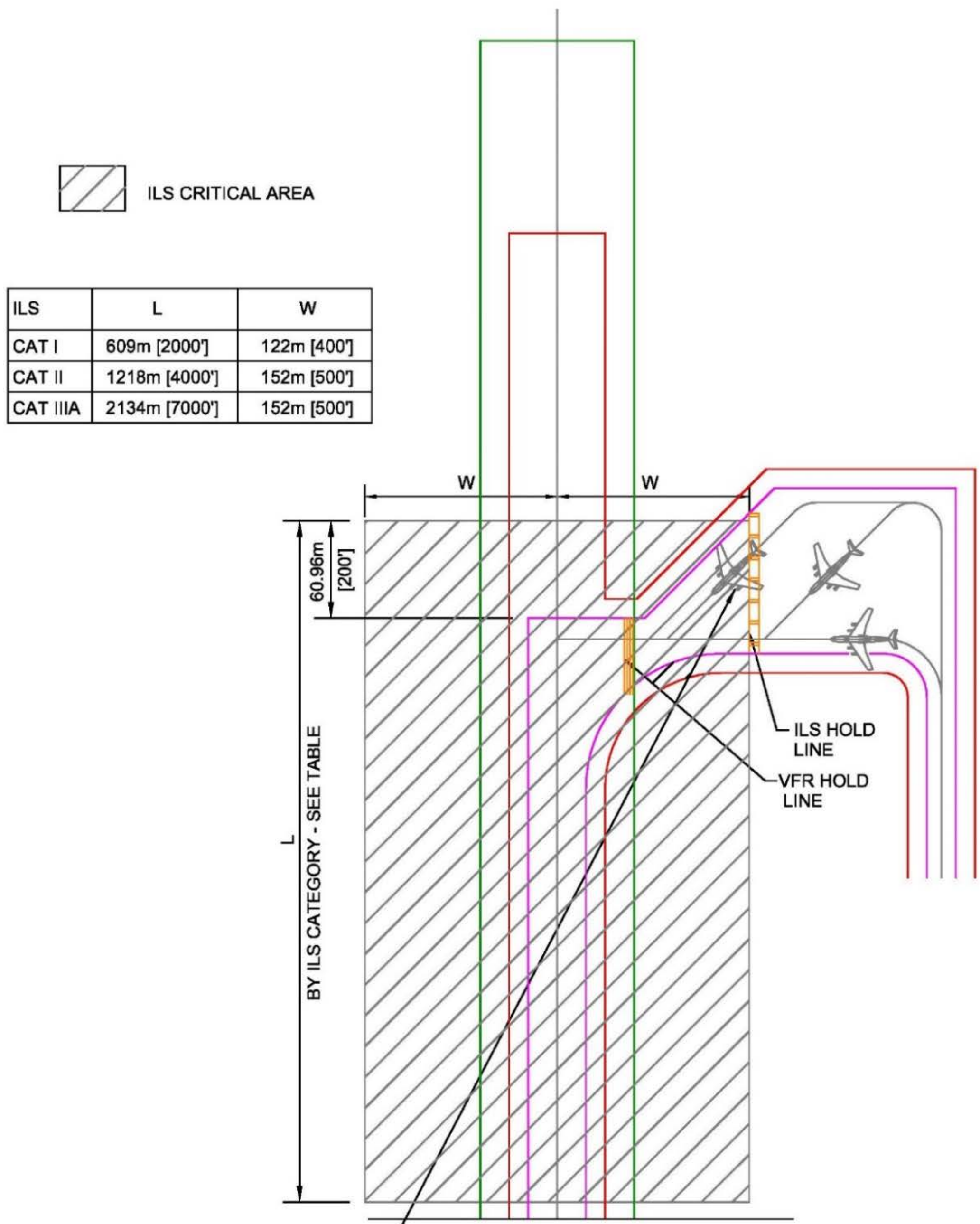


Figure 6-19. Warm-Up Pad/CAT II ILS Critical Area

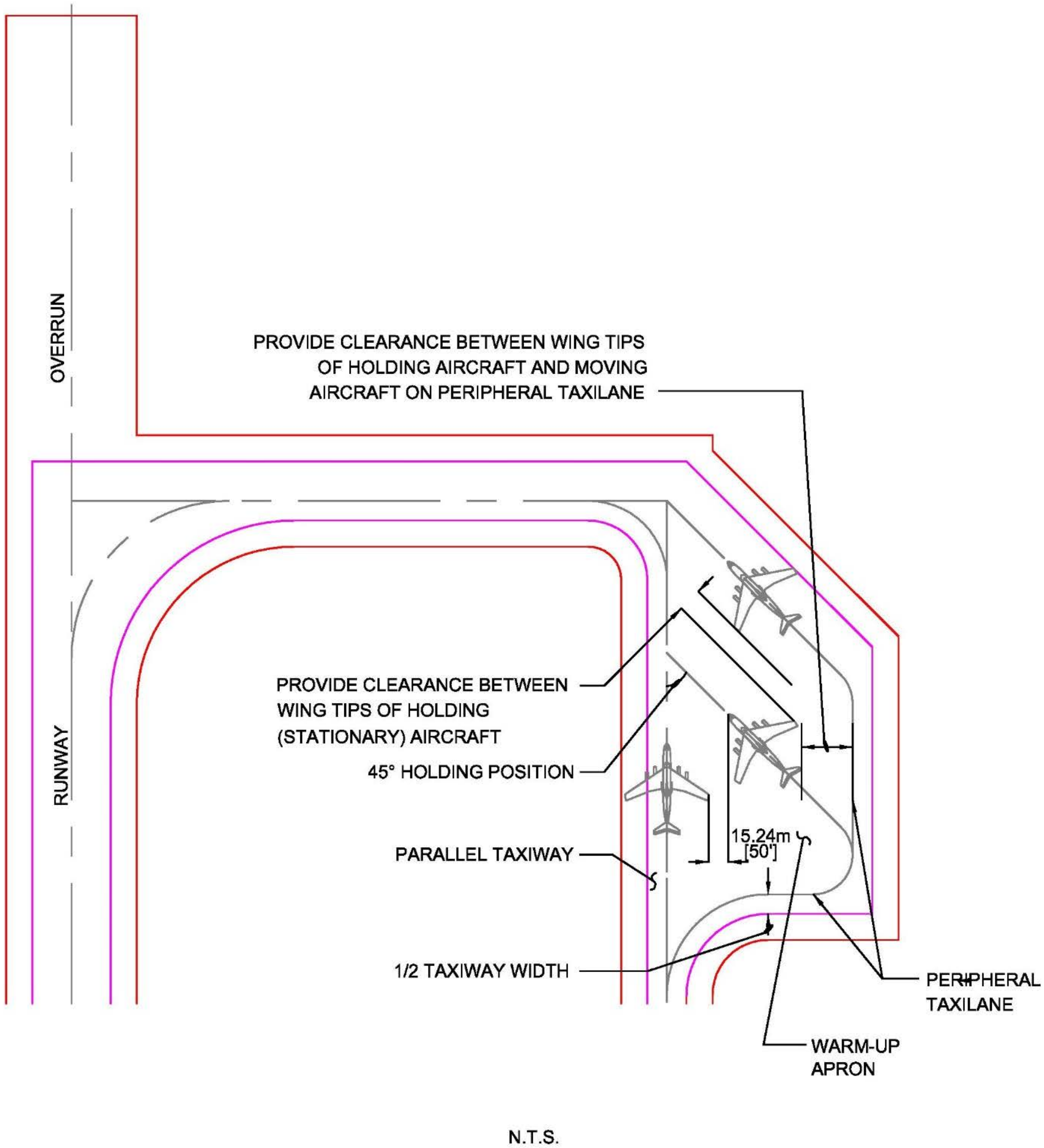


ILS	L	W
CAT I	609m [2000']	122m [400']
CAT II	1218m [4000']	152m [500']
CAT IIIA	2134m [7000']	152m [500']

NOTES

1. THIS HOLDING SPOT CANNOT BE USED DURING IFR CONDITIONS. AIRCRAFT IN THIS PARTICULAR POSITION ARE WITHIN THE LOCALIZER CRITICAL AREA IDENTIFIED BY THE ILS HOLD LINE. UNDER INSTRUMENT FLIGHT CONDITIONS THIS AREA SHOULD BE CLEAR OF OBJECTS THAT COULD REFLECT OR BLOCK THE ILS SIGNAL.
2. SITING OF WARM-UP PAD BASED ON CAT 1 CRITERIA MAY LIMIT FUTURE USE OF FIRST HOLD POSITION IF HIGHER CATEGORY APPROACHES ARE INSTALLED.

Figure 6-20. Warm-Up Pad Taxiing and Wingtip Clearance Requirements



6-8.6 Parking Angle.

Aircraft should be parked at a 45-degree angle to the parallel taxiway to divert the effects of jet blast away from the parallel taxiway. (See Appendix B, Section 7, for minimum standoff distances.) This is shown in Figure 6-20.

6-8.7 Turning Radius.

The turning radius on warm-up pads will be designed to provide the minimum allowable turn under power for the largest aircraft assigned to the base.

6-8.8 Taxilanes on Warm-Up Pads.

Taxilanes on the warm-up pad will meet the lateral clearance requirements discussed in Table 6-1. Lateral and wingtip clearance for a taxilane on a warm-up pad is illustrated in Figure 6-20.

6-8.9 Tie-Downs and Grounding Points.

Tie-downs, mooring points, and grounding points are not required on warm-up pads.

6-9 POWER CHECK PAD.

An aircraft power check pad is a paved area, with an anchor block in the center, used to perform full-power engine diagnostic testing of aircraft engines while the aircraft is held stationary.

6-9.1 Location and Siting Considerations.

Unsuppressed power check pads should be located near maintenance hangars, but at a location where full-power engine diagnostic testing of jet engines can be performed with minimal noise exposure to inhabited areas on and off the base.

6-9.2 Unsuppressed Power Check Pad Layout.

Power check pads may be rectangular, square, or circular.

6-9.2.1 Army and Air Force.

Power check pad layouts for Army and Air Force aviation facilities are shown in Figures 6-21, 6-22, and 6-23.

6-9.2.2 Navy and Marine Corps.

Power check pad layouts for Navy and Marine Corps aviation facilities are found in UFC 4-212-01N.

6-9.3 Access Taxiway/Towway.

An access taxiway will be provided for access from the primary taxiway to the power check pad. If the aircraft is to be towed to the unsuppressed power check pad, the access pavement should be designed as a towway. Taxiway and towway design requirements are presented in Chapter 5.

6-9.4 Grading.

The surface of the unsuppressed power check pad must slope 3.5% away from the anchor block in the direction of jet blast to the pavement edge to divert the effect of jet blast away from the concrete surfaces and pavement joints. See Figure 6-24.

6-9.5 Thrust Anchors/Mooring Points.

Thrust anchors (Air Force) or mooring points (Army) or tie-down mooring eyes (Navy and Marine Corps) are required on unsuppressed power check pads. Layout for these anchors is interdependent of joint spacing, and the two should be coordinated together. Tie-down and grounding points are discussed further in Appendix B, Section 11.

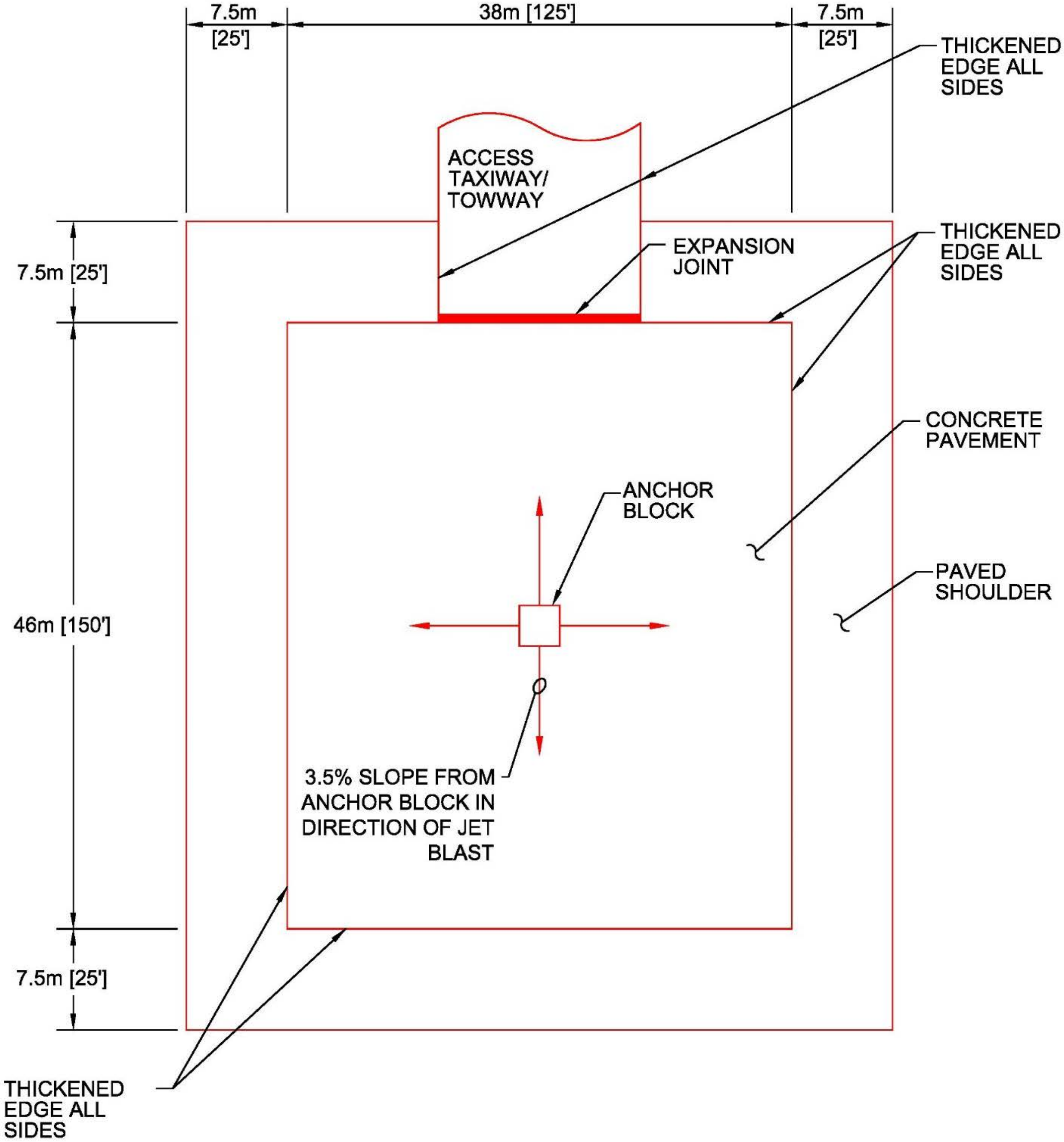
6-9.5.1 Army and Air Force.

Power check pad thrust anchors designed for 267 kilonewtons (kN) (60,000 lbf) (Army and Air Force aviation facilities) and for 445 kN (100,000 lbf) are provided in Appendix B, Section 15.

6-9.5.2 Navy and Marine Corps.

Power check pad tie-down mooring eye designed for Navy and Marine Corps aviation facilities are found in UFC 4-212-01N.

Figure 6-21. Geometry for Rectangular Power Check Pad



N.T.S.

Figure 6-22. Geometry for Square Power Check Pad

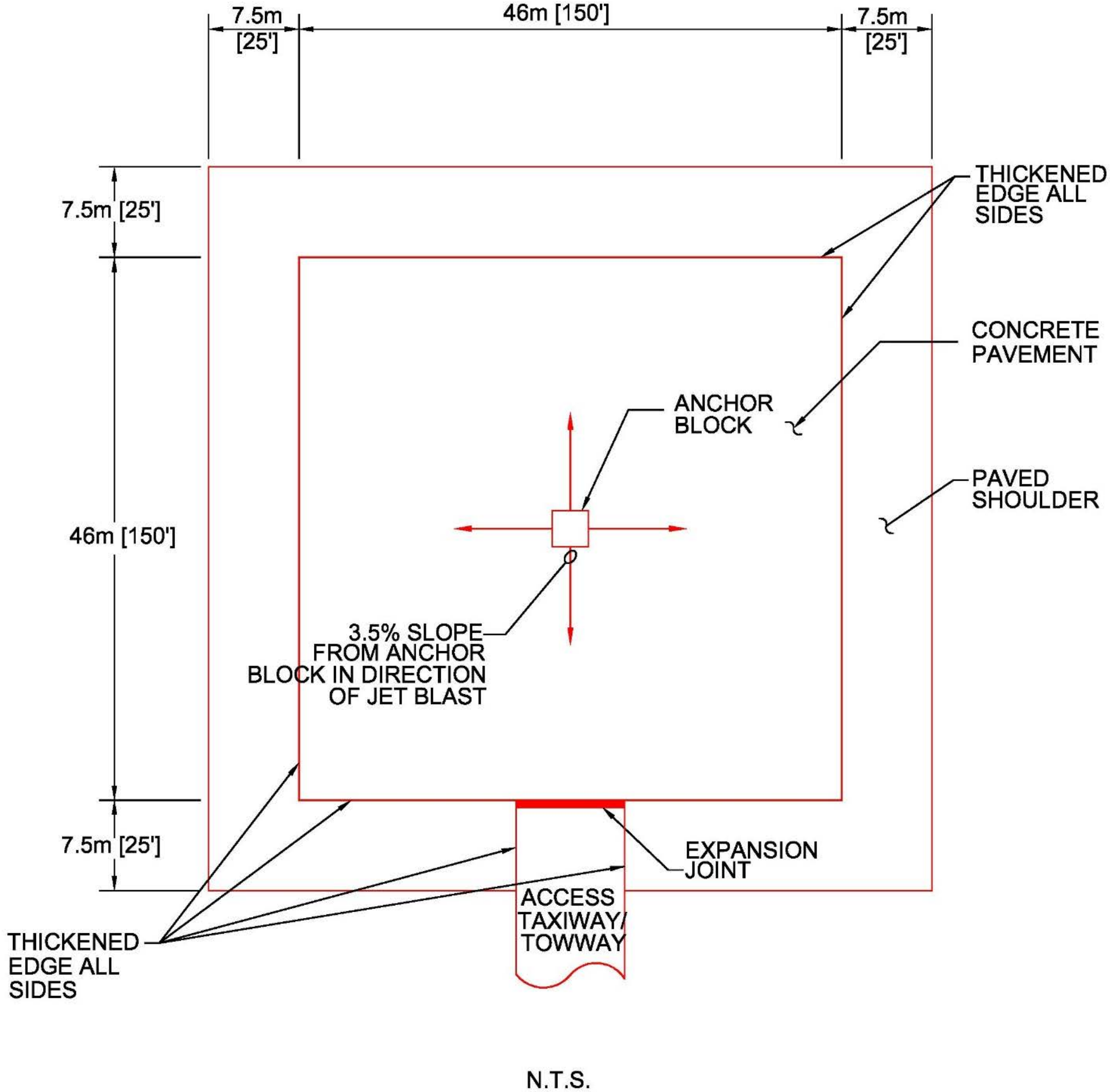
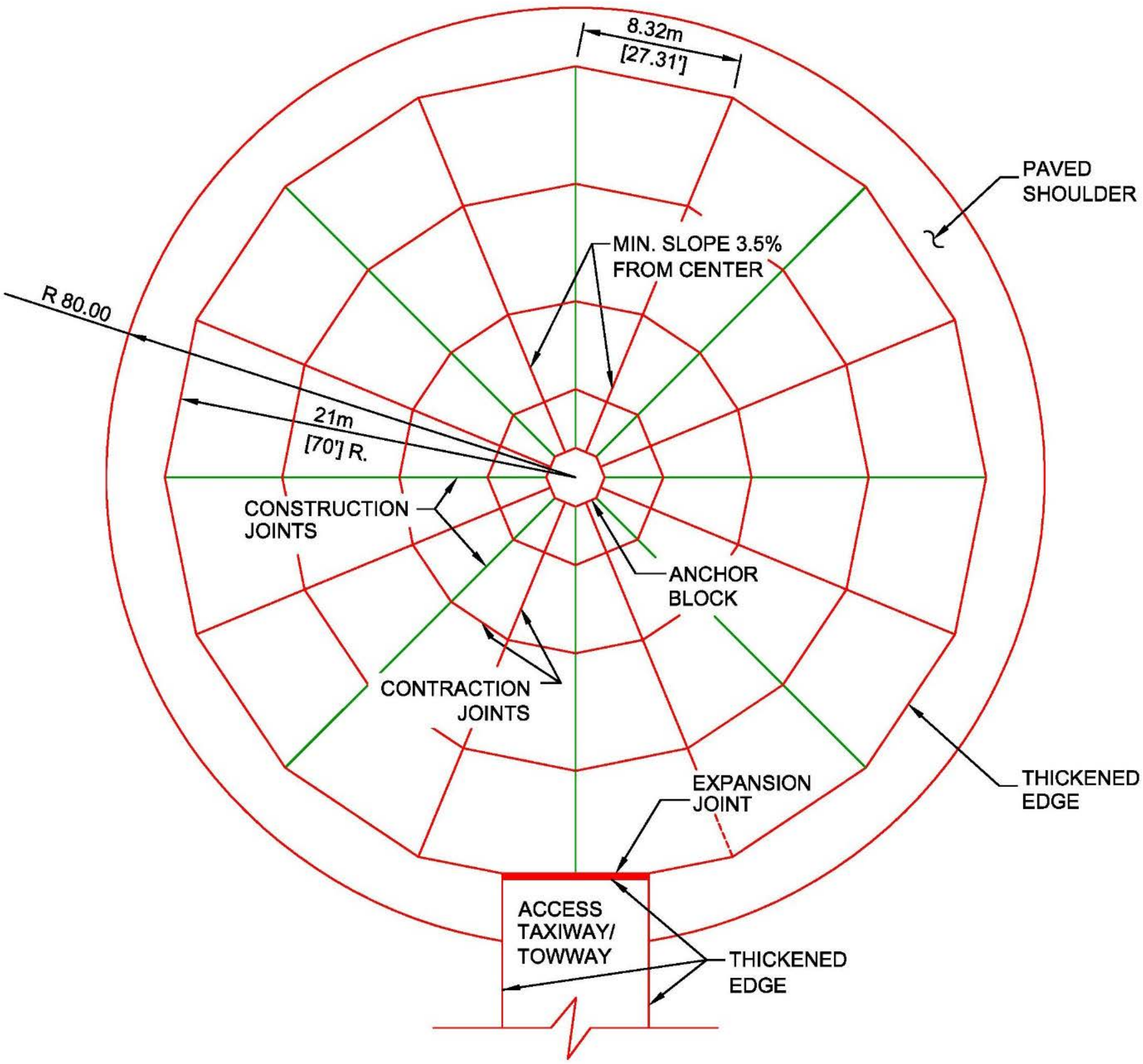
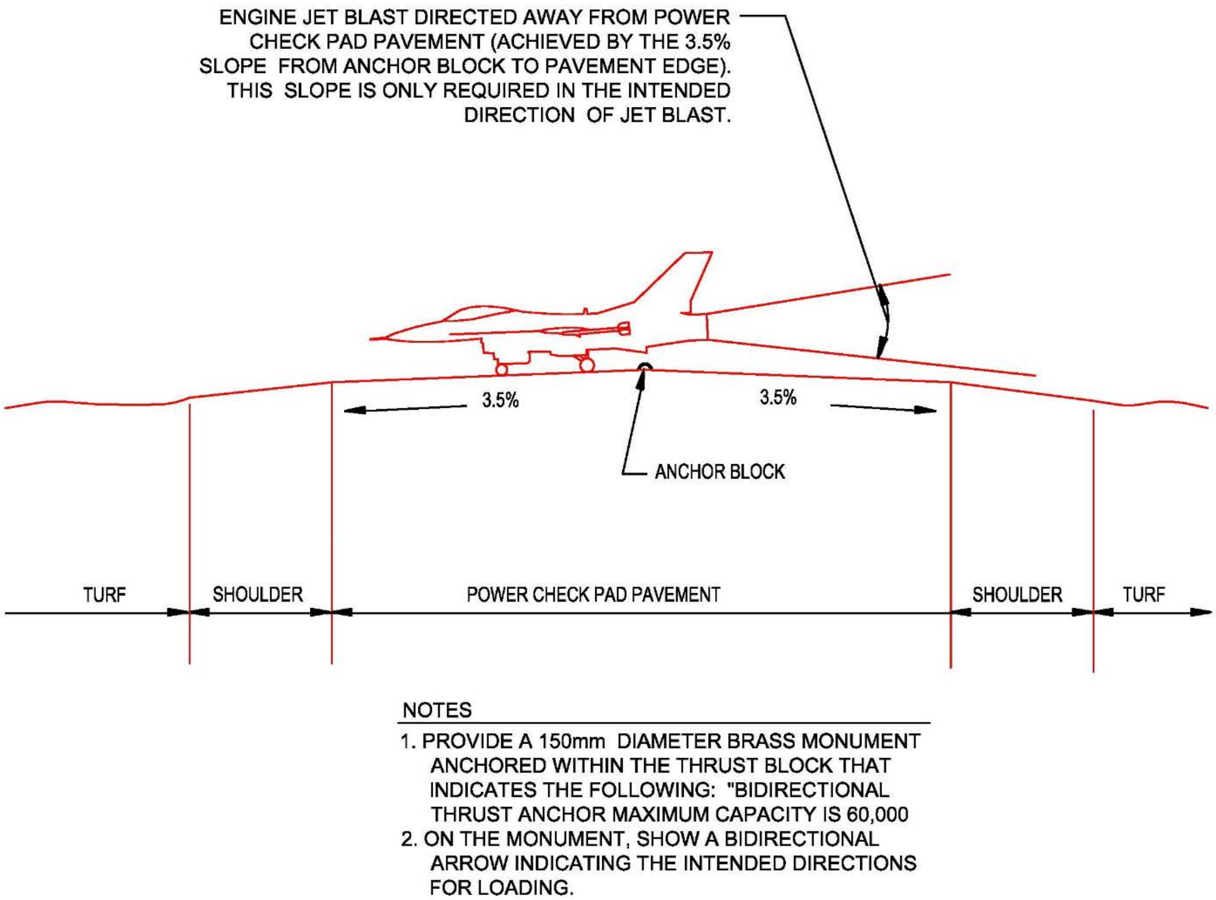


Figure 6-23. Geometry for Circular Power Check Pad



N.T.S.

Figure 6-24. Power Check Pad Grading



6-9.6 Anchor Blocks.

All unsuppressed power check pads have a thrust anchor block installed in the center of the power check pad to anchor the aircraft during engine testing. Anchor blocks are structurally designed for each individual aircraft. The designer must verify structural adequacy of the anchor block for the mission aircraft and engine type.

6-9.6.1 Army and Air Force.

Thrust anchor blocks for Army and Air Force aviation facilities are provided in Appendix B, Section 15.

6-9.6.2 Navy and Marine Corps.

Thrust anchor blocks for Navy and Marine Corps aviation facilities are provided in UFC 4-212-01N.

6-9.7 Power Check Pad Facilities.

Power check pads for Navy and Marine Corps aviation facilities are provided in UFC 4-212-01N

6-9.7.1 Required Facilities.

The unsuppressed power check pad should consist of these required items:

- Paved surface
- Paved shoulders (see Appendix B, Section 7, for minimum standoff distances)
- A thrust anchor or anchors for aircraft serviced at the pad
- Blast deflectors if required to protect the surrounding area from jet blast damage

6-9.7.2 Optional Facilities.

The unsuppressed power check pad may include these items:

- Floodlighting for night operations
- Water supply to wash down fuel spills
- Oil separators, holding tanks, and fuel treatment to address fuel spillage prior to discharge into sanitary or storm sewer
- Communication link with the maintenance control room
- Fire hydrants
- A paved roadway to the unsuppressed power check pad for access by firefighting, towing, and aircraft maintenance support vehicles

6-9.8 Noise Considerations.

The noise level at unsuppressed power check pads may exceed 115 decibels (dB(a)) during power-up engine tests. Caution signs should be placed around the power check pad indicating both the presence of hazardous noise levels and the need for hearing protection.

6-10 ARM/DEARM PADS.

The arm/dearm pad is used for arming aircraft immediately before takeoff and for dearming (safing) weapons retained or not expended upon their return. Do not site arm/dearm pads, other aprons, hot cargo spots, or taxiways to these facilities in a way that will allow penetration of the approach-departure clearance surface.

6-10.1 Navy and Marine Corps Requirements.

Navy and Marine Corps requirements for arm/dearm pads are provided in UFC 2-000-05N.

6-10.2 Location.

Air Force arm/dearm pads should be located adjacent to runway thresholds and sited such that armed aircraft are oriented in the direction of least populated areas or towards revetments.

6-10.3 Siting Considerations.

6-10.3.1 Aircraft Heading.

The criteria for establishing the exact heading of the parked aircraft depends on the type of aircraft and associated weapons. This information is contained within the classified portion of the aircraft manuals. The most economical means of parking aircraft on the arm/dearm pads is at 45 degrees to the taxiway; however, because of the requirement to orient armed aircraft away from populated areas, this angle may vary.

6-10.3.2 Forward Firing Munitions Protection Zone.

Coordinate with the responsible safety office to determine the specific risks associated with the mission aircraft and establish protection zones or available measures to mitigate risk. It is good practice to keep all buildings out of this protection zone to prevent damage from accidental weapon firing. This forward firing munitions protection zone may cross a runway, taxiway, or runway approach as long as the landing and taxiing aircraft can be seen by the arm/dearm quick check crews and the arming/dearming operations can cease for the period in which the aircraft passes. Parked aircraft or parked vehicles must not be located in the forward firing munitions protection zone. If a protection zone appropriate for the type of munitions to be used cannot be obtained, earth revetments or similar risk mitigation measures (barricades, etc.) should be used, but must be sited properly relative to wingtip and airspace clearance requirements.

6-10.3.3 Electromagnetically Quiet Location.

Prior to construction of any pad, local field measurements must be taken or verified with the installation weapons safety manager to ensure that the location is electromagnetically quiet. To avoid potential electromagnetic interference from taxiing aircraft, pads should be located on the side of a runway opposite the parallel taxiway. Use concrete encased rigid steel conduits for any electrical conductors located within 200 ft of the pad. Navy and Marine Corps aviation facilities must have an electromagnetic compatibility (EMC) background study by SPAWARSYSCEN Charleston, as described in NAVAIR 16-1-529. The Air Force conducts electromagnetic radiation (EMR) surveys with regard to explosives safety in accordance with AFI 91-

208. The specific information for each emitting device should be available through the installation communications squadron.

6-10.4 Arm/Dearm Pad Size.

Each arm/dearm pad should be capable of servicing four or six aircraft at a time. The dimensions of the pad must be based on the length, wingspan, and turning radius of the aircraft to be served. Jet blast must also be taken into account. Typical layouts of arm/dearm pads are shown in Figures 6-25, 6-26, 6-27, and 6-28.

6-10.5 Taxi-In/Taxi-Out Capabilities.

The parking locations should have taxi-in/taxi-out capabilities to allow aircraft to taxi to their arm/dearm location under their own power.

6-10.6 Parking Angle.

The parking angle depends on the type of aircraft, type of weapons, and the associated uninhabited clear zone location.

6-10.7 Turning Radius.

The turning radius for taxilanes on arm/dearm pads should be designed to provide the minimum allowable turn under power of the largest aircraft that will use the arm/dearm pad.

6-10.8 Access Road.

An all-weather access road should be constructed to the arm/dearm pad from outside the airfield's taxiway and runway clearance areas. Design this road in accordance with UFC 3-250-18FA and UFC 3-250-01FA. Access roads must not encroach on taxiway clearances or taxilane wingtip clearance requirements (except at necessary intersections with these areas), nor shall any parking area associated with the access road be sited so that maintenance vehicles will violate the approach-departure clearance surface or any NAVAID critical area.

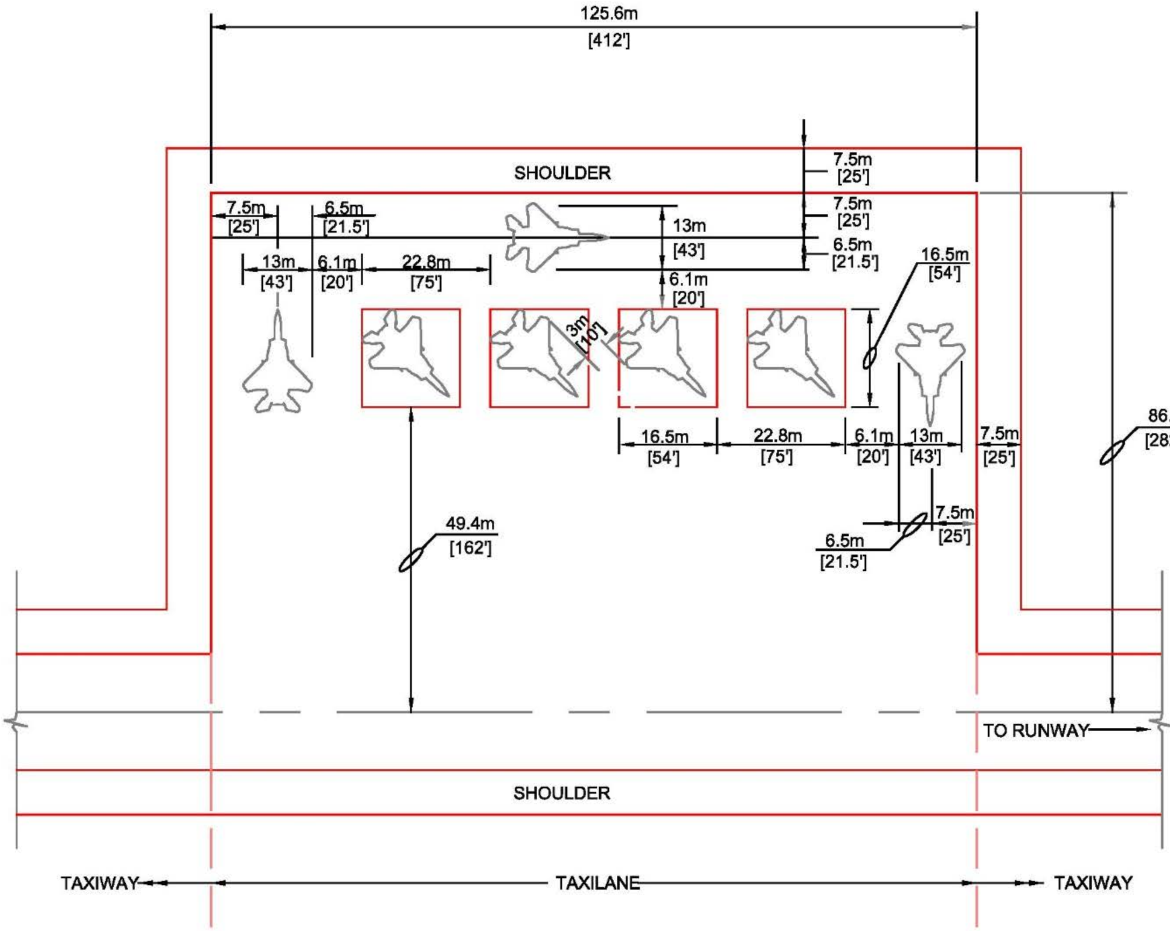
6-10.9 Tie-downs and Grounding Points.

Tie-downs and mooring points are not required on arm/dearm pads. See Appendix B, Section 11, for grounding requirements.

6-10.10 Ammunition and Explosives Safety Standards.

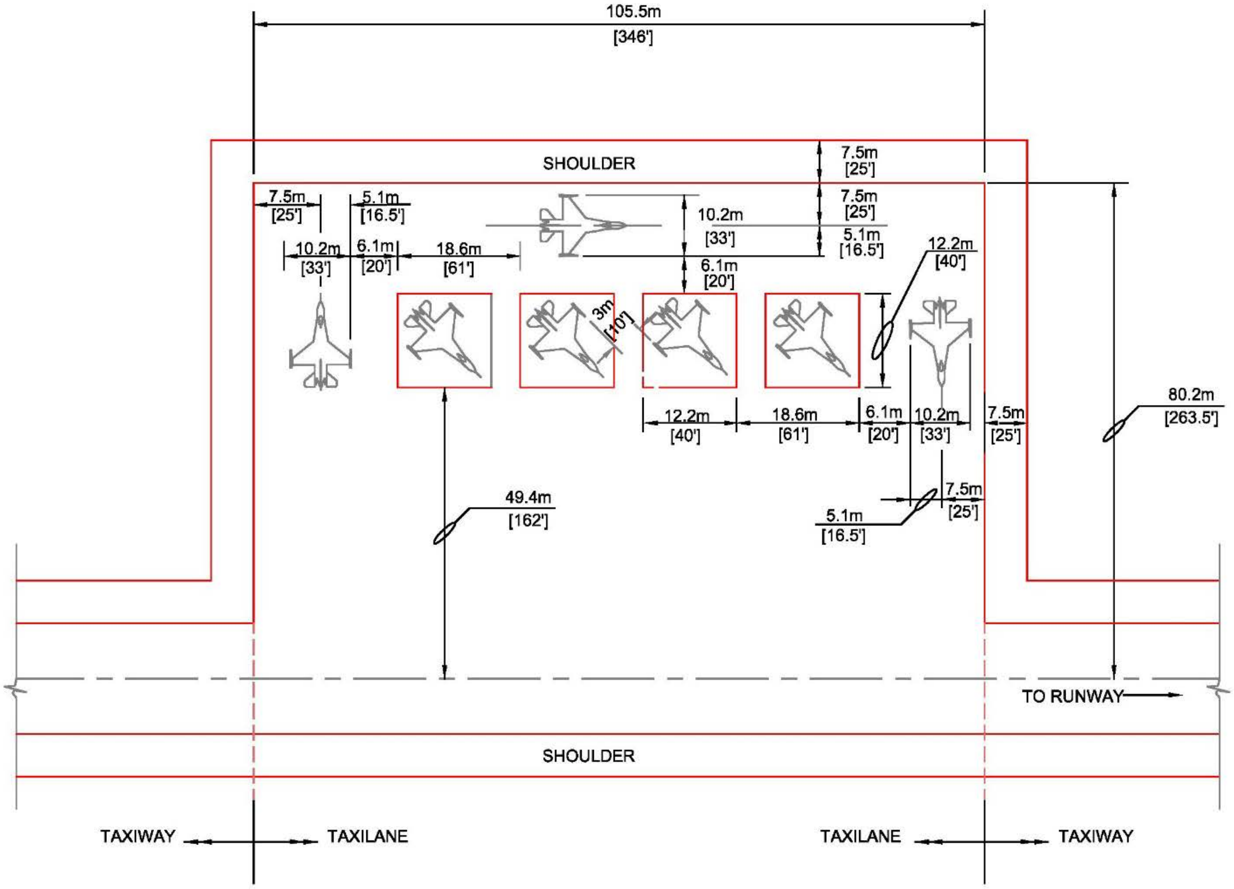
Ammunition and explosives safety standards are discussed in Appendix B, Section 9.

Figure 6-25. Arm-Dearm Pad for F-15 Fighter



N.T.S.

Figure 6-26. Arm-Dearm Pad for F-16 Fighter



N.T.S.

Figure 6-27. Arm-Dearm Pad for F-22 Fighter

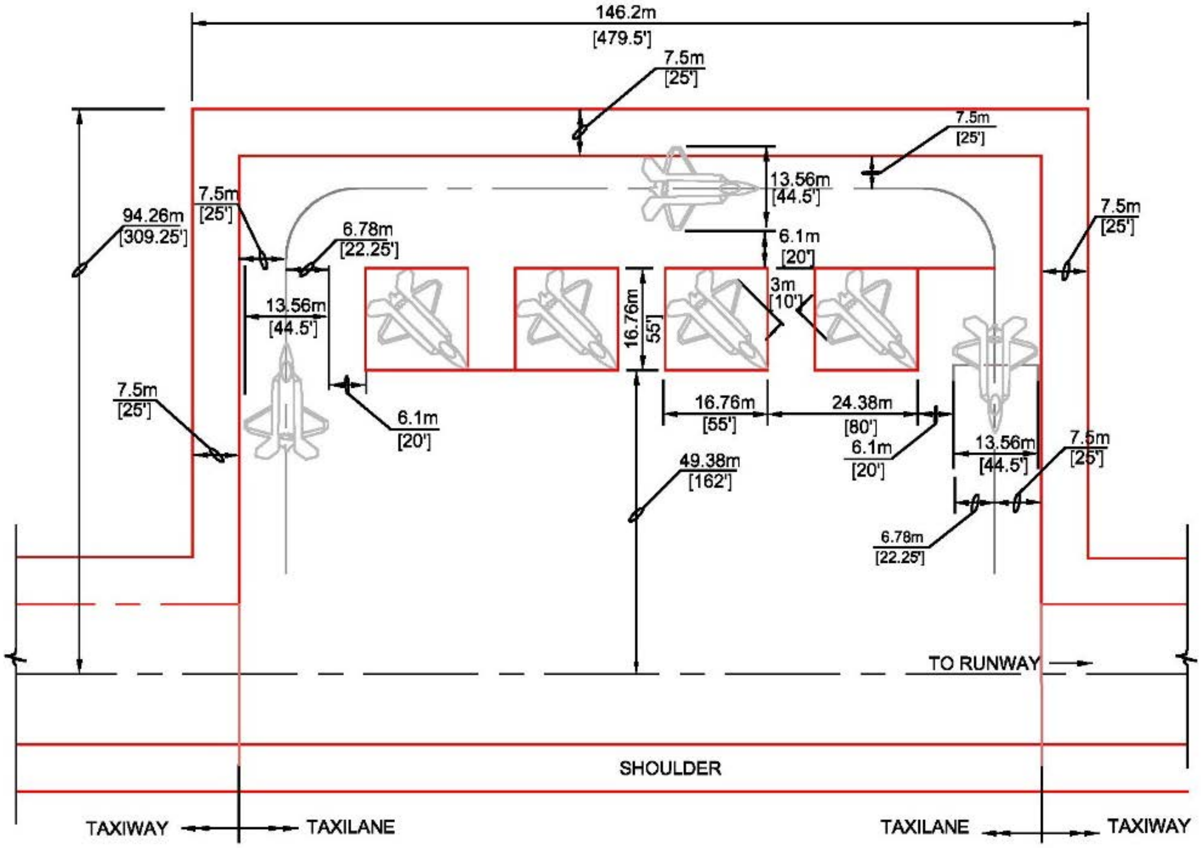
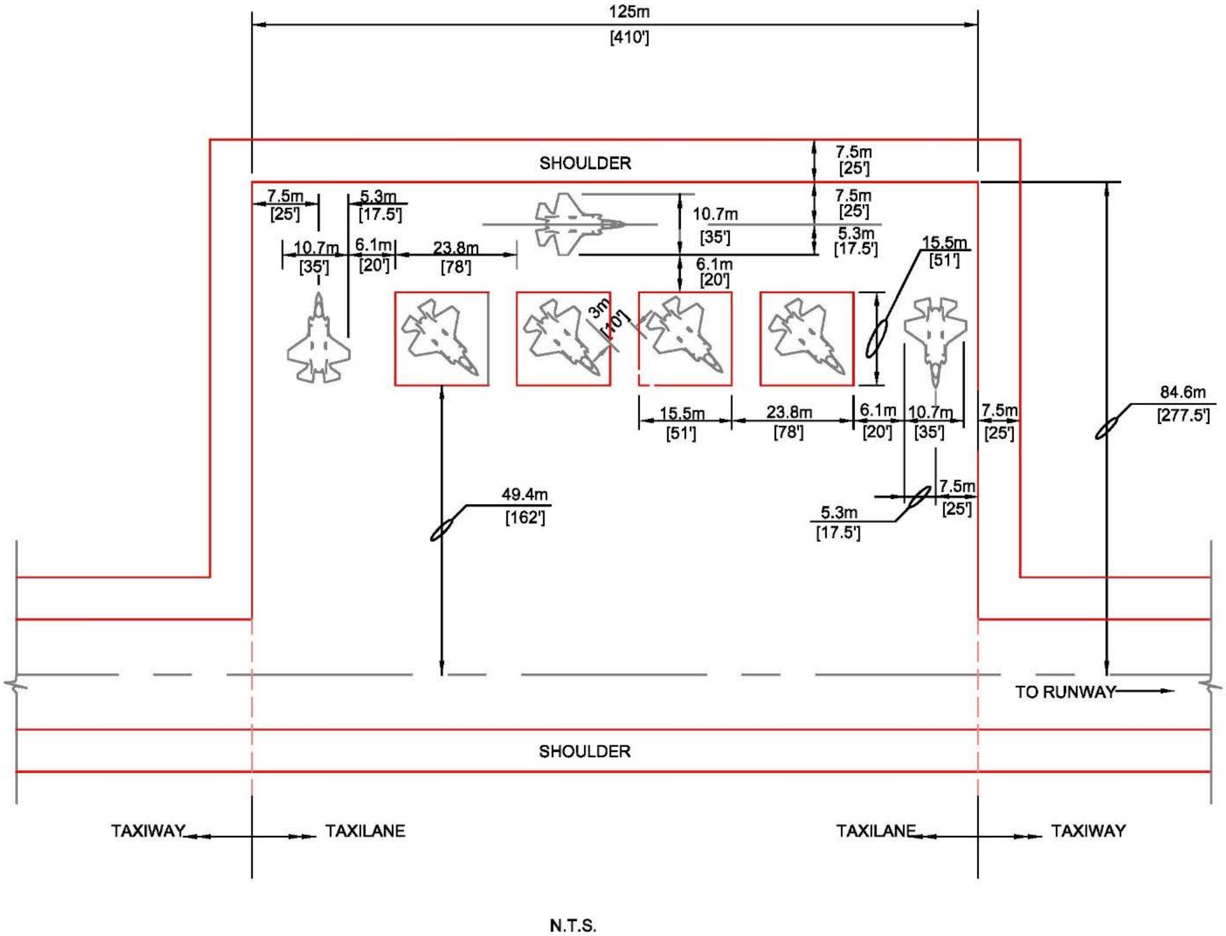


Figure 6-28. Arm-Dearm Pad for F-35 Fighter (JSF)



6-11 COMPASS CALIBRATION PAD (CCP).

An aircraft CCP is a paved area in a magnetically quiet zone where an aircraft's compass is calibrated.

6-11.1 Army.

A CCP is not required by the Army, but if one is provided, or used, then requirements of Paragraph 6-11 and applicable subparagraphs apply.

6-11.2 Air Force.

The Air Force has the option of using the criteria presented here or using the criteria provided in FAA AC 150/5300-13.

6-11.3 Navy and Marine Corps.

Prior to construction of, or major repair of, a CCP, a validation of need shall be filed through the maintenance department to NAVAIR for approval. For CCP marking requirements, use the controlling aircraft NAVAIR Technical Manual or use the criteria contained in Appendix B, Section 10, for general purpose CCPs.

6-11.4 Location.

The CCP should be located off the side of a taxiway at sufficient distance to satisfy the runway and taxiway lateral clearance distance and airspace criteria in Chapters 3, 4, and 5. Do not site CCPs, other aprons, hot cargo spots, or taxiways to these facilities in a way that will allow penetration of the approach-departure clearance surface.

6-11.5 Siting Consideration.

6-11.5.1 Separation Distances.

To meet the magnetically quiet zone requirements and prevent outside magnetic fields from influencing the aircraft compass calibration, efforts must be taken to make sure that minimum separation distances are provided. See Appendix B, Section 10 for CCP separation distances.

6-11.5.2 Preliminary Survey.

During the site selection process, the proposed sites for CCPs must be checked for magnetic influences to ensure that the area is magnetically quiet regardless of adherence to separation distances. A preliminary survey as described in Appendix B, Section 10, must be conducted to determine if the proposed site is magnetically quiet. A survey similar to the preliminary survey must be conducted after construction of any new item or building, within or near the separation distances of the pad. This will ensure that the newly constructed item has not created new magnetic influences in the magnetically quiet zone.

6-11.5.3 Magnetic Survey and Re-marking Requirements.

The CCP magnetic survey is an airfield engineering survey used to ensure that the CCP area is magnetically quiet, to determine the magnetic variation (MagVar) of the area, and to layout the markings for the pad. A magnetic survey shall be conducted after construction of a new CCP and at regular intervals thereafter to ensure the CCP remains suitable for aircraft magnetic compass calibrations. The procedure to conduct magnetic surveys is outlined in Appendix B, Section 10.

6-11.5.3.1 Magnetic Survey Frequency.

Because the Magnetic North Pole is constantly moving, the MagVar at any location on the Earth is constantly changing at varying rates. Check the MagVar and the MagVar rate of change for any latitude/longitude using https://www.ngdc.noaa.gov/geomag/declination.shtml. Every CCP must be re-surveyed periodically to update the MagVar, update the alignment with Magnetic North, and update the CCP markings. The CCP markings shall be removed and replaced when the new MagVar differs by more than 30 arc-minutes (0.5 degrees) from the existing CCP markings. In addition, periodic re-surveys ensure the CCP area remains a magnetically quiet zone, which is essential for accurate aircraft magnetic compass calibrations.

A CCP must be re-surveyed and the markings updated when the MagVar changes by more than 30 arc-minutes from the existing markings. For CCPs where the MagVar rate of change is low (7 arc-minutes or less per year), a re-survey must be conducted at an interval of 5 years or less. At locations where the MagVar rate of change is greater than 7 arc-minutes per year, more frequent re-surveys are required. Table 6-3 lists the re-survey frequency needed based on MagVar rates of change. If at any time the difference exceeds the tolerance of the aircraft compass or calibration equipment, the Airfield Manager may schedule a survey more frequently.

Periodic surveys to re-calibrate the marked directions on the CCP are required at a minimum every five years. In locations where the magnetic variation over time is high, more frequent re-calibration is required. Table 6-3 lists re-survey frequency needed to keep the difference between marked north and magnetic north less than 50 arc-minutes. If the difference exceeds the tolerance of the aircraft compass or calibration equipment, the Airfield Manager may schedule a survey more frequently.

Table 6-3. Magnetic Survey Frequency Requirements

Magnetic Variation Rate of Change [arc-minutes per year]	Re-Survey Frequency
≤ 7	5 years
8	4 years
9-10	3.5 years (42 months)
11	3 years
12-14	2.5 years (30 months)
15-18	2 years
≥ 19	1.5 years (18 months)

.

6-11.5.3.2 Additional Information.

The Naval Air Warfare Center-Aircraft Division (NAWCAD-4.5.3), an authority on CCPs, substantially contributed to this criteria. For additional information on CCP survey and maintenance, contact:

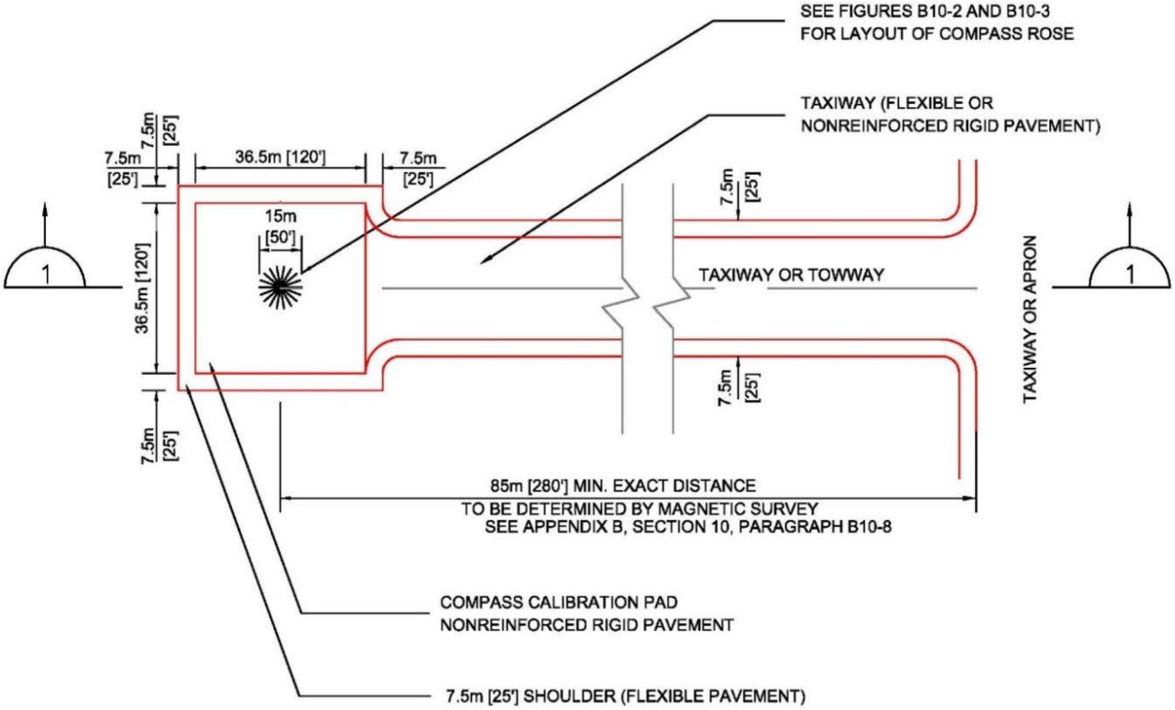
Naval Air Warfare Center-Aircraft Division
NAWCAD-4.5.3, Core Avionics Engineering Division

Building 2187
NAS Patuxent River, MD
(301) 342-9122

6-11.6 Compass Calibration Pad (CCP) Size.

Typical CCP size is shown in Figure 6-29.

Figure 6-29. Compass Calibration Pad



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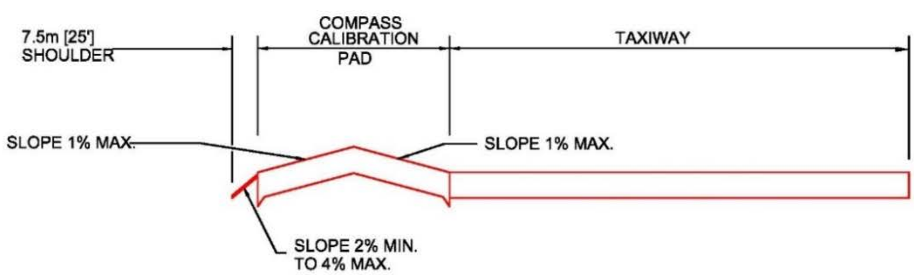


NOTE

THICKNESS OF CONCRETE AND BASE COURSE, BASE COURSE DENSITY, TYPE OF SHOULDER SURFACING AND CBR OF SHOULDER BASE COURSE ARE GOVERNED BY EXISTING CRITERIA OR ARE DEPENDENT UPON SITE CONDITIONS.

SECTION 1
N.T.S.

6-11.7 Access Taxiway/Towway.

An access taxiway will be provided for access from the primary taxiway to the CCP. The access taxiway must be oriented to facilitate moving the aircraft onto the CCP on a magnetic north heading. At Army and Air Force aviation facilities, if the aircraft should be towed to the CCP, the access taxiway must be designed as a towway. At Navy and Marine Corps facilities, the taxiway should be designed as a taxiway. Taxiway and towway design requirements are presented in Chapter 5.

6-11.8 Grading.

CCPs will be graded as specified in this section.

6-11.8.1 Perimeter Elevation.

The elevation of the perimeter of the pad will be the same elevation around the entire perimeter.

6-11.8.2 Cross Slope.

The CCP should be crowned in the center of the pad with a constant cross slope of 1% in all directions to provide surface drainage while facilitating alignment of the aircraft pad.

6-11.9 Tie-Down/Mooring Point.

Do not place any aircraft tie-down/mooring points, tie-down/mooring eyes, or static grounding points in the CCP pavement.

6-11.10 Embedded Material.

Due to the influence of ferrous metal on a magnetic field, the PCC pavement for the CCP and access taxiway must not contain any embedded ferrous metal items such as dowels bars, reinforcing steel, steel fibers, or other items. In addition, ferrous metal must not be placed in or around the CCP site.

6-11.11 Control Points.

A control point will be set in the center of the CCP. This point will consist of a brass pavement insert into which a bronze marker is grouted in accurate alignment. This point will be stamped with "Center of Calibration Pad." The layout of the control points is discussed further in Appendix B, Section 10.

6-11.12 CCP Markings.

See Appendix B, Section 10.

6-12 HAZARDOUS CARGO PADS.

Hazardous cargo pads are paved areas for loading and unloading explosives and other hazardous cargo from aircraft. Hazardous cargo pads are required at facilities where the existing aprons cannot be used for loading and unloading hazardous cargo. Do not site hazardous cargo pads, other aprons, hot cargo spots, or taxiways to these facilities in a way that will allow penetration of the approach-departure clearance surface. A Hazardous Cargo Pad is not authorized in a Runway Clear Zone.

6-12.1 Navy and Marine Corps Requirements.

Hazardous cargo pads are not normally required at Navy and Marine Corps facilities; however, where operations warrant or an Air Force hazardous cargo aircraft is continuously present, hazardous cargo pads can be justified with proper documentation.

6-12.2 Siting Criteria.

Hazardous cargo pads require explosives site planning as discussed in Appendix B, Section 9.

6-12.3 Hazardous Cargo Pad Size

6-12.3.1 Circular Pad.

At aviation facilities used by small cargo aircraft, the hazardous cargo pad is a circular pad as shown in Figure 6-30.

6-12.3.2 Semicircular Pad.

At aviation facilities used by large cargo aircraft and at aerial ports of embarkation (APOE) and aerial ports of debarkation (APOD), the hazardous cargo pad is semicircular, as shown in Figure 6-31. The semicircular pad is adequate for aircraft up to and including the dimensions of the C-5.

6-12.3.3 Other Pad Size.

The hazardous cargo pad geometric dimensions as shown in Figures 6-30 and 6-31 are minimum requirements. Hazardous cargo pads may be larger than these dimensions if the design aircraft cannot maneuver on the pad. Sources for obtaining information concerning minimum turning radii for various aircraft are presented in Army USACE TSC Report 13-2..

6-12.4 Access Taxiway.

An access taxiway will be provided for access from the primary taxiway to the hazardous cargo pad. The taxiway should be designed for the aircraft to taxi into the hazardous cargo pad under its own power.

6-12.5 Tie-Down and Grounding Points.

Tie-down/mooring points and tie-down/mooring eyes must be provided on each hazardous cargo pad. Grounding points must be provided on each hazardous cargo pad. Tie-down and grounding points are discussed further in Appendix B, Section 11.

6-12.6 Miscellaneous Considerations.

These items need to be considered for hazardous cargo pads:

6-12.6.1 Utilities.

Telephone service, apron flood lighting, airfield lighting, and water/fire hydrants are required for safety.

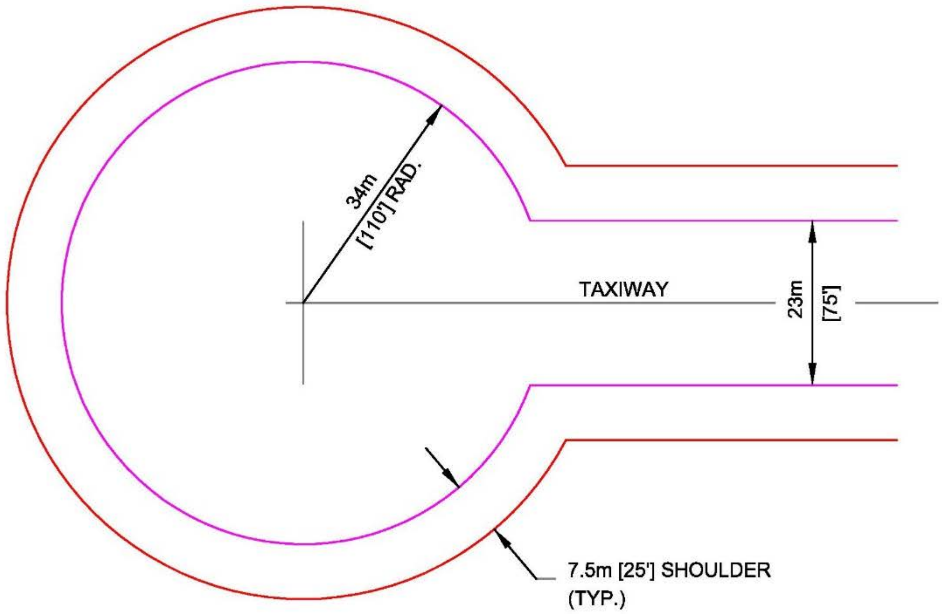
6-12.6.2 Access Road.

Consider providing a paved roadway to the hazardous cargo pad for access by trucks and other vehicles.

6-13 ALERT PAD.

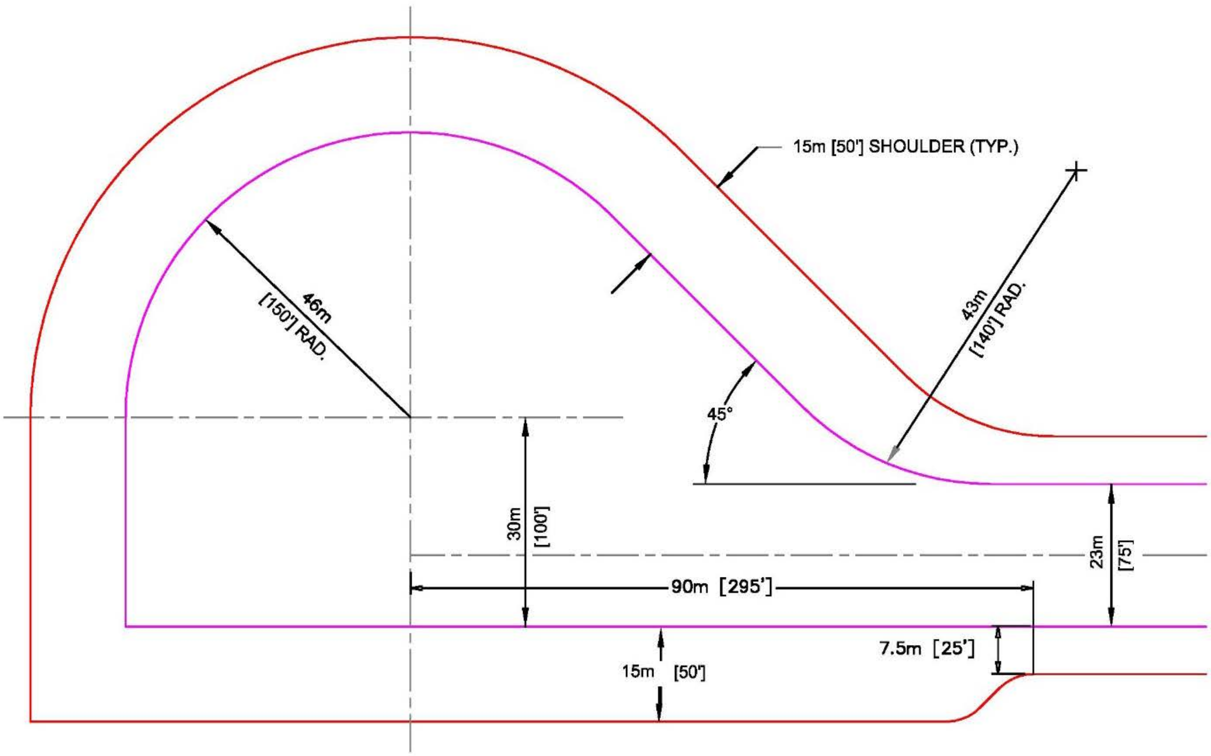
An alert pad, often referred to as an alert apron, is an exclusive paved area for armed aircraft to park and have immediate, unimpeded access to a runway. In the event of a declared alert, alert aircraft must be on the runway and airborne in short notice. This chapter will refer to both alert aprons and alert pads as "alert pads." An alert apron is shown in Figure 6-32. An alert pad is shown in Figure 6-33.

Figure 6-30. Hazardous Cargo Pad Other than APOE/Ds



N.T.S.

Figure 6-31. Typical Hazardous Cargo Pad for APOE/Ds

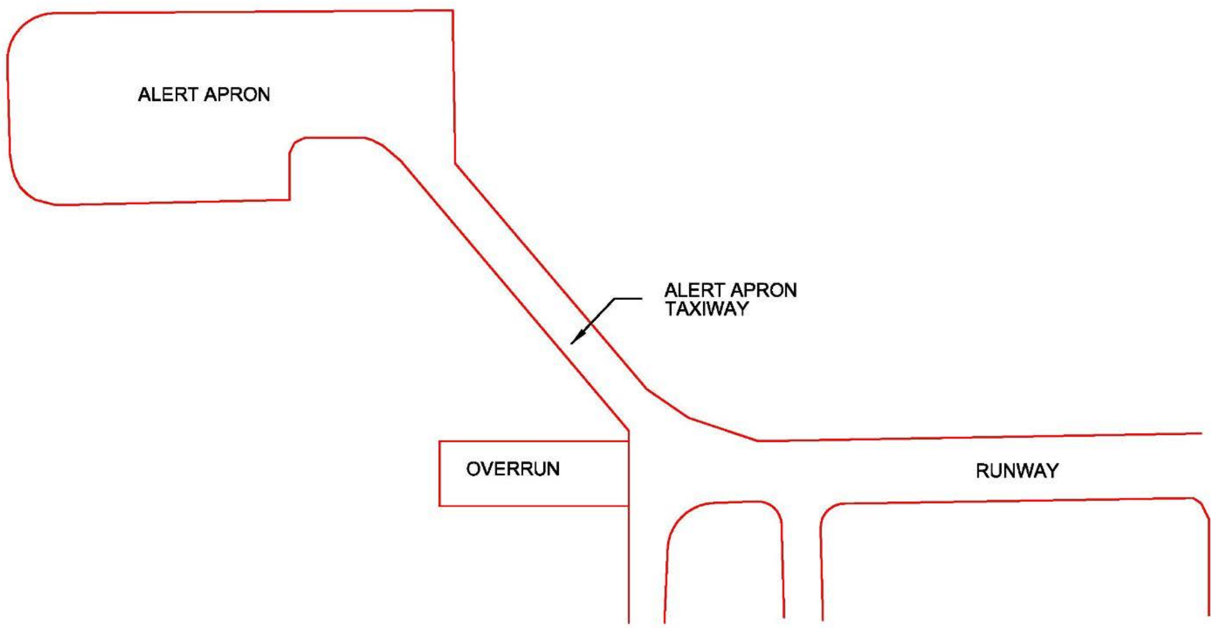


N.T.S.

NOTE

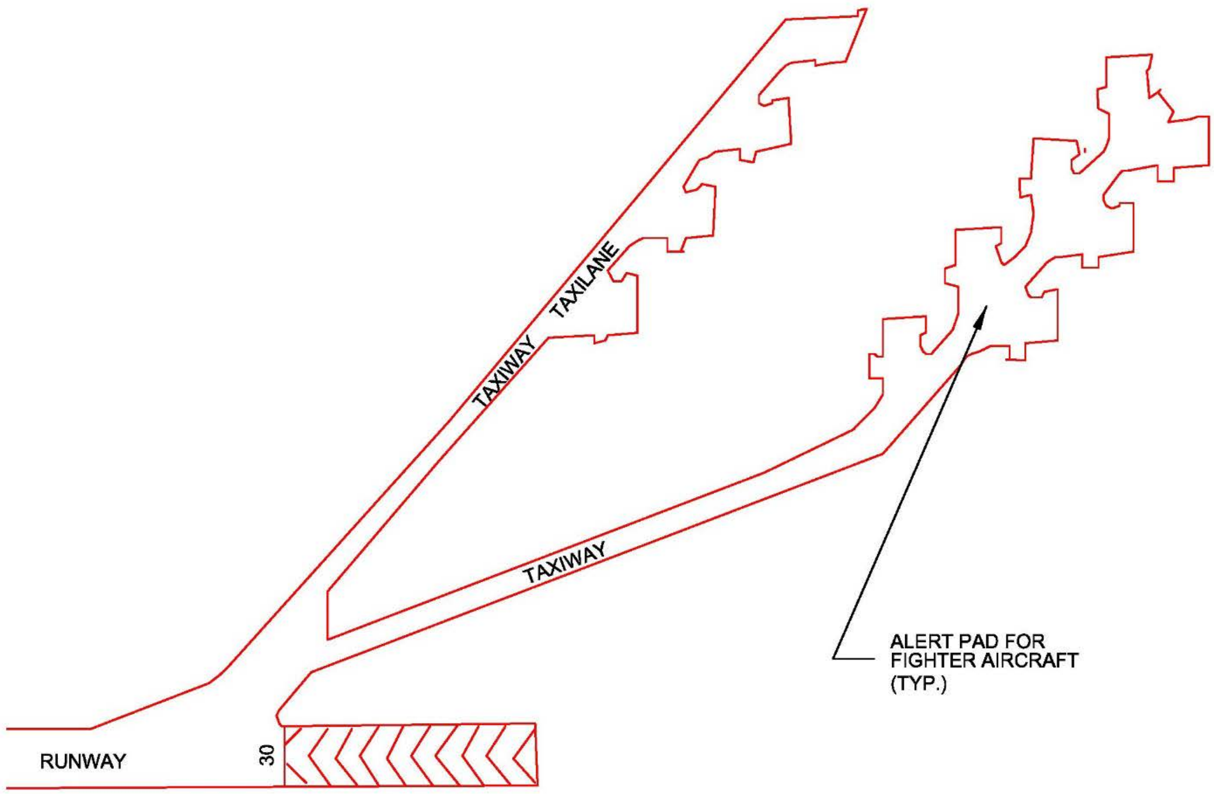
THIS HAZARDOUS CARGO PAD IS ADEQUATE FOR AIRCRAFT UP TO AND INCLUDING THE C-5. THE DIMENSIONS MAY BE ADJUSTED TO ACCOMMODATE LIMITING CONSTRAINTS AT INDIVIDUAL FACILITIES.

Figure 6-32. Typical Alert Apron for Bombers and Tanker Aircraft



N.T.S.

Figure 6-33. Typical Alert Pad for Fighter Aircraft



N.T.S.

6-13.1 Navy and Marine Corps Requirements.

Alert pads are not normally required at Navy and Marine Corps facilities. When justified, the criteria provided in this UFC will be used.

6-13.2 Location.

Locating the alert pad adjacent to a runway end will allow alert aircraft to proceed directly from the apron to the runway threshold without interruptions from other traffic. Alert pads must be located close to the runway threshold to allow alert aircraft to be airborne within the time constraints stipulated in their mission statements. The preferred location of alert pads is on the opposite side of the runway, away from normal traffic patterns to allow aircraft on the alert pad direct, unimpeded access to the runway. Alert pads and alert aprons must not be located so that the aircraft or shelters are within the graded area of the clear zone, or penetrate the approach-departure clearance surface.

6-13.3 Siting Criteria.

6-13.3.1 Airspace Imaginary Surfaces.

As discussed in paragraph 6-8.3.2, aircraft parked on alert pads must not project into airspace imaginary surfaces.

6-13.3.2 Explosives Consideration.

Aircraft loaded with explosives on alert pads should be located to minimize the potential for explosive hazards. Explosives safety site plans must be prepared for explosive-loaded alert aircraft. See Appendix B, Section 9.

6-13.4 Alert Pad Size.

6-13.4.1 General Dimensions.

Alert pads should be sized to park all of the aircraft on alert. The dimensions of the pad should vary with the length and wingspan of the aircraft to be served and the explosives on the aircraft. Wingtip clearances, presented in Table 6-4, are minimum separation distances to be observed at all times.

Table 6-4. Minimum Separation Distance on Tanker or Bomber Alert Aprons from the Centerline of a Through Taxilane to a Parked Aircraft

Aircraft	Standard (m)	Standard (ft)	Minimum (m)	Minimum (ft)
B-52 or B-52 mixed force B-1 B-2	45.72	150	38.10	125
KC-46	41.91	137.5	34.29	112.5
KC-135	38.10	125	30.48	100
KC-10	30.48	100	22.86	75

6-13.4.2 Air Force Waivers.

6-13.4.2.1 Wingtip Clearances.

The MAJCOM may grant waivers to the 15.24 m (50 ft) wingtip clearance requirement when sufficient ramp area is not available. In no case will the wingtip clearance be waived to less than 9.14 m (30 ft).

6-13.4.2.2 Wingtip Clearances Based on Taxilane Width.

When the minimum separation distance between a taxilane centerline and the nose/tail of a parked aircraft is reduced below the distance shown in Table 6-1, the minimum waiver wingtip clearance distance of 9.14 m (30 ft) must be increased 0.3 m (1 ft) for each 0.3-m (1-ft) reduction in separation distance. Example: Referencing Table 6-4, the standard B-52 nose to taxiway centerline distance is 150 ft. If a B-52 nose to taxilane centerline is 43 m (140 ft)—minimum waiver wingtip distance 12 m (40 ft), adding the reduction in separation distance (10 ft) to the minimum waiver wingtip clearance (30 ft); if the nose to centerline distance is 40 m (130 ft) or less—no waiver permitted or required, since the reduction in separation distance (20 ft) added to the minimum waiver wingtip clearance (30 ft) would equal 50 ft, the standard wingtip clearance requirement, therefore for value of 130 ft or less, comply with 15-m (50-ft) minimum wingtip clearance.

6-13.5 Design Aircraft.

To facilitate flexibility in future operations, new alert ramp construction should conform to B-52 standards. Aircraft parked in shelters are exempt from the parking separation criteria in 6-13.4.2.1.

6-13.6 Alert Aircraft Parking Arrangements.

6-13.6.1 Fighter Arrangements.

Fighter aircraft are parked at 45-degree angles to dissipate the heat and velocity of jet blast.

6-13.6.2 Non-Fighter Arrangements.

Non-fighter aircraft should be parked in rows.

6-13.7 Jet Blast Distance Requirements.

Jet blast safe distances should be considered when planning and designing parking locations on alert pads. Safe distance criteria are presented in Appendix B, Section 7.

6-13.8 Taxi-In/Taxi-Out Capabilities.

Alert aprons and pads should be designed either for taxi-in/taxi-out parking or for push-back parking. Taxi-in/taxi-out parking, shown in Figure 6-34, is preferred because alert aircraft can be taxied quickly into position under their own power. Back-in parking, shown in Figure 6-35, requires less paved area.

6-13.9 Turning Radius.

The turning radius on alert pad taxilanes will be designed to provide the minimum allowable turn under power of the largest aircraft that will use the alert pad. In no case will the initial turnout from the alert apron parking space to the through taxilane exceed 90 degrees. For Air Force alert pads for bombers and tankers, the initial turn radius from the parking space will equal the distance from the taxilane centerline to the nose of the aircraft. This is shown in Figure 6-34.

Figure 6-34. Alert Apron Taxi-In/Taxi-Out Parking

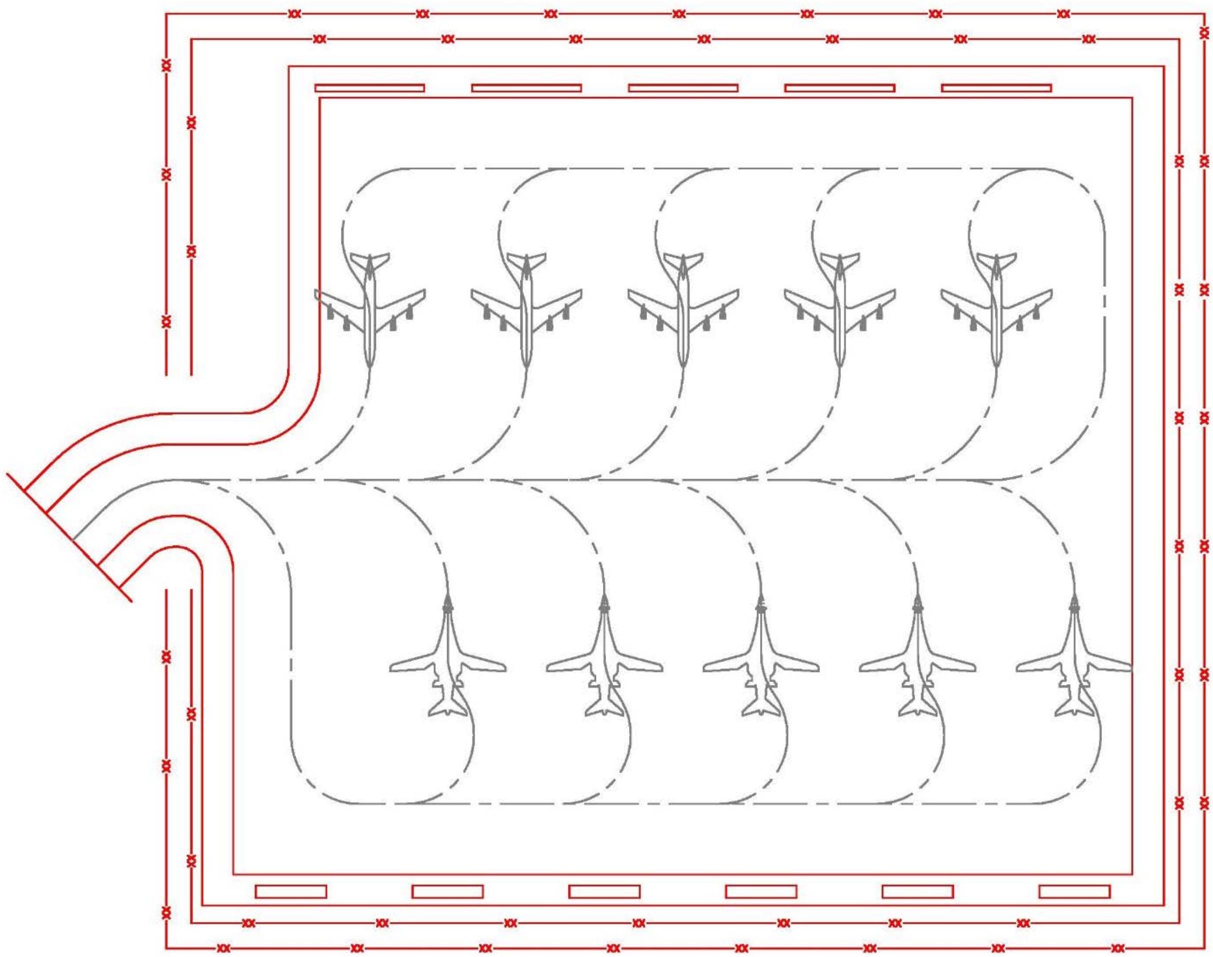


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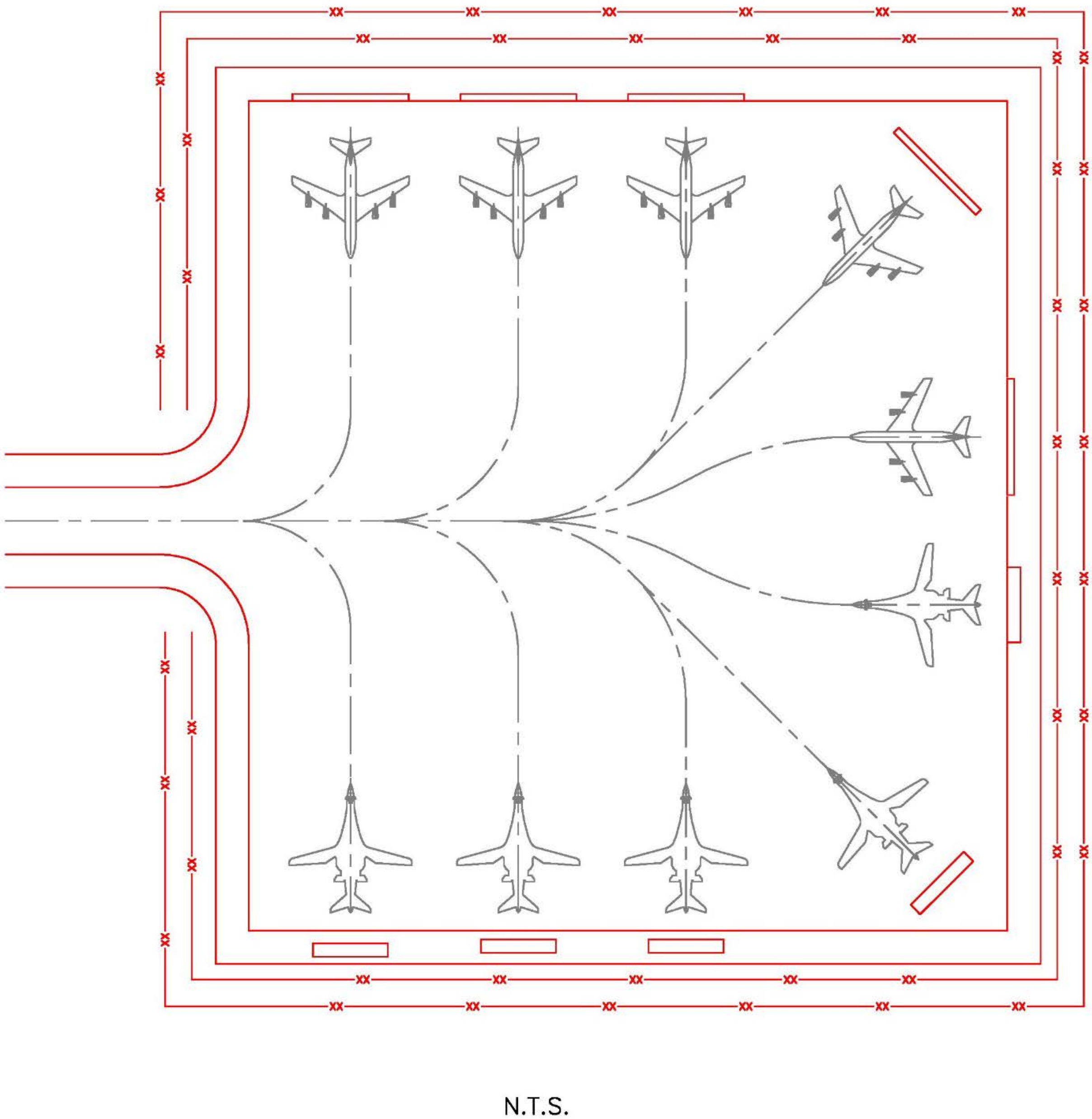
Figure 6-35. Alert Apron Back-In Parking



6-13.10 Dedicated Access Taxiway.

At alert pads, provide a single dedicated taxiway from the alert pad to the runway for aircraft to progress directly without traffic interruptions. Having no other taxiways intersect the dedicated taxiway is the ideal way to ensure that the dedicated taxiway is not obstructed.

6-13.11 Tie-Down and Grounding Points.

Tie-down/mooring points, tie-down/mooring eyes, and grounding points will be provided at each aircraft parking location as discussed in Appendix B, Section 11.

6-14 AIRCRAFT WASH RACKS.

Aircraft wash racks are paved areas or facilities provided at all aircraft base facilities for the purpose of cleaning aircraft in conjunction with periodic maintenance and corrosion control activities.

This Section applies to Exterior Aircraft Wash Racks which are defined as open (non-environmentally controlled), covered or uncovered paved areas designed for the purpose of washing aircraft. Where required, the wash rack must be provided with a cover to protect the aircraft from sun induced heat or inclement weather preventing efficient wash operations. Interior Aircraft Wash Racks are addressed in UFC 4-211-02, Aircraft Corrosion Control Facilities.

6-14.1 Location.

Covered and uncovered aircraft wash racks should be located adjacent to the hangar area or maintenance facilities and contiguous to aircraft parking or access aprons. Existing pavements can be used where curbing can be installed, drainage adjusted as necessary, and other required facilities such as utilities can be provided to make a usable wash rack. Where possible, wash racks should be located near existing facilities where existing utility and pollution control systems are accessible. In siting wash racks, support facilities such as pump houses and tanks should be located either outside apron clearance distances or below grade. Follow aircraft wingtip clearance requirements presented in this chapter for siting the washrack in relation to parked aircraft and adjacent facilities.

6-14.2 Size and Configuration.

There are two standard shapes of wash racks for fixed wing aircraft as indicated in Figures 6-37 and 6-38: Type F, which accommodates fighters and other small aircraft; and Type L, which accommodates heavy bombers and large cargo aircraft. The Wash Rack Selection Chart, Figure 6-36, may be used to assist in determining the Wash Rack Type. Figure 6-40 represents a wash rack for rotary-wing facilities.

At mixed mission facilities, it may be possible to accommodate several smaller (fighter) aircraft on one larger Type F aircraft wash rack pavement. Size the pavement area to accommodate the larger of four small aircraft or one larger aircraft. The dimensions for wash racks to accommodate multiple smaller aircraft must include the minimum clearances indicated between aircraft and from the aircraft to the curb.

Figure 6-36. Wash Rack Selection Chart

AIRCRAFT WINGSPAN or ROTOR DIAMETER

AIRCRAFT LENGTH	0' - 20'	20' - 40'	40' - 60'	60' - 80'	80' - 100'	100' - 120'	120' - 140'	140' - 160'	160' - 180'	180' - 200'	200' - 250'	
0' - 20'	**Normal Aspect Ratio (L/WS)**											
20' - 40'			MQ-1	MQ-9					**Long Wingspan**			
40' - 60'		F-16 F-35	A-10 C-12	F-15	E-2		RQ-4C MQ-4C					**Type "F"**
60' - 80'			F-22 UH-60			U-2			B-2			
80' - 100'				CH-47 CH-53	CH-53K (future)		C-130					
100' - 120'					P-3	C-40	MC_130					
120' - 140'							C-135 KC-135 P-8					
140' - 160'							B-1	E-3, E-6 E-8		B-52		
160' - 180'		**Long Length**						KC-46	C-17			
180' - 200'									KC-10			**Type "L"**
200' - 250'										E-4 (AF-1)	C-5A	

NOTE: SEE FIGURE 6-40 FOR HELICOPTER WASH RACKS. HOWEVER, DUAL USE (FIXED AND ROTARY WING) WASHRACKS MAY USE FIGURE 6-36.

Figure 6-37. Wash Rack Type "F"

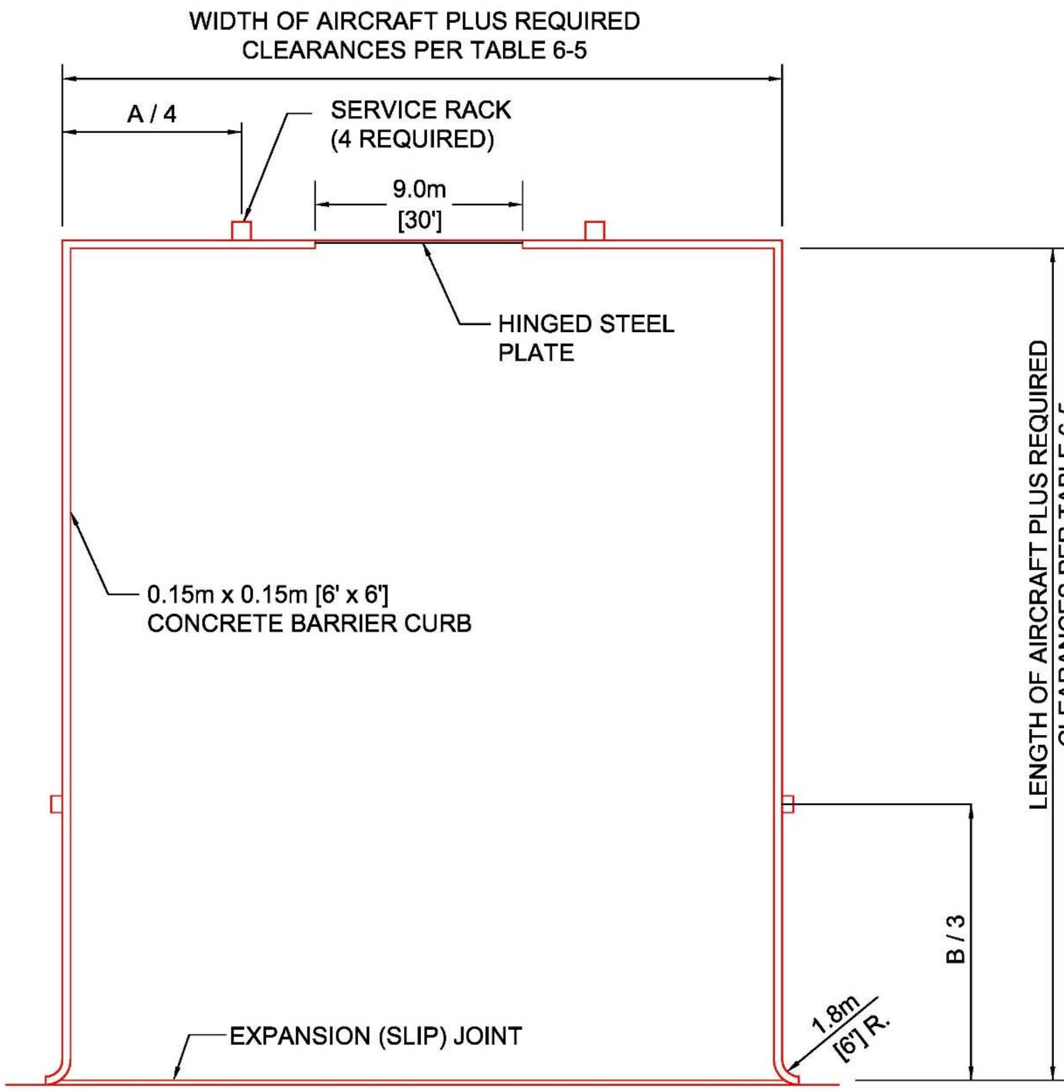


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Figure 6-38. Wash Rack Type "L"

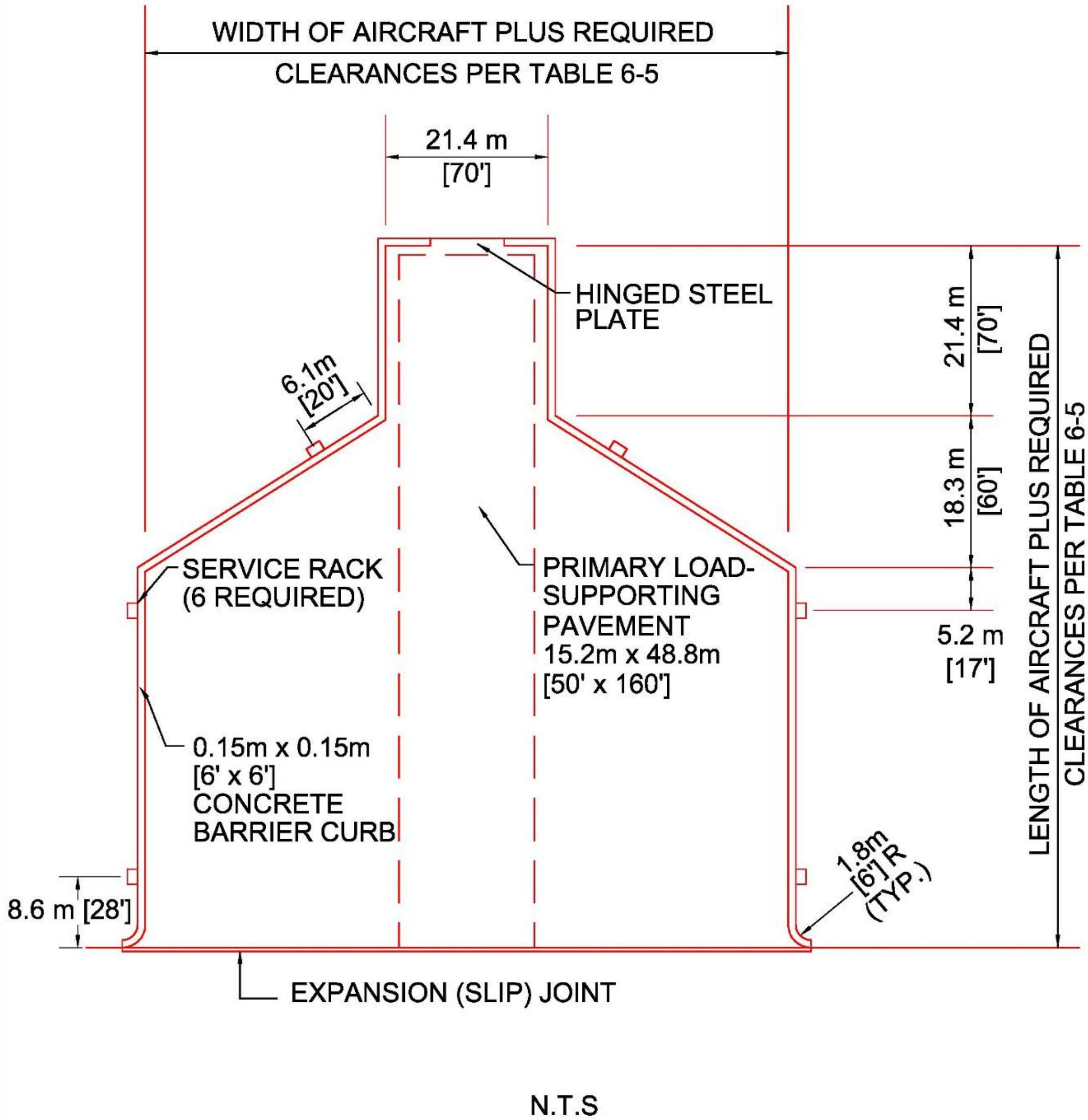


Figure 6-39. Utilities and In-Pavement Structures

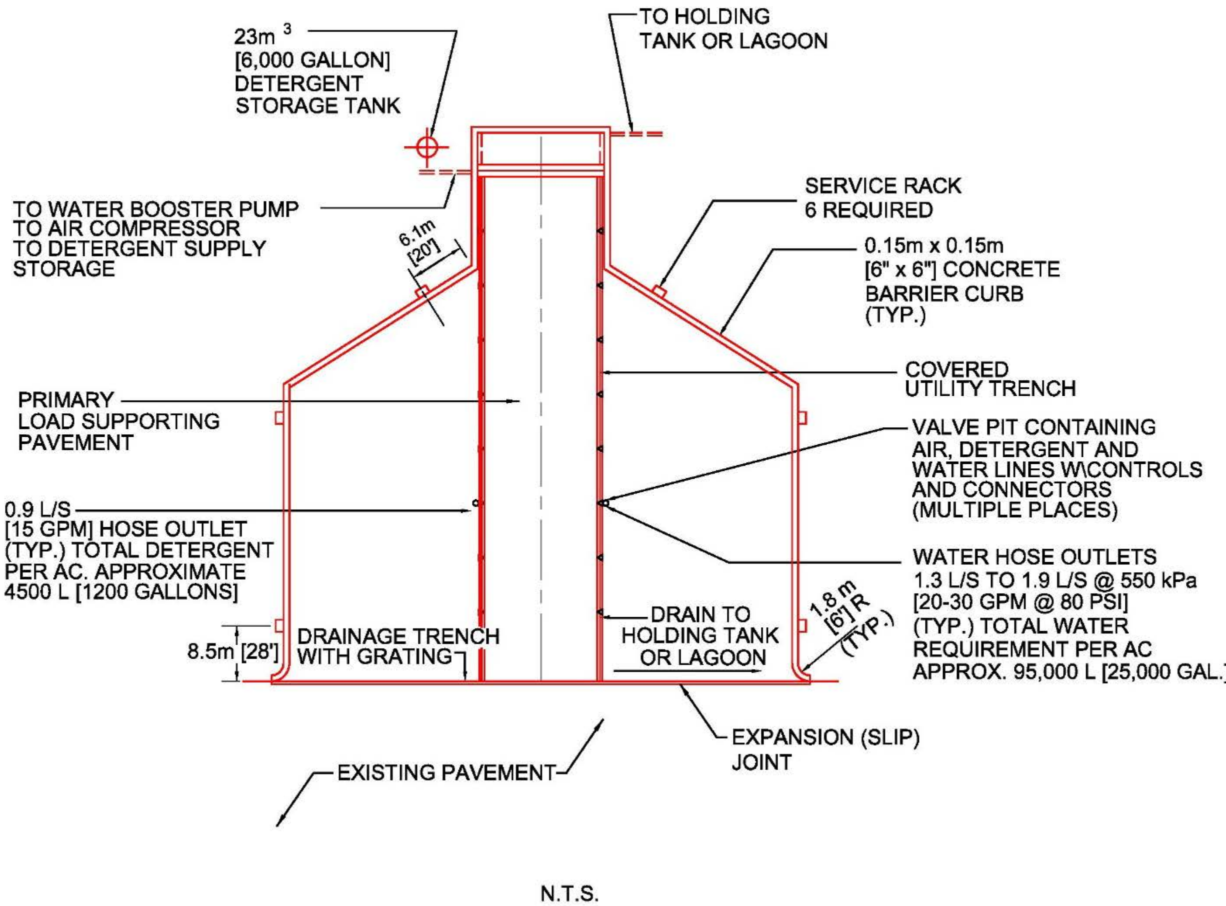
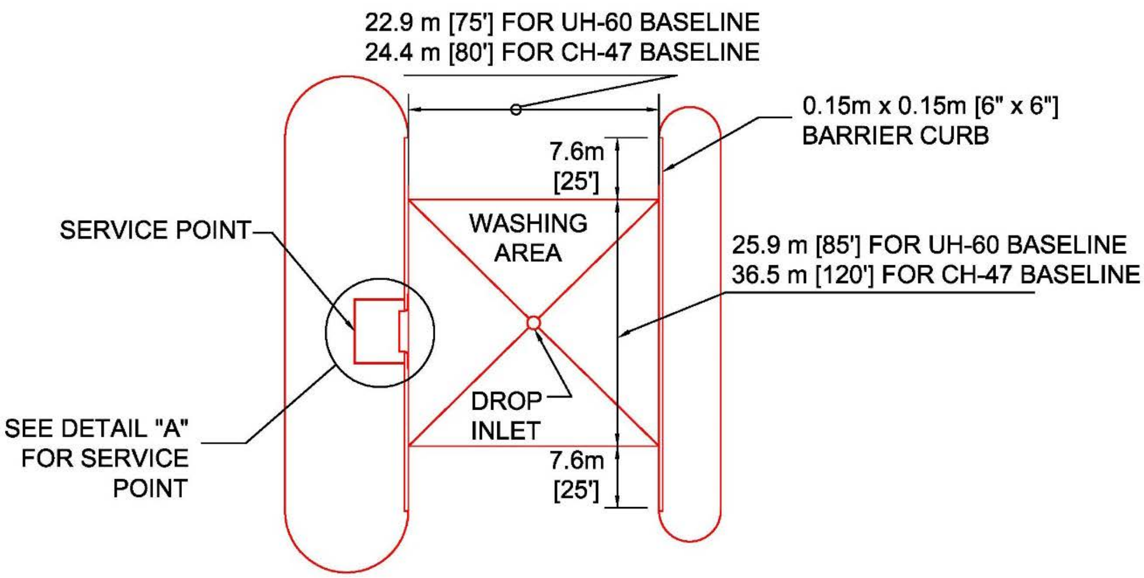


Figure 6-40. Helicopter Wash Rack (Single Helicopter)



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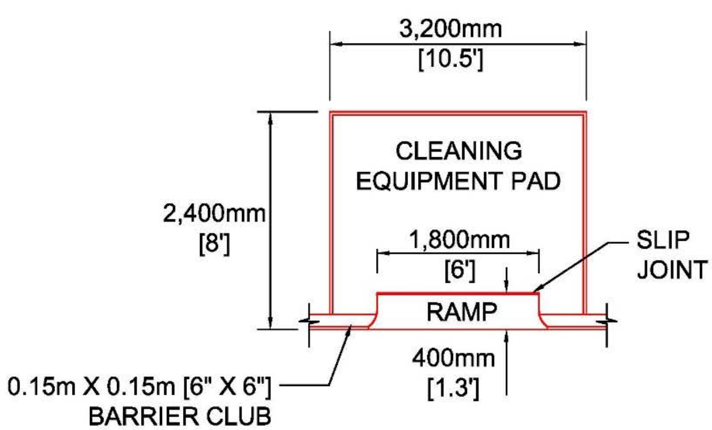

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6-14.3 Wash Rack Size.

The size and configuration of an aircraft wash rack is determined by the type of mission aircraft expected to use it. The dimensions of the largest aircraft plus the clearances shown in Table 6-5 determine the minimum wash rack pavement dimensions. At mixed mission facilities, it may be possible to accommodate several smaller (fighter) aircraft on one larger aircraft wash rack pavement.

Table 6-5. Wash Rack Clearances From Aircraft to Curb

Wash Rack Clearances From Aircraft to Curb					
Aircraft	**From**	**To**	**Direction**	**Distance (m)**	**Distance (ft)**
Heavy bomber, medium bomber, and cargo	Wingtip	Curb	Horizontally	4.6	15
	Tail	Curb	Horizontally	4.6	15
	Nose	Curb	Horizontally	4.6	15
Fighter	Wingtip	Curb	Horizontally	3.1	10
	Tail	Curb	Horizontally	3.1	10
	Nose	Curb	Horizontally	3.1	10
Helicopter	Rotor-tip	Curb	Horizontally	See note 1.	See note 1.
	Tail	Curb	Horizontally	See note 2.	See note 2.
	Nose	Curb	Horizontally	See note 3.	See note 3.

NOTES:

1. For light to medium helicopter (UH-60 baseline), the width of the wash rack is based on the addition of 3.1-m (10-ft) buffers to the rotor diameter. For heavy helicopter (CH-47 baseline), the width of the wash rack is based on the addition of 3.1-m (10-ft) buffers to the rotor diameter. For wash racks servicing multiple aircraft, a 6.1-m (20-ft) buffer is required between rotor tips.
2. 3.1 m (10 ft) for light and medium helicopter (UH-60 baseline). 10.4 m (34 ft) for heavy helicopter (CH-47 baseline).
3. 6.7 m (22 ft) for light and medium helicopter (UH-60 baseline). 10.4 m (34 ft) for heavy helicopter (CH-47 baseline).

6-14.4 Wash Rack Facilities.

The wash rack should consist of these required items:

- Paved surface
- Concrete curbs
- Paved shoulder (for rotary-wing only)
- In-pavement structures
- Wastewater collection
- Wastewater treatment

- Utility control building
- Utilities

6-14.5 Wash Rack Grading.

The pavement surface of the wash rack will be sloped at 1.5% to assure positive drainage to waste drains. UFC 3-260-02 *Pavement Design for Airfields* addresses configuration and grading criteria for aircraft wash racks. Wash racks are considered as Type "C" traffic area. See UFC 3-260-02 for type "C" traffic area requirements.

6-14.6 Tie-Down and Grounding Points.

Tie-down/mooring points, tie-down/mooring eyes, and grounding points are not required for wash racks.

6-14.7 Concrete Curbs.

Concrete curbs will be constructed on the perimeter of the wash rack pavement to confine wastewater to the wash rack pavement. Do not install curbs in wash racks which must be built within an active apron due to mission or space constraints. At these locations, concrete trenches with heavy duty flush metal grating must be utilized to carry the wash water to the central holding basin separator, or pump pit. The existing slope should be utilized as much as possible to minimize the amount of concrete apron which must be replaced.

6-14.8 Service Points.

6-14.8.1 Army and Air Force.

Wash racks are designed with service points incorporated into the pavement floors. The following in-pavement structures should be considered for wash rack design:

- Valve pits containing air, detergent, and water lines with controls and connectors
- Water hose outlets
- Covered utility trench
- Service rack – Point of service for wash rack equipment (i.e. hose reels, high pressure nozzle sprayers, etc.)

Typical locations for these structures are shown in Figure 6-39.

6-14.8.2 Navy and Marine Corps.

Wash rack service points are required for the Navy and Marine Corps.

6-14.9 Wash Rack Utilities.

6-14.9.1 Required Wash Rack Utilities.

Aircraft wash racks contain utilities that are not normally considered in airfield geometric design; however, the designer may need to be aware that they are an integral part of the wash rack. Design guidance for these utilities has not been included in this UFC. The following utilities are considered integral to the design of the Wash Rack and must be provided to the service outlets located along the perimeter as noted in the diagrams provided:

- Hot and cold water
- Detergent/Water solution
- Compressed Air
- Electrical power as required for portable lighting and/or portable hot water generating systems

Utilities must be run from the Utilities Control Building (or other enclosed mechanical space) to the Wash Rack via below grade installation or Service Trenches. Portable hot water generating systems may be utilized in lieu of a permanent water heater and tank arrangement. Designers must check the maximum flow rates required for mission aircraft and size utilities appropriately. Provide freeze protection for areas where environmental conditions require. Ensure backflow prevention is included to create positive separation from the potable water system.

6-14.9.2 Utility Controls Building.

Wash Racks are generally supported by an adjacent Utilities Control Building. This building houses detergent make-up equipment, a detergent mixing tank, a water heater, pumps, and operating controls. An enclosed space inside the nearby serving hangar may also be utilized to house the Wash Rack mechanical equipment. Storage and sanitary facilities may also be provided as the operational requirements dictate. The Utilities Control Building must be located a sufficient distance away from the Wash Rack to preclude fire hazards associated with heating and associated electrical equipment.

6-14.9.3 Service Utility Connections (Service Points).

Wash racks must be provided with an adequate number of service utility connections proportionate to the number of personnel required to wash the aircraft. The service connections must be installed in sub-surface pits and include all appropriate valving for each service with the appropriate number of outlets with quick disconnects. Typical locations for the Service Points are shown in Figure 6-39. Electrical outlets, where required, will be provided in separate or isolated pits appropriately designed for subsurface electrical installations.

6-14.9.4 Lighting.

Provide exterior lighting at the washrack at a minimum of 50-foot candles (FC) to accommodate night washing operations. Lighting can be provided via either installed or portable systems. Portable lighting equipment as allowed by and coordinated with ramp operations is recommended for active flight line areas. If the wash operation is of a reduced and non-elevated scale, consideration may be given to the reduction in light level down to a minimum of 25 FC. A safe environment for the operating personnel, however, is primary and must be considered first and foremost in equipping the wash rack with lighting.

6-14.9.5 Wastewater Collection/Treatment.

Locate waste drains in the center of the wash rack pavement to collect wash water contaminates (oils, alkaline, salts, and other contaminants) generated from aircraft washing operations. Off-center waste and trench drains are permitted only where necessitated by the aircraft landing gear configuration or where the off-center drains reduce construction costs or suit existing conditions. Sewers must drain wastewater from waste drains to a holding tank sized appropriately for the anticipated workload or flow. Due to the wash soap, the tank will not act as oil water separators. Oil-water separators or other water treatment/disposal systems appropriate for the expected contaminates must be incorporated into the wash facility design.

6-14.9.6 Wastewater System Design.

Wastewater collection/treatment systems must be designed in accordance with the following documents:

- UFC 3-240-01, *Wastewater Collection*
- UFC 4-832-01N, *Design: Industrial and Oily Wastewater Control*

Provide diversion systems for rainfall events to prevent treating excessive amounts of rainfall as wastewater or overflowing the holding tank due to rain events.

6-14.10 Aircraft Wash Equipment.

6-14.10.1 Storage and Mixing Capability for Aircraft Cleaning Compounds.

Generally, bulk storage tanks are recommended for high use wash facilities for dispensing the soap solutions onto the aircraft. These tanks are used in conjunction with cleaning compounds and equipment capable of mixing the detergents with water in the proper dilution ratios. However, in situations where relatively small quantities of cleaning compounds are expected to be used (i.e. at bases with a limited number of small aircraft), it may be appropriate to omit bulk storage capability from the facility design and incorporate storage space and handling capability for 55-gallon barrels.

6-14.10.2 Pressurized Cleaning Dispensing and Rinse Water Systems.

Pressurized dispensing systems will be used for the application of diluted cleaning compounds and rinse water generally and provide reductions in man-hours expended and quantities of water and cleaning materials used.

Refer to service specific guidance for recommendations or limitations on pressures and temperatures for pressurized cleaning systems.

6-14.11 Safety and Health.

6-14.11.1 Eyewash Units and Emergency Showers.

- Emergency shower and eyewash units must be provided in areas where harmful materials may be splashed into the eyes or on parts of the body. Follow UFC 3-420-01 Appendix D for guidance on design and installation of Eyewash Units and Emergency Showers. Also see AFOSHSTD 91-17 and ANSI Z358.1 for additional information.
- Emergency shower and eyewash units must be located in accessible locations that require no more than 10 seconds to reach and must be within 100 feet of the harmful substance
- Permanently installed units and self-contained units installed in fixed locations must be identified with a highly visible sign. The area around or behind the unit, or both, may be painted with green and white stripes if needed to increase visibility. If highlighted, the painted area will be large enough to be easily identified by the user.
- Emergency units must be well lighted. Where practical, a minimum of 50-foot candles of illumination must be provided.
- Units will be connected to a supply of water that is free from contamination and equal in purity to potable water.

6-14.11.2 Fall Protection.

Adequate fall protection is required in most newly constructed aircraft wash facilities. Primarily, personnel should avoid walking on wet surfaces to the greatest extent possible and utilize separate elevated work platforms and long-handle brushes to the maximum extent possible. However, experience has shown that it is impossible to adequately access most upper surfaces of large aircraft by these means. Therefore, personnel often must walk on aircraft wings or other surfaces during washing operations, which creates the possibility that they may fall 4 feet or more. In these situations, fall arrest or fall restraint systems are mandatory. Experience has shown that systems which utilize a lifeline, to which safety harnesses can be attached, are the most effective means of accessing upper surfaces of the aircraft during aircraft wash operations. Refer to AFOSHSTD 91-100, EM 385-1-1, Section 5, Personal Protective and Safety Equipment, and Section 21, Safe Access and Fall Protection, and AFOSHSTD 91-501 for complete guidance on fall protection requirements.

Due to the significant impact loads that the lifeline and anchor points impart to the building structure, attention must be given to installation of the fall restraint system in the earliest stages of facility design so that the loads are included in the design of the building's structural components. See UFC 4-211-02, *Aircraft Corrosion Control and Paint* Facilities, Paragraph 3-8.2 for a detailed description of fall protection systems and design requirements.

6-14.11.3 Personal Amenities.

In remote areas, where personal amenities must be provided to support the installed Wash Rack, these amenities must conform to the General Construction section of this guide and EM 385-1-1, Section 2, Safety and Health Requirements- Sanitation.

6-14.12 Aircraft Rinse Facilities – Birdbaths.

An Aircraft Rinse Facility referred to as a "Birdbath" provides an unattended taxi-through treadle operated freshwater deluge system to rinse aircraft typically subjected to accelerated corrosion due to low-level over water operations or a corrosive atmosphere at the installation.

See UFC 2-000-05N Section 116 15 for information concerning the requirements for a typical Birdbath. The following requirements and associated Figure 6-41 are for a Type "F" size aircraft (ref. Fig, 6-36). The information presented may be used as a guide and modified as appropriate for the configuration of the specific aircraft. If the aircraft manufacturer has recommended guidelines for a specific aircraft, the wash facility must be designed and constructed in accordance with the manufacturer's recommendations.

Aircraft Rinse Facility – Requirements

a) Constant water pressure of 100 to 150 pounds per square inch (690 to 1034 kPA). A booster pump and storage tank must be provided to maintain specified quantity and pressure of water. Provide backflow prevention or an air gap.

b) Provide drainage into sanitary sewer at an acceptable flowrate to prevent overloading downstream pump stations or the treatment facility. Verify with Base Environmental if an oil water separator is required. Provide diversion for rain events to prevent overloading the sewer and treatment plant with non-process water.

c) Pavement must be Portland cement concrete designed to the same criteria as the aircraft wash rack. If aircraft exhaust will be directed directly at pavement for extended periods of time, give consideration to using high temperature concrete to mitigate damage that may be caused by hot exhaust.

d) Each nozzle must have adjustable tips that can be adjusted with a swivel mount.

e) Three nozzle types: A; B; and C

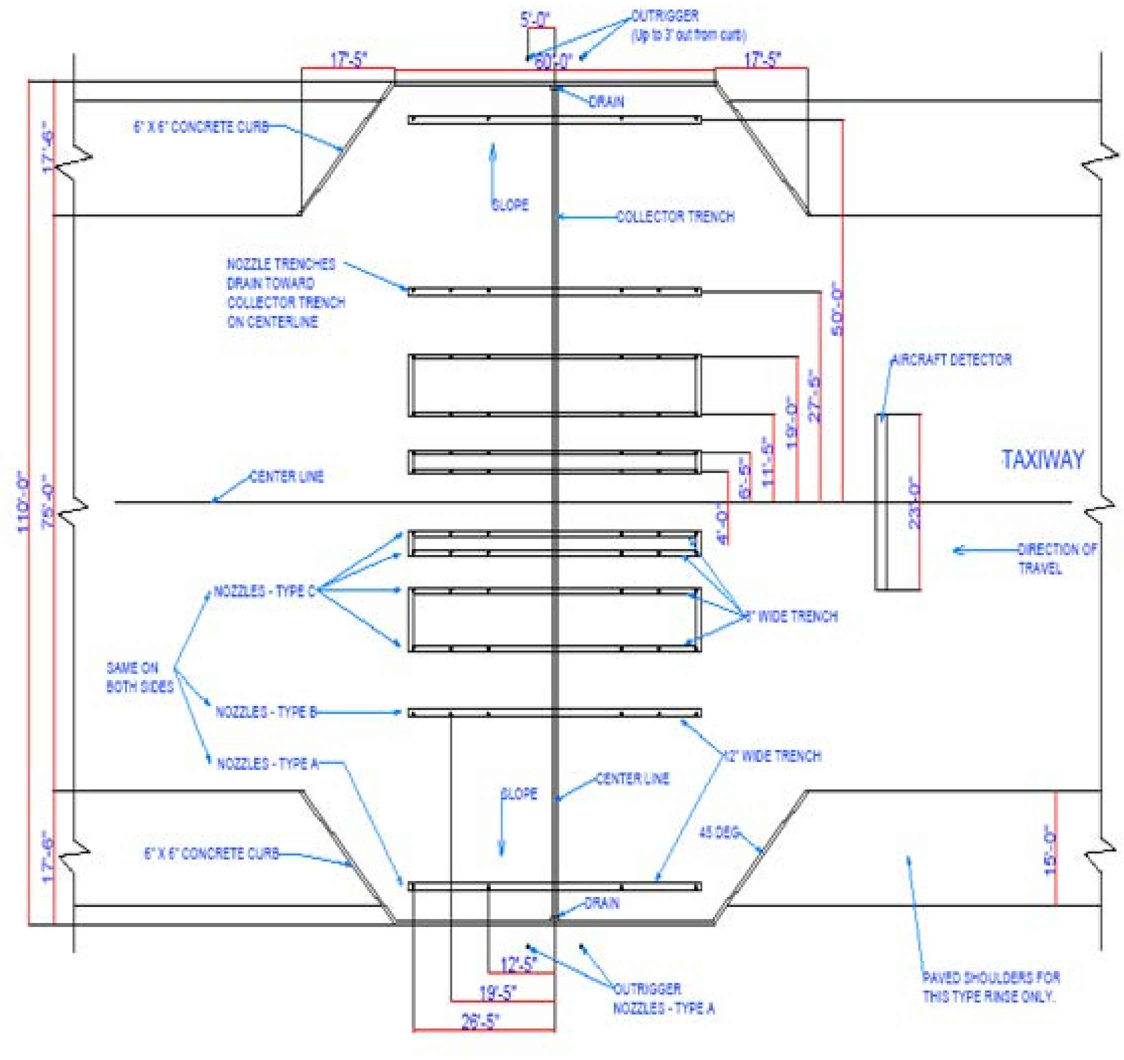
- Type A – (12) Used on the outriggers and in the edge of pavement trench. 50 gallons per minute (0.19 m^3/minute) flow, solid stream. Tip set at 55 degrees F (12.8 degrees C).
- Type B – (12) Used in the fifth trench from the centerline on both sides. 10 to 12 gallons per minute (0.04 to 0.05 m^3/minute) flow, 15 degree flat spray. Tip set at 55 degrees F (12.8 degrees C).
- Type C – (48) Used in the inside four trenches on both sides. 10 to 12 gallons per minute (0.04 to 0.05 m^3/minute) flow, 30 degree flat spray.

f) All nozzles are to be trenched with the exception of the outriggers. Each trench is to be covered with steel plate that has slots providing for the nozzle and water spray. The outriggers are elevated 1 foot off of the ground.

g) Include freeze protection in areas prone to freezing.

h) Include “soft-start” pump to prevent damage to the system when energized.

Figure 6-41. Aircraft Rinse Facility (Birdbath)



TYPE "4" RINSE FACILITY - V-22 AIRCRAFT

6-15 HANGAR ACCESS APRONS.

Hangar access aprons provide access to the hangars from the parking apron and allow free movement of aircraft to the various hangar maintenance facilities. Hangar access aprons should be provided as a supporting item for each authorized hangar and should be sized for the type of hangar and aircraft to be accommodated.

6-15.1 Dimensions.

Generally, hangar access aprons should be as wide as the hangar doors and extend from the edge of the apron to the hangar door. Hangar access apron dimension requirements are summarized in Table 6-6.

6-15.2 Grades for Aircraft Fueling Ramps.

Grades for hangar access ramps on which aircraft fueling will occur must slope away from aircraft hangars in accordance with NFPA Standard 415.

6-15.3 Grades for Aircraft Access into Hangars.

The grades in front of the hangar must allow access into the hangar. When aircraft are backed into the hangar, a tug vehicle pushes the aircraft in, tail first. Due to the location of the aircraft gear and the slope of the hangar access apron, the tail of the aircraft may be higher than the top of the hangar door. The hangar access apron grades may require adjustment to allow the aircraft tail to clear the hangar door.

Table 6-6. Hangar Access Apron

Table 6-6. Hangar Access Apron				
Item		Class A Runway	Class B Runway	
No.	Description	Requirement	Requirement	Remarks
1	Length	30 m (100 ft)	40 m (125 ft)	Army facilities for fixed-wing aircraft
		Distance to adjoining operational pavement		Air Force facilities for fixed-wing aircraft. **NOTE:** If the distance from the main operational pavement to the hangar exceeds the apron clearance distance (see Table 6-1, item 15), consider constructing a maneuvering area immediately outside the hangar, large enough to allow turning the aircraft around. The width of the maneuvering area should be equal to the width of the hangar door opening. Connect this maneuvering area to the main apron with a taxiway or towway.
		23 m (75 ft)		Army facilities for rotary-wing aircraft, except as noted below.
		30 m (100 ft)		Air Force facilities for rotary-wing aircraft, except as noted below Includes additional 50ft vehicular buffer required in front of hangars.
		15 m (50 ft)		Navy and Marine Corps facilities for fixed- and rotary-wing aircraft
		See Remarks		Access aprons are located between the apron and the front of the hangar. The hangar cannot be located within the apron clearance distance.

Table 6-6. Hangar Access Apron

Item		Class A Runway	Class B Runway	
No.	**Description**	**Requirement**	**Requirement**	**Remarks**
2	Width	At least as wide as the hangar door width		Pavement should be sized for type of aircraft, number of hangar bays, and location of hangar bays.
3	Grades in direction of drainage	Min ±0.5% Max ±1.5%		Avoid grades that prevent aircraft tails from clearing hangar doors.
		Min -1.0% first 15 m (50 ft) from hangar		NFPA 415 requires aircraft fueling ramps to slope away from terminal buildings, aircraft hangars, aircraft loading walkways, or other structures.
4	Width of shoulders (total width including paved and unpaved)	7.5 m (25 ft)		
5	Width of paved shoulders	Not required		
6	Sight distance	N/A (See note 1.)		
7	Transverse grade of unpaved shoulder	(a) 40 mm (1.5 in) drop-off at edge of pavement. (b) 2.0% min, 4.0% max.		
8	Wingtip clearance to fixed or mobile obstacles	7.6 m (25 ft)		Along length of access apron. Wingtip clearance at entrance to hangar may be reduced to 3.05 m (10 ft).
9	Grade (area between access apron shoulder and wingtip clearance line)	Max 10.0% (See note 2.)		If the wingtip clearance line falls within the access apron shoulder, no grading is required beyond the access apron shoulder.

NOTES:
1. N/A = not applicable
2. Bed of channel may be flat.
3. Metric units apply to new airfield construction and, where practical, modification to existing airfields and heliports, as discussed in paragraph 1-3.4.
4. The criteria in this manual are based on aircraft specific requirements and are not direct conversions from inch-pound (English) dimensions. Inch-pound units are included only as a reference to the previous standard.
5. Airfield and heliport imaginary surfaces and safe wingtip clearance dimensions are shown as a direct conversion from inch-pound to SI units.

6-16 TAXIING CHARACTERISTICS ON APRONS FOR ROTARY-WING AIRCRAFT.

Taxi routes across parking aprons are marked to provide safe passage of the aircraft across the apron. A hoverlane is a designated aerial traffic lane used exclusively for the movement of helicopters. A taxilane is a designated ground traffic lane.

6-16.1 Hoverlane/Taxilane Width at Army Facilities.

At Army Facilities, the hoverlane/taxilane widths are fixed distances based on type of aircraft, as noted in Table 6-2.

6-16.2 Hoverlane/Taxilane Width at Air Force Facilities.

At Air Force facilities, the hoverlane/taxilane width is based on the rotor diameter of the largest helicopter generally using the apron.

6-17 FIXED-WING AND ROTARY-WING GRADING STANDARDS.

6-17.1 Fixed-Wing Aircraft.

Grading standards for fixed-wing parking aprons and shoulders are presented in Table 6-1. All parking aprons, pads, and miscellaneous pavements should follow these grading standards unless a particular mission requirement, such as a power check pad, dictates otherwise. Surface drainage patterns with numerous or abrupt grade changes can produce excessive pavement flexing and structural damage of aircraft and therefore should be avoided.

6-17.2 Rotary-Wing Aircraft.

Grading standards for rotary-wing parking aprons are presented in Table 6-2 for Army facilities. Air Force activities should use the grading criteria for the Army presented in this UFC for all rotary-wing aircraft except CH-53 and CH-54. For those aircraft, see the Mission Design Series Facility Requirements Documents.

6-17.3 Grades for Aircraft Fueling Ramps.

Grades for ramps on which aircraft fueling will occur should be in accordance with NFPA Standard 415.

6-18 SHOULDERS.

Paved shoulders are provided around the perimeter of an apron to protect against jet blast and FOD, to support blast deflectors, for support equipment storage, to provide paved access to fire hydrants, and to facilitate drainage. Criteria for apron shoulders are presented in Table 6-1 for fixed-wing aprons, Table 6-2 for Army rotary-wing aprons, and AFMAN 32-1084 for Air Force rotary-wing facilities. To prevent storm water from ponding on the outside edge of the shoulder, the turf adjacent to the paved shoulder should be graded to facilitate drainage. See Paragraph 2-12 for requirements for designing buried utility structures in shoulders.

6-19 MISCELLANEOUS APRON DESIGN CONSIDERATIONS.

In addition to the apron design criteria, consider providing room for support structures, equipment (e.g., aerospace ground equipment, hydrant refueling systems), and facilities.

6-19.1 Jet Blast Deflectors.

Jet blast deflectors will substantially reduce the damaging effects of jet blast on structures, equipment, and personnel, as well as the related noise and fumes associated with jet engine operation. Additional information on jet blast deflectors is provided in Appendix B, Section 8.

6-19.2 Line Vehicle Parking.

Vehicle parking areas are provided for parking mobile station-assigned and squadron-assigned vehicles and equipment (e.g., aerospace ground equipment). Additional information on line vehicle parking is located in Appendix B, Section 12.

6-19.3 Utilities.

The items listed here are normally found on parking aprons. These items are not a part of airfield geometric design; however, the designer needs to be aware that they are an integral part of a parking apron and should make provisions for them accordingly.

- Storm water runoff collection system, including inlets, trench drains, manholes, and pipe
- De-icing facilities and de-icing runoff collection facilities
- Apron illumination
- Fire hydrants
- Refueling facilities
- Apron edge lighting

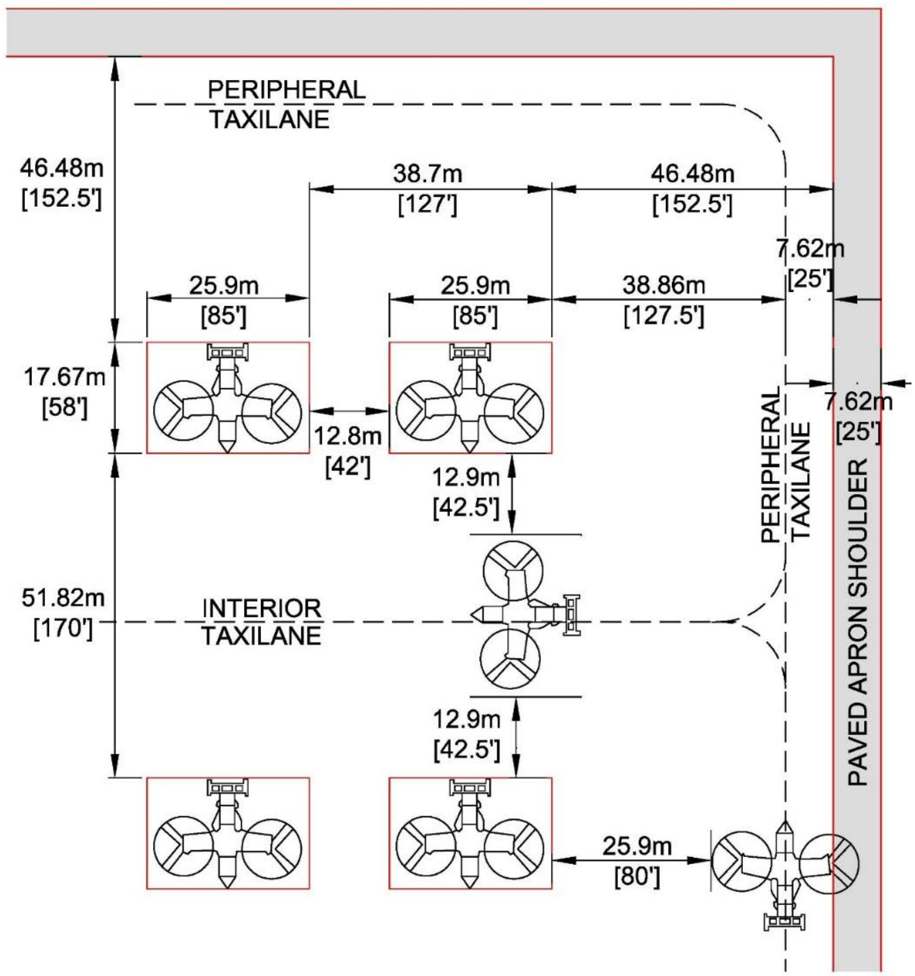
6-20 V-22 APRON CLEARANCES.

Figure 6-42 provides parking block dimensions as well as peripheral and interior taxilane clearance requirements. The V-22 Parking Block will not overhang the apron shoulder.

6-21 US NAVY AND MARINE CORPS AIRCRAFT BLOCK DIMENSIONS.

Figures 6-43 and 6-44 and Tables 6-7 through 6-10 provide Navy/Marine Corps aircraft parking apron criteria. The source of this information is UFC 2-000-05N and provided here for convenience. See source document for additional apron requirements.

Figure 6-42. V-22 Apron Clearance Requirements

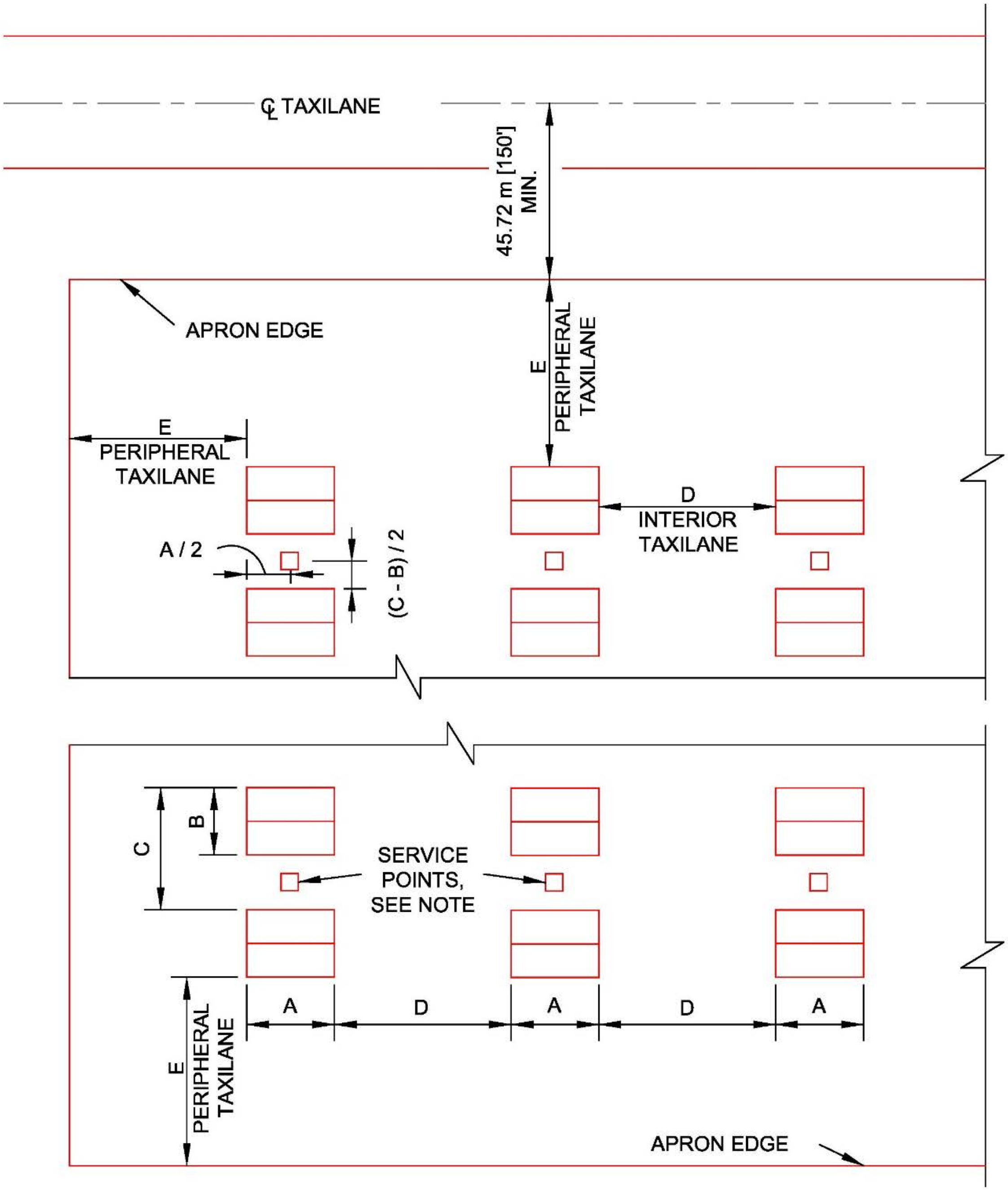


NORMAL PARKING ARRANGEMENT

NOT TO SCALE

NOTE: FOR NAVY ONLY - WHERE 7.6m [25'] PAVED SHOULDER IS NOT PROVIDED AROUND APRON, MOVE PERIPHERAL TAXILANE CENTERLINE TO 12.9m [42.5'] FROM APRON EDGE.

Figure 6-43. Navy/Marine Corps, 90-Degree Aircraft Parking Configuration



90° PARKING

NOTES

1. FOR DIMENSIONS A, B, C, D AND E SEE NAVY AIRCRAFT PARKING CONFIGURATION TABLES.
2. PARKED AIRCRAFT SHALL NOT PENETRATE 7:1 TRANSITIONAL SURFACE.

Table 6-7. Navy/Marine Corps Aircraft Parking Spacing, Helicopter Aircraft, 90-Degree Parking

Table 6-7. Navy/Marine Corps Aircraft Parking Spacing, Helicopter Aircraft, 90° Parking							
Aircraft Type	Wingspan m (ft/in)	Length m (ft/in)	A m (ft/in)	B m (ft/in)	C m (ft/in)	D m (ft/in)	E m (ft/in)
H-46	15.24 m (50 ft 0 in)	25.7 m (84 ft 4 in)	25.6 m (84 ft 0 in)	15.24 m (50 ft-0 in)	22.86 m (75 ft 0 in)	30.48 m (100 ft 0 in)	28.96 m (95 ft 0 in)
H-53D	22.02 m (72 ft 3 in)	26.9 m (88 ft 3 in)	26.82 m (88 ft 0 in)	21.95 m (72 ft 0 in)	32.92 m (108 ft 0 in)	43.89 m (144 ft 0 in)	39.01 m (128 ft 0 in)
H-53E	24.08 m (79 ft 0 in)	30.18 m (99 ft 0 in)	30.17 m (99 ft 0 in)	24.08 m (79 ft 0 in)	36.27 m (119 ft 0 in)	48.16 m (158 ft 0 in)	42.37 m (139 ft 0 in)
H-60	16.36 m (53 ft 8 in)	19.76 m (64 ft 10 in)	19.81 m (65 ft 0 in)	16.46 m (54 ft 0 in)	24.69 m (81 ft 0 in)	32.92 m (108 ft 0 in)	30.78 m (101 ft 0 in)

Table 6-8. Navy/Marine Corps Aircraft Parking Spacing, Propeller Aircraft, 90-Degree Parking

Table 6-8. Navy/Marine Corps Aircraft Parking Spacing, Propeller Aircraft, 90° Parking							
Aircraft Type	Wingspan m (ft/in)	Length m (ft/in)	A m (ft/in)	B m (ft/in)	C m (ft/in)	D m (ft/in)	E m (ft/in)
E-2	24.56 m (80 ft 7 in)	17.17 (56 ft 4 in)	17.07 m (56 ft 0 in)	24.69 m (81 ft-0 in)	30.78 m (101 ft 0 in)	36.88 m (121 ft 0 in)	45.72 m (150 ft 0 in)
P-3	30.38 m (99 ft 8 in)	35.61 m (116 ft 10 in)	35.66 m (117 ft 0 in)	30.48 m (100 ft 0 in)	36.58 m (120 ft 0 in)	42.67 m (140 ft 0 in)	45.72 m (150 ft 0 in)
OV-10	12.19 m (40 ft 0 in)	12.67 m (41 ft 7 in)	12.80 m (42 ft 0 in)	12.19 m (40 ft 0 in)	15.24 m (50 ft-0 in)	27.43 m (90 ft 0 in)	45.72 m (150 ft 0 in)
KC-130	40.40 m (132 ft 7 in)	29.82 m (97 ft 10 in)	29.87 m (98 ft 0 in)	40.54 m (133 ft 0 in)	48.16 m (158 ft 0 in)	55.78 m (183 ft 0 in)	45.72 m (150 ft 0 in)
T-28	12.37 m (40 ft 7 in)	10.52 m (34 ft 6 in)	10.67 m (35 ft 0 in)	12.50 m (41 ft 0 in)	15.54 m (51 ft 0 in)	27.43 m (90 ft 0 in)	45.72 m (150 ft 0 in)
T-34	10.16 m (33 ft 4 in)	8.76 m (28 ft 9 in)	8.84 m (29 ft 0 in)	10.06 m (33 ft 0 in)	13.11 m (43 ft 0 in)	27.43 m (90 ft 0 in)	45.72 m (150 ft 0 in)

Table 6-8. Navy/Marine Corps Aircraft Parking Spacing, Propeller Aircraft, 90° Parking							
Aircraft Type	**Wingspan m (ft/in)**	**Length m (ft/in)**	**A m (ft/in)**	**B m (ft/in)**	**C m (ft/in)**	**D m (ft/in)**	**E m (ft/in)**
T-44	15.32 m (50 ft 3 in)	10.82 m (35 ft 6 in)	10.97 m (36 ft 0 in)	15.24 m (50 ft 0 in)	19.81 m (65 ft 0 in)	27.43 m (90 ft 0 in)	45.72 m (150 ft 0 in)
V-22	25.81 m (84 ft 8 in)	17.48 m (57 ft 4 in)	17.67 m (58 ft 0 in)	25.91 m (85 ft 0 in)	38.71 m (127 ft 0 in)	51.82 m (170 ft 0 in)	46.48 m (152 ft 6 in)

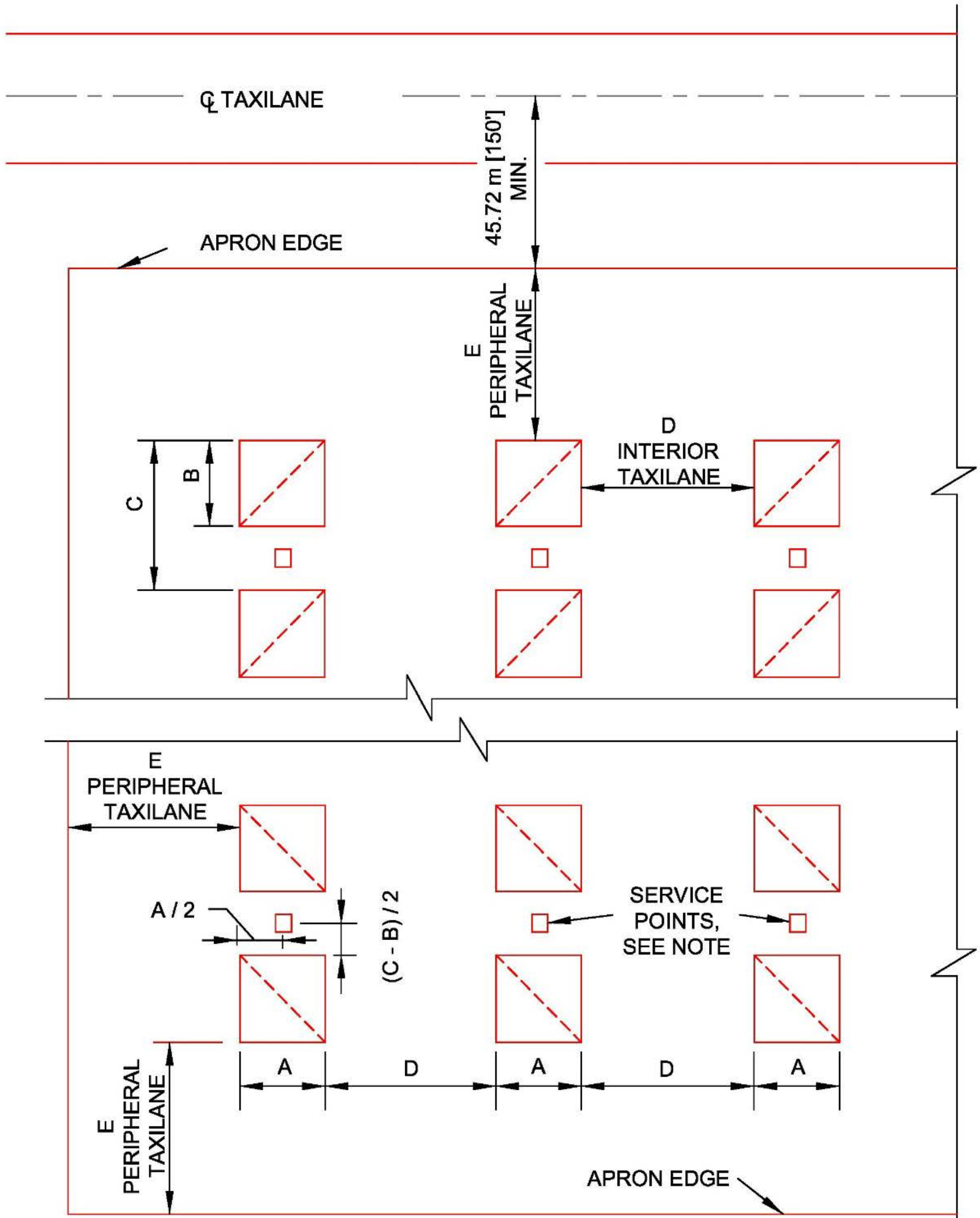
Table 6-9. Navy/Marine Corps Aircraft Parking Spacing, Jet Aircraft, 90-Degree Parking

Table 6-9. Navy/Marine Corps Aircraft Parking Spacing, Jet Aircraft, 90° Parking							
Aircraft Type	**Wingspan m (ft/in)**	**Length m (ft/in)**	**A m (ft/in)**	**B m (ft/in)**	**C m (ft/in)**	**D m (ft/in)**	**E m (ft/in)**
F/A-18	12.32 m (40 ft 5 in)	17.07 m (56 ft 0 in)	17.07 m (56 ft 0 in)	12.19 m (40 ft 0 in)	15.24 m (50 ft 0 in)	35.05 m (115 ft 0 in)	45.72 m (150 ft 0 in)
F/A-18 E/F	13.64 m (44 ft 9 in)	18.34 m (60 ft 2 in)	18.59 m (61 ft 0 in)	13.72 m 45 ft 0 in	16.76 m (55 ft 0 in)	38.4 m (126 ft 0 in)	45.72 m (150 ft 0 in)
AV-8A	7.62 m (25 ft 0 in)	13.72 m (45 ft 0 in)	13.72 m (45 ft 0 in)	7.62 m (25 ft 0 in)	10.67 m (35 ft 0 in)	30.48 m (100 ft 0 in)	45.72 m (150 ft 0 in)
AV-8B	9.25 m (30 ft 4 in)	16.23 m (53 ft 3 in)	14.02 m (46 ft 0 in)	9.14 m (30 ft 0 in)	12.19 m (40 ft 0 in)	30.48 m (100 ft 0 in)	45.72 m (150 ft 0 in)
S-3	20.92 m (68 ft 8 in)	16.23 m (53 ft 3 in)	16.15 m (53 ft 0 in)	21.03 m (69 ft 0 in)	25.6 m (84 ft 0 in)	38.1 m (125 ft 0 in)	45.72 m (150 ft 0 in)
C-5	67.89 m (222 ft 9 in)	74.96 m (245 ft 11 in)	74.98 m (246 ft 0 in)	67.97 m (223 ft 0 in)	75.59 m (248 ft 0 in)	83.21 m (273 ft 0 in)	45.72 m (150 ft 0 in)
C-9	28.45 m (93 ft 4 in)	36.37 m (119 ft 4 in)	36.27 m (119 ft 0 in)	28.35 m (93 ft 0 in)	34.44 m (113 ft 0 in)	40.54 m (133 ft 0 in)	45.72 m (150 ft 0 in)
KC-135	39.88 m (130 ft 10 in)	41.53 m (136 ft 3 in)	41.45 m (136 ft 0 in)	39.92 m (131 ft 0 in)	47.54 m (156 ft 0 in)	55.17 m (181 ft 0 in)	45.72 m (150 ft 0 in)

Table 6-9. Navy/Marine Corps Aircraft Parking Spacing, Jet Aircraft, 90° Parking							
Aircraft Type	**Wingspan m (ft/in)**	**Length m (ft/in)**	**A m (ft/in)**	**B m (ft/in)**	**C m (ft/in)**	**D m (ft/in)**	**E m (ft/in)**
T-2	11.56 m (37 ft 11 in)	11.81 m (38 ft 9 in)	11.89 m (39 ft 0 in)	11.58 m (38 ft 0 in)	14.63 m (48 ft 0 in)	33.53 m (110 ft 0 in)	45.72 m (150 ft 0 in)
T-39	13.54 m (44 ft 5 in)	13.41 m (44 ft 0 in)	13.72 m (45 ft 0 in)	13.41 m (44 ft 0 in)	16.46 m (54 ft 0 in)	35.05 m (115 ft 0 in)	45.72 m (150 ft 0 in)
T-45	9.7 m (31 ft 10 in)	11.96 m (39 ft 3 in)	11.89 m (39 ft 0 in)	9.45 m (31 ft 0 in)	12.5 m (41 ft 0 in)	30.48 m (100 ft 0 in)	45.72 m (150 ft 0 in)
F-35 B	10.7 m (35 ft 0 in)	15.6 m (51 ft 3 in)	13.7 m (45 ft 0 in)	13.7 m (45 ft 0 in)	19.8 m (65 ft 0 in)	61.0 m (200 ft 0 in)	45.7 m (150 ft 0 in)
F-35 C	13.1 m (43 ft 0 in)	15.6 m (51 ft 4 in)	14.3 m (47 ft 0 in)	14.3 m (47 ft 0 in)	19.8 m (65 ft 0 in)	61.0 m (200 ft 0 in)	45.7 m (150 ft 0 in)

* Information not available

Figure 6-44. Navy/Marine Corps, 45-Degree Aircraft Parking Configuration



45° PARKING

NOTES

1. FOR DIMENSIONS A, B, C, D AND E SEE NAVY AIRCRAFT PARKING CONFIGURATION TABLES.
2. PARKED AIRCRAFT SHALL NOT PENETRATE 7:1 TRANSITIONAL SURFACE.

Table 6-10. Navy/Marine Corps Aircraft Parking Spacing, Jet Aircraft, 45-Degree Parking

Table 6-10. Navy/Marine Corps Aircraft Parking Spacing, Jet Aircraft, 45° Parking							
Aircraft Type	**Wingspan m (ft/in)**	**Length m (ft/in)**	**A m (ft/in)**	**B m (ft/in)**	**C m (ft/in)**	**D m (ft/in)**	**E m (ft/in)**
F/A-18	12.32 m (40 ft 5 in)	17.07 m (56 ft 0 in)	14.33 m (47 ft 0 in)	14.33 m (47 ft 0 in)	21.64 m (71 ft 0 in)	27.43 m (90 ft 0 in)	45.72 m (150 ft 0 in)
F/A-18 E/F	13.64 m (44 ft 9 in)	18.34 m (60 ft 2 in)	15.54 m (51 ft 0 in)	15.54 m (51 ft 0 in)	23.77 m (78 ft 0 in)	27.43 m (90 ft 0 in)	45.72 m (150 ft 0 in)
AV-8A	7.62 m (25 ft 0 in)	13.72 m (45 ft 0 in)	9.75 m (32 ft 0 in)	9.75 m (32 ft 0 in)	17.37 m (57 ft 0 in)	27.43 m (90 ft 0 in)	45.72 m (150 ft 0 in)
AV-8B	9.25 m (30 ft 4 in)	16.23 m (53 ft 3 in)	10.97 m (36 ft 0 in)	10.97 m (36 ft 0 in)	17.37 m (57 ft 0 in)	27.43 m (90 ft 0 in)	45.72 m (150 ft 0 in)
S-3	20.92 m (68 ft 8 in)	16.23 m (53 ft 3 in)	15.54 m (51 ft 0 in)	15.54 m (51 ft 0 in)	34.75 m (114 ft 0 in)	30.18 m (99 ft 0 in)	45.72 m (150 ft 0 in)
C-5	67.89 m (222 ft 9 in)	74.96 m (245 ft 11 in)	60.66 m (199 ft 0 in)	60.66 m (199 ft 0 in)	106.68 m (350 ft 0 in)	83.21 m (273 ft 0 in)	45.72 m (150 ft 0 in)
C-9	28.45 m (93 ft 4 in)	36.37 m (119 ft 4 in)	29.57 m (97 ft 0 in)	29.57 m (97 ft 0 in)	48.77 m (160 ft 0 in)	40.54 m (133 ft 0 in)	45.72 m (150 ft 0 in)
KC-135	39.88 m (130 ft 10 in)	41.68 m (136 ft 3 in)	39.62 m (130 ft 0 in)	39.62 m (130 ft 0 in)	67.06 m (220 ft 0 in)	55.17 m (181 ft 0 in)	45.72 m (150 ft 0 in)
T-2	11.56 m (37 ft 11 in)	11.81 m (38 ft 9 in)	12.19 m (40 ft 0 in)	12.19 m (40 ft 0 in)	20.73 m (68 ft 0 in)	27.43 m (90 ft 0 in)	45.72 m (150 ft 0 in)
T-39	13.54 m (44 ft 5 in)	13.41 m (44 ft 0 in)	11.58 m (38 ft 0 in)	11.58 m (38 ft 0 in)	23.77 m (78 ft 0 in)	27.43 m (90 ft 0 in)	45.72 m (150 ft 0 in)
F-35 B	10.7 m (35 ft 0 in)	15.6 m (51 ft 3 in)	13.7 m (45 ft 0 in)	13.7 m (45 ft 0 in)	19.8 m (65 ft 0 in)	43.0 m (141 ft 0 in)	45.7 m (150 ft 0 in)
F-35 C	13.1 m (43 ft 0 in)	15.6 m (51 ft 4 in)	14.3 m (47 ft 0 in)	14.3 m (47 ft 0 in)	19.8 m (65 ft 0 in)	43.0 m (141 ft 0 in)	45.7 m (150 ft 0 in)

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CHAPTER 7
LANDING ZONES FOR C-130 AND C-17

7-1 GENERAL INFORMATION.

Landing zones (LZ) for C-130 and C-17 are special use airfields for aircrew training or contingency operations. This chapter provides guidance for planning, design, construction and evaluation of LZs. It includes criteria for the runway, taxiways, aprons, and airspace requirements, and addresses construction of non-airfield-related facilities near the airfield for both austere and built-up areas.

7-1.1 Differences in Service Criteria.

Air Force, Army, Navy and Marine Corps have generally agreed to the same criteria, except where noted in the text, tables or figures.

7-1.2 Landing Zone Marking and Lighting Standards.

This chapter currently includes LZ marking and lighting criteria. However, that criteria may get incorporated into other UFCs in the future.

7-1.3 LZ Grade Evaluation.

The minimum transverse slopes for LZ runways, taxiways, aprons, shoulders, graded areas and maintained areas are intended for use during the construction and maintenance of the LZ to promote adequate drainage and prolong service life. When evaluating an existing LZ, if these areas are level or less than the minimum and the slope does not impact the suitability of the LZ for aircraft operations, a waiver is not required.

7-2 DEFINITIONS.

The terms in this section are defined only as they are used in this chapter.

7-2.1 Accident Potential Zone–Landing Zone (APZ-LZ).

The land use control area beyond the clear zone of an LZ that possesses a significant potential for accidents; therefore, land use is a concern. See Figures 7-2 and 7-5.

7-2.2 Clear Zone-LZ.

A surface on the ground or water, beginning at the runway threshold and symmetrical about the extended runway centerline, graded to protect aircraft operations and in which only properly sited NAVAIDs are allowed. See Figures 7-1, 7-2, and 7-5.

7-2.3 Contingency Operations.

Typically, short-term operations conducted in support of conflicts or emergencies.

7-2.4 Exclusion Area.

Areas required for all paved and semi-prepared (unpaved) LZs. The purpose of the exclusion area is to restrict the development of facilities around the LZ. Only features required to operate the LZ or an adjacent airfield are permissible in the exclusion area, such as operational surfaces (e.g., runways, taxiways, and aprons), NAVAIDs, aircraft and support equipment, and cargo loading and unloading areas and equipment. Personnel formations, encampments, parked vehicles, storage areas, buildings, etc. are excluded from this area; roads, fences and trees are acceptable. In addition, only properly sited facilities are allowed in this area (see Appendix B, Section 13). The exclusion area extends the length of the runway, plus the clear zone on each end. See Figures 7-1, 7-2, and 7-5, and Table 7-8.

7-2.5 Flashing Strobe Light (FSL).

A flashing light used to mark the beginning or end of the usable runway surface when an LZ is used for night operations and configured in airfield marking pattern (AMP) -1 or AMP-3.

7-2.6 Graded Area.

An area beyond the runway shoulder where grades are controlled to prevent damage to aircraft that may depart the runway surface (see Figure 7-6 and Table 7-1). Graded areas will not have any obstacles over 75 millimeters (3 inches) high, except vegetation, visual landing zone marker panels (VLZMP), or other visual or electronic navigational aids which must be sited in this area due to their function. Culverts, headwalls, and elevated drainage structures are not allowed in this area. Properly sited, frangible NAVAIDs are allowed.

7-2.7 Imaginary Surfaces-LZ.

Surfaces in space established around an LZ in relation to runways, helipads, or helicopter runways, and designed to define the protected airspace around the airfield. The imaginary surfaces for LZs are the primary surface and approach-departure clearance surface. See Figures 7-1, 7-2, and 7-5, and Table 7-8. Minimum clearances over highways, railroads, waterways and trees are defined in Chapter 3, Table 3-8.

7-2.8 Infield Area.

The area between runways and between runways and taxiways that is graded or cleared for operational safety. All obstructions must be removed from the infield area.

7-2.9 Landing Zone (LZ).

Consists of a runway, a runway and taxiway, or other aircraft operational surfaces (e.g., aprons, turnarounds). It is a prepared or semi-prepared (unpaved) airfield used to conduct operations in an airfield environment similar to forward operating locations. LZ runways are typically shorter and narrower than standard runways. Because training airfields are constructed for long-term operations, semi-prepared surface structural requirements are more stringent than those for contingency airfields.

7-2.10 Overrun-LZ.

An area the width of the runway, plus prepared shoulders, extending 91.5 meters (300 feet) from the end of the runway into the clear zone. This portion is an elongation of the runway and is constructed to support aircraft traffic. See Figure 7-1, and Table 7-5.

7-2.11 Maintained Area.

A land area, extending outward at right angles to the runway centerline and the extended runway centerline, that is outside the graded area but still within the exclusion area. This area must be free of obstructions. Culvert and culvert headwalls are permitted in the maintained area, provided headwalls are flush with the surrounding grade. The maintained area is 21.5 m (70 ft) wide for C-17 operations or 18.5 m (60 ft) wide for C-130 operations. The grade may slope up or down to provide drainage but may not exceed +10% nor -20% slope. See Figure 7-6 and Table 7-1.

7-2.12 Parking Maximum on Ground (MOG).

The highest number of aircraft that will be allowed on the ground at any given time based on airfield configuration limitations and safety considerations.

7-2.13 Paved Landing Zone (LZ).

A prepared and surfaced LZ designed to carry aircraft traffic. **NOTE:** Paved LZs were formerly called “shortfields” and later known as “prepared assault landing zones” (ALZ). The principal components of a paved LZ include one of the following:

- A flexible or non-rigid pavement, or one that includes a bituminous concrete surface course designed as a structural member with weather- and abrasion-resistant properties
- A rigid pavement, or one that contains PCC as an element
- A combination of flexible and rigid pavement layers, such as an overlay, where a flexible pavement is placed over an existing rigid pavement layer to strengthen the rigid pavement layer

7-2.14 Primary Surface-LZ.

An imaginary surface symmetrically centered on the LZ. The elevation of any point on the primary surface is the same as the elevation of the nearest point on the runway centerline or extended runway centerline. See Figures 7-1, 7-2, and 7-5 and Table 7-7, Item 1.

7-2.15 Runway End.

As used in this chapter, the runway end is where the normal threshold is located. When the runway has a displaced threshold, the responsible airfield authority will evaluate each individual situation and, based on this evaluation, will determine the point of beginning for runway and airspace imaginary surfaces. See Figure 7-1.

7-2.16 Semi-Prepared Landing Zone (LZ).

A semi-prepared LZ (formerly called a “semi-prepared ALZ”) refers to an unpaved LZ. The amount of engineering effort required to develop a semi-prepared LZ depends on the planned operation, the service life needed to support these operations, and the existing soil and weather conditions. Semi-prepared construction/maintenance preparations may range from those sufficient for limited use to those required for continuous, routine operations. Options for surface preparation may include stabilization, adding an aggregate course, compacting in-place soils, or matting.

7-2.17 Turnaround (or Hammerhead).

An operational surface with dimensions to allow an aircraft to execute 180-degree turns without using reverse operations. Turnarounds can provide loading/off-loading capability on LZs with a parking MOG of one. See Figure 7-3 and 7-11.

7-2.18 Visual Landing Zone Marker Panels (VLZMP).

Vertical, colored panels installed along runway edges to indicate the threshold location and distance remaining. See Figures 7-7, 7-8a, 7-8b, 7-12, 7-13, and 7-14.

7-3 SITE PLANNING FOR LANDING ZONES (LZ).

When planning the layout of an LZ that will be used for extended operations (generally defined as more than one year), site conditions beyond the safety of the aircraft-related operations must be considered. These conditions include land use compatibility with clear zones, primary surfaces, exclusion areas, and approach-departure surfaces, and with existing and future use of the areas that surround the LZ. In planning an LZ, consider the use and zoning of surrounding land for compatibility with aircraft operations. The purpose is to protect the operational capability of the LZ and prevent incompatible development, thus minimizing health and safety concerns in areas subject to high noise and accident potential resulting from frequent aircraft overflights. The minimum criteria in this chapter establish standards for a safe environment for aircraft and ground operations. For long-term-use LZs, restricting use of available land beyond the minimum distances contained in this chapter is highly recommended. This will protect operational capability and enhance the potential for future mission expansion. Land use and zoning restrictions for training LZs must also comply with AFH 32-7084. The goal is to provide an LZ environment that provides the greatest margin of safety and compatibility for personnel, equipment, and facilities.

7-3.1 Future Development (Land or Aircraft Technology).

Adequate land for future aviation growth must be considered when planning an LZ. The LZ should be compatible with the existing installation plan. Potential instrument meteorological conditions/instrument flight rules (IMC/IFR) capability will require additional criteria considerations.

7-3.2 Prohibited Land Uses.

LZ criteria prohibit certain land uses within the exclusion area, clear zone, and APZ. These restrictions are described in Tables 7-6, 7-7 and 7-8.

7-3.3 APZs not on DoD Property.

APZs that are not on DoD property may require easements to control development and removal of vegetation that may violate the approach-departure clearance surface. The need must be determined on a case-by-case basis.

7-4 SITING CONSIDERATIONS.

Site considerations include topography, vegetative cover, existing construction, weather elements, wind direction, soil conditions, flood hazard, natural and man-made obstructions, adjacent land use, availability of usable airspace, accessibility of roads and utilities, and potential for expansion. Also consider the effects of ambient lighting for operations with night vision goggles (NVG). The potential for encroachment and the effects of noise on the local community must also be considered.

7-4.1 Training Landing Zones (LZs).

For training LZs, it is preferred to site the runway within an airfield environment to take advantage of existing runway and taxiway clearance areas. To maximize the training environment, avoid aligning LZ runways parallel to existing runways.

7-4.2 Siting Landing Zones (LZs).

Siting of LZs must take into account noise levels on existing facilities.

7-4.3 FAA Requirements.

When a new LZ is sited, in addition to local permitting requirements, file FAA Form 7480-1 in accordance with FAA Order 7400.2.

7-4.4 Siting LZs in Built-Up Areas.

When siting a training LZ runway within an existing built-up and occupied area, use a 305-m-wide (1000-ft-wide) exclusion area rather than the 213.5-m (700-ft) exclusion area for LZs in unoccupied areas. The 305-m-wide (1,000-ft-wide) exclusion zone extends from clear zone end to clear zone end, centered on the runway centerline. In addition, the APZ-LZ is widened to 305 m (1,000 ft) wide. Built-up and occupied locations are defined as locations where occupied buildings/facilities exist around the potential LZ site that are not related to the LZ mission. Unoccupied locations are where no buildings/facilities exist around the proposed LZ except those that are LZ mission-related. The same rules apply for siting future facilities near existing LZs. If the facility and occupants are not related to the LZ mission, then the wider exclusion zone and APZ-LZ apply.

7-4.5 Siting LZs Superimposed on Class A or B Runways.

When an LZ is marked on a Standard Class A or B runway, conduct and document a risk assessment to determine any risk associated with the operation or impact on current mission aircraft. This will include an evaluation of any existing waivers to UFC 3-260-01 that exist for current obstructions/non-compliant conditions and any portion of the LZ area that may have been built to a previous standard. New waivers will be needed for any non-compliant condition to the required LZ criteria. All non-compliant conditions will be identified and documented and any risk associated with these conditions will be coordinated with the aircraft unit using the LZ and approved by the responsible airfield authority.

7-5 GEOMETRIC CRITERIA FOR RUNWAYS AND OVERRUNS.

Tables 7-1 through 7-5 provide dimensional criteria for the layout and design of LZ runways, taxiways, aprons, and overruns.

Table 7-1. Runways for LZs

Table 7-1. Runways for LZs						
Item		Paved		Semi-Prepared (Unpaved)		
No.	Description	C-130	C-17	C-130	C-17	Remarks
1	Length	Min. 914 m (3000 ft)	Min. 1067 m (3500 ft) See Remarks.	Min. 914 m (3000 ft)	Min. 1067 m (3500 ft) See Remarks.	See paragraph 7-5.1 and Table 7-2 for LZ length requirements for the C-17. For lengths less than 1067 m (3500 ft), a waiver from the responsible airfield authority is required prior to initiating flying operations (see paragraph 7-7).
2	Width	18.5 m (60 ft)	27.5 m (90 ft)	18.5 m (60 ft)	27.5 m (90 ft)	See Note.

Table 7-1. Runways for LZs						
Item		**Paved**		**Semi-Prepared (Unpaved)**		
No.	**Description**	**C-130**	**C-17**	**C-130**	**C-17**	**Remarks**
3	Width of shoulders	Min. 3 m (10 ft)				Remove all tree stumps and loose rocks in shoulder areas. Shoulders for paved LZs will be paved. Shoulders for semi-prepared LZs should be stabilized to prevent erosion by jet blast. Where adequate sod cover cannot be established, the shoulders should be chemically stabilized.
4	Longitudinal grades of runway and shoulders	Max. 3% at any location on profile C-17: Effective Gradient 2% Maximum				Hold to minimum practicable. Grades may be both positive and negative but must not exceed the limit specified. Effective Gradient = (Max LZ Centerline elevation – Min LZ Centerline elevation)/Total LZ Length.
5	Longitudinal runway grade change	Max. 1.5% per 61 m (200 ft)				Grade changes should be held to a minimum and should be gradual. Minimum distance between grade changes is 61 m (200 ft). Grade changes cannot exceed 1.5% measured at 61 m (200 ft) intervals.
6	Transverse grade of runway	0.5% Min. 3.0% Max.				Transverse grades should slope down from the runway centerline. The intent of the transverse grade limit is to provide adequate cross slope to facilitate drainage without adversely affecting aircraft operations.
7	Transverse grade of runway shoulders	1.5% Min. 5.0% Max.				Transverse grades should slope down from the runway edge. The intent of the transverse grade limit is to facilitate drainage.
8	Width of graded area	10.5 m (35 ft)				Cut trees flush with the ground. Remove or embed rocks such that no parts of rocks protrude more than 75 mm (3 in) above surrounding surface. Remove vegetation (excluding grass) to within 75 mm (3 in) of the ground. Jet blast may cause erosion of the graded area. For paved LZs where adequate vegetation cannot be established to prevent erosion, the graded area may be covered with a thin 38 mm to 51 mm (1.5 in. to 2.0

Table 7-1. Runways for LZs						
Item		Paved		Semi-Prepared (Unpaved)		
No.	Description	C-130	C-17	C-130	C-17	Remarks
						in) asphalt layer or with an engineered surface such as articulated concrete blocks or a stone bed (4” to 8” stones in 12” layer on geotextile fabric) spread and compacted to present an even surface with no protrusions or indentations more than 75 mm (3 inches). Open culverts, headwalls, and elevated drainage structures are not allowed in this area.
9	Transverse grade of graded area	2.0% Min. 5.0% Max.				Grades may slope up or down, but may not penetrate the primary surface. Grade changes (including positive to negative) are permitted within the graded area.
10	Width of maintained area	18.5 m (60 ft)	21.5 m (70 ft)	18.5 m (60 ft)	21.5 m (70 ft)	Remove obstructions; cut trees flush with ground. Remove or embed rocks that protrude more than 75 mm (3 in) above grade. Remove vegetation (excluding grass) to within 150 mm (6 in) of the ground.
11	Maintained area: transverse grade	Maximum range: +10.0% to -20.0%				Grades may slope up or down to provide drainage, but may not exceed +10.0% nor -20.0% slope.
12	Runway-Taxiway Separation	81 m (265 ft)		93 m (305 ft)		

NOTE: For C-17 LZs without parallel taxiways, turnarounds must be provided at both ends of the runway. Turnarounds for C-17 aircraft should be 55 m (180 ft) long and 50.5 m (165 ft) wide (including the overrun/runway width), with 45-degree fillets. The aircraft must be positioned within 3 m (10 ft) of the runway edge prior to initiating this turn. If provided, turnarounds for C-130 aircraft should be at least 30 m (100 ft) in diameter.

7-5.1 LZ Runway Lengths.

Table 7-1 provides minimum runway lengths for C-130 LZs and Table 7-2 provides minimum runway lengths for C-17 LZs. Consult with flying group to determine runway length required to support the mission. For a C-17 LZ located between sea level and 915 m (3,000 ft) pressure altitude, the minimum length requirement for C-17 operations is 1067 m (3,500 ft) with 91.5-m (300-ft) overruns on each end. This length requirement, based on a runway condition reading (RCR) of 20, assumes an ambient temperature of 32.2 degrees Celsius (90 degrees Fahrenheit) and a landing gross weight of 202,756 kg (447,000 lb). Based on these same temperature and weight assumptions, the runway length will vary with different RCRs. Typically, paved surfaces will have RCRs of 23 dry, 12 wet, and 5 icy. Mat surfaces will have RCRs of 23 dry and 10 wet. A semi-prepared runway with stabilized soil surfaces will have RCRs of 20 dry and 10 wet. Unstabilized soil surfaces will have RCRs of 20 dry and 4 wet.

Table 7-2. C-17 LZ Runway Lengths

Table 7-2. C-17 LZ Runway Lengths		
202,756 kg (447,000 lb): NORMAL Max Weight for *Soil Surfaced LZs*		
RCR	**Pressure Altitude, m (ft)**	**Runway Length, m (ft) ***
20 (dry soil)	0 to 914 (3000)	1067 (3500)
	915 (3001) to 1829 (6000)	1219 (4000)
10 (wet soil)	0 to 609 (2000)	1524 (5000)
	610 (2001) to 1524 (5000)	1676 (5500)
	1525 (5001) to 1829 (6000)	1829 (6000)
220,446 kg (486,000 lb): INCREASED Max Weight for *Soil Surfaced LZs*		
RCR	**Pressure Altitude, m (ft)**	**Runway Length, m (ft) ***
20 (dry soil)	0 to 914 (3000)	1067 (3500)
	915 (3001) to 1219 (4000)	1219 (4000)
	1220 (4001) to 1524 (5000)	1372 (4500)
	1525 (5001) to 1829 (6000)	1524 (5000)
	1830 (6001) to 2134 (7000)	1676 (5500)
10 (wet soil)	0 to 609 (2000)	1676 (5500)
	610 (2001) to 914 (3000)	1829 (6000)
	915 (3001) to 1524 (5000)	1981 (6500)
	1525 (5001) to 1829 (6000)	2134 (7000)
227,703 kg (502,000 lb): Max Weight for Contingency Operations on *Paved LZs*		
RCR	**Pressure Altitude, m (ft)**	**Runway Length, m (ft)**
23 (dry pavement)	0 to 609 (2000)	1067 (3500)
	610 (2001) to 914 (3000)	1219 (4000)
	915 (3001) to 1219 (4000)	1372 (4500)
	1220 (4001) to 1524 (5000)	1524 (5000)
	1525 (5001) to 1829 (6000)	1676 (5500)
	1830 (6001) to 2134 (7000)	1829 (6000)
12 (wet pavement)	0 to 609 (2000)	1676 (5500)
	610 (2001) to 914 (3000)	1829 (6000)
	915 (3001) to 1524 (5000)	1981 (6500)
	1525 (5001) to 1829 (6000)	2134 (7000)
	1830 (6001) to 2134 (7000)	2286 (7500)
5 (icy pavement)	0 to 304 (1000)	2134 (7000)
	305 (1001) to 914 (3000)	2438 (8000)
	915 (3001) to 1219 (4000)	2591 (8500)
	1220 (4001) to 1524 (5000)	2744 (9000)
	1525 (5001) to 1829 (6000)	2897 (9500)
	1830 (6001) to 2134 (7000)	3048 (10000)

***NOTE:** Runway lengths **do not** include overruns.

7-5.2 LZ Runway Widths.

Table 7-1 provides the minimum width for LZ runways. The widths of these landing surfaces provide the minimum-width operating surface for the given aircraft.

7-5.3 Operating Surface Gradient Allowances.

Operational surface gradient constraints are based on reverse aircraft operations conducted on hard surfaces. See Tables 7-2, 7-3, 7-4, and 7-5 for specific allowances.

7-5.4 LZ Shoulders.

Shoulders are graded and cleared of obstacles and slope downward away from the operating surface, where practical, to facilitate drainage. See Tables 7-2, 7-3, 7-4, and 7-5.

Table 7-3. Taxiways for LZs

Table 7-3. Taxiways for LZs						
Item		**Paved**		**Semi-Prepared (Unpaved)**		
No.	**Description**	**C-130**	**C-17**	**C-130**	**C-17**	**Remarks**
1	Width	9 m (30 ft)	15.0 m (50 ft)	9 m (30 ft)	15.0 m (50 ft)	
2	Turning radii	21.5 m (70 ft)	27.5 m (90 ft) See Remarks.	21.5 m (70 ft)	27.5 m (90 ft) See Remarks.	C-17 aircraft can execute “star turns,” which require forward and reverse taxi within 27.5 m (90 ft); however, for normal 180-degree turn maneuvers, the C-17 turn radius is 35.36 m (116 ft).
3	Shoulder width	3 m (10 ft)				Shoulders for paved LZs should be paved. Shoulders for semi-prepared LZs should be stabilized to prevent erosion by jet blast. Where adequate sod cover cannot be established, the shoulder should be chemically stabilized. Remove all tree stumps and loose rocks.
4	Longitudinal grade	Maximum 3.0%				Hold to minimum practicable. Grades may be both positive and negative.

Table 7-3. Taxiways for LZs						
Item		**Paved**		**Semi-Prepared (Unpaved)**		
No.	**Description**	**C-130**	**C-17**	**C-130**	**C-17**	**Remarks**
5	Rate of longitudinal grade change	Maximum 2.0% per 30 m (100 ft)				Grade changes should be held to a minimum and should be gradual. Minimum distance between grade changes is 30 m (100 ft). Grade changes cannot exceed 2.0% measured at 30 m (100 ft) intervals.
6	Transverse grade of taxiway	0.5% to 3.0%				Transverse grades should slope down from the taxiway centerline. The intent of the transverse grade limitation is to provide adequate cross slope to facilitate drainage without adversely affecting aircraft operations. The surfaces should slope so that the centerline of the taxiway is crowned.
7	Transverse grade of taxiway shoulder	1.5% to 5.0%				Transverse grades should slope down from the taxiway edge. The intent of the transverse grade limit is to facilitate drainage.
8	Runway-Taxiway Separation	81 m (265 ft)	93 m (305 ft)	81 m (265 ft)	93 m (305 ft)	Measured from the runway centerline to the taxiway centerline.
9	Infield area					All areas located between the runway and taxiways must be cleared of obstructions.
10	Clearance to fixed or mobile obstacles	29 m (95 ft)	33.5 m (110 ft)	29 m (95 ft)	33.5 m (110 ft)	Measured from the taxiway centerline. Required to provide minimum 7.5-m (25-ft) wingtip clearance.

Table 7-3. Taxiways for LZs						
Item		Paved		Semi-Prepared (Unpaved)		
No.	Description	C-130	C-17	C-130	C-17	Remarks
11	Taxiway clear area – width	21.5 m (70 ft) for C-130 22.9m (75 ft) for C-17				Measured from the outer edge of the taxiway shoulder to the obstacle clearance line. Remove or embed rocks that protrude more than 75 mm (3 in) above the surrounding surface. Cut tree stumps, brush, and other vegetation (excluding grass) to within 150 mm (6 in) of the ground.
12	Taxiway clear area – grade	Maximum range: +10.0% to -5.0%				Transverse grades may slope up or down to provide drainage but may not exceed a +10% nor -5% slope.
13	Taxiway Edge Safety Margin	2.1 m (7 ft)	2.1 m (7 ft)	2.1 m (7 ft)	2.1 m (7 ft)	Distance between outside of main gear and edge of full strength runway or taxiway.

Table 7-4. Aprons for LZs

Table 7-4. Aprons for LZs						
Item		Paved		Semi-Prepared (Unpaved)		
No.	Description	C-130	C-17	C-130	C-17	Remarks
1	Apron size	See Remarks.			See Note.	Sized to accommodate mission. Maximum visibility must be maintained at all times. As a minimum, the pilot must be able to clearly see all parked aircraft when taxiing. On paved aprons, clearance between wing tips of parked aircraft will be minimum 7.5 m (25 ft). Clearance between wing tips of taxiing aircraft and parked aircraft will be minimum 7.5 m (25 ft) for paved aprons and 15 m (50 ft) for semi-prepared aprons.
2	Apron grades in the direction of drainage	1.5 to 3.0%				
3	Width of apron shoulder	3 m (10 ft)				Apron shoulders for paved LZs should be paved. Shoulders for semi-prepared LZs should be stabilized to prevent erosion by jet blast. Where adequate sod cover cannot be established, the shoulders should be chemically stabilized.
4	Transverse grade of shoulder away from the apron edge	1.5 to 5.0%				Apron shoulder should be graded to carry storm water away from the apron. In shoulder areas, remove all tree stumps and loose rocks.
5	Apron Parking Setback	58 m (190 ft)	65.5 m (215 ft)	58 m (190 ft)	65.5 m (215 ft)	Measured from the runway centerline to the setback line. Aprons may be contiguous with the runway, but parked aircraft and vehicles must be behind this line. See Figure 7-4.
6	Clearance from edge of apron to fixed or mobile obstacles	26 m (85 ft)	30.5 m (100 ft)	26 m (85 ft)	30.5 m (100 ft)	Measured from the outer edge of the apron to obstacle clearance line. Remove or embed rocks that protrude more than 75 mm (3 in) above the surrounding surface. Cut tree stumps, brush, and other vegetation (excluding grass) to within 150 mm (6 in) of the ground.

Table 7-4. Aprons for LZs						
Item		Paved		Semi-Prepared (Unpaved)		
No.	Description	C-130	C-17	C-130	C-17	Remarks
7	Apron clear area grade	Maximum range: +10.0% to -5.0%				Grades may slope up or down to provide drainage, but may not exceed a +10% nor -5% slope. Centerline of drainage ditches must be established away from apron shoulders to prevent water from backing up onto the shoulder area.

NOTE: To eliminate the potential for FOD created by jet blast to parked and taxiing aircraft, individual parking aprons should be provided for each C-17 aircraft on semi-prepared LZs (other than AM-2 mat surfaced). Each apron should be a minimum of 61 m (200 ft) wide and 68.5 m (225 ft) long. Topography, mission, and obstructions determine the location and spacing between multiple aprons, but the aprons should not be located less than 152.5 m (500 ft) apart. All loose material must be stabilized or removed before the aprons can be operational.

Table 7-5. Overruns for LZs

Table 7-5. Overruns for LZs						
Item		Paved		Semi-Prepared (Unpaved)		
No.	Description	C-130	C-17	C-130	C-17	Remarks
1	Overrun length	91.5 m (300 ft)				The overruns must be constructed to the same standards as the runway. Overruns for mat surfaced runways must also be mat.
2	Overrun width	18.5 m (60 ft)	27.5 m (90 ft)	18.5 m (60 ft)	27.5 m (90 ft)	
3	Longitudinal grade of overruns	Maximum 3%				After first 30.5m (100 ft), overrun will be 0.0% or downward to avoid penetrating the ADCS.
4	Longitudinal Overrun Grade Change	Max. 2.0% per 30.5 m (100 ft)				First 30.5 m (100 ft) of overrun grade must match runway grade. Vertical curve at grade transition is desirable, but not required. No more than one grade change is allowed within the overrun. For Training LZs, minimize grade changes within the overrun and always use vertical curves at transitions.
5	Transverse grade of overruns	0.5% min. 3.0% max.				Grades should slope downward from overrun centerline.

Table 7-5. Overruns for LZs						
Item		Paved		Semi-Prepared (Unpaved)		
No.	Description	C-130	C-17	C-130	C-17	Remarks
6	Width of overrun shoulder	3m (10 ft)				Overrun shoulders for paved LZs should be paved. Shoulders for semi-prepared LZs should be stabilized to prevent erosion by jet blast. Where adequate sod cover cannot be established, the shoulders should be chemically stabilized.
7	Transverse grade of overrun shoulders	1.5% min. 5.0% max.				Transverse grades should slope down from the overrun edge. The intent of the transverse grade limit is to facilitate drainage.

7-5.5 Turnarounds.

For C-17 LZs without parallel taxiways, turnarounds must be provided at both ends of the runway. In other cases, turnarounds may be located on overruns or taxiways, depending upon mission or terrain requirements. The shoulder, structural, gradient, and clearance requirements for a turnaround are the same as those for the overrun or taxiway area where the turnaround is constructed. Turnarounds for C-130 aircraft should be at least 30 m (100 ft) in diameter. Turnarounds for C-17 aircraft should be 55 m (180 ft) long and 50.5 m (165 ft) wide (including the overrun/taxiway width) with 45-degree fillets. The aircraft landing gear must be positioned within 3 m (10 ft) of the runway edge prior to initiating this turn.

7-6 IMAGINARY SURFACES AND LAND USE CONTROL AREAS.

Minimum requirements for APZ-LZs and Exclusion Areas, clear zones and imaginary surfaces must be established to provide a reasonable level of safety for LZs. These criteria are provided in Tables 7-6, 7-7, and 7-8, respectively. These areas and the imaginary surfaces are shown in Figures 7-1, 7-2, 7-5 and 7-6. Airfield airspace criteria prohibit certain land uses within the clear zone, APZ. These land uses include storage and handling of munitions and hazardous materials, and live fire weapons ranges. See DoDI 4165.57 for more information.

Table 7-6. Accident Potential Zones (APZs) and Exclusion Areas for LZs

Table 7-6. APZs and Exclusion Areas for LZs						
Item		Paved		Semi-Prepared (Unpaved)		
No.	Description	C-130	C-17	C-130	C-17	Remarks
1	APZ-LZ length	762 m (2,500 ft)				Limit the following, where possible within the APZ-LZ: Actions that release any substances into the air that would impair visibility or otherwise interfere with operating aircraft, such as steam, dust, and smoke. Actions that produce electrical emissions that would interfere with aircraft and/or communications or navigational aid systems. Actions that produce light emissions, direct or indirect (reflective), that might interfere with pilot vision. Items that unnecessarily attract birds or waterfowl, such as sanitary landfills, feeding stations, or certain types of crops or vegetation. Explosive facilities or activities. Troop concentrations, such as housing areas, dining or medical facilities, and recreational fields that include spectators.
2	APZ-LZ width	Unoccupied Area: 152.5 m (500 ft) Occupied and Built-Up Area: 305 m (1,000 ft)				For cases where a training LZ may be sited near permanently occupied facilities or where new facilities may be sited near an LZ, use a 305-m-wide (1,000-ft-wide) APZ-LZ. See section 7-5 for all necessary modifications and considerations.

Table 7-6. APZs and Exclusion Areas for LZs

Item		Paved		Semi-Prepared (Unpaved)		
No.	**Description**	**C-130**	**C-17**	**C-130**	**C-17**	**Remarks**
3	Exclusion area width	Unoccupied Area: 213.5 m (700 ft) Occupied and Built-Up Area: 305 m (1,000 ft) Navy/Marine Corps Permanent Training LZ: 305 m (1,000 ft)				Exclusion areas are required for all paved and semi-prepared LZs. The purpose of the exclusion area is to restrict development of facilities around the LZ. Only features required to operate the LZ, such as operational surfaces (e.g., taxiways, aprons), NAVAIDs, airfield lights and signs, aircraft and support equipment, and cargo loading and unloading areas and equipment, are permissible in the exclusion area. Personnel formations, encampments, parked vehicles, storage areas, buildings, etc. are excluded from this area. Roads, fences and trees are acceptable. The exclusion area is centered on the runway. For long-term use LZs, restricting use of available land beyond the minimum distances contained in this UFC is highly recommended. The goal is to provide the greatest margin of safety for personnel, equipment, and facilities. For cases where a training LZ may be sited near permanently occupied facilities or where new facilities may be sited near an LZ, use a 304.8-m-wide (1,000-ft-wide) exclusion area. See paragraph 7-4.4 for a clarification of built-up and occupied areas. Navy/Marine Corps Permanent Training LZs: Treat the Exclusion Zone like the primary surface, which must be clear of all above-grade obstacles.
4	Exclusion Area Length	Runway length + length of Clear Zones				See requirements in Item 3.

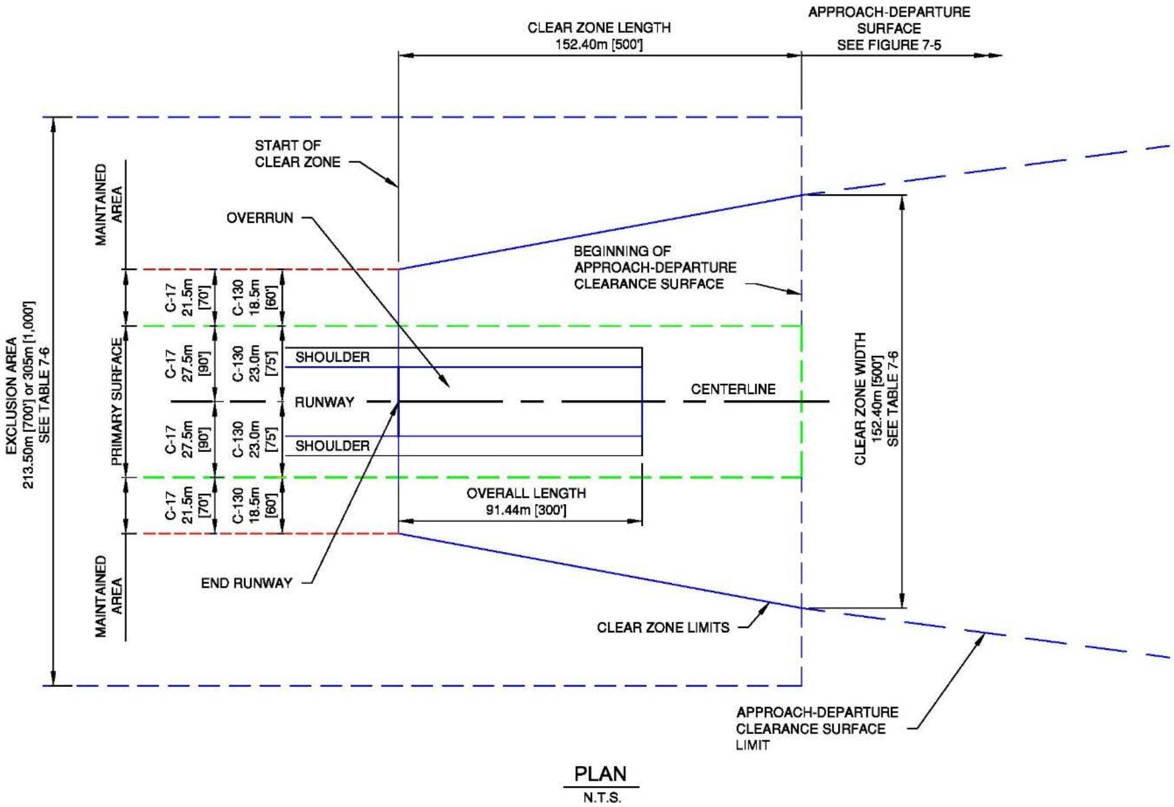
Table 7-7. Runway End Clear Zone for LZs

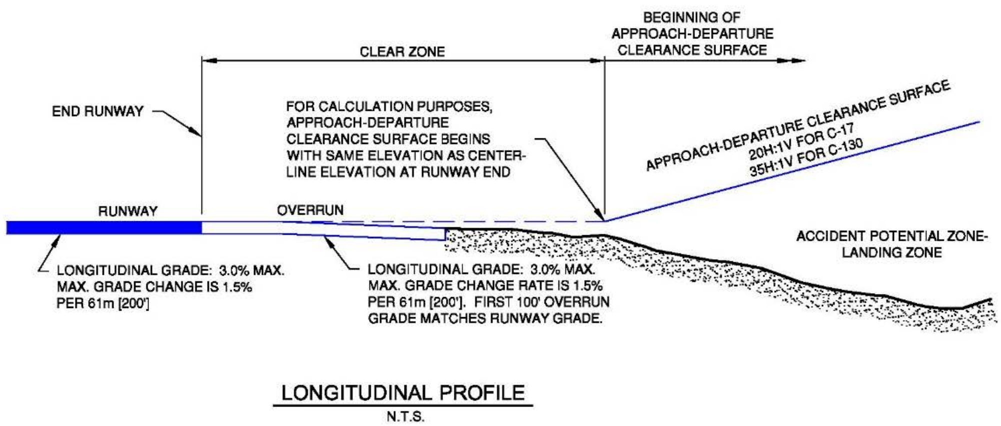
Table 7-7. Runway End Clear Zone for LZs						
Item		Paved		Semi-Prepared (Unpaved)		
No.	Description	C-130	C-17	C-130	C-17	Remarks
1	Length	152.5 m (500 ft)				Measured along the extended runway centerline; begins at the runway threshold.
2	Width at inner edge	82.5 m (270 ft)	98 m (320 ft)	82.5 (270 ft)	98 m (320 ft)	
3	Width at outer edge	152.5 m (500 ft)				
4	Longitudinal and transverse grade of surface	Maximum 5.0%				Grades are exclusive for clear zone and are not part of the overrun but are shaped into the overrun grade. Grades may slope up or down to provide drainage. Exception: Essential drainage ditches may be sloped up to 10% in the clear zones. Do not locate these ditches within 23 m (75 ft) of a C-130 runway centerline or within 27.5 m (90 ft) of a C-17 runway centerline. Such ditches should be essentially parallel with the runway. Remove or embed rocks that protrude more than 100 mm (4 in) above the surrounding grade. Cut tree stumps, brush, and other vegetation (excluding grass) to within 150 mm (6 in) of the ground.

Table 7-8. Imaginary Surfaces for LZs

Table 7-8. Imaginary Surfaces for LZs						
Item		Paved		Semi-Prepared (Unpaved)		
No.	Description	C-130	C-17	C-130	C-17	Remarks
1	Primary surface length	Runway length plus 305 m (1,000 ft)				Centered on the runway (includes lengths of clear zones)
2	Primary surface width	45.5 m (150 ft)	55 m (180 ft)	45.5 m (150 ft)	55 m (180 ft)	Centered on the runway
3	Primary surface elevation	See Remarks				The elevation of the primary surface is the same as the elevation of the nearest point on the runway centerline or extended runway centerline.
4	Approach-departure clearance surface (ADCS) -- inner edge	152.5 m (500 ft)				Measured from runway end
5	ADCS Width at inner edge	152.5 m (500 ft)				
6	ADCS Slope	35H:1V	20H:1V	35H:1V	20H:1V	Remains constant throughout length
7	ADCS Slope length	Minimum 3200 m (10,500 ft)				The desired slope length is 9733 m (32,000 ft).
8	ADCS Width at outer edge	762 m (2,500 ft) at 3200 m (10,500 ft) from inner edge				Width of ADCS is constant from 3200 m (10,500 ft) to 9753 m (32,000 ft) from the inner edge.

Figure 7-1. LZ Primary Surface End Details

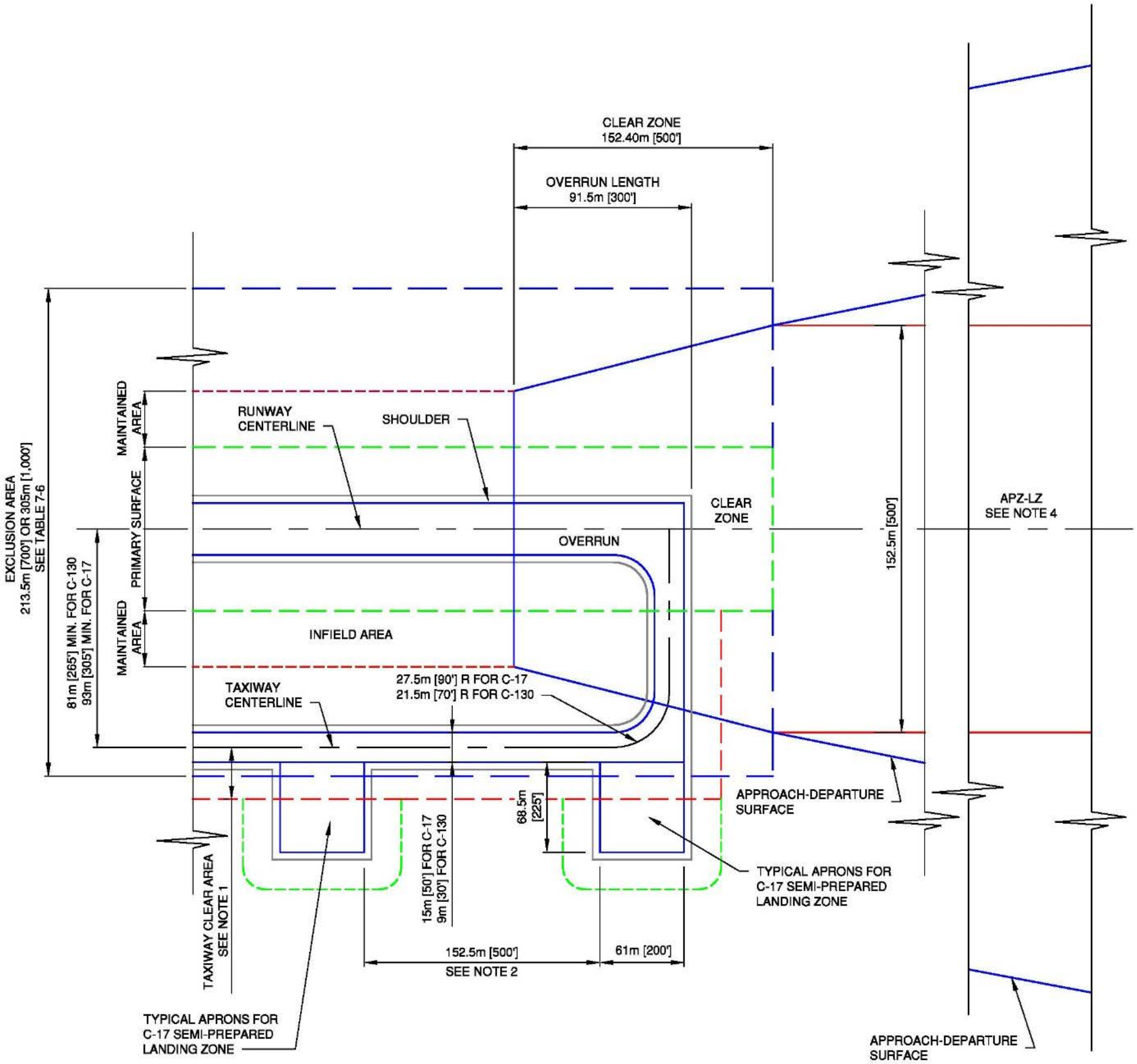




NOTE

1. SEE PARAGRAPH 7-4 FOR INFORMATION ON SITING NEW LANDING ZONES.

Figure 7-2. LZ Details



PLAN
N.T.S.

NOTES

1. TAXIWAY CLEAR AREA WIDTH 33.5m [110'] FOR C-17 AND 29m [95'] FOR C-130 MEASURED FROM TAXIWAY CENTERLINE (TABLE 7-3, ITEM 11).
2. LOCATION AND SPACING BETWEEN MULTIPLE APRONS IS DETERMINED BY TOPOGRAPHY, MISSION AND OBSTRUCTIONS, BUT SHALL NOT BE LESS THAN 152.5m [500'] APART.
3. PARALLEL TAXIWAY OR TURNAROUND AREAS AT BOTH ENDS OF THE RUNWAY MUST BE PROVIDED.
4. SEE PARAGRAPH 7-4 FOR INFORMATION ON SITING NEW LZ'S.

Figure 7-3. LZ with Contiguous Aprons and Turnarounds

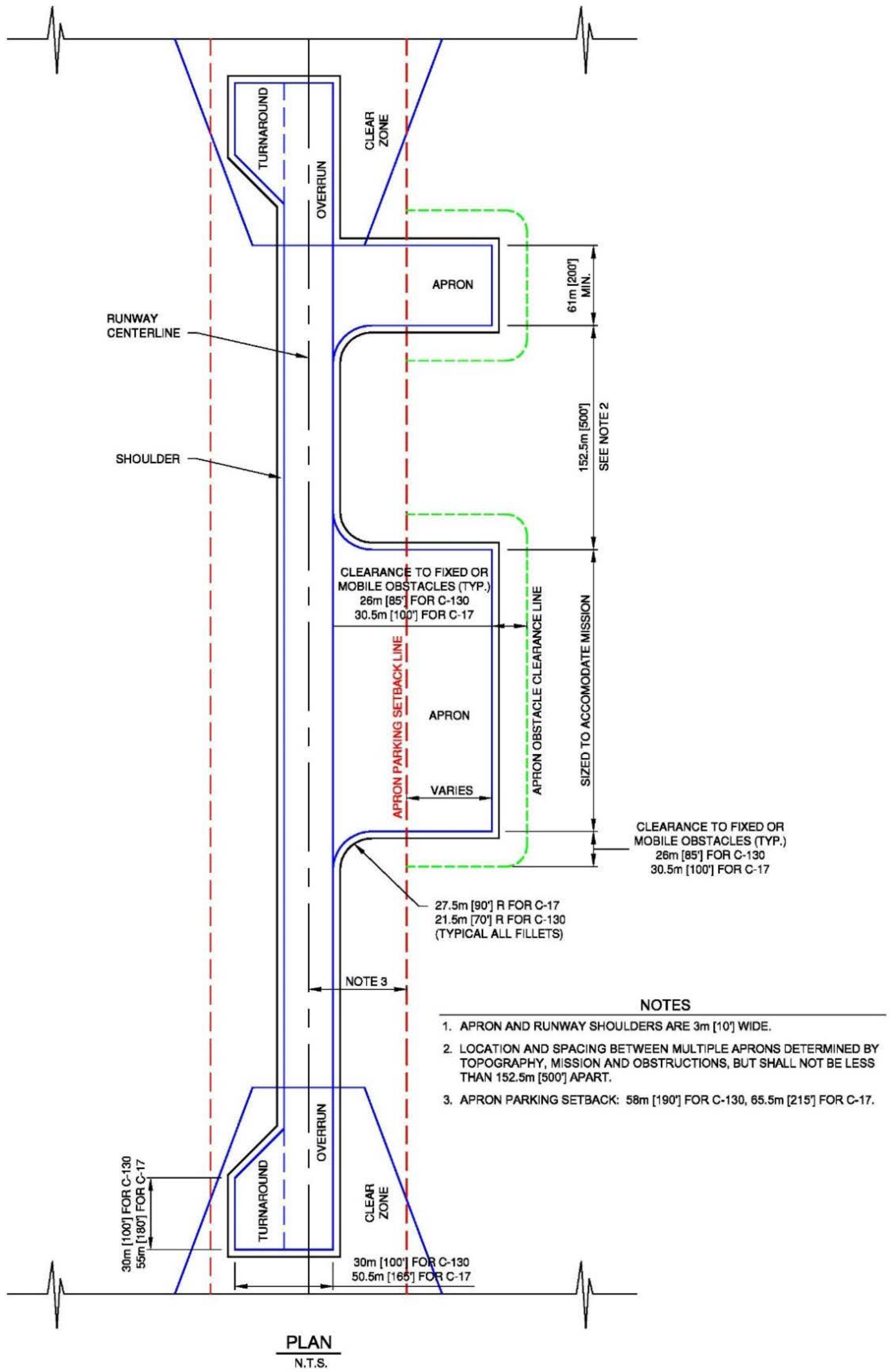


Figure 7-4. LZ Apron Layout Details

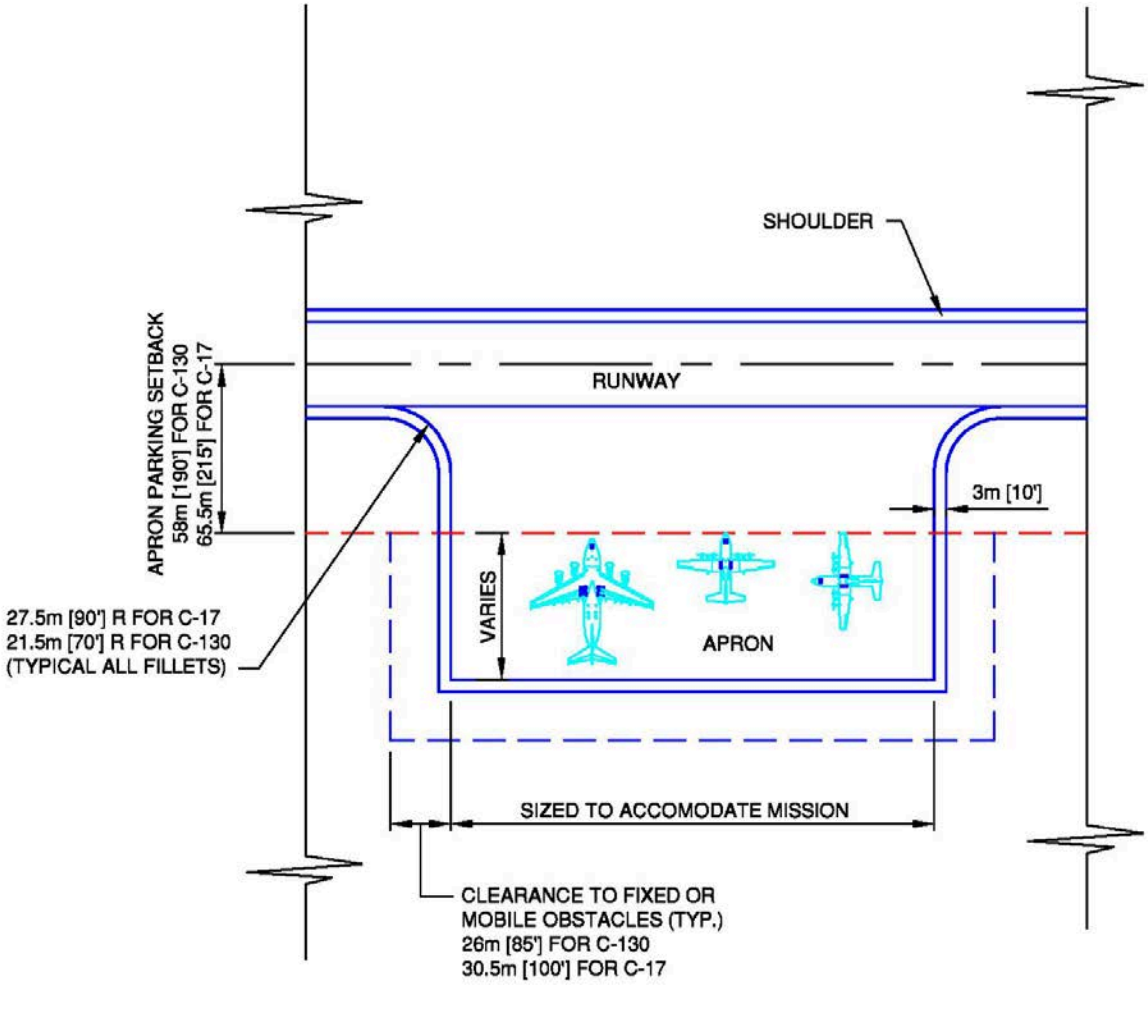


Figure 7-5. LZ Runway Imaginary Surfaces

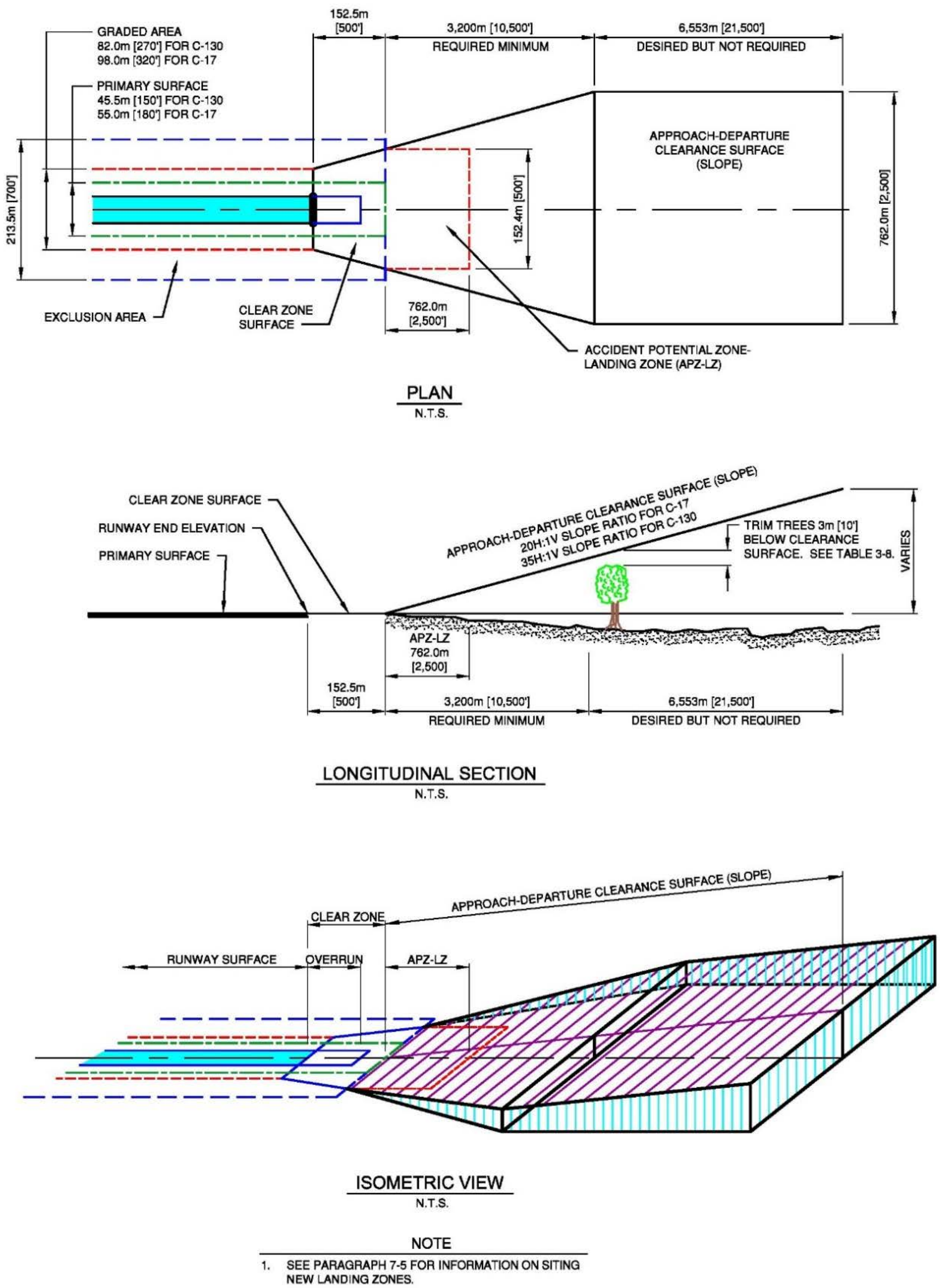
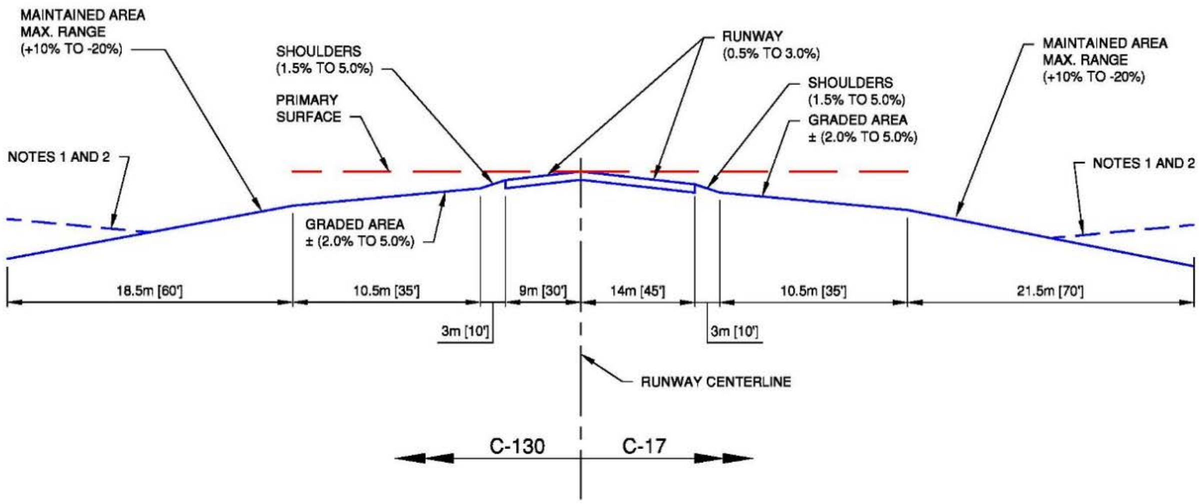
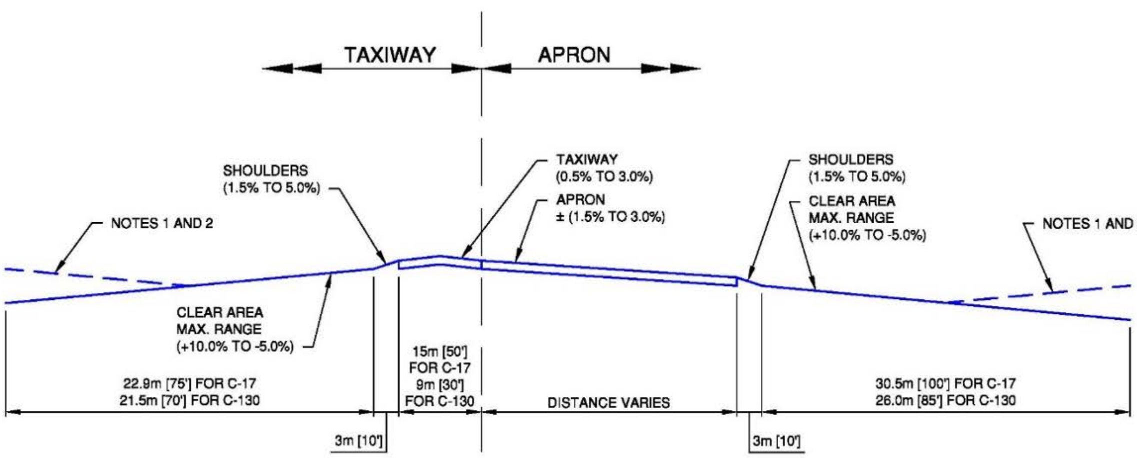


Figure 7-6. LZ Runway, Taxiway, and Apron Sections



RUNWAY CROSS SECTION
N.T.S.



TAXIWAY / APRON CROSS SECTION
N.T.S.

NOTES

1. A ± (1.5% TO 5.0%) GRADE MEANS THE SURFACE WILL BE SLOPED, EITHER POSITIVELY BETWEEN +1.5% AND +5.0% OR NEGATIVELY BETWEEN -1.5% AND -5.0%, BUT NOT LEVEL.
2. GRADE CHANGES (INCLUDING REVERSALS) ARE PERMITTED WITHIN THE RUNWAY GRADED AND MAINTAINED AREAS AND WITHIN THE TAXIWAY AND APRON CLEAR AREAS.

7-7 OPERATIONAL WAIVERS TO CRITERIA.

The criteria in this chapter are the minimum permissible for C-17 and C-130 operations. When deviations exist or occur at a specific location, an operational waiver must be obtained before beginning flying operations. Ensure a risk assessment is performed on all proposed operational waiver requests prior to submitting to the approval authority. The office of primary responsibility (OPR) for the mission or exercise will initiate the waiver request. If IFR procedures apply, proposed waivers must be coordinated with the appropriate TERPS office. The appropriate airfield survey team will verify existing LZ dimensions and grades. See Paragraph 1-7 and Appendix B, Section 1 for waiver processing procedures.

7-8 SEPARATION DISTANCES BETWEEN PERMANENT RUNWAYS/HELIPADS AND LZ RUNWAYS.

7-8.1 Separation Distances between Permanent Runways/Helipads and LZ Runways for Simultaneous Operations.

When simultaneous operations are desired on a permanent runway or helipad and an LZ runway, minimum separation distances are required as stipulated in Table 7-9.

7-8.2 Separation between Permanent Class A or Class B Runways and LZ Runways for Non-Simultaneous Operations.

At a minimum, LZ runways will be separated from permanent runways so as not to conflict with distance-remaining signs, runway edge lights, NAVAIDs (including glideslope signals), and other facilities associated with the runway.

Table 7-9. Runway Separation for Simultaneous Operations

Table 7-9. Runway Separation for Simultaneous Operations

Item		Requirement	Remarks
No.	Description		
1	Distance between centerlines of parallel runways	762 m (2,500 ft)	IFR using simultaneous operation (depart-depart) (depart-arrival)
		1310.6 m (4,300 ft)	IFR using simultaneous approaches
2	Distance from the centerline of a fixed-wing runway to the centerline of a parallel rotary-wing runway, helipad, or landing lane	Min 213.4 m (700 ft)	Simultaneous VFR operations for Class A runway and Army Class B runway
		Min. 304.8 m (1,000 ft)	Simultaneous VFR operations for Class B runway for Air Force, Navy, and Marine Corps
		Min 213.4 m (700 ft)	Non-simultaneous operations Distance may be reduced to 60.96 m (200 ft); however, waiver is required and must be based on wake-turbulence and jet blast. In locating the helipad, consideration must be given to hold position marking. Rotary-wing aircraft must be located on the apron side of the hold position markings (away from the runway) during runway operations.
		Min. 762 m (2,500 ft)	IFR using simultaneous operations (depart-depart) (depart-approach)
		Min. 1310.6 m (4,300 ft)	IFR using simultaneous approaches

7-9 SURFACE TYPES.

1\ Semi-prepared (unpaved) LZ surfaces may be composed of stabilized soils, aggregate surfaces, compacted native soils, or matting. Paved LZs may be surfaced with asphalt concrete (AC) or PCC pavement. On runways, taxiways, turnarounds, and aprons used by C-17 aircraft, asphalt pavement distress has been observed in areas where 90- to 180-degree turns are made; for this reason, PCC is preferred in areas where turning movements occur. Designers should consider durability and maintenance of the pavement, as well as economics, when selecting a surface type for an area associated with an LZ intended for long-term use. AC and PCC pavement structures will be designed to support the traffic level defined in UFC 3-260-02, *Pavement Design for Airfields*. /**1**/

7-9.1 Runways and Overruns.

7-9.1.1 Semi-prepared Runway and Overrun Surfaces.

Unpaved LZ runway and overrun surfaces will be designed to support the anticipated aircraft type, weight, and number of planned operations. Overruns will be designed to the same standard as the runway.

7-9.1.2 Paved Runway and Overrun Surfaces.

Paved runways and overruns may be surfaced with AC or PCC pavement. Sawcut grooving may be used to improve drainage characteristics on runway surfaces only. Overruns will be designed to the same standard as the runway. Special design consideration is needed if the overrun is used as a taxiway or turnaround area.

7-9.1.3 Runway and Overrun Shoulders.

For semi-prepared runways, the shoulder structure will be designed to the same standard as the runway. For paved runways, shoulders will be surfaced with AC or PCC pavement and will be designed to support the traffic level defined in UFC 3-260-02.

7-9.2 Turnarounds.

Semi-prepared Turnarounds. Unpaved turnarounds will be designed to support the anticipated aircraft type, weight, and number of operations. Designers should give special consideration to stabilization for turnarounds used by C-17 aircraft because the surface can be easily damaged by the turning action of the main landing gear.

7-9.2.1 Paved Turnarounds.

Paved turnarounds may be surfaced with AC or PCC. Special consideration should be given to surface durability for turnarounds used by C-17 aircraft; for this reason, PCC pavement is preferred.

7-9.3 Taxiways.

7-9.3.1 Semi-prepared Taxiways.

Unpaved taxiways will be designed to support the anticipated aircraft type, weight, and number of operations. Designers should give special consideration to stabilization at taxiway turns used by C-17 aircraft because the surface can be easily damaged by the turning action of the main landing gear.

7-9.3.2 Paved Taxiways.

Paved taxiways may be surfaced with AC, PCC. Special consideration should be given to surface durability for taxiways used by C-17 aircraft; for this reason, PCC pavement is preferred.

7-9.4 Aprons.

7-9.4.1 Semi-prepared Aprons.

Unpaved aprons will be designed to support the anticipated aircraft type, weight, and number of operations. Designers should give special consideration to stabilization on aprons used by C-17 aircraft because the surface can be easily damaged by the turning action of the main landing gear.

7-9.4.2 Paved Aprons.

Paved aprons may be surfaced with AC, PCC. Special consideration should be given to surface durability and fuel resistance for aprons used by C-17 aircraft; for this reason, PCC pavement is preferred.

7-10 VISUAL LANDING ZONE MARKER PANELS (VLSMP).

Various systems are used during daytime operations to provide visual cues to pilots about the location and dimensions of the LZ runway. The type of marker panels selected depends on the mission requirements and anticipated duration of LZ use. The following paragraphs describe requirements for temporary and long-term applications, respectively.

7-10.1 Minimum Marking Requirements for Temporary Applications.

7-10.1.1 Temporary Panels.

LZ runways intended for short-term or temporary use should be marked with one of the arrangements of airfield marking patterns (AMP) defined in AFI 13-217, *Drop Zone and Landing Zone Operations*. The special tactics team (STT) will decide which arrangement of panels will be installed. The AMP-1, AMP-2 and AMP-3 layouts are illustrated in Figures 7-8a, 7-8b, and 7-8c. Although AMP-2 is also defined in AFI 13-217, the AMP-2 configuration will not be used for newly constructed temporary or permanent LZs by AMC. AMP-4 does not require any marker panels or lights and is only used for appropriate special operations.

7-10.1.2 Materials and Size.

Temporary panels may be constructed of fabric, wood, or other materials determined to be suitable by the STT. Panel faces will be at least 1524 millimeters (60 inches) wide and 432 millimeters (17 inches) tall. Airfield signs with solid panels rated for 300 mph have been commonly used.

7-10.1.3 Orientation and Color.

Marker panels should be erected upright and facing toward the aircraft approach to increase visibility to the pilot. The panels will be orange (Federal Standard 595, Color FS 18913, *Fluorescent Red Orange*), cerise (Federal Standard 595, Color FS 28915, *Fluorescent Red*), or other color acceptable to the STT. The specific color used and layout must be briefed to all participating units before operations commence.

7-10.1.4 Frangibility.

For temporary applications, frangible marker panels and supports are preferred to avoid excessive damage if struck by an aircraft. If available, VS-17 marker panels (National Stock Number [NSN] 8345-00-174-6865, Part Number MIL-P-400-61) should be used to mark temporary LZs for daytime operations.

7-10.2 Marking Requirements for Long-Term Applications.

7-10.2.1 Permanent Panels.

LZs intended for long-term use should have permanently installed panels of the type described below. Panel locations are derived from the patterns shown in AFI 13-217, Figures 3.1, 3.3, and 3.5. Panels will be installed at the locations shown in Figures 7-8a or 7-8b, depending on the desired AMP. In AMP-1, spacing will be consistent through the intermediate panels. If a conflict with the panels exists on one or both sides of the LZ (e.g., at locations where a taxiway connects to the LZ), that panel should be omitted. For bi-directional operations, panels of the appropriate color will be attached to each side of the support posts. See Figures 7-8a and 7-8b, Note 2, for the distance between the panels and the runway edge. Panels should be 1.8 meters (6 feet) apart at locations where panels are placed in pairs.

7-10.2.2 Materials and Size.

Panel surfaces may be constructed of any lightweight yet durable material suitable for the environment. Panel surfaces will be at least 1524 millimeters (60 inches) wide and 610 millimeters (24 inches) tall. Airfield signs with solid panels rated for 300 mph have been commonly used.

7-10.2.3 Orientation and Color.

Marker panels should be erected upright and facing toward the aircraft approach to increase visibility to the pilot. The panels should be covered with reflective sheeting material or painted orange (Federal Standard 595, Color FS 18913, *Fluorescent Red Orange*), or cerise (Federal Standard 595, Color FS 28915, *Fluorescent Red*), the colors indicated in Figures 7-8a and 7-8b. (**Note:** Alternate colors may be used if all participating units are briefed and concur with the color selection. For example, all panels may be orange.) Reflective sheeting will be 3M™ diamond grade or equivalent. Panels must be designed to withstand jet blast effects. A panel design that has been used successfully is illustrated in Figure 7-7.

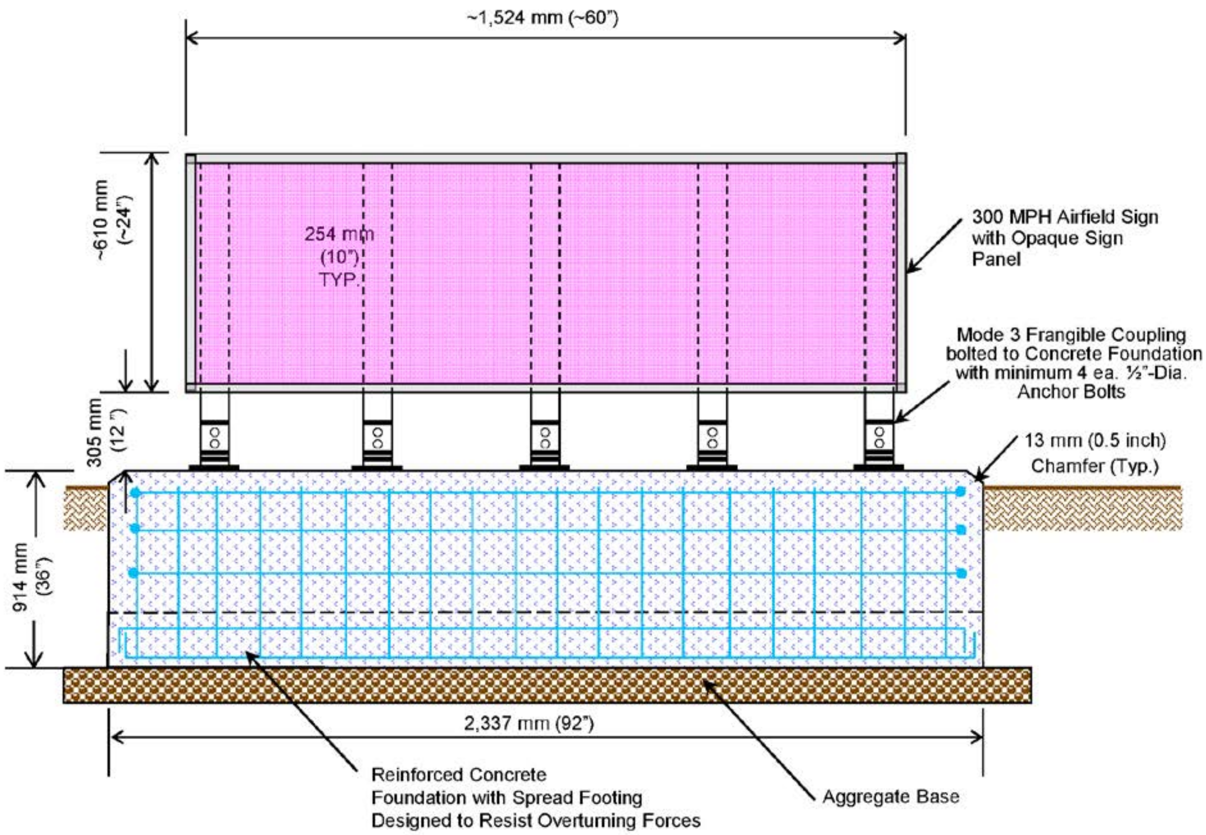
7-10.2.4 Foundations.

A reinforced concrete foundation pad should be used to support and anchor the panel support posts. Sample details for a foundation are shown in Figure 7-7.

7-10.2.5 Support Posts.

Support posts are needed to hold the panels upright. Posts must be strong enough to withstand jet blast and also frangible to break away upon impact. Posts will meet the frangibility definitions, acceptance criteria, analysis and testing requirements defined in Appendix B, Section 13. The support will have frangible points located 51 millimeters (2 inches) or less above the concrete pad. The frangible points will withstand wind loads due to jet blasts of 482 kilometers per hour (300 miles per hour) but will break or give way before reaching an applied static load over the surface of the sign of **\1** 19.3 kilopascals (2.8 pounds per square inch). **/1/**

Figure 7-7. Example VLZMP on Concrete Base Detail

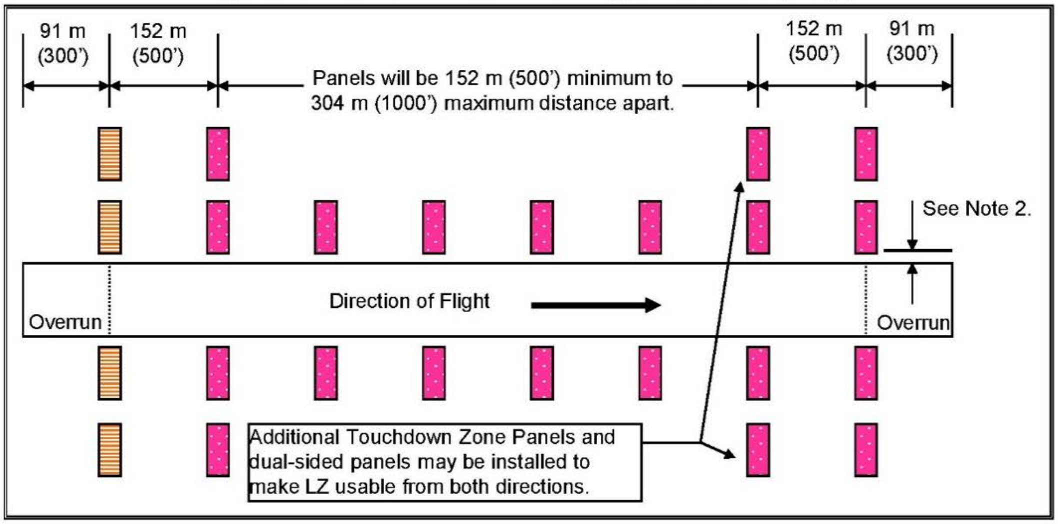


Notes:

1. Example panel design. Panel minimum dimensions must be met, but panel materials, posts, and foundation can be modified by the designer.
2. Refer to Figure 7-8a or 7-8b for locations and color scheme layout.
3. Foundation depth shall be minimum 914 millimeters (36 inches) or 152 millimeters (6 inches) deeper than the frost line. Foundation upper wall width shall be minimum 305 mm (12 inches). Foundation spread footing shall be minimum 305 mm (12 inches) thick. Spread footing width shall be as needed to resisting overturning moment created by jet blast and 300 mph wind on sign. Reinforcing shall be determined by designer.
4. Top of concrete pad shall be 13 millimeters (0.5 inch) above surrounding ground. Maximum allowable height above ground is 38 millimeters (1.5 inches). Slope concrete 6 millimeters (0.25 inch) per foot away from panel.
5. Frangible coupling or hinge point shall be located 13 millimeters (0.5 inch) above top of concrete pad.
6. For erosion protection and to ease mowing, install minimum 1.5 m (5 ft) asphalt pad around concrete foundation, flush with ground surface and sloped to promote drainage.

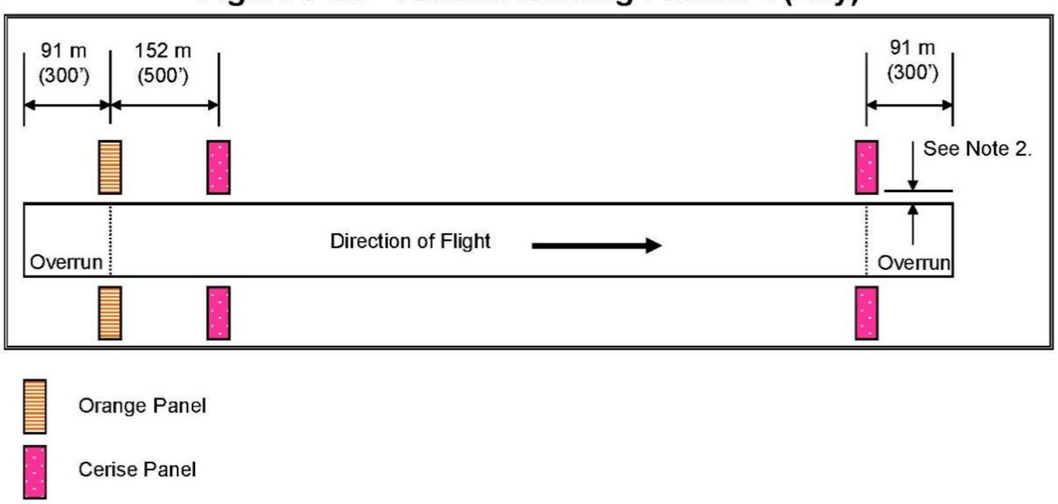
Figure 7-8. Airfield Marking Patterns (AMP)

Figure 7-8a – Airfield Marking Pattern 1 (Day)



Airfield Marking Pattern 2 (Day) - NOT USED

Figure 7-8b – Airfield Marking Pattern 3 (Day)



Notes:

1. Alternate colors may be used if all participating units are briefed and concur with the color selection. For example, all panels may be orange.
2. If runway edge lights are not installed on the LZ, place inner edge of panels 1.2 m (4') minimum, 3 m (10') maximum from the edge of the runway. If runway edge lights are installed, place inner edge of panels 3.6 m (12') minimum, 9 m (30') maximum from the edge of the runway so that panels do not block view of the runway edge lights.
3. See Figure 7-14 for additional panel layout dimensional details.

7-11 LZ LIGHTING.

Various systems are used during daytime operations to provide visual cues to pilots about the location and dimensions of the LZ runway. The type of marker panels selected depends on the mission requirements and anticipated duration of LZ use. The following paragraphs describe requirements for temporary and long-term applications, respectively.

7-11.1 Minimum Lighting Requirements for Temporary Applications.

7-11.1.1 Lights.

If available, lights should be omni-directional steady-burn or flashing with a minimum output rating of 15 candela for night operations. In accordance with AFI 13-217, virtually any type of lighting system is acceptable if all participating units are briefed and concur with its use. Contingency lighting kits (emergency airfield lighting system [EALS]) or other materials may be used as available and determined to be suitable by the STT.

7-11.1.2 Location.

There are three types of airfield lighting patterns for LZs, designated AMP-1, AMP-2, and AMP-3, as defined in AFI 13-217. AMP-4 is lights-out, no markings, and used only for appropriate special operations. The STT will decide which arrangement of lights will be installed. The AMP-1, AMP-2, and AMP-3 layouts are illustrated in Figures 7-9a, 7-9b, and 7-9c. Although AMP-2 is also defined in AFI 13-217, the AMP-2 configuration will not be used for newly constructed temporary or permanent LZs by the Air Force. When constructing new LZs, even if the immediate operational need is for AMP-3, consideration should still be given to installing the light bases and conduits to support the AMP-1 configuration.

7-11.2 Lighting Requirements for Permanent Applications.

When intended for long-term use, use permanently installed lights of the type and in the locations described below.

7-11.2.1 Light Fixtures.

Certify all light fixtures. Procure and install only those light fixtures listed in FAA AC 150/5345-53, *Airport Lighting Equipment Certification Program*, and FAA AC 150/5345-46, *Specification for Runway and Taxiway Light Fixtures*. IR filters will be used with fixtures listed in paragraph 7-11.7 when IR capabilities are required as part of the installation.

7-11.2.1.1 Runway Lights.

Runway high-intensity edge light fixtures will be used for permanent LZ lighting installations. Runway edge lights will be elevated FAA Type L-862. Use the L-850C when an inset light is required in place of the L-862. If the LZ is superimposed on an existing runway or taxiway where normal flight operations are conducted then use semi-flush light fixtures. If all edge lights are semi-flush edge lights, use the FAA Type L-850A, Style 3 (Runway, Uni-directional) towards the approach. (Where circling guidance is needed, bi-directional light fixtures may be used.) LZ light lens colors will be as indicated in Figures 7-9a, 7-9b, and 7-9c. Five-step regulators will be installed. (Steps 1 through 3 are compatible with NVG operations using a five-step regulator.)

7-11.2.1.2 Taxiway Lights.

Taxiway medium-intensity edge light fixtures will be used for permanent lighting installations. Taxiway edge lights will be elevated FAA Type L-861T. If needed, semi-flush edge lights will be FAA Type L-852T, Style 3 (Taxiway, Omni-directional). Taxiway and turnaround edge light lenses will be blue. Three-step regulators will be installed for intensity control.

7-11.2.1.3 Flashing Strobe Lights (FSL).

These light fixtures are located at the end of the LZ in the AMP-3 and AMP-2 configurations and at each side of the approach threshold in the AMP-1 configuration. These lights are uni-directional and must flash at a rate of 28 to 34 flashes per minute, producing a white light. Semi-flush fixtures (FAA-E-2952, Style A, white) will be installed with the edge of the fixture extending no more than 1.5 millimeters (0.0625 inch) below and 0.0 millimeter (0.0 inch) above the pavement top. Aim the fixture(s) down the runway parallel to the centerline for AMP-2 and AMP-3 and towards the approach for AMP-1.

7-11.2.2 Light Bases.

Light fixtures will be attached to full-depth light bases (L-868, Class IB). Light bases will be offset so the fixture center is a minimum of 0.6 meter (2 feet) from any pavement joint. Light bases will be installed in accordance with UFC 3-535-01. For elevated light fixtures, provide steel adaptor rings. Light construction tolerances are:

Longitudinal	± 13 millimeters (0.5 inch) from stationing
Transverse	± 13 millimeters (0.5 inch) transverse from centerline
Base orientation	Parallel to T/W centerline ± 0.5 degree
Elevation	+0 to -1.5 millimeters (+0 to –0.0625 inch) from finished pavement surface, flush with the surrounding grade or pavement.

7-11.3 Light Locations.

See paragraph 7-11.6 for guidance on LZ lights superimposed on Class A or Class B runways.

7-11.3.1 AMP-1.

Lights will be placed at each threshold and at 152 meters (500 feet) from each threshold. Intermediate lights will be 152 meters minimum/305 meters maximum (500 feet minimum/1000 feet maximum) spacing throughout the length of the runway, as illustrated in Figures 7-9a and 7-13. Spacing will be consistent through the intermediate lights. If a conflict with the lights exists on one or both sides of the LZ (e.g., at locations where a taxiway connects to the LZ), that light will be a semi-flush light. Synchronized FSLs will be installed at the threshold as illustrated in Figures 7-9a and 7-13. Steady-burning light fixtures will be installed at 1.6 meters (5 feet) plus 0.6 meter (2 feet) to minus 0.0 meter (0.0 foot) from the edge of the LZ surface (i.e., within the shoulder pavement). Light pairs will be perpendicular and equidistant from the runway centerline to be symmetrical about the runway or LZ centerline.

7-11.3.2 AMP-2.

Lights will be placed at each threshold and at 152 meters (500 feet) from each threshold. Intermediate lights will be 152 meters minimum/305 meters maximum (500 feet minimum/1000 feet maximum) spacing throughout the length of the runway, as illustrated in Figure 7-9b. Spacing will be consistent through the intermediate lights. If a conflict with the lights exists on one or both sides of the LZ (e.g., at locations where a taxiway connects to the LZ), that light will be a semi-flush light. An FSL is also installed on the centerline of the departure end threshold not more than 1.6 meters (5 feet) from the threshold or overrun end. Locate the FSL as close to the runway centerline as possible. Steady-burning light fixtures will be installed 1.6 meters (5 feet) plus 0.6 meter (2 feet) to minus 0.0 meter (0.0 foot) from the edge of the LZ surface (i.e., within the shoulder pavement). Installations requiring infrared capability will include the provisions of paragraph 7-11.7.

7-11.3.3 AMP-3.

Light locations and colors are derived from the AMP-3 configuration in AFI 13-217, Figure 3.6. Steady-burning lights will be placed at the threshold and at 152 meters (500 feet) from the approach end threshold, forming a box, as shown in Figures 7-9c, 7-14, and 7-15. An FSL is also installed on the centerline of the departure end threshold not more than 1.6 meters (5 feet) from the threshold or overrun end. Locate the FSL as close to the runway centerline as possible. Steady-burning light fixtures will be installed at 1.6 meters (5 feet) plus 0.6 meter (2 feet) to minus 0.0 meter (0.0 foot) from the edge of the LZ surface (i.e., within the shoulder pavement). Installations requiring infrared capability will include the provisions of paragraph 7-11.7.

7-11.3.4 Turnaround, Taxiway, and Apron Edge Lights.

All lights will be installed at 1.6 meters (5 feet) plus 0.6 meter (2 feet) or minus 0.0 meter (0.0 foot) from the edge of the load-bearing surface. On straight sections of taxiway or turnaround, lights will be spaced evenly with a maximum of 152 meters (500 feet) between lights. See Figures 7-12 and 7-13, for typical turnaround and taxiway edge light locations. Light spacing will be reduced to between 3 meters and 10.6 meters (10 feet and 35 feet) on curves and at corners or intersections. On curved sections, lights will be evenly spaced from point of tangency (PT) to PT, with the maximum spacing between lights equal to half the taxiway width. For all corners and all curves exceeding 30 degrees of arc, there will be a minimum of three lights. See UFC 3-535-01, Chapter 5, for additional edge light location details.

7-11.3.5 Overrun Edge Lights.

Overruns do not normally require edge lights; however, for overruns used as taxiways or turnarounds, edge lights may be installed using the location criteria stated in paragraph 7-11.3.4. In addition, the first pair of edge lights installed on overruns should not be more than 30.5 meters (100 feet) from the runway threshold.

7-11.4 Light Circuits and Controls.

Designers should investigate all required configurations of lighting (AMP-1, AMP-3 (Visual Spectrum), Infrared AMP-3, etc.) and develop a circuit and control system that can achieve all the required configurations.

7-11.4.1 Ferro-Resonant Regulators.

All new regulators used for LZ lighting systems will be ferro-resonant type.

7-11.4.2 Multi-Regulator Systems.

In this configuration, separate regulators will be needed to control lights for AMP-1, AMP-3 (Visual Spectrum), Infrared AMP-3, and taxiway circuits.

7-11.4.3 Single-Regulator Systems with Addressable Lights.

Systems are now available to have “assignable control” of individual lights via a carrier signal. For this type of configuration, all LZ runway lights could be powered by one regulator, with each configuration assigned to a different control setup.

7-11.5 Light Reflector Panels (Optional).

Light reflectors may be installed at the mid-point between LZ runway edge lights or taxiway edge lights. Contact the STT for information on obtaining light reflector panels.

Figure 7-9. Lighting Plans

Figure 7-9a – AMP-1 Lighting Plan

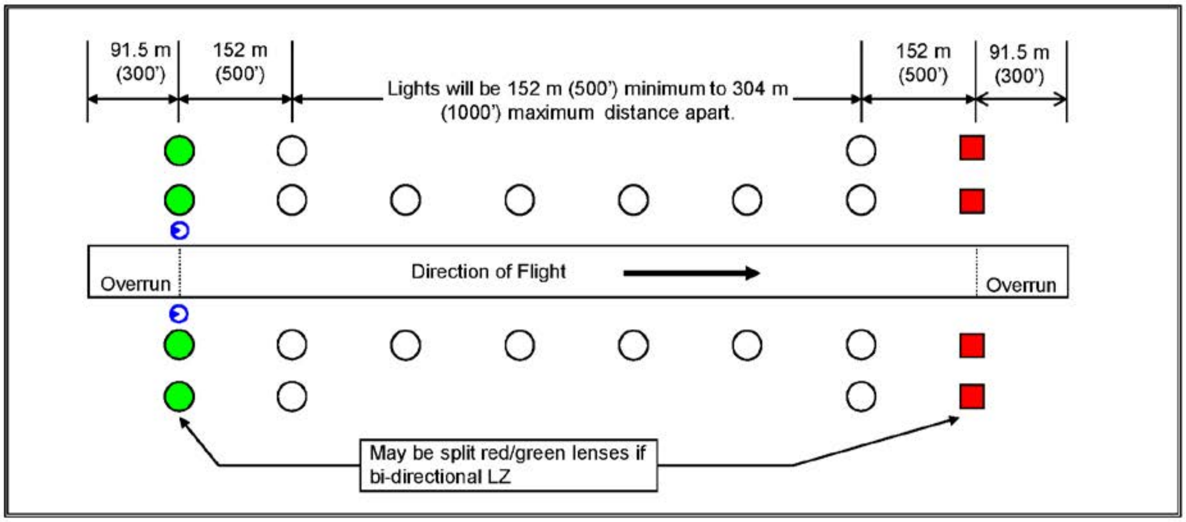
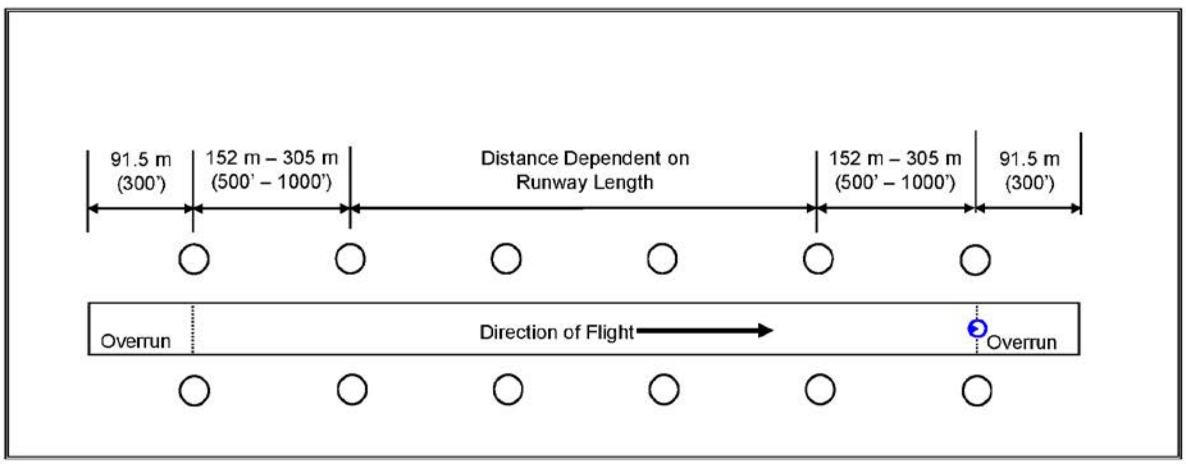
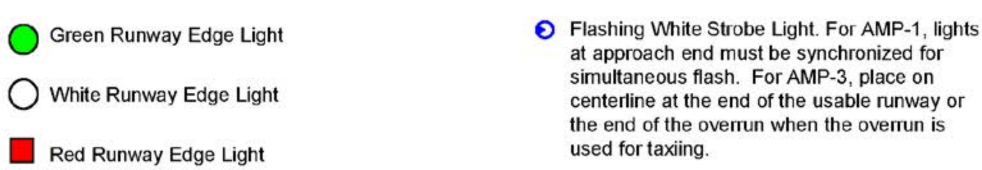


Figure 7-9b – AMP-2 Lighting Plan

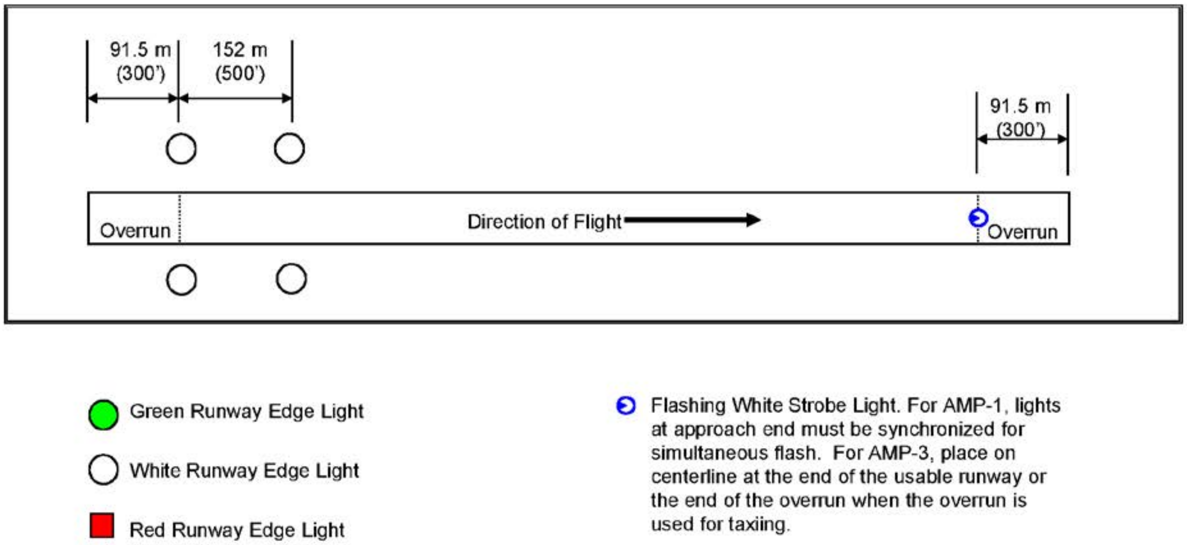




Notes:
1. See Figure 7-13 for additional light layout dimensional details.

Figure 7-9. Lighting Plans (continued)

Figure 7-9c – AMP-3 Lighting Plan



Notes:
1. See Figure 7-13 for additional light layout dimensional details.

7-11.6 AMP-3 (Visual Spectrum) LZ Lights Superimposed on Standard Operational Runways.

In some cases, it may be desirable to use a standard full-length runway for LZ training operations. Only the AMP-3 configuration should be installed in this situation. For this purpose, the LZ lighting scheme illustrated in Figures 7-15, 7-16 and 7-17, will be applied, subject to the following conditions. Service-specific airfield management approval is required before installation of AMP-2 configuration.

7-11.6.1 LZ Light Fixtures.

High-intensity light fixtures must be installed flush with the pavement surface to allow traffic to pass over them. Semi-flush lights will be FAA Type L-850A, Style 3, uni-directional, or an International Civil Aviation Organization (ICAO) equivalent. LZ light lens colors will be white. Five-step regulators will be installed on the LZ circuit(s) for light intensity control compatible with NVG operations (steps 1 through 3 are compatible with NVG operations).

7-11.6.2 LZ Location on the Runway.

When possible, the LZ threshold should be sited between 91 meters (300 feet) and 152 meters (500 feet) from the runway threshold. This will ensure aircraft loads are concentrated in the portion of the runway designed for heavier loads and avoid conflicts with runway pavement markings.

7-11.6.3 LZ Lighting Conflicts with Standard Runway Markings.

The LZ should be sited so the LZ light fixtures do not conflict with threshold markings, runway designation markings, touchdown zone markings, or fixed distance markings. An ideal location for the LZ threshold is 91 meters (300 feet) from the runway threshold. This will position the LZ light fixtures in the gaps between the standard runway markings. If LZ lights fall within a standard marking, the light fixture should be masked whenever repainting occurs.

7-11.6.4 LZ Lighting Conflicts with Approach Lights and Touchdown Zone (TDZ) Lights.

Runway approach lights and TDZ lights are spaced every 30 meters (100 feet) throughout the overrun and for the first 914 meters (3000 feet) of the runway. TDZ lights are installed in groups of three, starting 11 meters (36 feet) each side of the runway centerline and spaced over a 3-meter (10-foot) light bar. LZ lights for C-17s will not conflict with TDZ lights because LZ lights are 15 meters (50 feet) each side of the centerline. C-130 LZ lights are installed 10.5 meters (35 feet) each side of the centerline, so conflicts should not occur. If TDZ lights are installed on the runway, move the LZ lights closer to the LZ edge to position them inside the TDZ lights.

7-11.7 Infrared (IR) AMP-3 and AMP-2 Lights.

7-11.7.1 Installation.

At some locations, IR lights may be needed in addition to standard visual spectrum lights. IR lights can be installed in accordance with Figures 7-12, 7-13, 7-14 and 7-15.

7-11.7.2 IR Light Fixtures.

Procure and install FAA L-850A Style 3 fixtures, with infrared transmitting filter installed on the lens. Use only infrared transmitting filters will meet the specifications in Table 7-10 and the spectral transmittal limits required by the contracting officer. Use only infrared transmitting filters that are certified by an FAA-approved laboratory (currently Intertek Test Lab) to comply with the specifications in this paragraph and the required spectral transmittal limits. Submit to the contracting officer an FAA approved lab (currently Intertek Test Lab) report certifying compliance prior to installation.

Table 7-10. Infrared Transmitting Filter Specifications

Physical Properties	
Nominal thickness range	4–6 mm 0.17–0.23 in
Thermal linear expansion	$110x10^{-7}$/°C (30–300 °C) (86–572 °F)
Refractive index (n)	1.53
Density	2.67 g/cc
Strain temperature	492 °C (918 °F)
Transition temperature	510 °C (950 °F)
Anneal temperature	526 °C (979 °F)
Deformation temperature	563 °C (1045 °F)

7-11.8 Snowplow Rings.

Steel rings are used to protect semi-flush light fixtures in areas that are plowed for snow removal. See guidance on materials, configuration and installation procedures in FAA Engineering Brief No. 85, *Ductile Snowplow Protection Ring and Installation Procedures*.

7-12 PAVEMENT MARKINGS.

7-12.1 Minimum Requirements.

1\ The surface perimeter of non-contingency LZs, whether paved or semi-prepared, are required to be marked. For semi-prepared surfaces, the perimeter of landing surfaces, including the turn-around ends, will be marked with reflective markers referenced in AFTTP 3-32.13, *Airfield Marking and Striping After Major Attack*, or lighting options determined to be suitable for night operations in accordance with AFI 13-217. Stake chasers mentioned below are not suitable markings for night time operations. Reflective painted markings should be applied to paved surfaces where long-term use is intended. See Figures 7-11, 7-12, and 7-13 for illustrations of LZ pavement markings. /**1**/

7-12.2 Markings on Semi-Prepared LZs.

7-12.2.1 Paint.

It is generally not practical to apply paint to unpaved surfaces. However, markings are desirable to delineate the edge of operational surfaces, particularly turnaround areas. If the semi-prepared surfaces are stabilized, then painted markings may be feasible but will likely require frequent repainting.

7-12.2.2 Alternate Markings.

Alternatively, “stake chasers” can be installed along the edges of semi-prepared surfaces. Stake chasers are 150-millimeter (6-inch) flexible plastic bristles that attach to a 60-penny (60d) nail or a wooden stake. They are available in a variety of colors and can be purchased from survey supply stores. When used, the stake chasers should be installed at 7.6 to 15.2 meters ± 1.5 meters (25 to 50 feet ± 5 feet) intervals and driven into the ground so only 100 millimeters (4 inches) of the 150-millimeter (6-inch) whiskers are visible (exposed length may be dependent on soil conditions). This will help ensure the stakes are not dislodged by traffic or jet blast. When possible, install stake chasers with colors corresponding to the edge light (white = runway edge, blue = taxiway and turnaround edge). Stake chasers are illustrated in Figure 7-10.

Figure 7-10. Stake Chasers for Marking Edges of Semi-Prepared LZs, Taxiways and Turnarounds

7-12.3 Marking Requirements for Long-Term Use on Pavements.

7-12.3.1 Marking Material.

Use paint to apply markings to paved LZs, turnarounds, aprons, and taxiways. Paint should be applied at 0.305 to 0.356 millimeter (12 to 13 mils) wet film thickness for a desired dry film thickness of approximately 0.203 millimeter (8 mils). At this rate, coverage will be approximately 11 square meters (121 square feet) per gallon.

Normally, LZ markings should not be reflective to improve realism for operating on a semi-prepared LZ. However, for LZs that need additional reflectivity, glass beads (Type I or Type III) will be applied at a rate of approximately 3.6 to 4 kilograms (8 to 9 pounds) per gallon of paint.

7-12.3.2 Threshold Bar.

White threshold stripes may be marked at each end of the LZ runway to distinguish between the overrun and LZ runway surface. The marking will be 1.2 meters (4 feet) wide and extend from edge to edge of the LZ surface.

7-12.3.3 LZ Edge Stripes.

White side stripes should only be painted when there is no visual distinction between the LZ runway surface and the paved shoulder (e.g., both LZ runway and shoulder are asphalt). Edge stripes will be 0.3 meter (1 foot) wide and extend along the entire length of the LZ runway.

7-12.3.4 Taxiway Centerline.

If the LZ runway has connecting taxiways, the taxiway centerline turn radius will not be extended onto the LZ runway surface.

7-12.3.5 Taxiway, Apron, and Turnaround Edge Stripes.

If taxiways, aprons or turnarounds have paved shoulders and there is no visual distinction between the edge of load-bearing pavement and the shoulder, the edge of full-strength pavement will be marked with two 152-millimeter (6-inch) wide yellow stripes separated by a 152-millimeter (6-inch) wide gap.

7-12.3.6 Holding Position Markings.

The holding position is located a minimum of 30.5 meters (100 feet) from the near edge of the runway. This distance is measured perpendicular to the long axis of the LZ. For holding position marking dimensions, see Service-specific airfield marking guidance.

7-12.3.7 Touchdown Box Markings (Optional).

When desired by the airfield manager, touchdown box markings may be applied. These markings consist of 0.9-meter (3-foot) -wide white stripes that extend transversely across the entire width of the runway surface. The stripes are located 30.5 meters and 152 meters (100 feet and 500 feet) from the approach end threshold.

7-12.3.8 Runway Designation Markings.

Runway designation markings will not be used on LZ runways.

7-12.3.9 Runway Centerline (Optional).

When desired by the airfield manager, runway centerline stripes may be applied. Stripes are 0.5 meter to 0.9 meter (1.5 feet to 3 feet) wide and 30.5 meters (100 feet) long, with an 18.3-meter (60-foot) gap between stripes.

Figure 7-11. LZ Painted Marking Layout

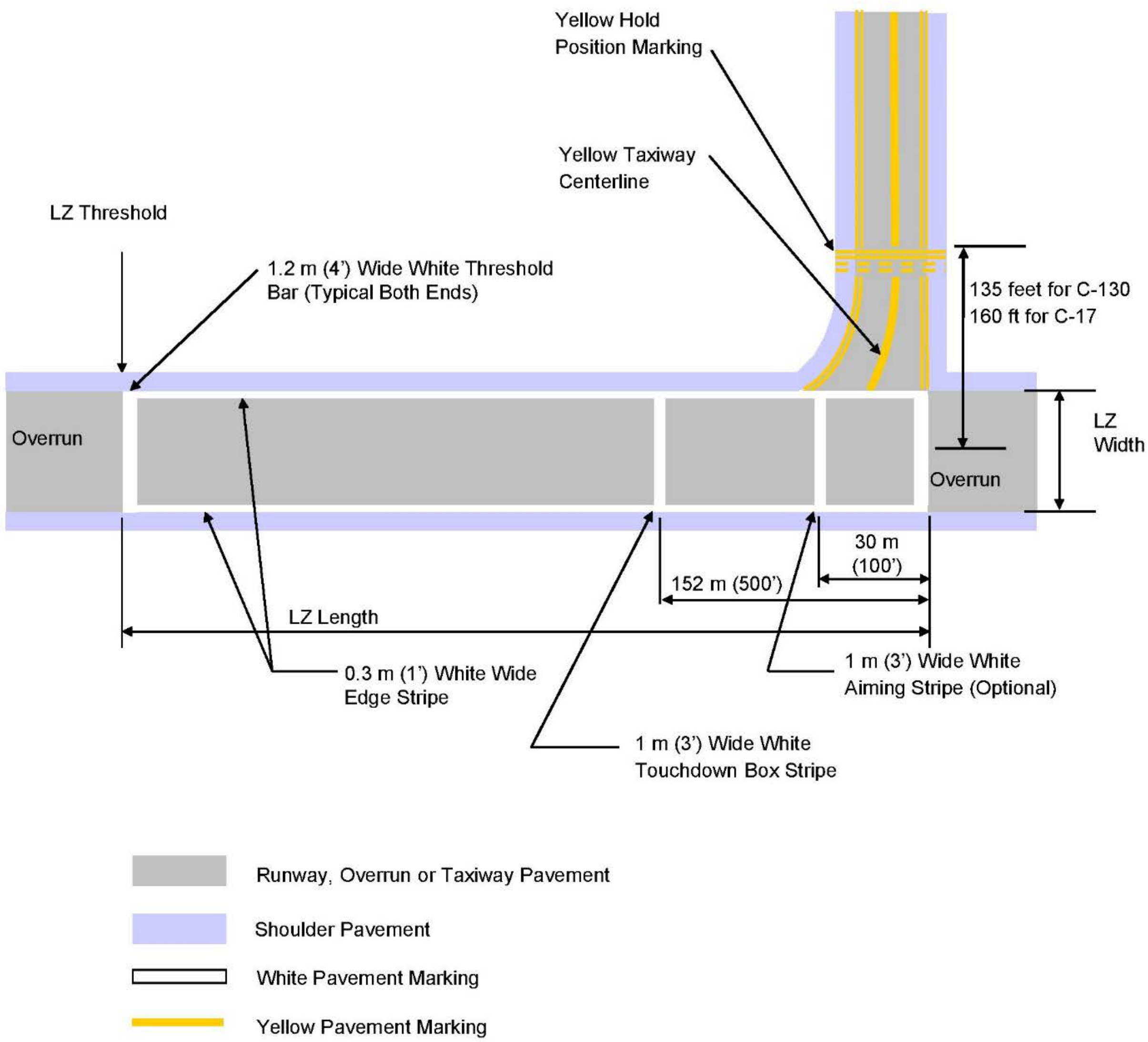
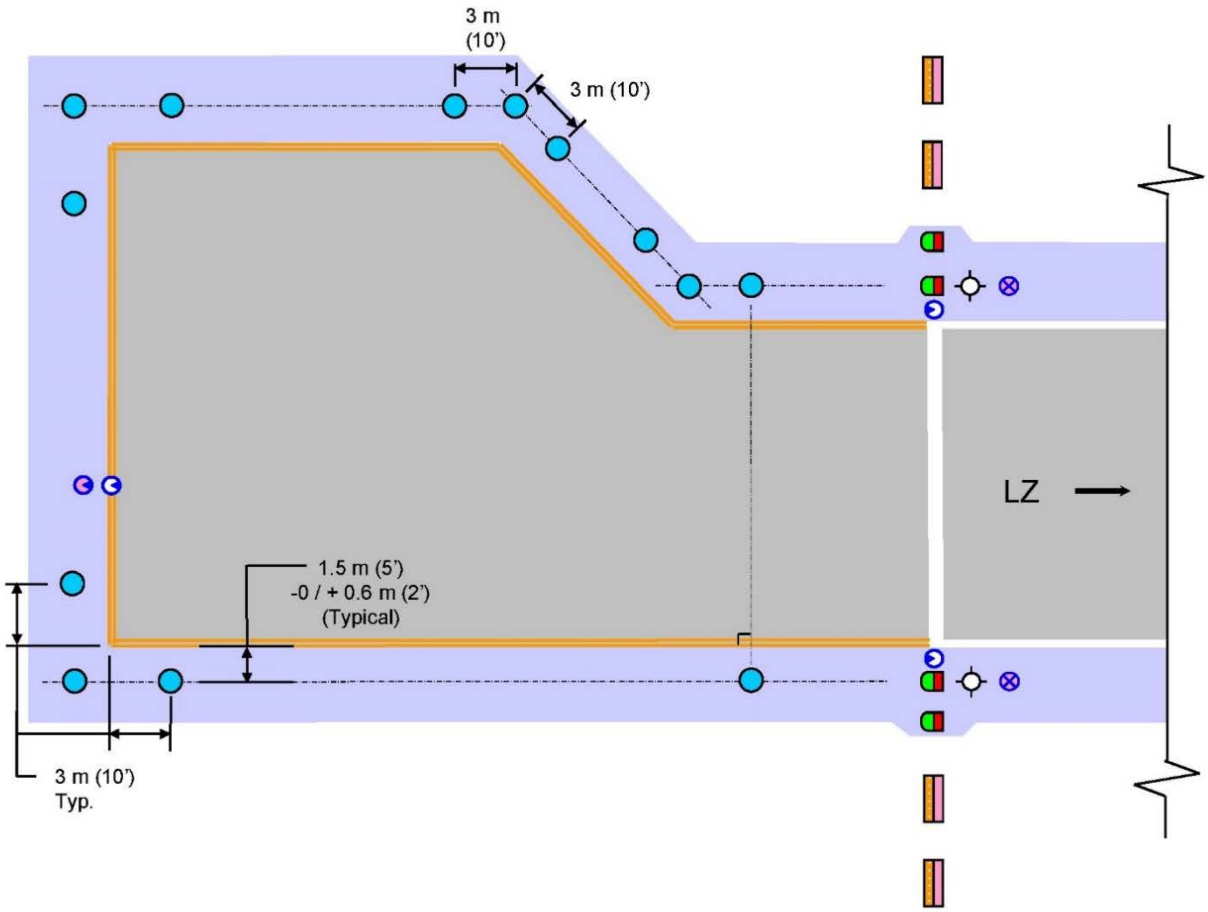


Figure 7-12. Typical Turnaround Marking and Lighting Plan



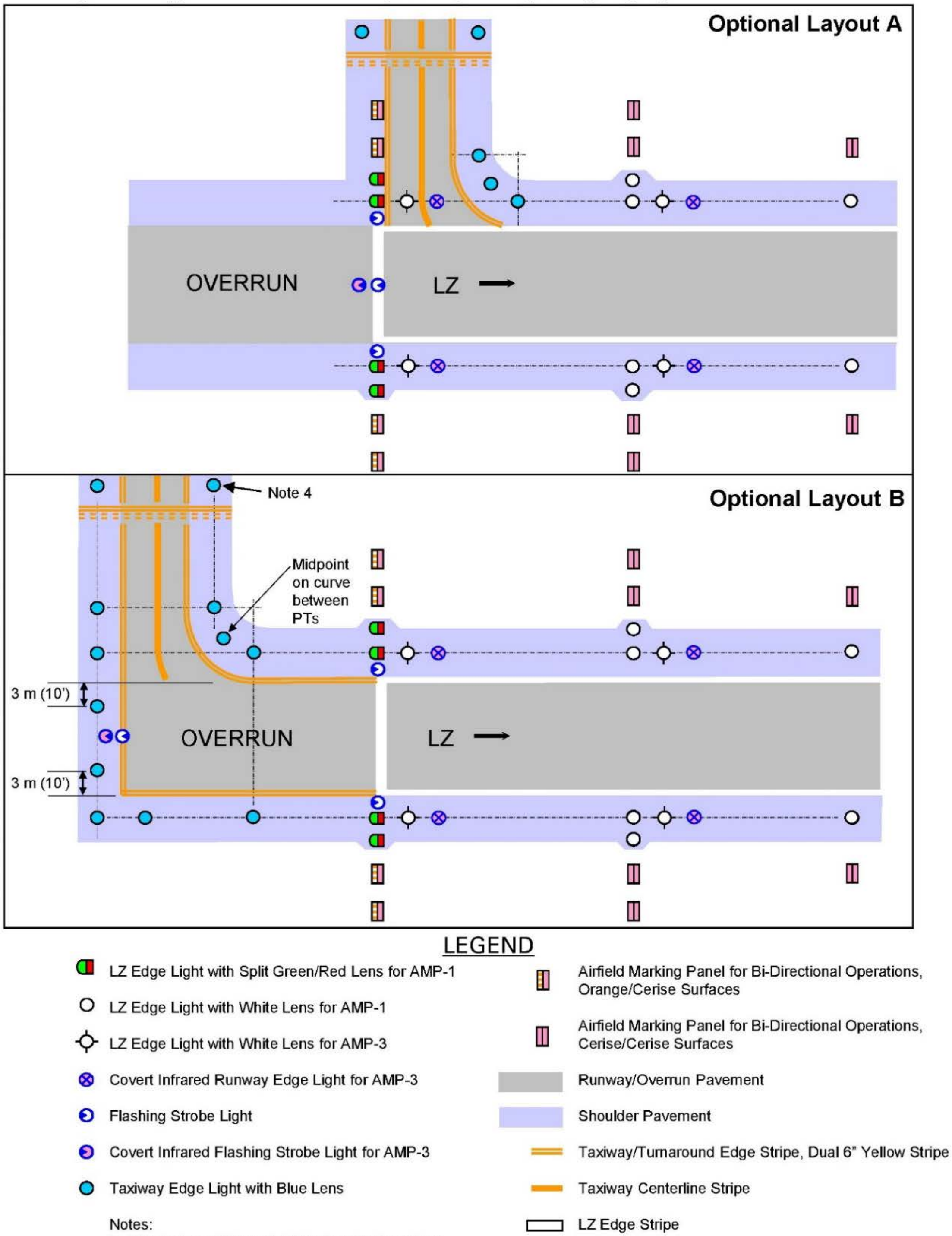
LEGEND

- LZ Edge Light with Split Green/Red Lens
- LZ Edge Light with White Lens for AMP-3
- Covert Infrared Runway Edge Light for AMP-3
- Flashing Strobe Light
- Covert Infrared Flashing Strobe Light for AMP-3
- Taxiway Edge Light, Blue Lens
- Airfield Marking Panel for Bi-Directional Operations, Orange/Cerise Surfaces
- Runway/Overrun Pavement
- Shoulder Pavement
- Taxiway/Turnaround Edge Stripe, Dual 6" Yellow Stripe
- LZ Edge or Threshold Stripe
- Layout Line
- 90-degree Layout Angle

Notes:

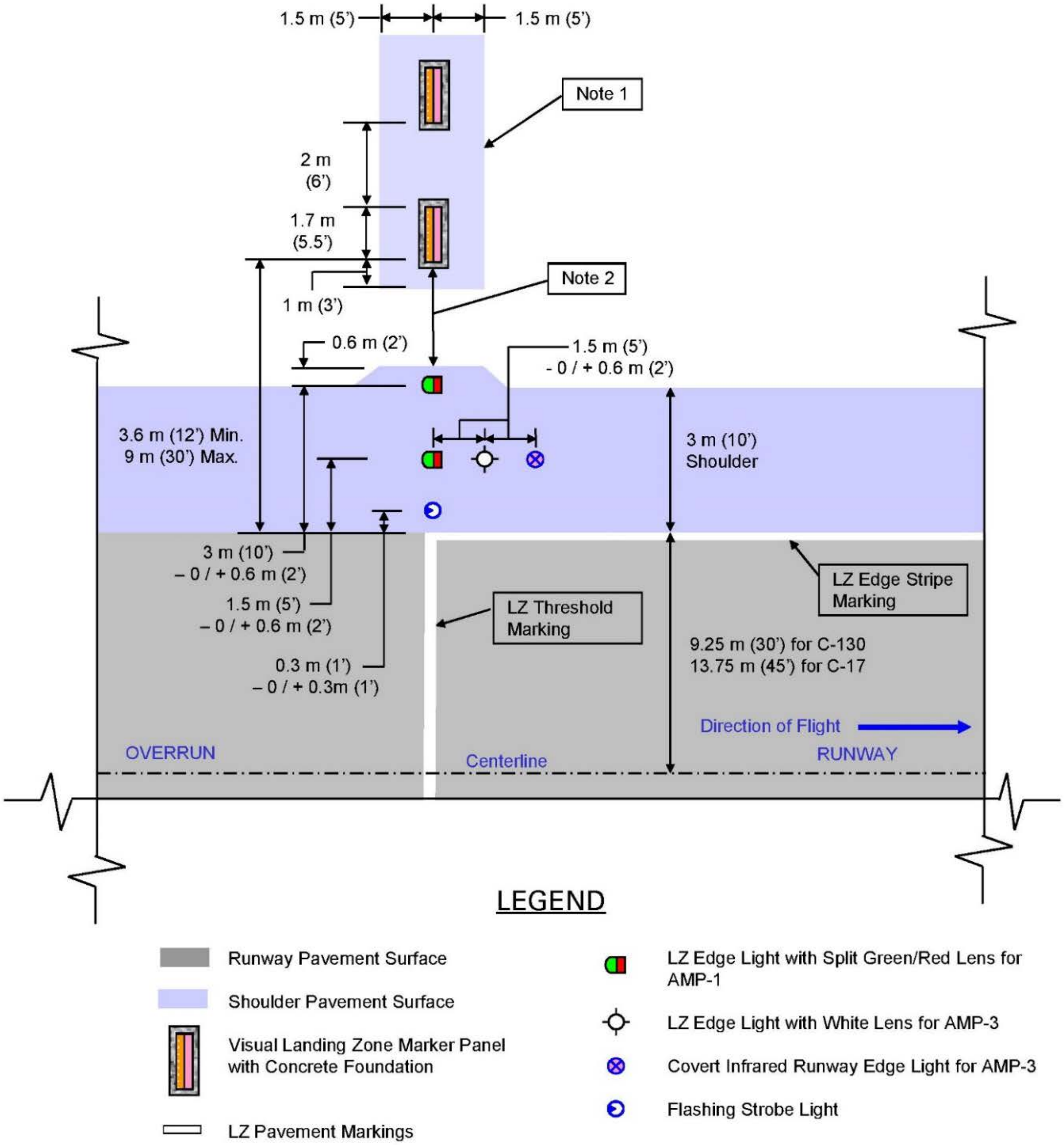
1. See text and Figure 7-14 for layout dimensions.
2. LZ is configured for bi-directional operations.
3. All taxiway lights shall be equidistant from taxiway/turnaround edge. Design tolerance is 1.5 m (5') – 0 / + 0.6 m (2').

Figure 7-13. Typical Bi-Directional Runway/Taxiway Marking and Lighting Layout



Notes:
1. See text and Figure 7-14 for layout dimensions.
2. LZ is marked and lighted for bi-directional operations.
3. All taxiway lights shall be equidistant from taxiway/turnaround edge. Design tolerance is 1.5 m (5') – 0 / + 0.6 m (2').
4. Locate taxiway lights behind the hold line according to UFC3-535-01, but no more than 60 m (200') from the point of tangency.

Figure 7-14. Light and Marker Panel Layout Detail on a Landing Zone with Combination AMP-1, AMP-3 (Visual Spectrum) and Infrared AMP-3



Notes:

1. Paved pad surrounding sign bases is recommended to eliminate need for mowing close to and between signs.
2. If gap between paved shoulder and sign foundation is less than 2.4 m (8'), pave entire gap.
3. LZ Edge lights must be on the same longitudinal alignment throughout the length of the LZ. Pairs of lights should be perpendicular and equidistant from the centerline.
4. All LZ lights should be located at least 0.6 m (2') from PCC pavement joints.
5. Minimum 1.2 m (4') spacing between Flashing Strobe and inboard Edge Light. Minimum 1.5 m (5') spacing between edge light pairs.

7-12.4 LZ Markings on Class A or B Runways.

In some cases, it may be desirable to use a standard full-length runway for LZ training operations. For this purpose, the LZ marking schemes illustrated in Figures 7-16 and 7-17 should be applied, subject to the following conditions.

7-12.4.1 LZ Marking Dimensions.

Non-reflective white markings, 3 meters (10 feet) by 1.7 meters (5.5 feet) are applied in the same pattern as VLZMP for the AMP-3 configuration.

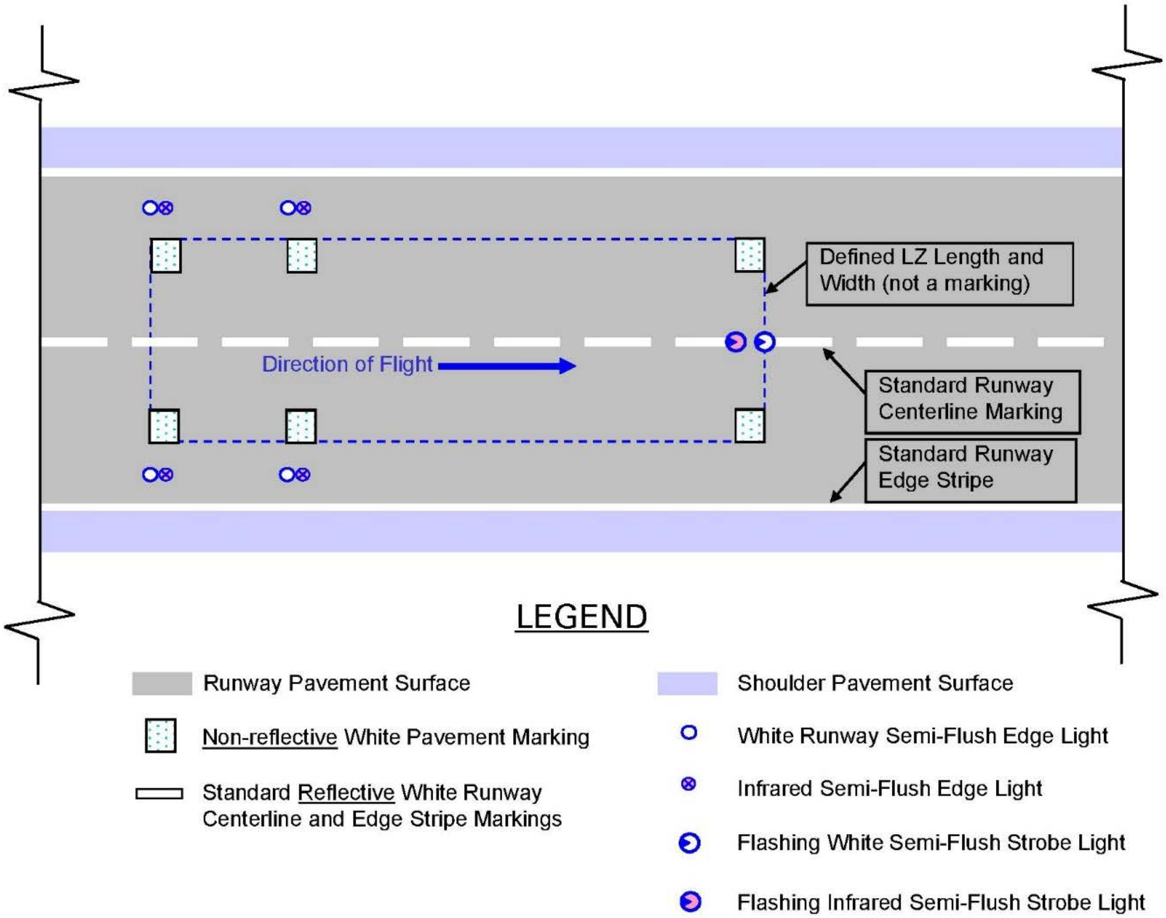
7-12.4.2 LZ Location on the Runway.

When possible, the LZ threshold should be sited so the LZ touchdown area is within the first 305 meters (1000 feet) of the runway pavement, and the 91-meter (300-foot) LZ overrun falls on the runway surface (not overrun). This will ensure that aircraft loads are concentrated on the portion of the runway designed for heavier loads. As described in paragraph 7-11.6.2, siting the LZ threshold 91 meters (300 feet) from the runway threshold will accomplish this objective.

7-12.4.3 LZ Marking Conflicts with Standard Runway Markings.

The LZ will be sited so the markings do not conflict with threshold markings, runway designation markings, touchdown zone markings, or fixed distance markings. An ideal location for the LZ threshold is 91 meters (300 feet) from the runway threshold. This will position the LZ markings in the gaps between the standard runway markings. See UFC 3-260-04 for standard airfield pavement marking criteria. When there is a conflict with Standard Runway Markings the Standard Runway Marking will take precedence. Any deviation from the standard runway marking requires a waiver to criteria.

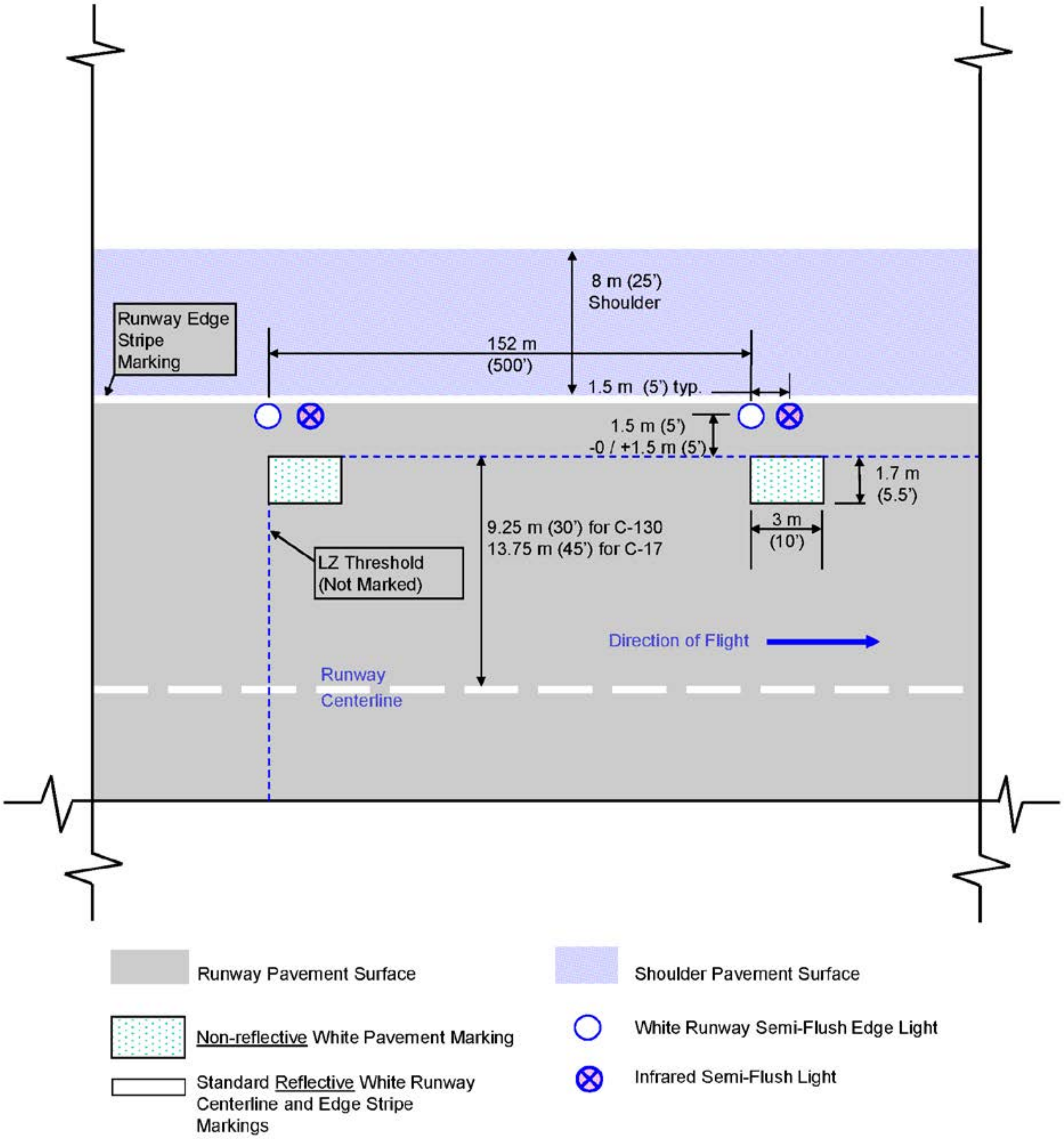
Figure 7-15. AMP-3 Lighting and Marking Scheme for LZ Superimposed on Class A or B Runway



Notes:

1. LZ Pavement Markings should be installed with the inside edge aligned with the edge of the LZ. The back edge should be aligned with the measurement from the threshold. Markings should be 3.0 m (10') long (parallel to runway centerline) and 1.7 m (5.5') wide.
2. If the flashing strobe light is not semi-flush, install at the end of the usable runway.
3. See Figure 7-16 and 7-17 for detailed layout of lights and markings.

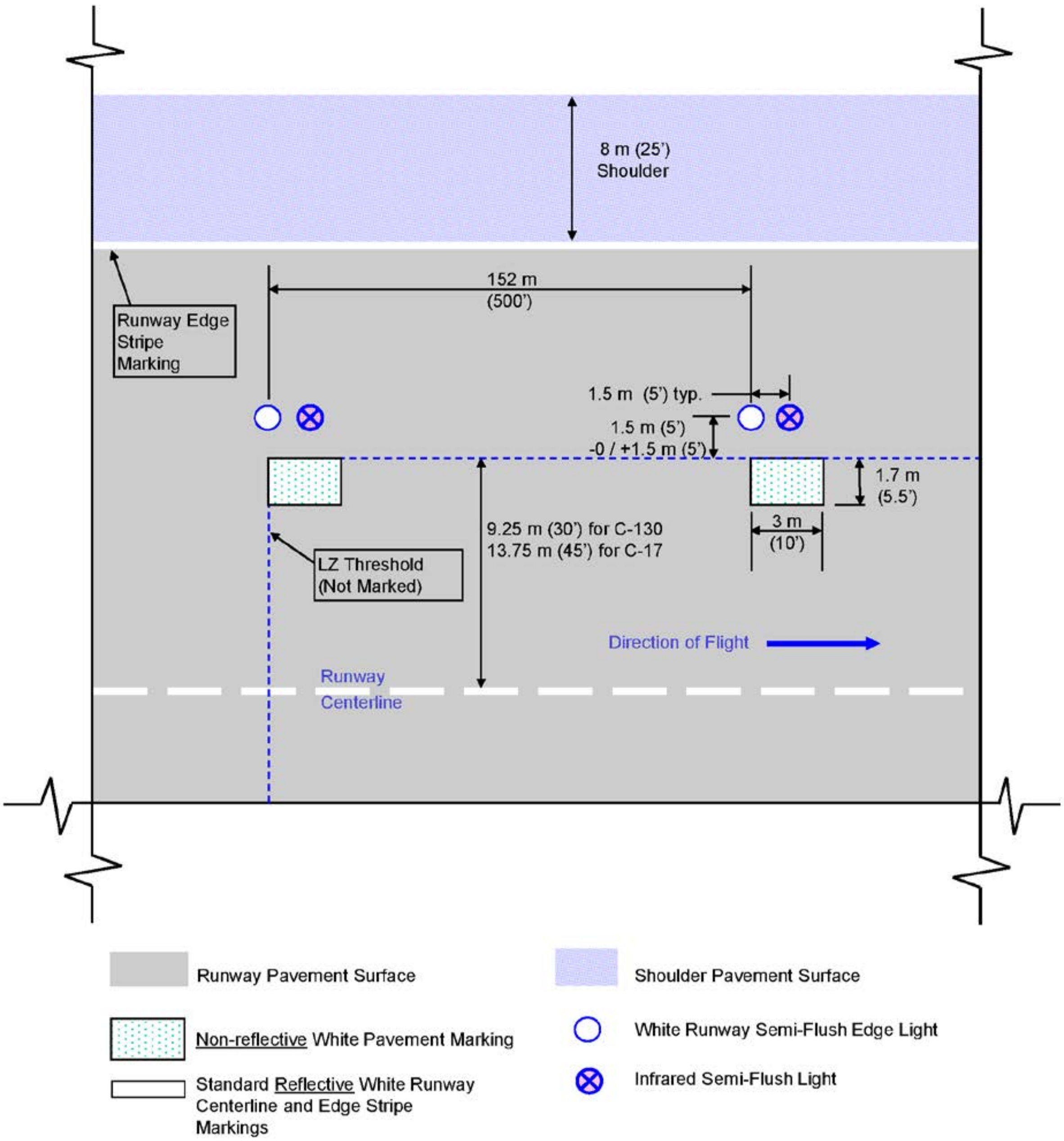
Figure 7-16. AMP-3 Visible and Infrared Lighting and Marking Layout Detail for LZ Superimposed on Class A Runway



Notes:

1. LZ threshold should be sited so that conflicts with standard lights and markings are avoided.
2. All LZ lights should be located at least 0.6 m (2') from PCC pavement joints.
3. See paragraphs 7-12.6 and 7-13.4 for additional details.
4. Ensure paint markings are not applied to LZ light fixtures.
5. Visible and Infrared light order may be reversed.

Figure 7-17. AMP-3 Visible and Infrared Lighting and Marking Layout Detail for LZ Superimposed on Class B Runway



Notes:

1. LZ threshold should be sited so that conflicts with standard lights and markings are avoided.
2. All LZ lights should be located at least 0.6 m (2') from PCC pavement joints.
3. See paragraphs 7-12.6 and 7-13.4 for additional details.
4. Ensure paint markings are not applied to LZ light fixtures.
5. Visible and Infrared light order may be reversed.

CHAPTER 8
FIXED-WING SHORT TAKEOFF AND VERTICAL LANDING (STOVL) FACILITIES

8-1 GENERAL INFORMATION.

This chapter discusses the airspace requirements, physical construction criteria, and general usage considerations for four types of STOVL facilities: LHD (amphibious assault ship) training facility, Vertical Landing (VL) pad, Forward Operating Base (FOB) facility, Tilt-Rotor Outlying Landing Field (OLF).

8-1.1 Chapter Organization.

Paragraphs 8-1, 8-2 and 8-3 provide general background information, definitions, and planning considerations that apply to all fixed-wing STOVL facilities. Paragraphs 8-4 through 8-7 provide specific requirements for designing the four types of STOVL facilities (LHD, VL Pad, FOB and OLF), including geometry, airspace, marking, lighting and pavement surface type.

8-1.2 Facility Concepts.

The STOVL facilities will support the training of F-35B and V-22 aircrew and ground personnel prior to ship-borne deployments and expeditionary operational environments. The smaller size of the amphibious assault ship (LHD) flight deck, as compared to the aircraft carrier (CVN) flight deck, and difference in landing type is significant enough to require its own dedicated training facility.

8-1.3 Basis of Design.

Criteria in this chapter were developed from the basis of design aircraft listed below; however, this is not intended to prohibit operations of other aircraft on these facilities. Each using aircraft, including the basis of design aircraft, must evaluate the facility for operational suitability.

Facility Type	Basis of Design Aircraft
LHD	F-35B and V-22 (LHD 5 ship deck)
FOB	F-35B
VL Pad	F-35B
Tilt-Rotor OLF	V-22

8-1.4 Background.

Due to the unique training requirements for F-35B and V-22 Flying Training Squadrons (FTSs) and the need for Operational Squadrons to train pilots for the rigors of ship and forward base deployments, those squadrons will need land-based STOVL specific facilities. This chapter addresses the criteria needed to design and construct land-based STOVL specific facilities and the imaginary surfaces necessary to support the STOVL facilities. The criteria presented in this document was developed from two main sources: Air Force ETL 14-4 "*Vertical Landing Zone (VLZ) and Other Airfield Pavement Design and Construction Using High Temperature Concrete*" dated 18 Aug 2014 and "F-35 Lightning II STOVL Airfield Facilities and Airspace Criteria Engineering Technical Letter (ETL), Document No: 2PSS00040, Rev 1" dated 30 July 2010. Criteria has been incorporated including changes, corrections, and other modifications resolving problems with original content. Non-applicable content has been omitted but may still be a useful reference to those seeking more background.

8-2 DEFINITIONS.

Only terms unique to this chapter are defined in this chapter. See the Glossary at the end of this UFC for general definitions.

8-2.1 Accident Potential Zone–STOVL (APZ-STOVL).

The land use control area beyond the clear zone of a STOVL that possesses a significant potential for accidents; therefore, land use is a concern.

8-2.2 Approach Clearance Surface.

An imaginary surface that is an inclined plane or combined incline and horizontal planes arranged symmetrically about the extended runway centerline covering the approach path for a directional STOVL facility. See Approach-Departure Clearance Surface for further detail.

8-2.3 Apron-STOVL.

A defined area on a STOVL facility intended to accommodate aircraft for loading or unloading passengers or cargo, refueling, parking, or maintenance. Aprons are sized to accommodate the mission.

8-2.4 Clear Zone-STOVL.

A surface on the ground or water, beginning at the runway threshold and symmetrical about the extended runway centerline, graded to protect aircraft operations and in which only properly sited NAVAIDs are allowed.

8-2.5 Departure Clearance Surface (DCS)-STOVL.

An imaginary surface that is an inclined plane or combined incline and horizontal planes arranged symmetrically about the extended runway centerline covering the departure path for a directional STOVL facility. See Approach-Departure Clearance Surface for further detail.

8-2.6 Forward Operating Base (FOB) STOVL Facility.

A FOB STOVL facility is one dedicated to short takeoff (STO) and rolling vertical landing (RVL) operations. These facilities have shorter and narrower runway dimensions than main airfields, and represent a mission oriented basing posture. The STO and RVL operations are performed to minimize ground roll and facility footprint.

8-2.7 Foul Line.

On an LHD STOVL Facility, a painted line that defines the edge of surface usable for takeoff and landing operations. The line is parallel to the centerline (tramline) and offset towards the LSO Tower. It consists of an alternating red and white stripe, with black outline.

8-2.8 High Temperature Concrete.

Portland cement concrete mixtures using expanded aggregates (also known as lightweight aggregates) or approved traprock sources are referred to as High Temperature Concrete (HTC). In this chapter, HTC only refers to high temperature concrete that meets the requirements of UFGS 32 13 13.43. HTC can be a specific formulation to support only V-22 aircraft, or V-22 and F-35B aircraft.

8-2.9 Imaginary Surfaces-STOVL.

Surfaces in space established around a STOVL Facility in relation to runways, helipads, or helicopter runways, and designed to define the protected airspace around the airfield. The imaginary surfaces for STOVL facilities are the primary surface, transitional surface, inner horizontal surface and ADCS.

8-2.10 LHD STOVL Facility.

A full size simulated land-based LHD ship flight deck used for field carrier landing practice (FCLP) consisting of short takeoff and vertical landing.

8-2.11 Primary Surface-STOVL.

An imaginary surface symmetrically centered on the STOVL Facility. The elevation of any point on the primary surface is the same as the elevation of the nearest point on the runway centerline or extended runway centerline.

8-2.12 Runway Centerline-STOVL.

The line extending the full length of the runway surface describing the center of the runway. For the LHD STOVL facility it is the tram line.

8-2.13 Safety Zones.

Safety zones are provided to prevent the erosion of graded surfaces by jet blast from aircraft transitioning to and from the STOVL facility.

8-2.14 STOVL Facility.

A STOVL facility is a takeoff and/or landing facility dedicated to short takeoff and vertical landing operations. For the purposes of this chapter there are four different types of STOVL facilities; LHD STOVL facility, Forward Operating Base (FOB) STOVL facility, Vertical Landing (VL) pad and Tilt-Rotor Outlying Landing Field (OLF).

8-2.15 STOVL Pavement Surface Types.

Several different surface types are required or recommended for STOVL Facilities because of the high temperature environment imposed by operations. For areas where F-35B vertical landings will occur, the surface will be constructed with High Temperature Concrete (HTC). See UFGS 32 13 13.43 and contact service-specific subject matter experts' guidance on HTC materials, mix design and construction techniques. Special considerations are needed for areas surrounding the landing surface and areas used for short takeoff operations. Four different types of pavement may be used on STOVL facilities.

- Continuously Reinforced High Temperature Concrete (CRHTC).
- Plain Jointed High Temperature Concrete (PJHTC)
- Plain Jointed Portland Cement Concrete (PJPCC)
- Hot Mix Asphalt (HMA)

8-2.16 Vertical Landing Pad (VL Pad.

Vertical landing pad is a paved surface of fixed dimension that affords a landing location for fixed-wing STOVL aircraft.

8-3 STOVL FACILITY PLANNING CONSIDERATIONS.

The landing and takeoff design considerations for a STOVL facilities will be directed to fulfill the requirements for the STOVL aircraft to include mission requirements, expected type and volume of air traffic, VFR and simulated IFR traffic patterns, runway (deck) length, runway orientation required by local wind conditions, local terrain, restrictions due to airspace obstacles or the surrounding community, noise impact, and aircraft accident potential. When planning to construct a new runway (deck) or reconstruct an existing runway (deck), in addition to local permitting requirements, file FAA Form 7480-1 in accordance with FAA Order 7400.2.

8-3.1 Site Conditions.

When planning the layout of a permanent STOVL, facility site conditions beyond safety of aircraft-related operations must be considered. These include land use compatibility with clear zones, primary surfaces, exclusion areas, impacts to existing instrument procedures and ADCS, and with existing and future use of the areas that surround the STOVL facility. In planning a STOVL facility, consider the use and zoning of surrounding land for compatibility with aircraft operations. The purpose is to protect the operational capability of the STOVL facility and prevent incompatible development, thus minimizing health and safety concerns in areas subject to high noise and accident potential resulting from frequent aircraft over-flights. The minimum criteria in this chapter establish standards for a safe environment for aircraft and ground operations. The goal is to provide a STOVL environment that provides the greatest margin of safety and compatibility for personnel, equipment, and facilities. Review the instructions and regulations for each Service and 32 CFR 989, *Environmental Impact Analysis Process (EIAP)* for guidance on the Environmental Impact Analysis Process.

8-3.2 Future Development (Land or Aircraft Technology).

Adequate land for future aviation growth must be considered when planning a STOVL facility. The facility should be compatible with the existing installation plan. Potential instrument flight rules (IFR) capability will require additional criteria considerations.

8-3.3 Prohibited Land Uses.

DoD and Service specific AICUZ directives govern land uses within the exclusion area, clear zone, and APZ. These restrictions are described in Tables 8-3, 8-6, 8-9 and 8-12.

8-3.4 APZs not on DoD Property.

APZs that are not on DoD property may require easements to control development and remove vegetation that may violate the ADCS. The need must be determined on a case-by-case basis.

8-3.5 SITING CONSIDERATIONS.

8-3.5.1 Site Considerations.

Site considerations include topography, vegetative cover, existing construction, weather elements, local wind conditions soil conditions, flood hazard, natural and man-made obstructions, adjacent land use, and availability of usable airspace, accessibility of roads and utilities, and potential for expansion capability. Applicable clearances, including separation distances, APZ, and imaginary surfaces must be. Siting approval must be obtained as part of planning and programming prior to any construction of new facilities or installation of equipment, including above ground infrastructure such as lights, pumps, etc. To minimize crosswinds, the strength, direction, and frequency of local winds must be considered when orienting a VL Pad. The potential for encroachment and effects of noise on the local community must also be considered.

8-3.5.2 Obstructions.

For training STOVL facilities, it is preferable to position the runway within an airfield environment to take advantage of existing runway and taxiway clearance areas. To maximize the training environment, the STOVL facility ADCS should be placed parallel to existing runway ADCS and with adequate separation to support parallel runway operations.

8-3.5.3 Orientation.

Runway orientation is the key to a safe, efficient, and usable aviation facility. Orientation is based on an analysis of wind data, terrain, local development, operational procedures, and other pertinent data. Procedures for analysis of wind data to determine wind orientation are discussed further in Appendix B, Section 4. Because an LHD runway is uni-directional, ensure the bow is oriented into the predominant wind direction.

8-3.5.4 Restricted Airspace.

Airspace through which aircraft operations are restricted, and possibly prohibited, is shown on sectional and local aeronautical charts. Runways should be oriented so that their approach and departure patterns do not encroach on restricted areas.

8-3.5.5 Noise Analysis.

The positioning of a STOVL facility must take into account noise levels on existing facilities, local communities, and noise-sensitive areas. Air Installations Compatible Use Zones (AICUZ) and Installation Compatible Use Zone (ICUZ) are programs initiated to implement Federal laws concerning land compatibility from the perspective of environmental noise impacts. The ICUZ program is the Army's extension of the AICUZ program, which was initiated by the DoD and undertaken primarily by Air Force and Navy aviation facilities. Studies under these programs establish noise abatement measures that help to eliminate or reduce the intensity of noise from its sources, and provide land use management measures for areas near the noise source.

8-3.5.5.1 Analysis.

Due to the widely varied aircraft, aircraft power plants, airfield traffic volume, and airfield traffic patterns, aviation noise at installations depends on both aircraft types and operational procedures. Aircraft noise studies should be prepared for aviation facilities to quantify noise levels and possible adverse environmental effects, ensure that noise reduction procedures are investigated, and plan land for uses that are compatible with higher levels of noise. While many areas of an aviation facility tolerate higher noise levels, many aviation landside facilities and adjoining properties do not. Noise contours developed under the AICUZ and ICUZ studies are used to graphically illustrate noise levels and provide a basis for land use management and impact mitigation. The primary means of noise assessment is mathematical modeling and computer simulation. Guidance regarding when to conduct noise studies is contained in the environmental directive for each Service.

8-3.5.6 Built-Up Areas.

Airfield sites and runway alignment will be selected and operational procedures adopted that will least impact local inhabitants. Additional guidance for facilities is found in DoDI 4165.57.

8-3.5.7 Clear Zones.

The purpose of the clear zone is to protect the safety of flight and safety of people on the ground. The entire clear zone area is a land use control area intended to protect people both flight safety and property on the ground. Land use for the clear zone area for STOVL facilities corresponds to the clear zone land use criteria for fixed-wing airfields as defined in DoD AICUZ and Service-specific standards and as discussed in Chapter 3.

8-3.5.8 Explosives.

8-3.5.8.1 General.

All explosives locations, including locations where aircraft loaded with explosives are parked must be sited in accordance with DoD Standard 6055.9 and applicable Service explosives safety regulations. Explosives site plans, approved through command channels to DoD, ensure that minimal acceptable risk exists between explosives and other airfield resources. To prevent inadvertent ignition of electro-explosive devices (EED), separation between sources of electromagnetic radiation is required. Separation distances must be according to safe separation distance criteria. Grounding requirements, lightning protection, and further considerations for explosives on aircraft are presented below. Where explosives or hazardous materials are handled at or near aircraft, safety and separation clearances are required. The clearances are based on quantity-distance criteria.

8-3.5.8.2 Separation Distance Requirements.

Minimum standards for separating explosives (explosion separation distances and quantity-distance [Q-D] relationships) -loaded aircraft from runways, taxiways, inhabited buildings, and other loaded aircraft are established in AR 385-10 for the Army; AFMAN 91-201 for the Air Force; and NAVSEA OP-5 and NAVAIR 16-1-529 for the Navy and Marine Corps. These documents also establish Q-D relationships for separating related and unrelated potential explosion site (PES) and explosive and non-explosive exposed sites.

8-3.5.8.3 Prohibited Zones.

Explosives, explosive facilities, and parked explosives-loaded aircraft (or those being loaded or unloaded) are prohibited from being located in Accident Potential Zones (APZ) I and II and clear zones as set forth in AR 385-10; DAPAM 385-64, Chapter 5; AFMAN 91-201; and AFI 32-7063.

8-3.6 FAA Requirements.

When a new STOVL facility is sited, in addition to local permitting requirements, file FAA Form 7480-1, *Notice of Landing Area Proposal*, in accordance with FAA Order 7400.2, *Procedures for Handling Airspace Matters*. Submit an FAA Form 7460-1, *Notice of Proposed Construction or Alteration*, for any above ground structures or modifications to existing airfields associated with the STOVL facilities.

8-3.7 Airspace Approval

Construction of new airfields, heliports, helipad or hoverpoints, or modifications to existing facilities affecting the use of airspace or changes in aircraft densities will be in conformance with JO 7400.2 (Procedures For Handling Airspace Matters).

8-3.8 Environmental.

Development of an aviation facility, including expansion of an existing aviation facility, requires compliance with a variety of laws, regulations, and policies. The National Environmental Policy Act (NEPA) requires all Federal agencies to consider the potential environmental impacts of certain proposed projects and activities, as directed by DoD Directive (DoDD) 6050.7. Implementation of these regulations is defined for each Service in these documents: Army: AR 200-1; Air Force: Title 32, Code of Federal Regulations, Part 989 (32 CFR 989); and Navy and Marine Corps: OPNAVINST 5090.1B (MCO 5090.2). Four broad categories of environmental review for a proposed action exist. The decision to conduct one study or another depends on the type of project and the potential consequences of a project to various environmental categories. Criteria for determining which type of study should be undertaken are defined in the environmental directives and regulations for each Service. Environmental studies should be prepared and reviewed locally. When additional assistance or guidance is necessary, this support may be obtained through various agencies such as the US Army Air Traffic Services Command (AFAT-ATC-CB), the US Army Corps of Engineers Transportation Systems Center (COE TSC), the US Army Corps of Engineers District Offices, NAVFAC Headquarters, and the Air Force Civil Engineer Center (HQ AFCEC).

8-3.9 Taxiway Connections.

Taxiways provide for ground movement of fixed- and rotary-wing aircraft. Taxiways connect the runways of the airfield with the parking and maintenance areas and provide access to hangars, parking aprons, and landing pads. Chapter 5 presents design standards and considerations for fixed- and rotary-wing taxiways.

8-3.9.1 Basic.

A basic taxiway layout provides low-volume access to single facility for a single purpose. For example, a single taxiway connecting a vertical landing pad to a main airfield parking apron or ramp supports the recovery of aircraft directly to the parking apron.

8-3.9.2 Parallel Taxiway.

A taxiway parallel for the length of the runway or STOVL facility, with connectors to the ends and the parking apron, provides multiple options for ground movement of aircraft.

8-3.9.3 Layout.

These considerations should be addressed when planning and locating taxiways to connect a STOVL facility to existing airfield infrastructure. Looking at our previous example, if the vertical landing pad is supported with a second taxiway departing and arriving traffic or multiple recovery aircraft can share the same STOVL facility.

8-3.9.3.1 Efficiency.

STOVL facility efficiency is enhanced by planning for multiple ground movement paths between the apron/fuel pits and the STOVL facility. Plans for aircraft movement in both directions should be included to support recovery of last landing aircraft and as the next evolution positions to begin their period of instruction.

8-3.9.3.2 Direct Access.

Taxiways should provide as direct an access as possible from the STOVL facility to the parking apron or fuel pits. The time spent taxiing the aircraft between training flights or STOVL training evolutions will directly affect the number of pilots trained during any given training period.

8-3.9.3.3 Simple Taxi Routes.

A sufficient number of taxiways should be provided to prevent complicated taxi routes or multiple hold points to give way to other aircraft. This consideration is magnified when flights of multiple aircraft are taxiing for departure or recovery. These flights sprawl and their taxi interval becomes extended complicating the movement of aircraft.

8-3.9.3.4 Delay Prevention.

A sufficient number of taxiways should be provided to prevent capacity delays that may result when one taxiway must service more than one STOVL Facility or multiple aircraft are planned to use the same STOVL facility. For example, if no parallel taxiway is available for aircraft using a FOB STOVL facility then only one aircraft at a time will be able to use the facility, because back taxiing on the runway will prohibit its use by a second aircraft.

8-3.9.4 Taxiway Shoulders.

Shoulders are provided along a taxiway to allow aircraft to recover if they leave the paved taxiway. Paved shoulders, also, prevent erosion caused by jet blast, support a potential aircraft that breaches the taxiway, support vehicular traffic, and reduce maintenance of unpaved shoulder areas. The shoulder for fixed-wing taxiways to support a STOVL facility should be paved to the maximum extent possible. Follow Table 5-1 for widths, slopes and grading requirements.

8-3.9.5 Aircraft Movement.

As can be seen from the description of the various factors going into taxiway design and layout, the potential exists to define the success or failure of a STOVL facility by the supporting taxiway structure. STOVL operations by definition involve a large number of takeoffs and landings as compared to normal T&R training events. This increased number of takeoffs and landings may or may not involve repositioning, ground loiter time, or a combination of both. Any delay between landing and subsequent takeoff will directly impact the number of aircraft the facility can support. Actions taken by planners and engineering to account for expected delays and provide movement options for aircraft on the ground will keep the STOVL facility deck clear of aircraft or other traffic and go a long way towards ensuring successful operations.

8-4 LHD STOVL FACILITIES.

8-4.1 LHD Concept.

STOVL carrier deployment training historically has incorporated the use of a full scale land-based LHD STOVL facility to include a Landing Signal Officer (LSO) tower, or V/STOL optical landing system (OLS), and Hover Position Indicator (HPI). The size and supporting structure of these facilities has afforded deploying forces the opportunity to train on the simulated LHD deck with significant flight deck realism. Training evolutions typically involve the pilots and LSOs, with a primary focus on practicing shipboard vertical landings followed by Short Take-Offs (STOs) under the supervision of a Launch Officer (LO). Additionally, these flight operations have included LSO under-training to train as launch officers, squadron personnel requiring flight deck familiarization, and the integration of ship’s personnel before actual operations afloat. The training benefits to the aircrew, LSO/LO and flight deck personnel are substantial, as they are taught to perceive the simulated flight deck as the actual deck. This realism affords them the opportunity to continue familiarization training beyond the simulator and builds on the training progression needed prior to deployment. VFR flight operations to and from the land-based facility will be assumed throughout this Chapter.

As stated in Paragraph 8-1.3, the basis of design shown in this UFC for an LHD facility is the LHD 5 ship deck. The dimensions, lights, and markings are typical for that ship, but new LHD or LHA ship configurations may change. Therefore, designers must determine current requirements at the time of design from:

Naval Air Warfare Center Aircraft Division (NAWCAD)
Route 547, Mail Stop 596-1
Joint Base MDL, NJ 08733-5000

Specific offices within NAWCAD are called out in later paragraphs for specific systems guidance.

8-4.2 LHD Standard Drawings.

NAVFAC Simulated LHD Shipdeck Standard drawings have been developed for this facility type. These include NAVFAC Drawing Numbers 14064429 through 14064452 and are available from the Whole Building Design Guide (http://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc/ufc-3-260-01), where this UFC is posted. Designer of Record must site-adapt, complete, and validate final design for construction. The original concept was developed for F-35B training; however, the design has been adapted to be compatible with V-22 operations also. These modifications include consideration of additional known F-35B operations, potential V-22 operations, lessons learned of pavement extents and materials. Existing facilities constructed prior to these modifications may need to be evaluated if such operational upgrades are desired.

8-4.3 LHD Background.

The LHD STOVL training facility will support the training of STOVL aircrew and ground personnel prior to ship-borne deployments. The smaller size of the LHD flight deck, as compared to the CVN flight deck, and difference in landing type is significant enough to require its own dedicated training facility.

STOVL carrier deployment training historically has incorporated the use of a full-scale land-based LHD STOVL facility to include a LSO tower, VSTOL optical landing system (OLS), and Hover Position Indicator (HPI). The size and supporting structure of these facilities has afforded deploying forces the opportunity to train on the simulated LHD deck with significant flight deck realism. Training evolutions typically involve the pilots and Landing Signal Officers (LSOs), with a primary focus on practicing ship-board vertical landings (VL) followed by Short Take-Offs (STOs) under the supervision of a Launch Officer (LO). Additionally, these flight operations have included LSO under-training to train as launch officers, squadron personnel requiring flight deck familiarization, and the integration of ship’s personnel before actual operations afloat. The training benefits to the aircrew, LSO/LO and flight deck personnel are substantial, as they are taught to perceive the simulated flight deck as the actual deck. This realism affords them the opportunity to continue familiarization training beyond the simulator and builds on the training progression needed prior to deployment. VFR flight operations to and from the land-based facility will be assumed throughout this Chapter. The pilot training requirements for field carrier landing practice (FCLP) have the pilots fly simulated instrument approaches until established on visual final for the STOVL deck.

However, these simulated carrier controlled approaches (CCAs) will be flown as self-contained VFR approaches or contact approach to the STOVL deck.

8-4.3.1 Assumptions.

- LHD criteria in this chapter is based on matching the dimensions, markings and lighting of an LHD 5 ship deck.
- The LHD STOVL facility is a unidirectional facility executing arrival and departures in the same direction.
- Airspace imaginary surfaces are defined for a standalone STOVL facility. When the LHD STOVL facility is collocated with an existing DoD airfield and their respective imaginary surfaces overlap, the most restrictive or lower surface will be utilized to ensure obstacle clearance.
- The imaginary surfaces for the LHD STOVL facility provide obstacle clearance for the F-35B day and night FCLP pattern. The day FCLP pattern altitude defines the inner horizontal surface and transitional area elevations. The night FCLP pattern defines the outer horizontal surface length and elevation, while the simulated IMC carrier controlled approach (CCA) profile defines the approach and departure path requirements. These surface dimensions are presented similar to the existing Class B runway criteria with the following exceptions; (1) the approach-departure paths were separated because the facility is not bi-directional, (2) the approach-departure slope is referenced to the LZ criteria because it provides clearance for the STO and vertical landing/rolling vertical landing (VL/RVL) profile, (3) the approach slope begins at the aft edge of the deck due to the VL approach profile, (4) the approach and departure horizontal distances terminate at the outer distance of the outer horizontal surface because this distance supports the simulated IFR CCA pattern, (5) inner surface radius corresponds with the approach-departure slope for the inner horizontal surface elevation, and (6) the width of the primary surface is reduced because all recoveries will be conducted under VMC and the close supervision of a Landing Signal Officer.
- The LHD STOVL facility is considered a directional facility with fixed approach and departure directions. These fixed approach and departure paths resulted in separate imaginary surface definition to minimize impact to surrounding environment and airfield infrastructure.
- A 300-foot primary surface width is used for LHD STOVL facilities because all recoveries will be conducted under Visual Meteorological Condition (VMC) and the close supervision of a Landing Signal Officer.
- Cross-axial approaches will not be conducted to the land based LHD STOVL facility.

8-4.4 LHD Geometry

8-4.4.1 Deck, Overrun and Safety Zone Descriptions.

Figures 8-1 through 8-13, and Table 8-1 provide dimensional criteria for layout and design of the LHD simulated ship flight deck, overruns, and safety zones. Safety zones are provided to prevent erosion of graded surfaces by jet blast from aircraft transitioning to and from the STOVL facility. Each zone or surface contains a brief description of its use and reference to where its specific dimension or graphic is located within the document.

8-4.4.2 Deck Length.

Table 8-1 provides the length of the overall simulated ship flight deck. Ideally the length varies slightly over the width of the simulated ship flight deck to reflect the actual outline of the deck it is designed to simulate.

8-4.4.3 Deck Width.

Table 8-1 provides the width of the simulated ship flight deck. Ideally the width varies slightly over the length of the simulated ship flight deck to reflect the actual outline of the deck it is designed to simulate.

8-4.4.4 Gradients of Operational Surfaces.

Gradient constraints are based upon sufficient slope to insure surface water runoff. A uniform slope is preferable to eliminate irregularities between landing gear at touchdown. For this reason the simulated deck surface can be crowned on the foul line or the entire deck surface sloped in one direction away from the LSO tower. Either sloping scheme will provide the pilot with a uniformly sloped surface for touchdown. See Table 8-1. After construction and prior to aircraft operations, each Landing Position will be surveyed on a 10' x 10' grid to determine elevations to the nearest 0.01'. This data will be analyzed using the procedures outlined in DM#315235 "Vertical Landing Pad Certification Requirements and Analysis" to verify the relative smoothness and certify the pads as "Authorized Level". If the pad does not meet the "Authorized Level" requirements, surface diamond grinding will be used to create a smooth surface with a consistent slope. The detailed requirements for conducting a pad levelness survey can be provided by the F-35 JPO. The purpose of the survey is to obtain measurements for analysis to verify that landing spot levelness and flatness complies with F-35B Flight Series Data (FSD). Post construction landing spot survey data should be sent to Lightning.Support.Team@jsf.mil for analysis. Analysis results will be provided to the requestor. Additionally, data, analysis, and results for all landing spots analyzed by the Lightning Support Team (LST) will be retained and archived for future reference; they may be found at DM#315485. Contact the F-35 JPO and Naval Air Surface Warfare Center Aircraft Division (NAWCAD) AR-6.7.8.2 NAVAIR Aviation Shore Facility Integration Branch for additional information on this subject.

8-4.4.5 Forward Safety Zone Length.

Table 8-1 provides the length of the overrun or forward safety zone. This length is dependent on the short takeoff (STO) profile and the distance from the simulated deck bow where the profile reaches a minimum altitude of 150 ft AGL.

8-4.4.6 Forward Safety Zone Width.

Table 8-1 provides the width of the overrun or forward safety zone. This width, at a minimum, reflects the width of the simulated flight deck plus a minimum shoulder width of 10 ft on each side (20 ft total). The width of the overrun may neck down or narrow by 50% if desired, however this narrowing of the overrun will be centered on the extended runway centerline or tram line for the simulated flight deck.

8-4.4.7 Shoulder Length.

Table 8-1 provides the length of the shoulder. This length is dependent on the length of the simulated ship deck and tied into the forward and aft safety zones for one continuous surface.

8-4.4.8 Shoulder Width.

Table 8-1 provides the width of the left and right shoulders. This width is designed to prevent soil erosion from decelerating aircraft alongside of the simulated flight deck before the aircraft crosses to the assigned landing spot.

8-4.4.9 Approach Safety Zone Length.

Table 8-1 provides the length of the approach safety zone. This length is dependent on the Field Carrier Landing Practice (FCLP) pattern and corresponds to distance from the aft deck edge where the profile reaches a minimum altitude of 150 ft AGL.

8-4.4.10 Approach Safety Zone Width

Table 8-1 provides the width of the approach safety zone. This width, at a minimum, reflects the width of the simulated flight deck plus the Left Shoulder or Abeam Safety Zone.

8-4.4.11 Supporting Facilities.

Several different types of supporting facilities may be adjacent to or connected to the LHD facility, depending on mission requirements. Generally, facilities should be connected on the right (starboard) side of the LHD. Use the appropriate criteria (such as Chapter 5 or 6 for connecting taxiways and aprons) in this UFC or other documents to design supporting facilities, such as:

Connecting Taxiway
Parking Apron
Refueling Systems

Bathroom
Airfield Lighting Vault

8-4.5 LHD Separation Distances.

Table 8-1 provides the minimum separation distances between permanent runways/helipads and the LHD STOVL facility for simultaneous operations. Table 8-1 also provides the minimum separation distances between permanent Class A or Class B Runways and LHD STOVL facility for non-simultaneous operations.

8-4.6 LHD Clear Zones, Imaginary Surfaces, and APZs.

Applicable clearances and grade controls must be established to provide a reasonable level of safety. Their description and layout are similar to other airfield types and are not unique to the LHD STOVL facility. Each zone or surface contains a brief description of their use and reference to where their specific dimension or graphic is located within the document.

8-4.6.1 Clear Zones.

Runway clear zones are areas on the ground, located at the ends of each runway. They possess a high potential for accidents, and their use is restricted to be compatible with aircraft operations. Runway clear zones are required for the runway and should be owned or protected under a long-term lease. See Table 8-3.

8-4.6.2 Imaginary Surfaces.

Surfaces in space established around a STOVL facility in relation to the simulated LHD deck, and designed to define the protected airspace around the facility. The imaginary surfaces for the LHD STOVL facilities are the primary surface, transitional surface, inner horizontal surface, conical surface, outer surface and approach-departure path surfaces. These surfaces provide obstacle clearance for the F-35B day and night FCLP pattern. The day FCLP pattern altitude defines the inner horizontal surface and transitional area elevations. The night FCLP pattern defines the outer horizontal surface length and elevation, while the simulated IMC carrier controlled approach (CCA) profile defines the approach and departure path requirements. See Table 8-2. Note: the imaginary surfaces described in this chapter were developed only for F-35B operations. Airspace for other aircraft using the LHD facility must be evaluated separately.

8-4.6.3 Accident Potential Zones.

A land use control area beyond the clear zone of a STOVL facility that possesses a significant potential for accidents. Land use within the APZ is restricted in accordance with DoDI 4165.57. The dimensions and layout are listed in Table 8-3. Navy planners will use OPNAVINST 11010.36C/MCO 11010.16 (or latest version) to determine specific AICUZ requirements. For the Air Force, land use guidelines within the clear zone (beyond the graded area) and APZ I and APZ II are provided in AFI 32-7063 and AFH 32-7084.

8-4.7 LHD Pavement Marking.

Apply markings to LHD pavements using airfield marking paint with reflective beads (except LHD tram line, aircraft elevator outlines and clear zone markings outside deck outline without beads), following the general scheme shown in Figures 8-14 and 8-15. See NAVFAC Simulated LHD Shipdeck Standard Drawings for specific layout and detailed dimensions. For new construction or modifications, ensure current marking requirements are obtained from NAWCAD 4.8.2.3. Taxiways and aprons connected to the LHD Facility will be marked according to UFC 3-260-04.

8-4.8 LHD Lighting.

Install airfield lights on the LHD deck following the general scheme shown in Figures 8-16 through 8-19. See NAVFAC Simulated LHD Shipdeck Standard Drawings for specific layout and detailed dimensions. For new construction or modifications, ensure current lighting requirements are obtained from NAWCAD 4.8.2.3. Shipboard lighting equipment will be certified annually by NAWCAD 4.8.7.5.

Special features of the lighting system include:

- Crows foot lighting for each landing spot should be on its own circuit so that the landing spot lights can be controlled individually.
- Airfield Lighting Power Supply may be from an airfield lighting vault adjacent to the LSO Tower within the island outline, or lighting systems may be powered from a nearby airfield lighting vault.
- LHD airfield lighting circuits do not require backup power.
- The following airfield lighting components should be placed on separate circuits:

  Tramline Lights
  STO Rotation Light (Pencil Line Light)
  Landing Spot Lights
  Landing Area Edge Light
  Athwartship Lights
  Nozzle Rotation Light

- Lighting systems and controls must be compatible with Night Vision Devices/Systems by stepped regulators or dimming.
- Taxiways and aprons connected to the LHD will be lit according to UFC 3-535-01.

8-4.8.1 LSO Tower on LHD STOVL Facility.

An LSO Tower will be included in all LHD STOVL facilities to provide lighting and control capabilities. Figure 8-20 shows key components and dimensions for the LSO Tower.

See NAVFAC Simulated LHD Shipdeck Standard Drawings for specific layout and detailed dimensions. Other design considerations are listed in the following paragraphs.

8-4.8.1.1 LSO Tower Structural Features.

The tower structure will be designed to support all components (tower cab, lighting systems, stairs, catwalk, etc.) and withstand live loads (wind, seismic, etc.) per local design requirements. Jet exhaust and/or propeller wash from using aircraft will also be considered. Tower structure may be open metal framework or solid wall concrete or masonry, depending on local design requirements or preferences. Tower shall be designed to minimize movement (vibration) of OLS and HPI systems due to wind, jet blast or propeller wash.

8-4.8.1.2 LSO Tower Cab Features.

The LSO Tower Cab is designed to match the dimensions and layout of a LHD 5 cab, with the same controls and components found on a ship. The cab will include windows providing a clear view in all directions and angled out to allow observation directly down to the deck. Windows will include tinted screens to reduce sun glare within the cab. A backlit deck lighting control panel will be installed, with control systems to match the same shipboard components. Inside lighting shall be compatible with Night Vision devices/systems. See UFGS 08 88 58, *Air Traffic Control Tower Glass*, for additional guidance on tower cab windows.

8-4.8.1.3 LSO Tower Lighting Features.

Several lighting systems are mounted directly on the LSO Tower Cab. The navigational lighting systems must match the shipboard systems type and location and must be mounted in the same locations relative to the landing spots as found on an LHD 5 ship. Non-navigational lighting systems (floodlights, obstruction lights) shall be placed as needed for function. Lighting systems on the LSO Tower include:

Visual Landing Aid (VLA) Systems
Optical Landing System (OLS)
Hover Point Indicator (HPI)
Wave-off and Cut Lights
Obstruction Lights
Overhead Floodlights (Forward, Amidships, Aft)

8-4.8.1.4 LSO Tower Communications Systems.

The LSO Tower will include the following systems for communications with the base:

Network data cable (for computer connection)
Airfield Radio (minimum two frequencies) for communications with Air Traffic Control Tower, aircraft, and ground support.
Telephone

8-4.8.1.5 LSO Tower HVAC Systems.

The LSO Tower Cab will be an air-conditioned space, designed to provide a comfortable temperature and humidity for occupants according to local design requirements, and considering heat loads from electronic components within the cab. Design indoor space to the same conditions as described in UFC 4-133-01, Para 3-4.1. The airfield lighting vault building associated with the LHD facility shall be designed to keep the vault interior within the acceptable operating conditions for the contained power and control equipment.

8-4.8.1.6 LSO Tower Weather Systems.

Basic weather measurement systems (at a minimum, temperature, wind speed and direction) will be installed on or near the LSO Tower with data displayed inside the LSO Tower Cab.

8-4.9 LHD Pavement Surface Types.

Figures 8-21 and 8-22 show the pavement types needed for LHD Facilities. Pavements in Landing Spots 7 and 9 as well as the short takeoff lane must be constructed with CRHTC. PJHTC must be used in the areas indicated to support landings and/or hover operations where pavements will be exposed to high exhaust temperatures and high pressures. Shoulder and Safety Zone pavements may be constructed with PJPCC or HMA, but life cycle cost analysis should be used to evaluate the best choice. The paved safety zone pavement thickness will be designed in accordance with UFC 3-260-02, as Traffic Area B, for 2,500 passes of an F-35B aircraft loaded at 61,500 pounds. Paved surfaces under and surrounding Landing Spots have been expanded beyond the deck edge to support landing, hover, and takeoff operations by MV-22 and rotary-wing aircraft. Paved shoulders surrounding these landing spots must also be provided, as indicated. Adjust pavement type dimensions as needed to provide minimum 0.75 m (2.5 ft) between center of in-pavement lights and nearest rigid pavement joint. Use neoprene joint sealant for jointed PJHTC pavements within parking positions. Use silicone sealant for PJHTC pavements outside the LHD deck surface.

Table 8-1. LHD STOVL Facility Deck Criteria

Item		Requirement	Remarks
No.	**Description**		
1	Simulated Deck Length	257.3 m (844 ft)	Simulated LHD Deck
2	Simulated Deck Width	36.6 m (120 ft)	Simulated LHD Deck
3	Left Paved Shoulder	Length: 257.3 m (844 ft) Width: 45.7 m (150 ft)	Left shoulder serves as a safety zone abeam the simulated L-class deck for approach and wave-off to prevent erosion of graded surfaces by jet blast from aircraft transition to and from the STOVL facility. See Paragraph 8-4.9 for pavement type in shoulder areas. Exceeds Air Force, Navy and Marine Corps airfields criteria.
4	Right Paved Shoulder	Length: 257.3 m (844 ft) Width: 7.6 m (25 ft)	Right shoulder serves as a safety zone abeam the simulated L-class deck to prevent erosion of graded surfaces by jet blast from aircraft transition to and from the STOVL facility. Consideration should be given to expanding the shoulder width directly abeam the primary landing spots to provide added protection against erosion. See Note 1. Meets Air Force criteria and exceeds Navy and Marine Corps airfields criteria.
5	Forward Safety Zone	Length: 152.4 m (500 ft) Width: 51.8 m (170 ft)	Forward safety zone serves as an overrun off the bow of the simulated L-class deck. Safety zones are provided to prevent erosion of graded surfaces by jet blast from aircraft departing from the STOVL facility. See Note 1.
6	Approach Safety Zone	Length: Min 457.2 m (1,500 ft) Width: Min 82.3 m (270 ft)	Approach safety zone is provided to prevent erosion of graded surfaces by jet blast from aircraft landing at the STOVL facility. See Note 1. The length of the approach safety zone will be dependent on the length of the STOVL facility plus any approach path length where the aircraft will be below 150 ft AGL. (For example: 1500 ft approach @ 3 deg. = 80 ft, plus 70 ft hover abeam spot = 150 ft AGL).
7	Longitudinal grades of runway and shoulders	0% min 0.87% max	Grades may be both positive and negative but must not exceed the limit specified. Maximum composite grade is 1.5%. Grade restrictions are exclusive of other pavements and shoulders. Where other pavements tie into runways, comply with grading requirements for towways, taxiways, or aprons as applicable, but hold grade changes to the minimum practicable to facilitate drainage.

Table 8-1. LHD STOVL Facility Deck Criteria			
Item		Requirement	Remarks
No.	Description		
8	Longitudinal runway grade change	No grade change is to occur	Where economically feasible, the runway will have a constant centerline gradient from end to end. Exception: Where HTC is built 2” higher than the surrounding pavement, transition down to the surrounding pavement elevation over a 15-ft length. As future HTC surface grinding occurs, the slope of the transition pavement will decrease.
9	Longitudinal safety zone grade	0% min 3% max	Grades may be both positive and negative but must not exceed the limit specified. Grade restrictions are exclusive of other pavements and shoulders. Where other pavements tie into runways, comply with grading requirements for towways, taxiways, or aprons as applicable, but hold grade changes to the minimum practicable to facilitate drainage. Slope pavement downwards from the foul line for simulated ship decks, which runs roughly down the center of the deck, or centerline for runways. The selected transverse grade is to remain constant for the length and width of the simulated L-class ship deck, except at or adjacent to intersections where the pavement surfaces must be warped to match abutting pavements.
10	Transverse grade of runway	Min 0.5% Max 0.87%	New STOVL training facility pavements will be foul line crowned or sloped decks. Maximum composite grade is 1.5%. A uniform slope is preferable to eliminate irregularities between landing gear during touchdown. The simulated deck surface will be foul line crowned with uniform slope in opposing directions to the edges of the simulated deck, or the entire deck slope to insure surface water drainage and runoff. Existing STOVL facility and runway pavements with insufficient transverse gradients for rapid drainage should provide increasing gradients when overlaid or reconstructed. Exception: Where HTC is built 2” higher than the surrounding pavement, transition down to the surrounding pavement elevation over a 15-ft length. As future HTC surface grinding occurs, the slope of the transition pavement will decrease.

Table 8-1. LHD STOVL Facility Deck Criteria

Item No.	Item Description	Requirement	Remarks
11	Transverse grade of paved shoulder	0.5% min 3% max	Paved portion of shoulder should slope downward from deck pavement. Reversals are not allowed. Ideally, 2% Min. for first 25 ft, then 0.5% Min. farther away from runway.
12	Transverse grade of safety zone	0.5% min 3% max	Slope pavement downwards from the simulated ship deck with no reversals to insure adequate drainage and surface water runoff. Exception is at or adjacent to intersections where the pavement surfaces must be warped to match abutting pavements.
13	Runway Lateral Clearance Zone (corresponds to half the width of primary surface)	Width: 45.72 m (150 ft)	Supports VFR operations. Width measured perpendicularly from the port deck edge of the simulated LHD surface. This area is to be clear of fixed and mobile obstacles. In addition to the lateral clearance criterion, the vertical height restriction on structures and parked aircraft as a result of the transitional slope must be taken into account. Fixed obstacles include man-made or natural features constituting possible hazards to moving aircraft. <u>Exception or Permissible Deviation (Air Force)</u>: LSO tower.
14	Longitudinal grades within Runway Lateral Clearance Zone	Max 10.0%	Does not apply to paved shoulders, safety zones, and cover over drainage structures. Slopes are to be as gradual as practicable. Avoid abrupt changes or sudden reversals. Rough grade to the extent necessary to minimize damage to aircraft.
15	Distance from Centerline of Fixed-Wing Runway to the Centerline of a parallel STOVL runway	Min 304.80 m (1,000 ft)	Simultaneous VFR operations for Class B runway for Air Force, Navy and Marine Corps.
		Min 213.36m (700 ft)	Non-simultaneous VFR and IFR operations. Distance may be reduced to 60.96m (200ft); however, waiver must be based on wake-turbulence and jet blast.
			NOTE: LSO Tower and other aboveground structure siting must be based on runway obstacle evaluation and must not be an obstruction to the adjacent runway(s) imaginary surfaces.
16	Width of Graded Area Each Side of LHD	45.72 m (150 ft)	Extends outward each side of Left and Right Paved Shoulders.
17	Length of Graded Area Each End of LHD	304.80 m (1,000 ft)	Extends outward from the Forward and Approach Safety Zones.

Table 8-1. LHD STOVL Facility Deck Criteria			
Item		Requirement	Remarks
No.	Description		
18	Longitudinal or Transverse Grade in Graded Area	Max. 10.0%	Preferred slope downward, but may include upward slopes provided graded elevation does not exceed Primary Surface elevation.

Table 8-2. LHD STOVL Facility Airspace Imaginary Surfaces

Table 8-2. LHD STOVL Facility Airspace Imaginary Surface				
Item		Legend	Requirement	Remarks
No.	Description			
1	Primary surface width	A	91.44 m (300 ft)	Centered on port deck edge of the Simulated LHD Deck. At US Navy and Marine Corps VTSOL facilities where the lateral clearance was established according to previous criterion, that distance may remain.
2	Primary surface length	A	Deck length + 60.96 m (200 ft) at departure end	Primary surface extends 60.96 m (200 ft) beyond the departure end of the simulated LHD Deck. The primary surface ends at the approach end or fantail of the simulated deck.
3	Primary surface elevation	A		The elevation of any point on the primary surface is the same as the elevation of the nearest point on the deck centerline
4	Clear zone surface (graded area)	B	Length: 304.8 m (1,000 ft) Width: 91.44 m (300 ft)	See LHD STOVL Deck Facility Criteria, Table 8-1, Item 14
5	Start of approach-departure surface	C	Approach: 0 m (0 ft) Departure: 60.96 m (200 ft)	Measured from the corresponding deck edge of the simulated LHD deck. The facility is not bi-directional so the requirements for the approach and departure surfaces reflect planned aircraft profile.
6	Length of sloped portion of approach-departure surface	C	5,334.0 m (17,500 ft)	Measured horizontally. This distance reflects the horizontal distance that corresponds with an increase in elevation to meet the outer surface elevation.
7	Slope of approach-departure surface	C	35:1	Slope ratio is horizontal: vertical. Example: 35:1 is 35 m (ft) horizontal to 1 m (ft) vertical.

Table 8-2. LHD STOVL Facility Airspace Imaginary Surface				
Item		**Legend**	**Requirement**	**Remarks**
No.	**Description**			
8	Width of approach-departure surface at start of sloped portion	C	91.44 m (300 ft)	Centered on the port deck edge of the simulated LHD surface and this width represent the same rate of change in width as a Class-A VFR runway. - At US Navy and Marine Corps STOVL facilities where the lateral clearance was established according to previous criterion, that distance may remain.
9	Width of approach-departure surface at end of sloped portion	C	891.50 m (2,925 ft)	Centered on the port deck edge of the simulated LHD surface and this width represent the same rate of change in width as a Class-A VFR runway. - The 1000:75 width ratio is horizontal length: horizontal width. This ratio is consistent with Class-A VFR runway requirements. - At US Navy and Marine Corps STOVL facilities where the lateral clearance was established according to previous criterion, that distance may remain.
10	Elevation of approach-departure surface at start of sloped portion	C	0 m (0 ft)	Same as the simulated ship deck centerline at the threshold
11	Elevation of approach-departure surface at end of sloped portion	C	152.4 m (500 ft)	Above the established simulated ship deck elevation
12	Start of horizontal portion of approach-departure surface	D	NA	Approach-departure horizontal surface not required
13	Length of horizontal portion of approach-departure surface	D	NA	Approach-departure horizontal surface not required

Table 8-2. LHD STOVL Facility Airspace Imaginary Surface				
Item		**Legend**	**Requirement**	**Remarks**
No.	**Description**			
14	Width of approach-departure surface at start of horizontal portion	D	NA	Approach-departure horizontal surface not required
15	Width of approach-departure surface at end of horizontal portion	D	NA	Approach-departure horizontal surface not required
16	Elevation of horizontal portion of approach-departure surface	D	NA	Approach-departure horizontal surface not required
17	Radius of inner horizontal surface	E	1,600 m (5,250 ft)	An imaginary surface constructed by scribing an arc with a radius of 1600 m (5250 ft) about the centerline at each end of the simulated ship deck and interconnecting these arcs with tangents. This radius (distance) corresponds to the increase in elevation for the sloped approach-departure surfaces.
18	Width between outer edges of inner horizontal surface	E	3,200 m (10,500 ft)	
19	Elevation of inner horizontal surface	E	45.72 m (150 ft)	Above the established simulated ship deck elevation. Exception: When the LHD is adjacent to an airfield, the inner horizontal surface is established to match the adjacent airfield's inner horizontal surface.
20	Horizontal width of conical surface	F	2,133.6 m (7,000 ft)	Extends horizontally outward from the outer boundary of the inner horizontal surface.
21	Slope of conical surface	F	20:1	Slope ratio is horizontal: vertical. Example: 20:1 is 20 m (ft) horizontal to 1 m (ft) vertical.

Table 8-2. LHD STOVL Facility Airspace Imaginary Surface				
Item		Legend	Requirement	Remarks
No.	Description			
22	Elevation of conical surface at the start of slope	F	45.72 m (150 ft)	Above the established simulated ship deck elevation.
23	Elevation of conical surface at the end of slope	F	152.4 m (500 ft)	Above the established simulated ship deck elevation.
24	Distance to outer edge of conical surface	G	3,733.6 m (12,250 ft)	
25	Width of outer horizontal surface	G	9144 m (30,000 ft)	Extending horizontally outward from the outer periphery of the conical surface.
26	Elevation of outer horizontal surface	G	152.4 m (500 ft)	Above the established simulated ship deck elevation.
27	Distance to outer edge of outer horizontal surface	G	12,877.0 m (42,250 ft)	An imaginary surface constructed by scribing an arc with a radius of 12,877.0 m (42,250 ft) about the centerline at each end of the simulated ship deck and interconnecting these arcs with tangents.
28	Start of transitional surface	H	45.72 m (150 ft)	Measured perpendicularly from the port deck edge of the simulated LHD surface.
29	End of transitional surface	H	Various	The transitional surface ends at the inner horizontal surface, conical surface, or at an elevation of 45.72 m (150 ft). See NOTE 1

Table 8-2. LHD STOVL Facility Airspace Imaginary Surface				
Item		Legend	Requirement	Remarks
No.	Description			
30	Slope of transitional surfaces	H	2:1	Slope ratio is horizontal: vertical. 2:1 is 2 m (ft) horizontal to 1 m (ft) vertical. Vertical height of vegetation and other fixed or mobile obstacles and/or structures will not penetrate the transitional surface. Taxiing aircraft are exempt from this requirement. For Navy and Marine Corps airfields, taxiway pavements are exempt from this requirement. For the USAF, the air traffic control tower is exempt from this requirement if the height will not affect TERPS criteria.

NOTES:

1. When the LHD STOVL facility is located within the boundaries of an existing DoD airfield and the imaginary surfaces of the two facilities overlap, the LHD transitional surface elevation will extend to meet the existing inner horizontal surface elevation of the DoD airfield. The LHD imaginary surface requirements may be waived provided the existing DoD airfield imaginary surfaces meet or exceed the obstacle clearance requirements defined by the imaginary surfaces in Table 8-2.
2. When the LHD STOVL facility is located parallel with an existing DoD runway use of the runway approach/departure surface may suffice for the LHD approach/departure surface provided a visual transition between the path and the LHD STOVL facility can be conducted while under VMC conditions.

Table 8-3. LHD STOVL Facility Clear Zone and APZs

Table 8-3. LHD STOVL Facility Clear Zone and Accident Potential Zone (APZ)				
Item		Legend	Requirement	Remarks
No.	Description			
1	Clear Zone	B	Departure Clear Zone Length: 304.80m (1,000 ft) Width: 91.44m (300 ft)	Length measured along the extended tram line beginning at the end of the primary surface. Width measured perpendicular to the extended tram line and is centered on the port deck edge of the simulated LHD surface.
			Approach Clear Zone Length: 914.40m (3,000 ft) Width: 91.44m (300 ft)	Length measured along the extended tram line beginning at the end of the primary surface. Width measured perpendicular to the extended tram line and is centered on the port deck edge of the simulated LHD surface.
2	APZ I	J	Departure Length: 762.00m (2,500 ft)	APZ I starts at the end of the clear zone, and is centered on the port deck edge of the simulated LHD surface.

			Width: 152.40m (500 ft)	
			Approach Length: 762.00m (2,500 ft) Width: 228.60m (750 ft)	APZ I starts at the end of the clear zone, and is centered on the port deck edge of the simulated LHD surface.
3	APZ II	J	Length: 2,133.60m (2,500 ft) Width: 304.80m (1,000 ft)	APZ II starts at the end of the APZ I and is centered on the port deck edge of the simulated LHD surface.

Figure 8-1. LHD STOVL Facility Outline

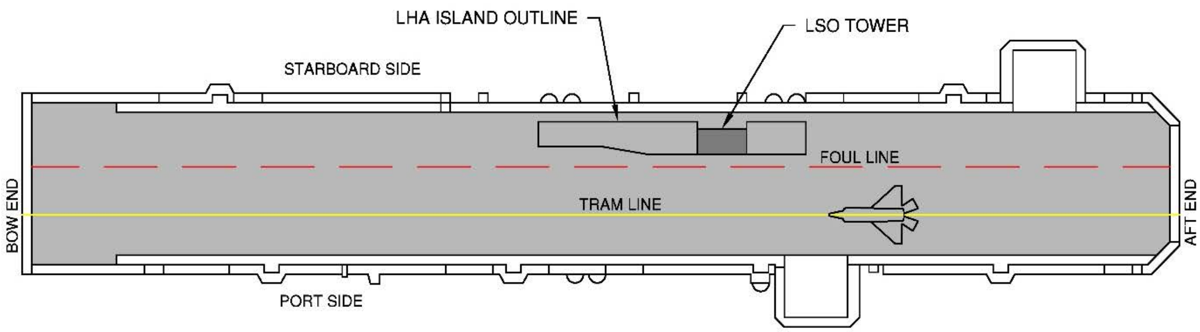


Figure 8-2. LHD STOVL Facility Safety Zones

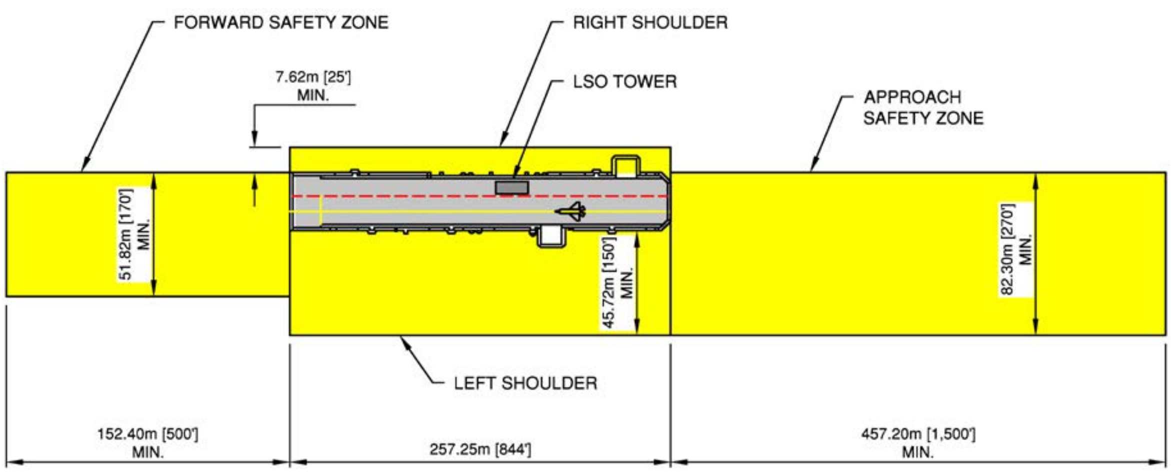
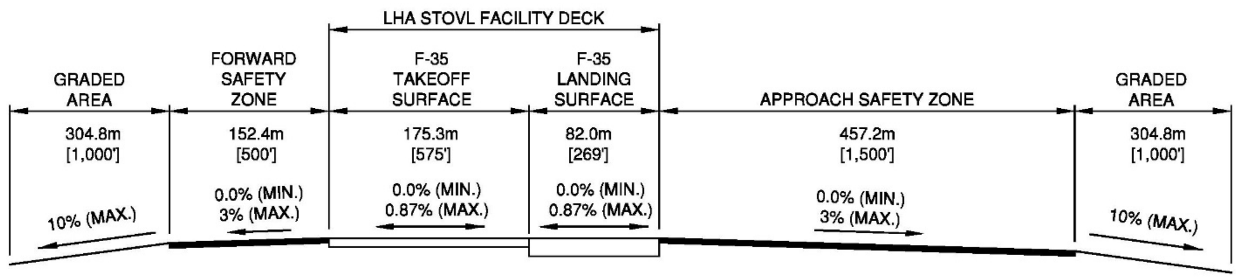
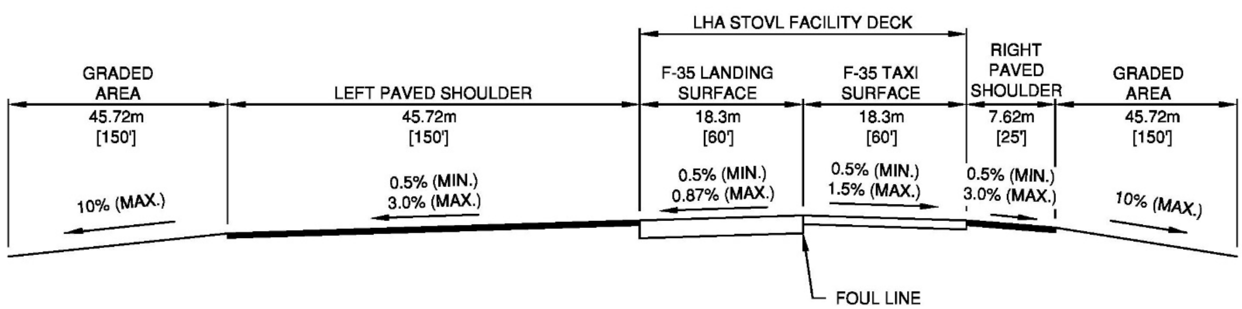


Figure 8-3. LHD STOVL Facility Longitudinal Gradient



LHA STOVL FACILITY LONGITUDINAL SECTION
N.T.S.

Figure 8-4. LHD STOVL Facility Transverse Section



LHA STOVL FACILITY TRANSVERSE SECTION
N.T.S.

Figure 8-5. LHD STOVL Facility Departure Clearance Surface and Clear Zone

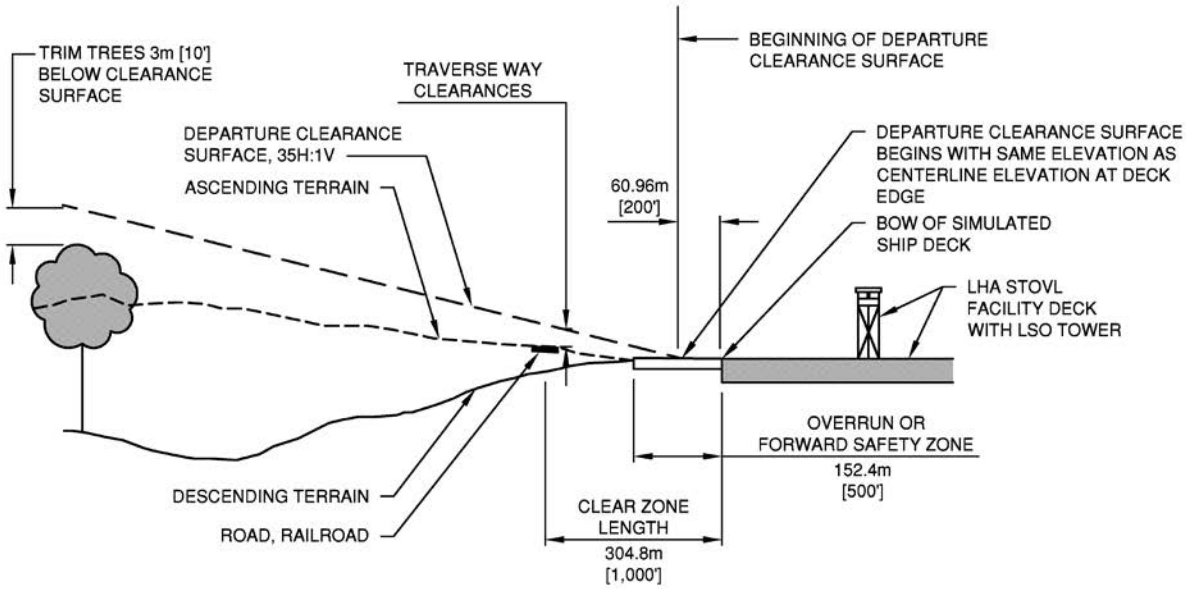


Figure 8-6. LHD STOVL Facility Departure Clear and Accident Potential Zones

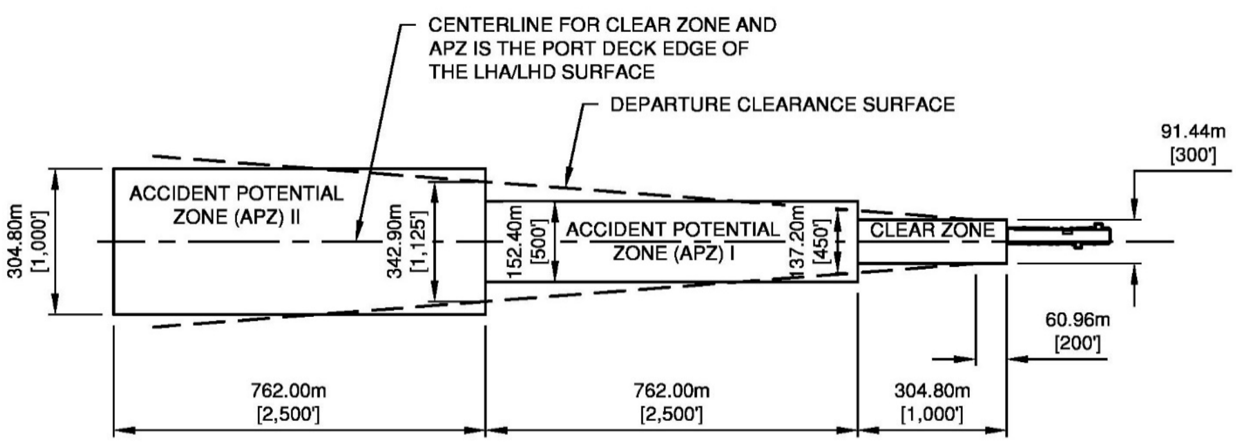
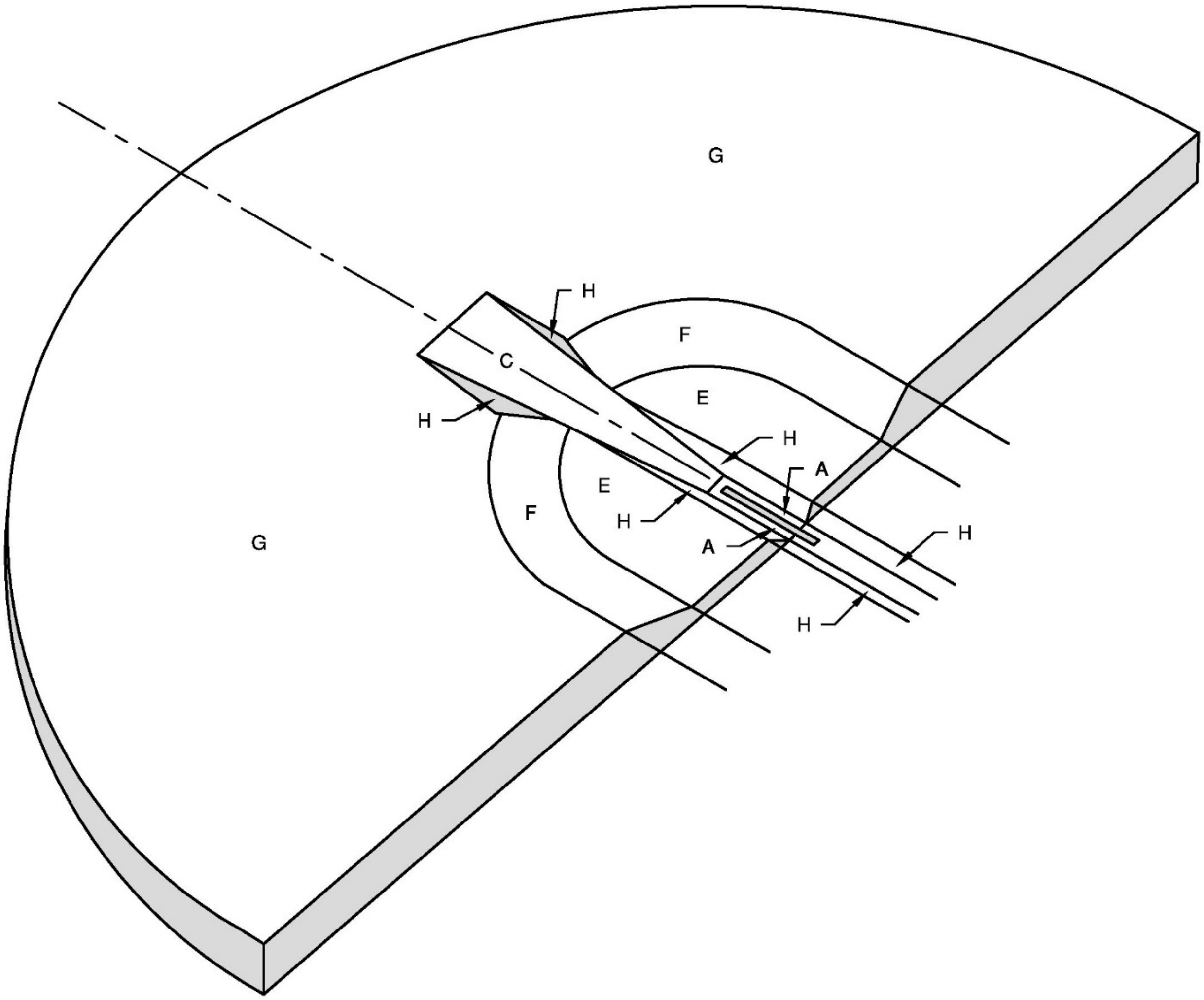


Figure 8-7. LHD STOVL Facility Departure Surface Isometric View



LEGEND

A PRIMARY SURFACE
B CLEAR ZONE SURFACE (NOT SHOWN)
C DEPARTURE CLEARANCE SURFACE (35:1 SLOPE RATIO)
D NOT USED
E INNER HORIZONTAL SURFACE (45.72m [150'] ELEVATION)
F CONICAL SURFACE (20:1 SLOPE RATIO)
G OUTER HORIZONTAL SURFACE (152.40m [500'] ELEVATION)
H TRANSITIONAL SURFACE (2:1 SLOPE RATIO)
I NOT USED
J ACCIDENT POTENTIAL ZONE (APZ) (NOT SHOWN)

ISOMETRIC
N.T.S.

Figure 8-8. LHD STOVL Facility Departure Surface and Transverse Imaginary Surfaces

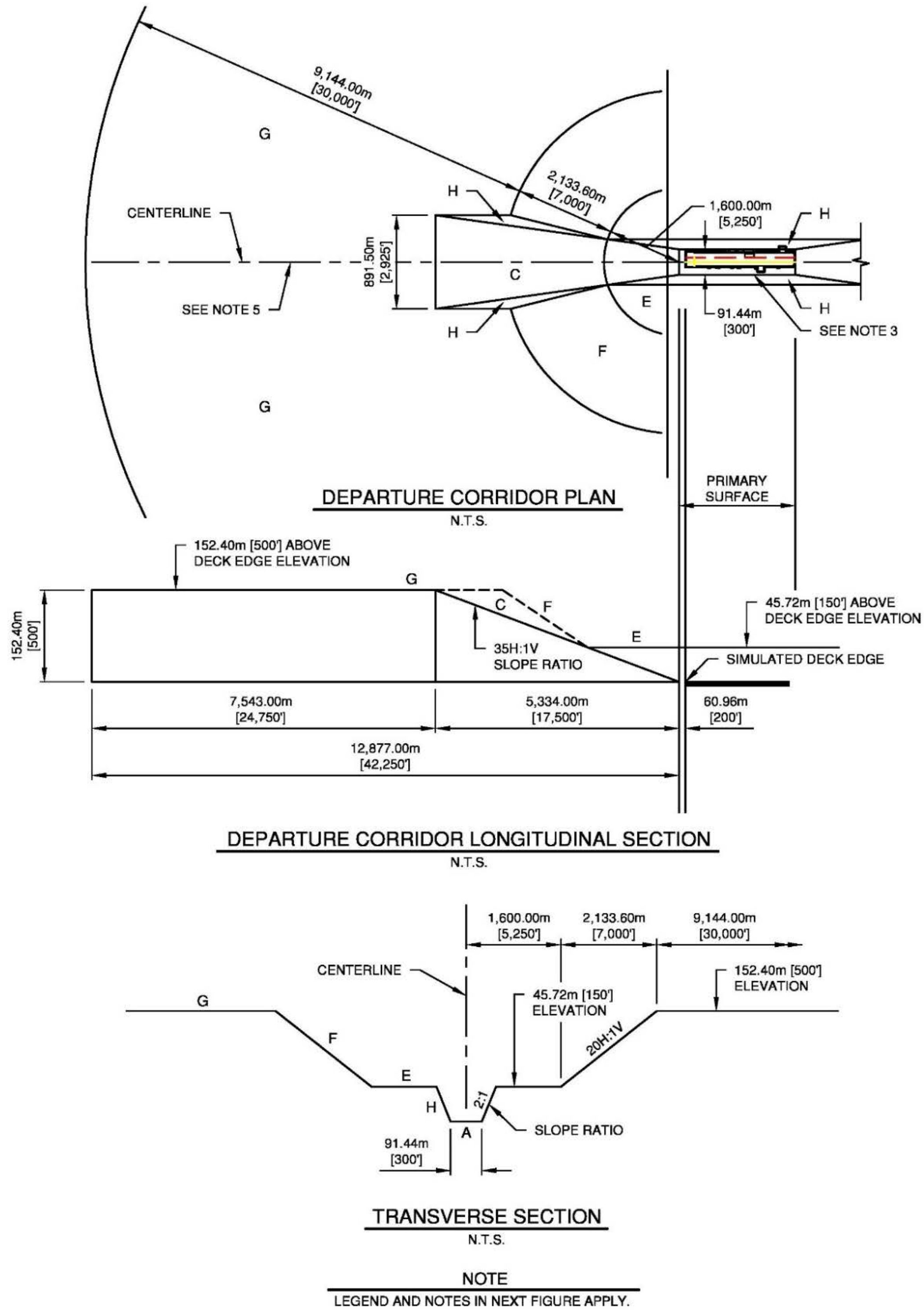
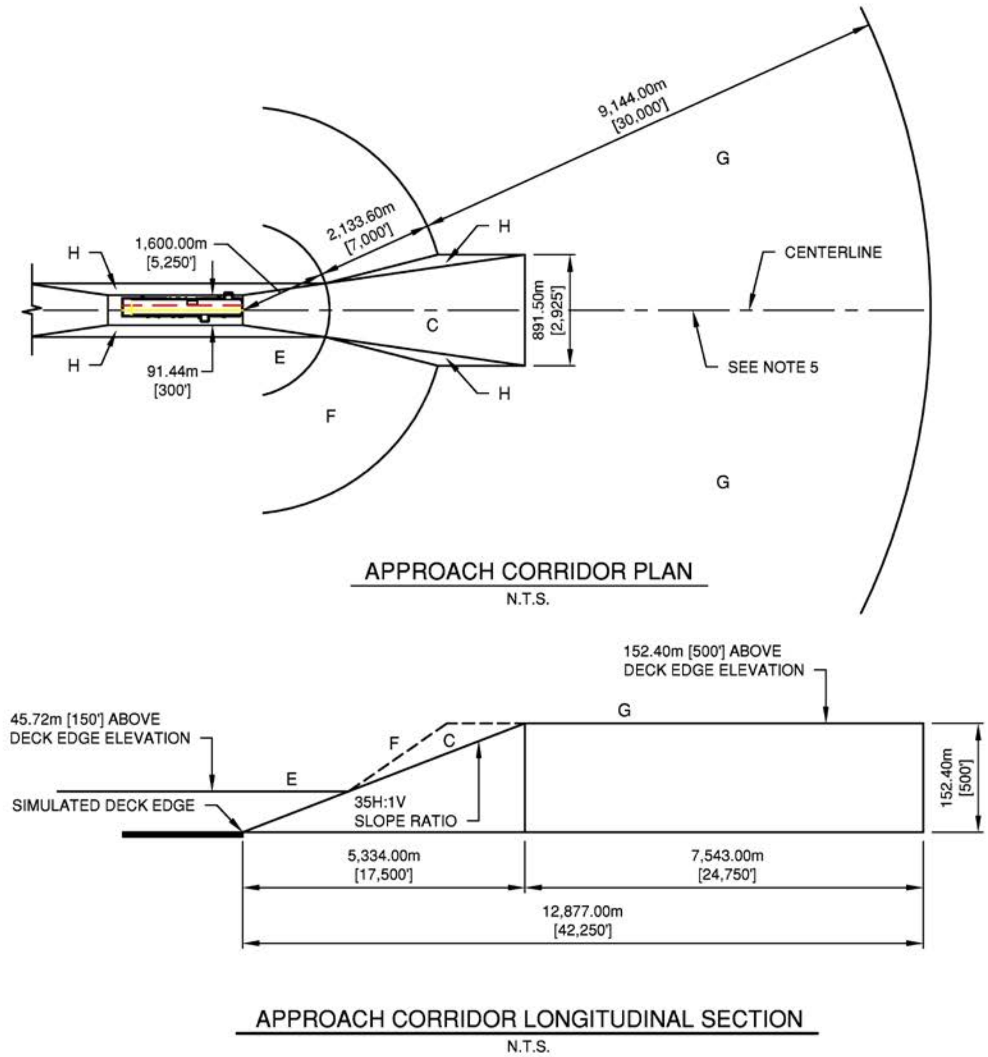


Figure 8-9. LHD STOVL Facility Approach Path Imaginary Surfaces



NOTES

1. DATUM ELEVATION FOR:
   a. SURFACES E, F AND G IS THE ESTABLISHED AIRFIELD ELEVATION.
   b. SURFACE C IS THE RUNWAY CENTERLINE ELEVATION AT THE THRESHOLD.
   c. SURFACE H VARIES AT EACH POINT ALONG THE RUNWAY CENTERLINE.
2. THE SURFACES SHOWN ON THE PLAN ARE FOR A LEVEL RUNWAY.
3. 91.44m [300'] PRIMARY SURFACE WIDTH FOR SIMULATED LHA DECK.
4. APPROACH AND DEPARTURE CORRIDORS END WHEN SLOPE SURFACE REACHES 500' AGL.
5. CENTERLINE FOR THE IMAGINARY SURFACES IS THE LEFT (PORT) DECK EDGE OF THE LHA SURFACE.

LEGEND

A	PRIMARY SURFACE
B	CLEAR ZONE SURFACE - NOT SHOWN
C	APPROACH - DEPARTURE CLEARANCE SURFACE (SLOPE)
D	NOT USED
E	INNER HORIZONTAL SURFACE
F	CONICAL SURFACE
G	OUTER HORIZONTAL SURFACE
H	TRANSITIONAL SURFACE
I	NOT USED
J	ACCIDENT POTENTIAL ZONE (APZ) - NOT SHOWN

Figure 8-10. LHD STOVL Facility Approach Surface Isometric View

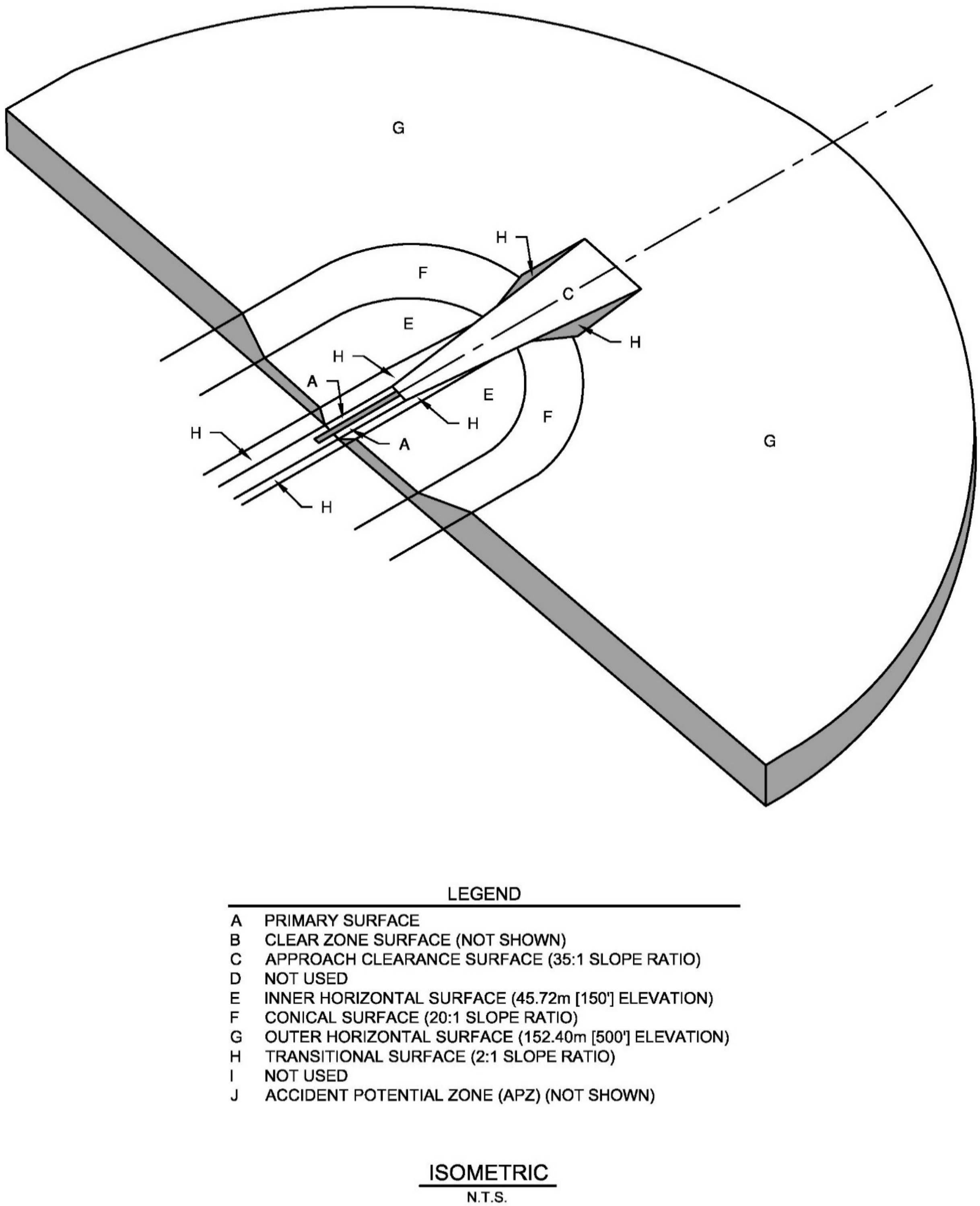


Figure 8-11. LHD STOVL Facility Approach Path Clear Zones and APZs

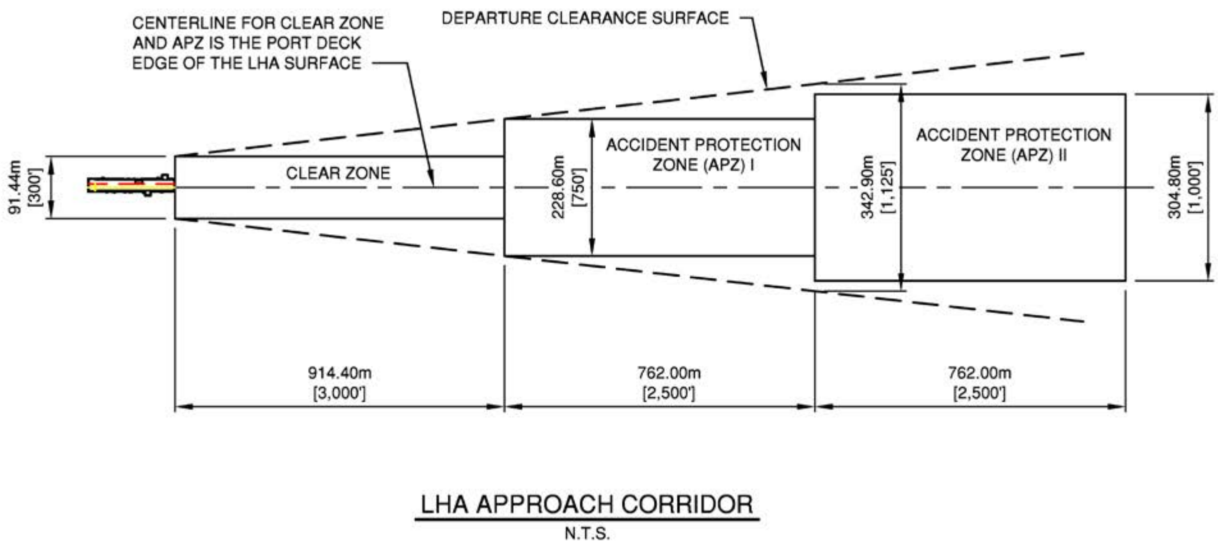


Figure 8-12. LHD STOVL Facility Approach Path Clear Zones

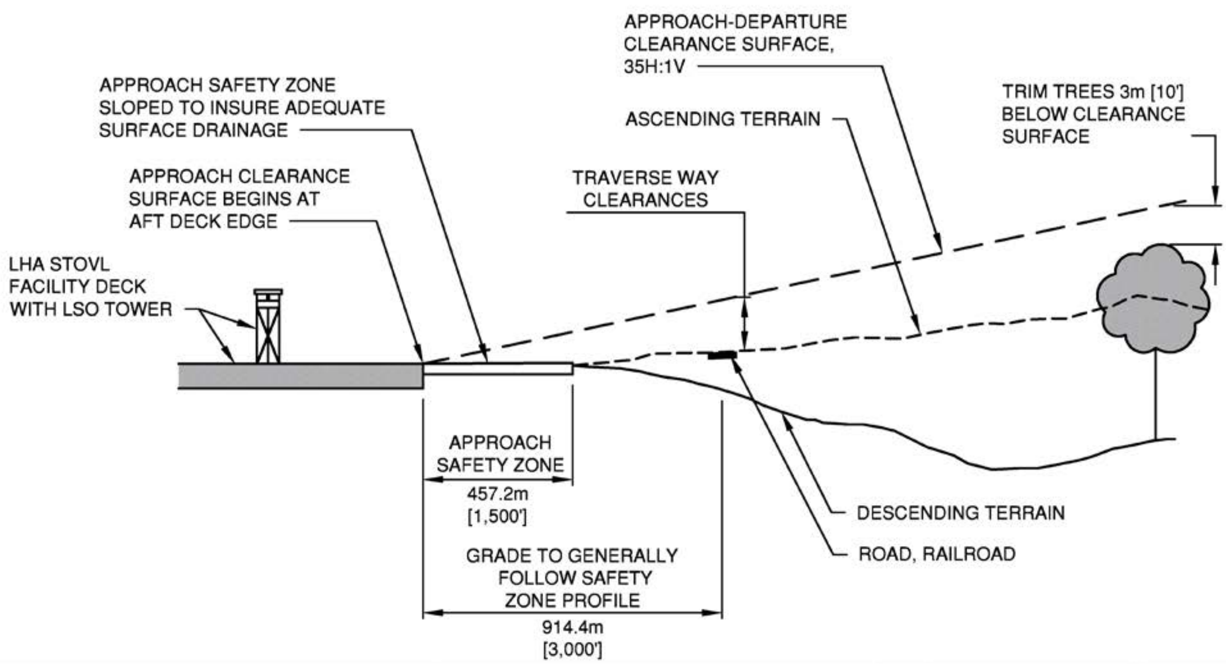


Figure 8-13. LHD STOVL Facility Approach End Details

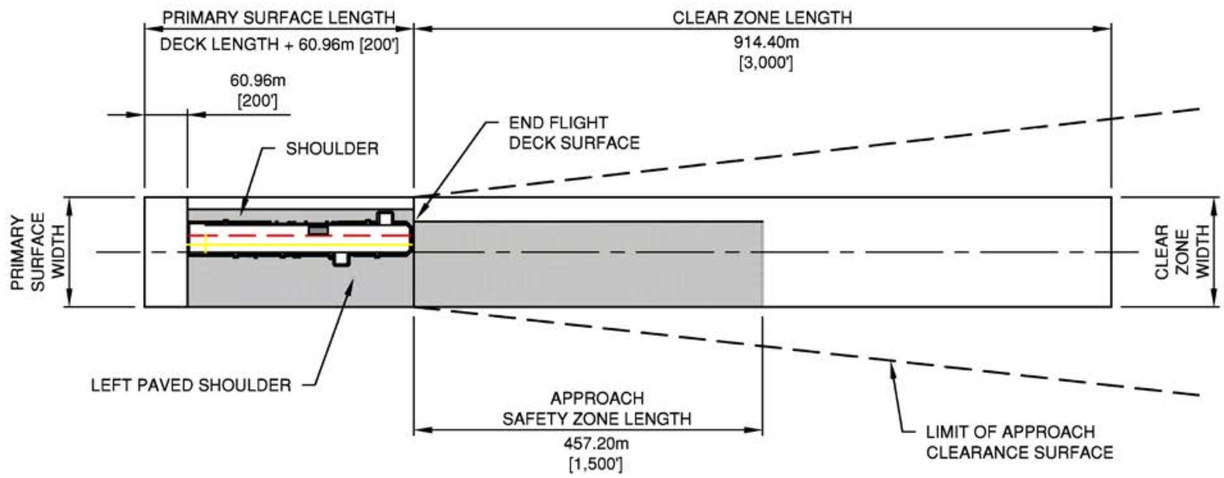


Figure 8-14. LHD Overall Marking

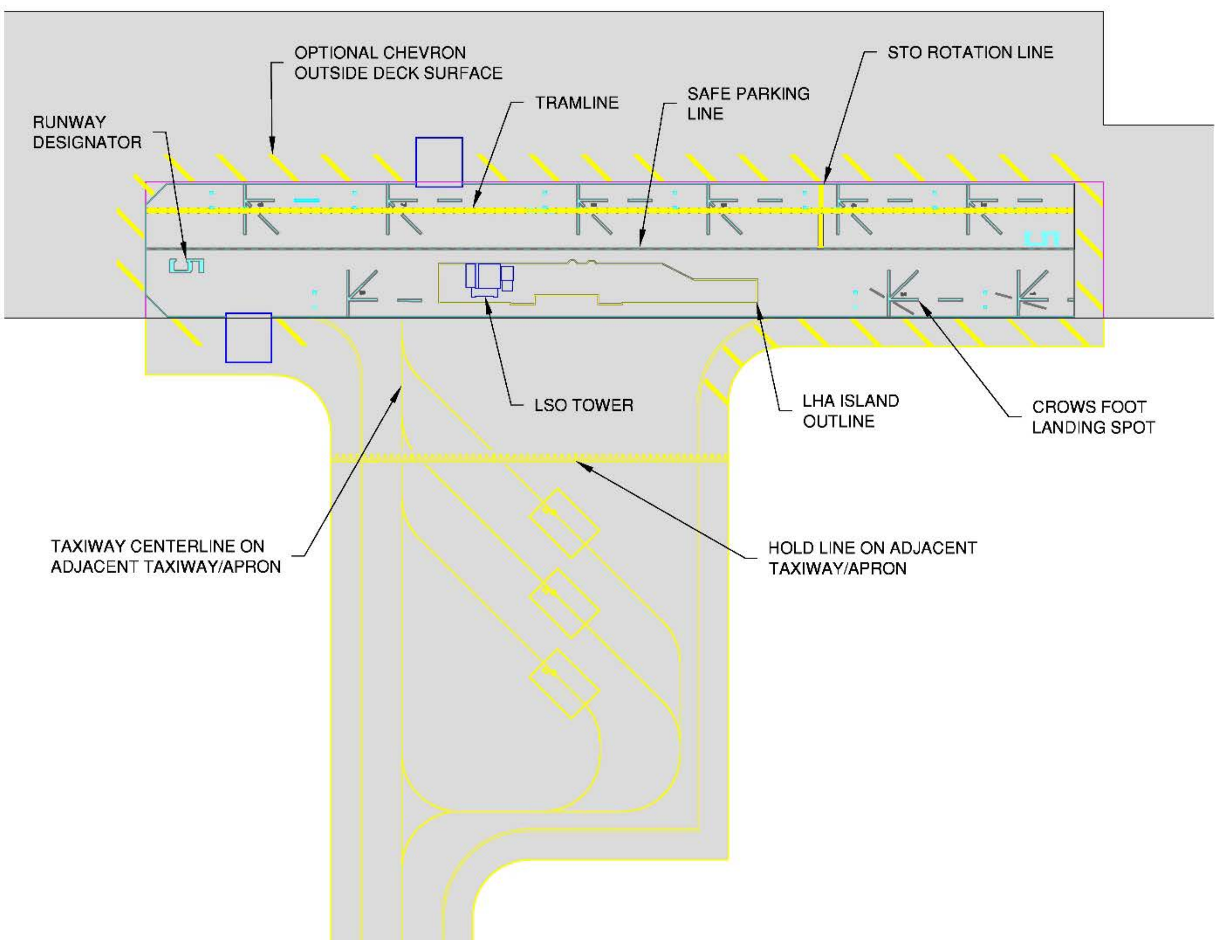


Figure 8-15. LHD Marking Details

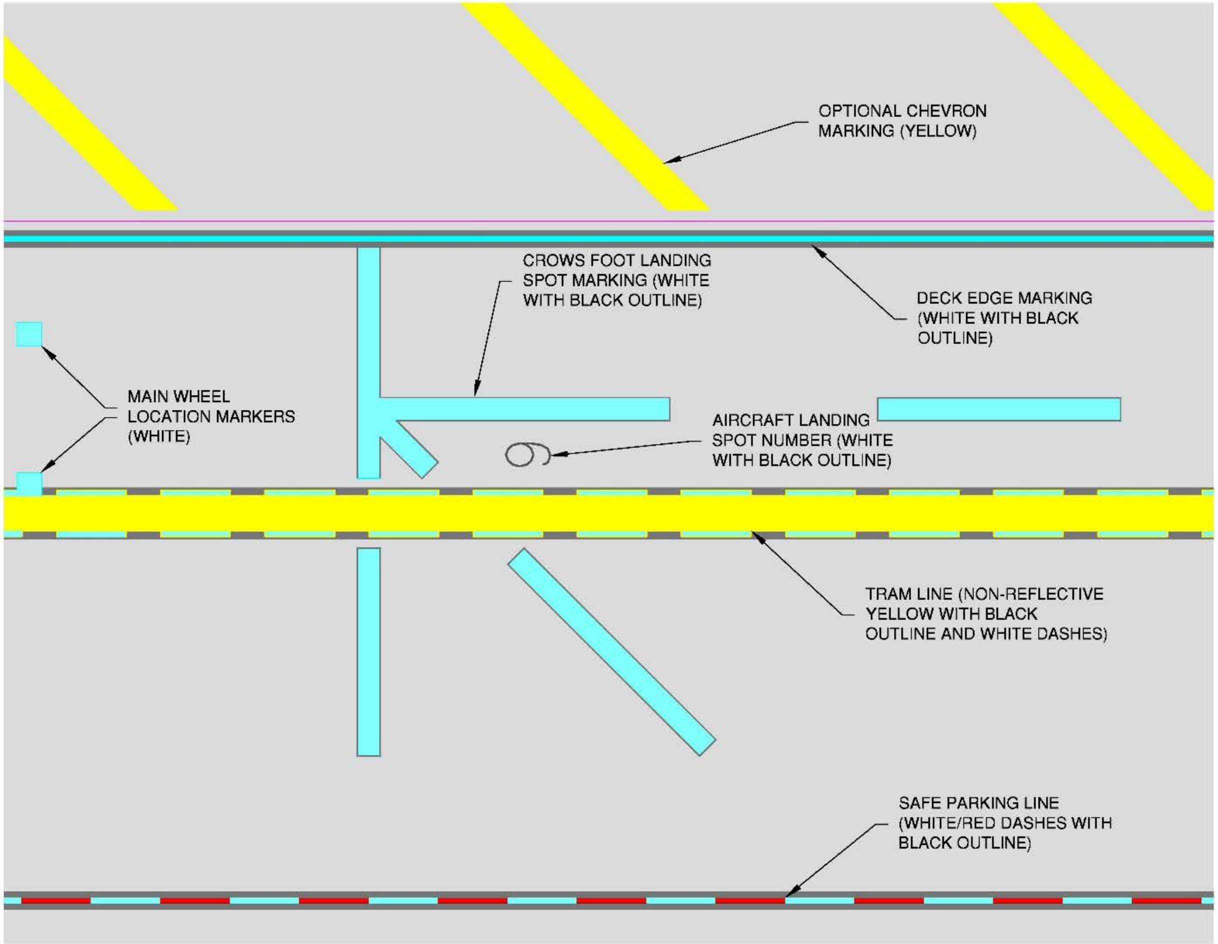


Figure 8-16. LHD Overall Lighting

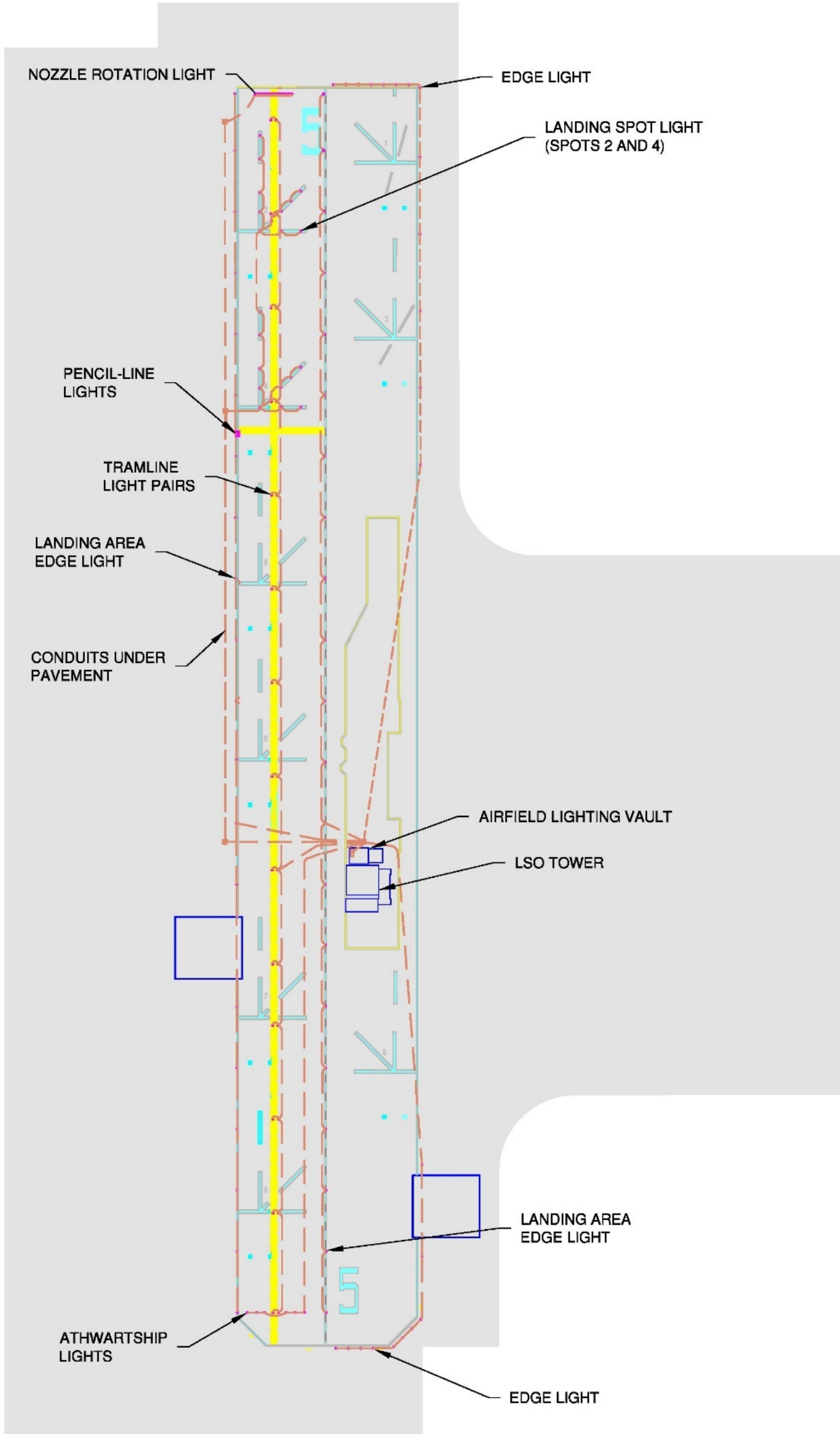


Figure 8-17. LHD Aft Deck Lighting

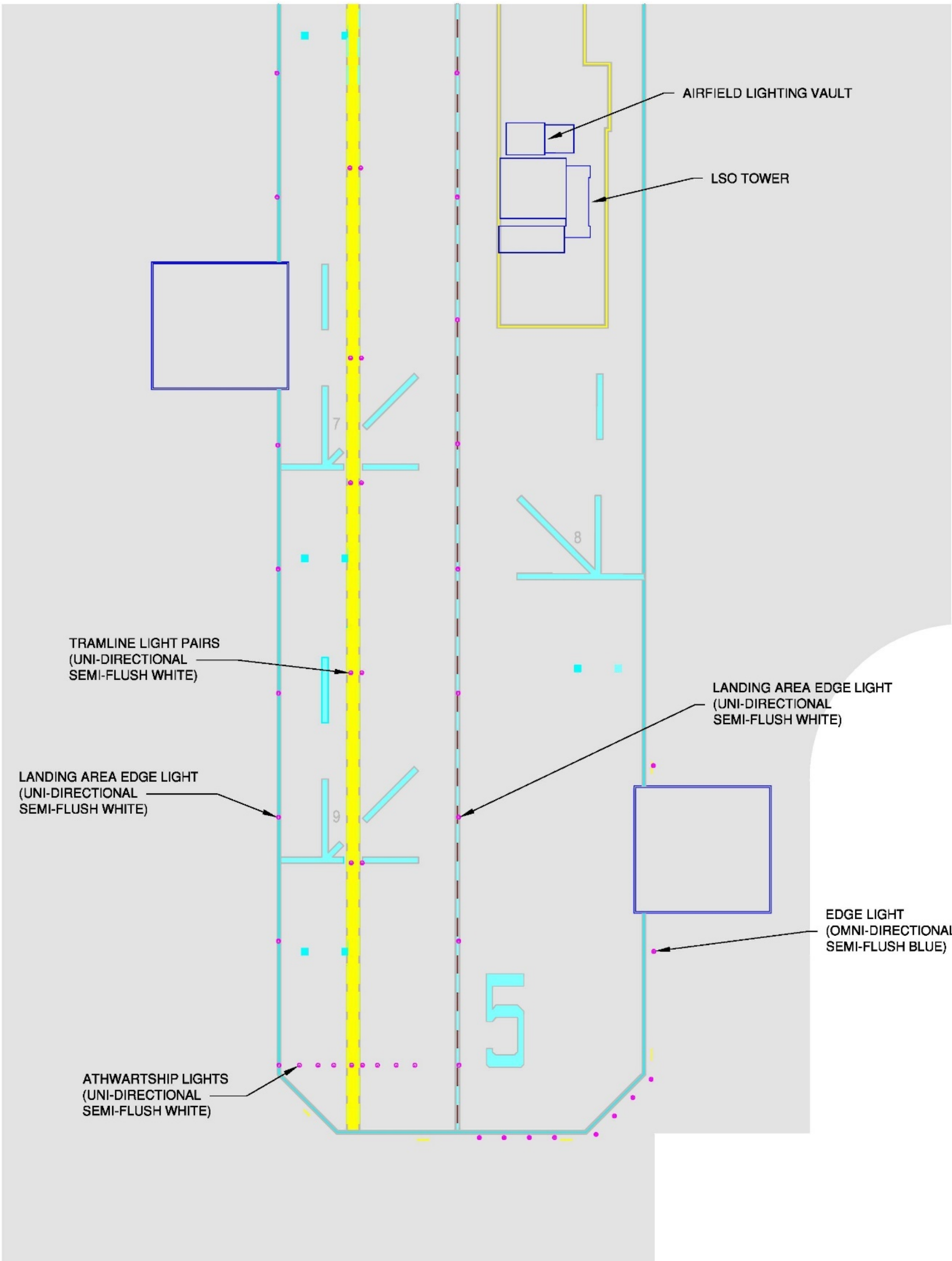


Figure 8-18. LHD Forward Deck Lighting

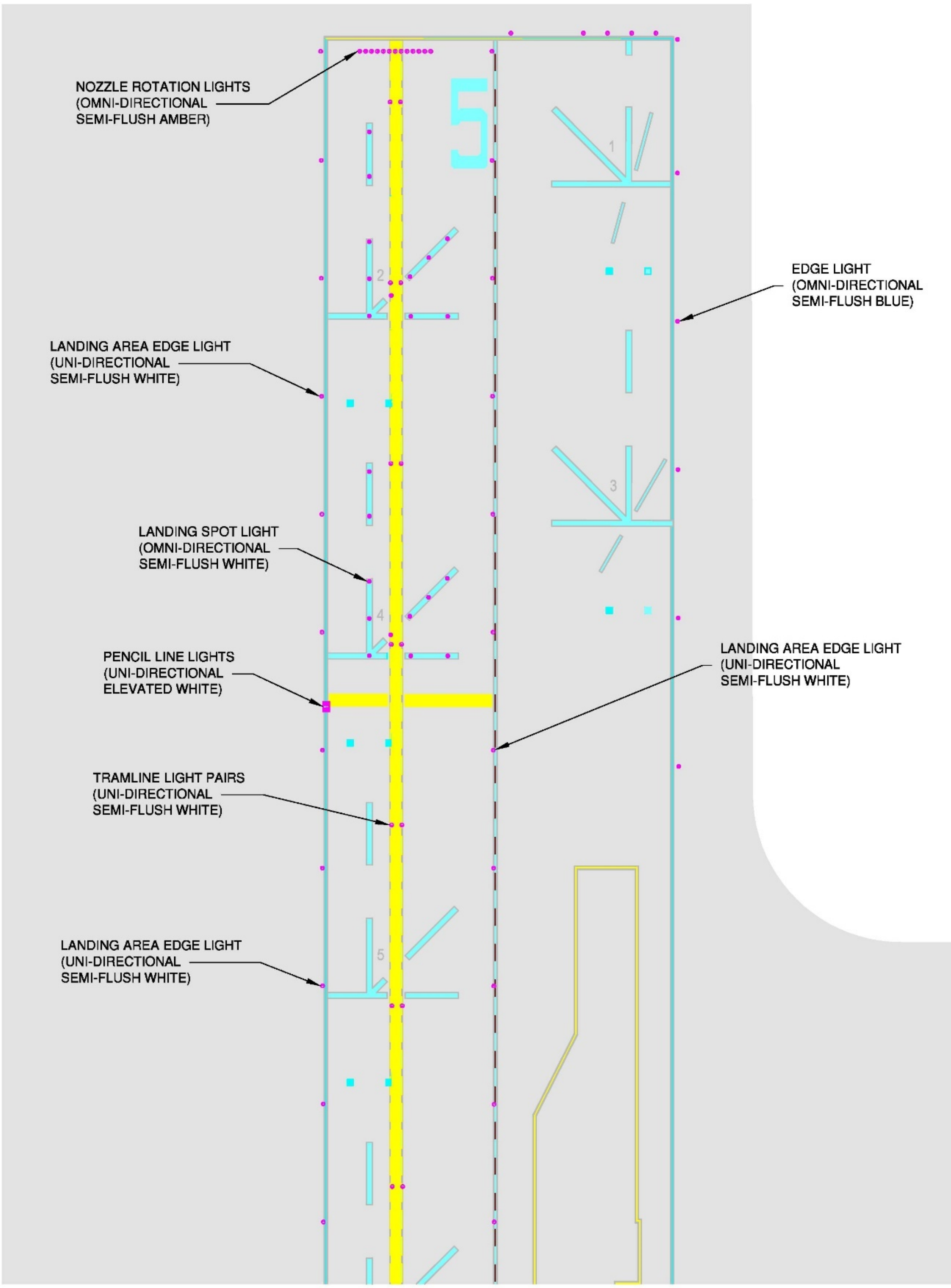


Figure 8-19. LHD Landing Spot Lighting Detail

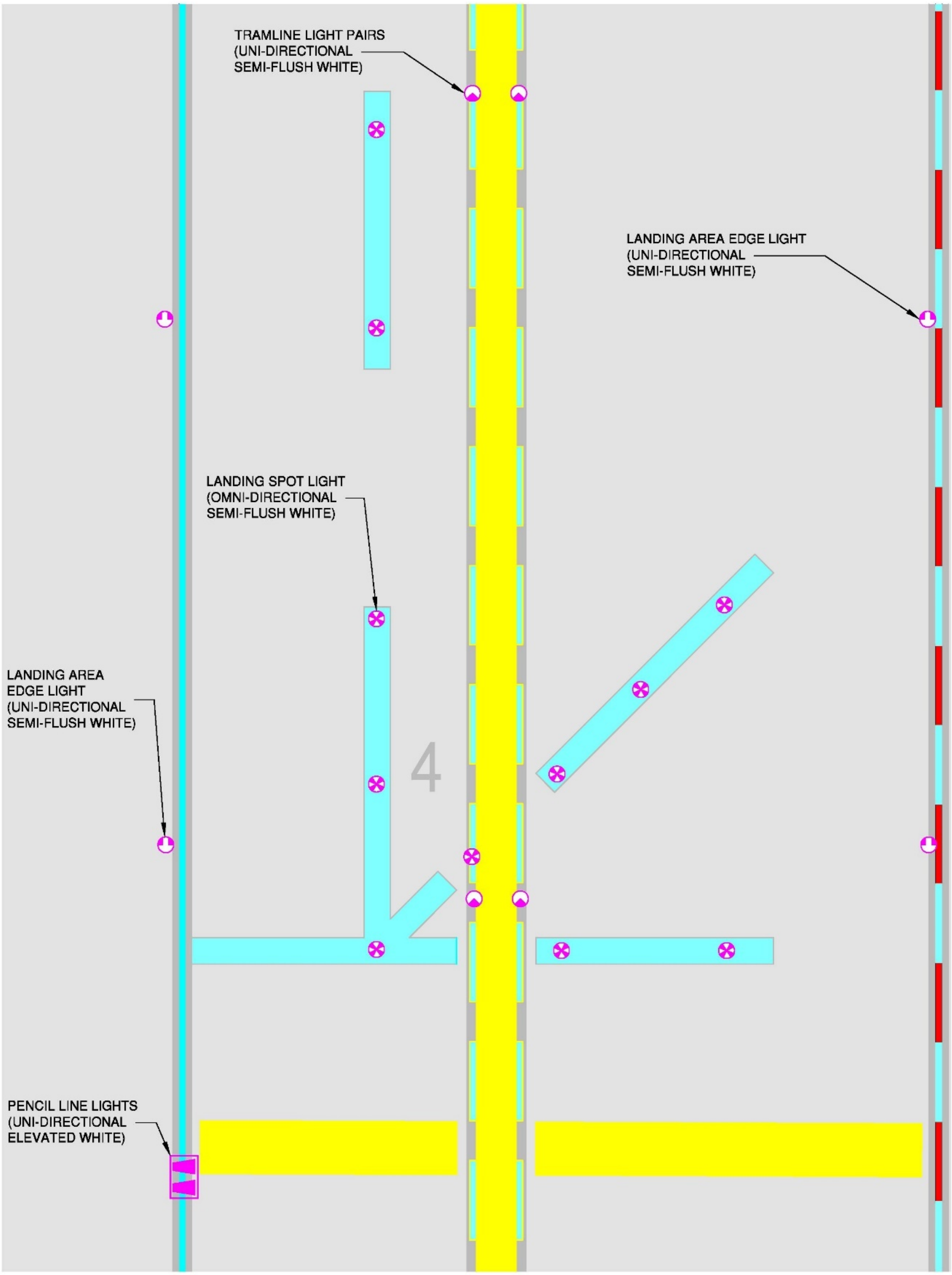


Figure 8-20. LHD LSO Tower Elevation Detail

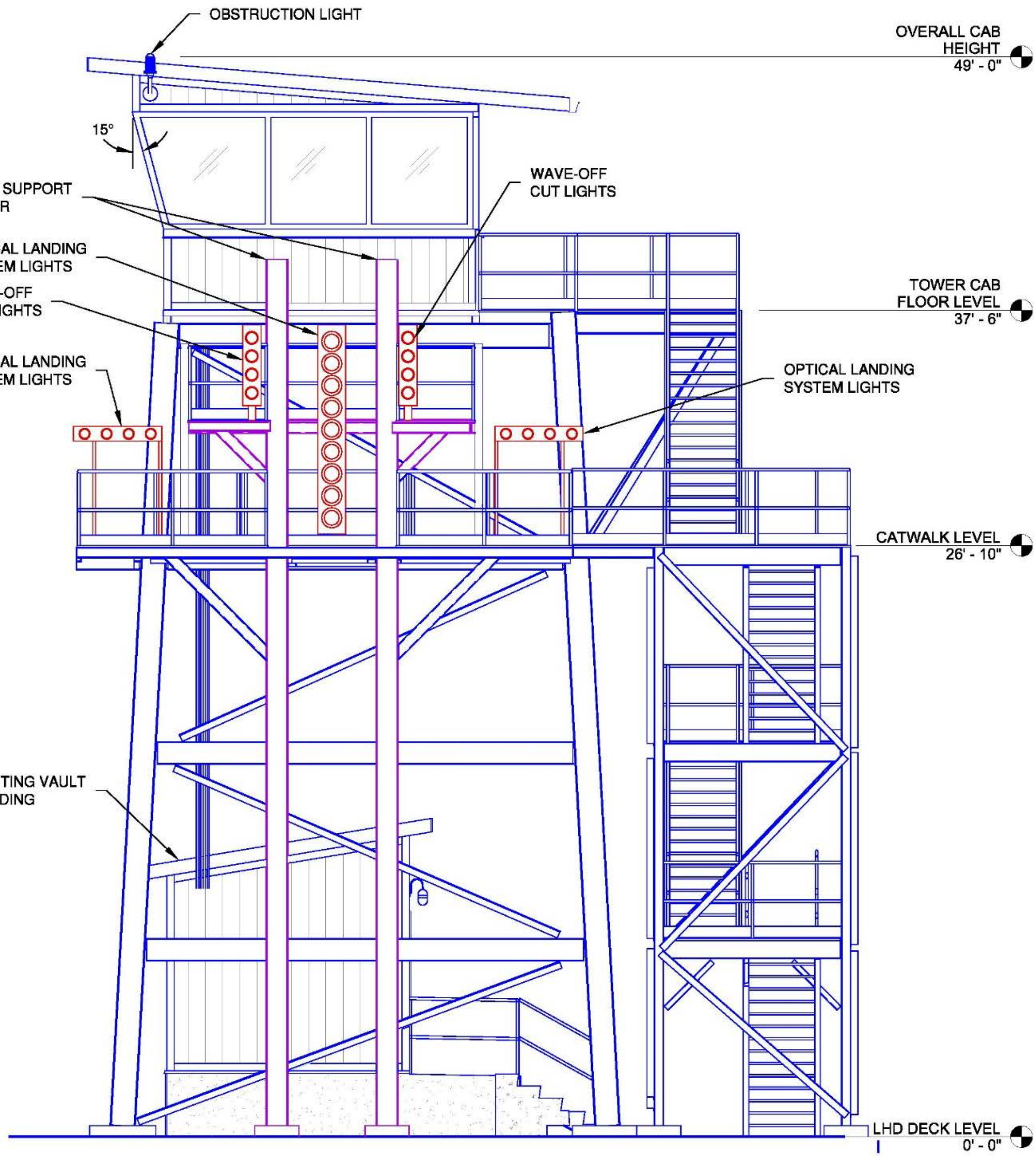


Figure 8-21. LHD Pavement Surface Types

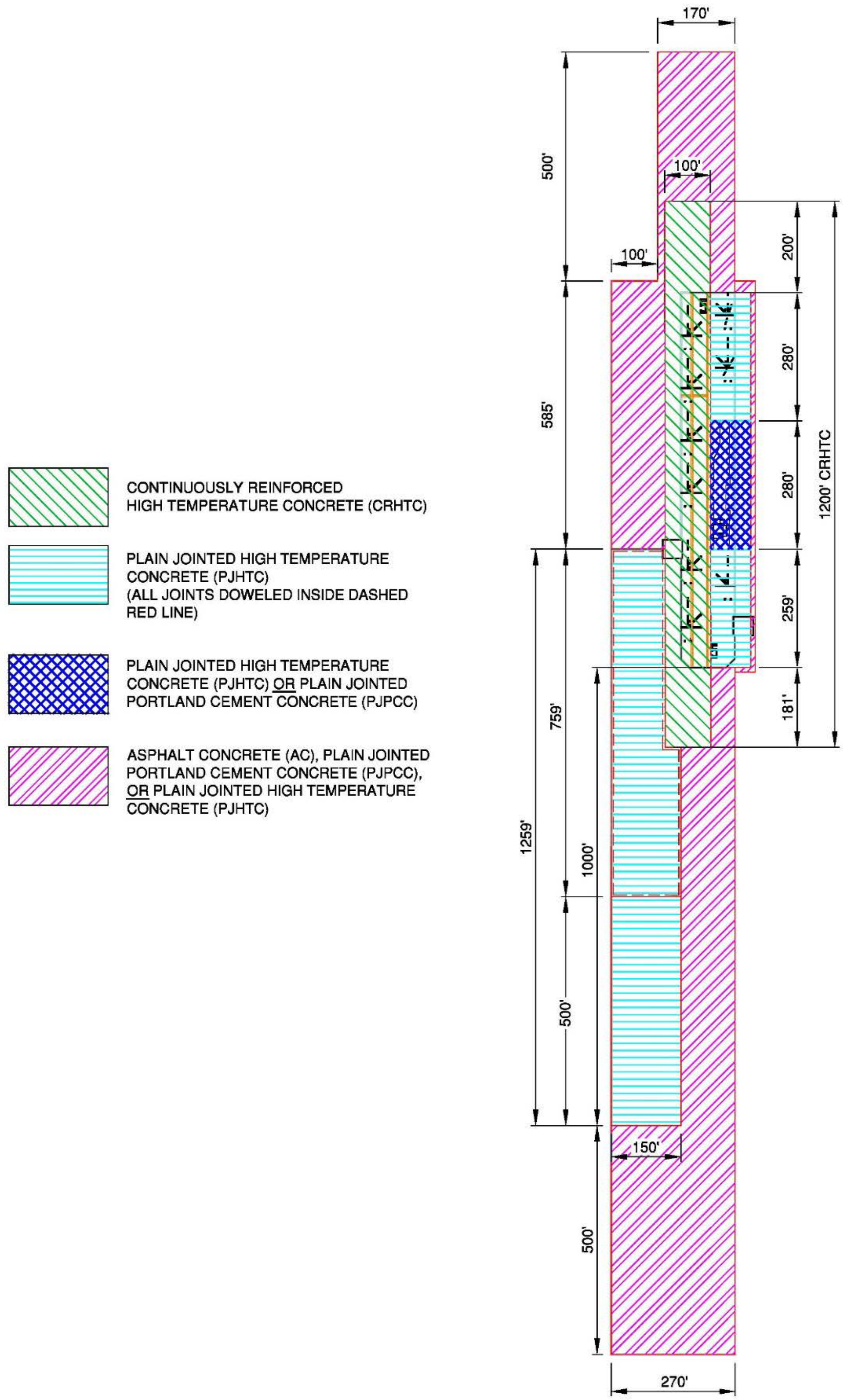


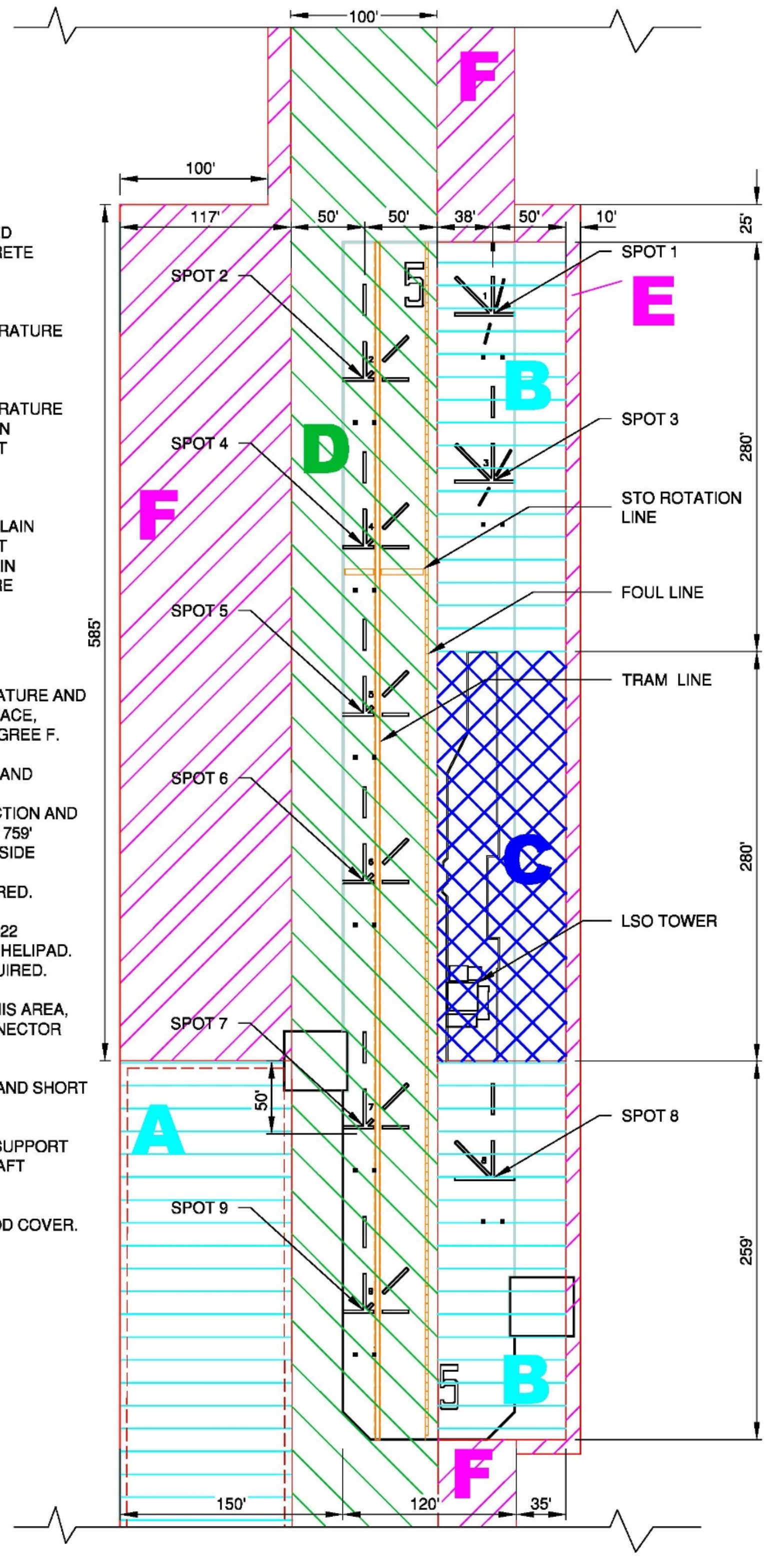
Figure 8-22. LHD Pavement Surface Types Detail

CONTINUOUSLY REINFORCED HIGH TEMPERATURE CONCRETE (CRHTC)

PLAIN JOINTED HIGH TEMPERATURE CONCRETE (PJHTC)

PLAIN JOINTED HIGH TEMPERATURE CONCRETE (PJHTC) <u>OR</u> PLAIN JOINTED PORTLAND CEMENT CONCRETE (PJPCC)

ASPHALT CONCRETE (AC), PLAIN JOINTED PORTLAND CEMENT CONCRETE (PJPCC), <u>OR</u> PLAIN JOINTED HIGH TEMPERATURE CONCRETE (PJHTC)



NOTES

AREA A: HTC REQUIRED DUE TO TEMPERATURE AND PRESSURE. AT 100' ABOVE SURFACE, HOVER TEMPERATURE IS 100 DEGREE F. AT 35' ABOVE SURFACE, HOVER TEMPERATURE IS 500 DEGREE F AND PRESSURE IS 25 PSI. ALL JOINTS DOWELED (CONTRACTION AND CONSTRUCTION) REQUIRED FOR 759' CLOSEST TO LANDING SPOTS (INSIDE DASHED RED LINE). SILICONE JOINT SEALANT REQUIRED.

AREA B: HTC REQUIRED TO SUPPORT MV-22 AIRCRAFT AND SIZED TO MATCH HELIPAD. NEOPRENE JOINT SEALANT REQUIRED.

AREA C: NO AIRCRAFT ANTICIPATED IN THIS AREA, EXCEPT WHERE USED AS A CONNECTOR TAXIWAY.

AREA D: CRHTC FOR VERTICAL LANDING AND SHORT TAKE-OFF OPERATIONS.

AREA E: PAVED SURFACE REQUIRED TO SUPPORT MV-22 AND ROTARY WING AIRCRAFT (HELIPAD SHOULDER).

AREA F: PAVED SURFACE TO PROVIDE FOD COVER.

8-5 F-35B VERTICAL LANDING (VL) PADS.

8-5.1 VL Pad Concept.

The vertical landing pads are located at main air base facilities or forward operating bases. They are positioned at these facilities to provide proficiency training and flexibility for degraded aircraft system recovery. Though not prohibited, the STOVL design of the F-35B aircraft was not intended for routine vertical takeoffs from VL pads. Instead the follow-on takeoff from an airfield with a VL pad will be a conventional or short takeoff based on the facilities available. For this reason, the approach surfaces will be the focus of obstacle clearance considerations for the VL pad. Departure surfaces are not considered because vertical takeoffs are not performed. When the VL pad is collocated with an existing DoD airfield or FOB STOVL training facility and their respective imaginary surfaces overlap, the most restrictive or lower surface will be utilized to ensure obstacle clearance.

8-5.2 VL Pad Standard Drawings.

NAVFAC Vertical Landing Pad (VLP) Standard Drawings have been developed for this facility type. These include NAVFAC Drawing Numbers 14064454 through 14064465 and are available from (http://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc/ufc-3-260-01), where this UFC is posted. Designer of Record must site-adapt, complete, and validate final design for construction. The original concept was developed for F-35B training; however, the design has been adapted to be compatible with rotary-wing aircraft operations also. These modifications include adjusting the approach surface to match the helipad criteria. Existing facilities constructed prior to these modifications may need to be evaluated if such operational upgrades are desired.

8-5.3 VL Pad Background.

Vertical landing pads are located at main air base facilities or forward operating bases. They are positioned at these facilities to provide proficiency training and flexibility for degraded aircraft system recovery. Though not prohibited, the STOVL design of the F-35B aircraft was not intended for routine vertical takeoffs from VL pads. Instead the follow-on takeoff from a VL pad equipped facility will be a conventional or short takeoff based on the facilities available. For this reason, the approach surfaces will be the focus of obstacle clearance considerations for the VL pad. When the VL pad is collocated with an existing DoD airfield or FOB STOVL training facility and their respective imaginary surfaces overlap, the most restrictive or lower surface will be utilized to ensure obstacle clearance.

8-5.3.1 Assumptions.

- Airspace imaginary surfaces are defined for a standalone facility. When the VL pad is collocated with an existing DoD airfield or FOB STOVL facility and their respective imaginary surfaces overlap, the most restrictive or lower surface will be utilized to ensure obstacle clearance.

- The imaginary surfaces for the VL pad provide obstacle clearance for the F-35B to approach the VL pad for a day or night landing under VMC. The supporting landing pattern altitude defines the inner horizontal surface and transitional area elevations. An overhead entry or straight-in visual approach will be the entry maneuver for the VL pad visual pattern, and the obstacle clearance needed for these maneuvers define the approach surface requirements.
- The VL pad is considered a directional facility with a fixed approach direction. When departures are planned from the VL pad the vertical takeoff altitude will exceed the inner horizontal surface elevation before the start of the departure transition ensuring obstacle clearance requirements are met.
- VFR operations under visual meteorological conditions will be assumed at the vertical landing pad for training and simulated mission profiles.
- A 300-foot primary surface width is used for the VL pad because all recoveries (landings) will be conducted under VMC, with slow approach speeds, and the terminal phase resulting in a hover. This primary surface width is consistent with rotary-wing criteria conducting similar approach profiles.

8-5.4 VL Pad Geometry.

8-5.4.1 Pad and Safety Zone Descriptions.

Figures 8-23 through 8-27 and Table 8-4 provide dimensional criteria for layout and design of the VL pad and safety zones. The VL pad and safety zones are provided to prevent erosion of graded surfaces by jet blast from aircraft transition to/from the pad and surface water runoff. Each zone or surface contains a brief description of their use and reference to where their specific dimension or graphic is located within the document.

8-5.4.2 Size.

Table 8-4 provides the overall size of the vertical landing pad. In general terms and dimension the vertical landing pad will be constructed as a single square surface to the dimensions presented here.

8-5.4.3 Shoulder Width.

Table 8-4 provides the width of the paved shoulder that surrounds the vertical landing pad. This dimension reflects the width required to maintain a visual transition from approach to stabilized hover over the pad. The shoulder width provides safety buffer against approach altitude deviations creating FOD debris on the intended point of landing, and protection against erosion of the graded unpaved surface surrounding the VL pad.

8-5.4.4 Grading.

Table 8-4 provides the grade constraints to insure surface water runoff. A uniform surface is required to eliminate irregularities between landing gear at touchdown. For this reason, the vertical landing pad will be sloped in one direction. **1**\ During the construction phase and prior to contract completion, each VL Pad must be constructed to tolerances and surveyed by an independent surveyor for smoothness and flatness. Construction tolerances and survey requirements are noted on the VL Pad Standard Drawings to facilitate the F-35 JPO survey process, which is separate. The F-35 JPO will conduct its own survey and certify the VL pad as "Authorized Level" prior to aircraft operations. /**1**/ If the pad does not meet the "Authorized Level" requirements, surface diamond grinding will be used to create a smooth surface with a consistent slope. **1**\ The F-35 JPO retains requirements for conducting its own pad levelness survey in DM#315235, "Vertical Landing Pad Certification Requirements and Analysis." /**1**/ The purpose of the survey is to obtain measurements for analysis to verify that pad levelness and flatness complies with F-35B Flight Series Data (FSD). Post construction VL pad survey data should be sent to Lightning.Support.Team@jsf.mil for analysis. Analysis results will be provided to the requestor. Additionally, data, analysis, and results for all pads analyzed by the Lightning Support Team (LST) will be retained and archived for future reference; they may be found at DM#315485. Contact the F-35 JPO and Naval Air Surface Warfare Center Aircraft Division (NAWCAD) AR-6.7.8.2 NAVAIR Aviation Shore Facility Integration Branch for additional information on this subject.

- **Raised Elevation.** To ensure an elevation that will allow future grinding of the HTC surface, the VL pad and safety zone must be constructed together such that up to 51 millimeters (2 inches) of material may be diamond-ground from the landing pad surface and still maintain the maximum and minimum grades to eliminate ponding. This higher elevation of the VL pad must be transitioned to the safety zone on all sides, using slopes as indicated in Table 8-4.
- **Primary Surface Elevation.** The primary surface elevation is the highest point on a VL pad. The designer will verify that the primary surface of a VL pad does not interfere with the primary surface and other clearances of adjacent runways, aprons, or taxiways.
- **Grades Within Primary Surface.** Exclusive of pavement and shoulders, grades within the primary surface must be at least two percent to a maximum of five percent, prior to drainage channelization; however, the channel bottom may be flat. The balance of the area is to be clear of obstructions and rough-graded to the extent necessary to minimize damage to aircraft in the event of an emergency landing. For VLZs, the grade requirements apply to the entire primary surface.

8-5.5 VL Pad Separation Distances.

VL pads may be constructed as stand-alone facilities. If co-located at a Class A or Class B airfield, plan for taxiways that provide VL pad access. Table 8-4 provides the minimum separation distances between permanent fixed-wing runways and vertical landing pads for simultaneous VFR operations. Table 8-4 provides the minimum separation distances between permanent fixed-wing runways and vertical landing pads for non-simultaneous VFR operations. Vertical landing pads, paved safety zones, paved shoulders, and unpaved shoulders will be located outside all taxiway clearance distances.

8-5.6 VL Pad Clear Zones, Imaginary Surfaces, and APZs.

Figures 8-25 and 8-26, and Tables 8-5 and 8-6 provide applicable clearances and grade controls for a reasonable level of safety. Their description and layout are similar to other STOVL facility and airfield types and are not unique to the vertical landing pad. Each zone or surface contains a brief description of their use and reference to where their specific dimension or graphic is located within the document. VL Pad Clear Zones and Imaginary Surfaces on the approach-departure path are compatible with rotary-wing (helipad) surfaces defined in Chapter 4. For only F-35B operations, the 2:1 Transitional Surface may be applied on all sides of the VL Pad and the ADCS will start at the edge of the Transitional Surface. See Figure 8-27 for an illustration of this configuration.

8-5.6.1 Clear Zones.

Clear zones are areas on the ground, located at the ends of the primary surface, along the approach-departure path of the VL pad. They possess a high potential for accidents and their use is restricted to be compatible with aircraft operations. VL pad clear zones are required and should be government owned or protected under long term lease. The clear zone will be cleared, graded and free of aboveground objects. See Table 8-9.

8-5.6.2 Imaginary Surfaces.

Surfaces in space established around a vertical landing pad that are designed to protect the airspace around the pad from encroachment and insure obstacle clearance. The imaginary surfaces for the vertical landing pad are the primary surface, transitional surface, inner horizontal surface, and approach-departure path surfaces. The lower approach-departure clearance surface (ADCS) will begin at edge of the primary surface. The upper ADCS will begin at the top of the lower ADCS. Both ADCS surfaces extend outward along the centerline of the approach or departure path. See Table 8-8.

8-5.6.3 Accident Potential Zones.

A land use control area beyond the clear zone of a vertical landing pad that possesses a significant potential for accidents, and their use is restricted in accordance with DoDI 4165.57. Their dimensions and layout are listed in Table 8-9. Navy planners will use OPNAVINST 11010.36C/MCO 11010.16 (or latest version) to determine specific AICUZ requirements. For the Air Force, land use guidelines within the clear zone (beyond the graded area) and APZ I and APZ II are provided in AFI 32-7063 and AFH 32-7084.

8-5.7 VL Pad Pavement Marking.

Apply markings to VL Pads using reflective airfield marking paint, following the general scheme shown in Figure 8-28. See NAVFAC Vertical Landing Pad (VLP) Standard Drawings for specific layout and detailed dimensions.

8-5.7.1 Diagonal Line-up Cue Markings.

Paved pads 1.5m x 1.5m (5 ft x 5 ft) will be constructed on the diagonals at 30m (100 ft) from the corners of the VL Pad Safety Zone to provide additional visual cues for pilots to line up over the VL Pads prior to descending. Pads will be at the same elevation as the surrounding turf and painted orange, as shown in Figure 8-28.

8-5.8 VL Pad Lighting.

Install edge lights on the VL Pad and the connector taxiway, following the general scheme shown in Figure 8-29. See NAVFAC Vertical Landing Pad (VLP) Standard Drawings for detailed light layout and installation details.

8-5.9 VL Pad Pavement Surface Types.

Figure 8-30 shows the pavement types needed for VL Pads. The vertical landing pad will be constructed using CRHTC. The surrounding Paved Safety Zone will be constructed with PJHTC. The taxiway within 50-ft adjacent to the VL Pad will be constructed with PJHTC. The taxiway connecting to adjacent runway or taxiway may be constructed with PJPCC or Hot Mix Asphalt. The paved shoulders will be constructed with PJPCC or HMA. Regardless of construction material or method, the vertical landing surface will have a smooth transition to surrounding safety zones, shoulders, and taxiways. The paved safety zone pavement thickness will be designed in accordance with UFC 3-260-02, as Traffic Area B, for 2,500 passes of an F-35B aircraft loaded at 61,500 pounds. **\1** Seal joints in PJHTC with silicone sealant. **/1/**

Table 8-4. Vertical Landing (VL) Pad Criteria

Table 8-4. Vertical Landing (VL) Pad Criteria			
Item		**Requirement**	**Remarks**
No.	**Description**		
1	Size	**\1** 30.48 m x 30.48 m **/1/** (100 ft x 100 ft)	Same as a Standard VFR and IFR Helipad
2	Paved Safety Zone	\1\ 15.24 m /1/ (50 ft)	- Safety zones are provided to prevent erosion of graded surfaces by jet blast from aircraft transitioning to and from the VL facility. - The VL pad will be centered on the safety zone making the outside dimensions of the safety zone 61m x 61m (200 ft x 200 ft).
3	Paved Shoulder	**\1** 3.05 m **/1/** (10 ft)	
4	VL Pad Grade	Min. 0.5% Max. 0.87%	A uniform slope is required to eliminate irregularities between landing gear during touchdown. -Uniformly sloped in one direction in both the longitudinal and transverse directions. - The resultant effective grade will not exceed 1.5%. - Crowning or peaking of these paved areas will not be allowed. - The pavement design engineer will verify that all areas of vertical landing pads, paved safety zones, connecting taxiways, and paved and unpaved shoulders, effectively drain surface water.
5	Safety Zone Grade	Min 0.5% Max 1.0%	Uniformly slope in one direction in both the longitudinal and transverse direction.
6	Shoulder Grade	Min 2.0% Max 4.0%	Uniformly slope in one direction in both the longitudinal and transverse direction.
7	Vertical landing pad lateral clearance zone (corresponds to half the width of primary surface)	46.7 m (150 ft)	Supports VFR operations - Measured perpendicularly from centerline of vertical landing pad. This area is to be clear of fixed and mobile obstacles. In addition to the lateral clearance criterion, the vertical height restriction on structures and parked aircraft as a result of the transitional slope must be taken into account. - Fixed obstacles include man-made or natural features constituting possible hazards to moving aircraft.
8	Grades within runway lateral clearance zone (Primary Surface)	Min 2.0% Max 5.0%	Does not apply to paved VL Pad, Safety Zone or Shoulder. - Grades within the primary surface must be at least two percent to a maximum of five percent, prior to drainage channelization; however, the channel bottom may be flat. Avoid abrupt changes or sudden reversals. - The balance of the area is to be clear of obstructions and rough-graded to the extent necessary to minimize damage to aircraft in the event of an emergency landing. Grade requirements apply to the entire primary surface.
9	Distance from centerline of	Min 213.36 m (700 ft)	Simultaneous VFR operations for Class A runway for Air Force, Navy and Marine Corps.

Table 8-4. Vertical Landing (VL) Pad Criteria

Item		Requirement	Remarks
No.	Description		
	fixed-wing runway to the centerline of the vertical landing pad	Min 304.8 m (1,000 ft)	Simultaneous VFR operations for Class B runway for Air Force, Navy and Marine Corps.
		Min 60.96 m (200 ft)	For non-simultaneous VFR and IFR operations. - Distance may be reduced to 60.96 m (200 ft); however, waiver must be based on wake-turbulence and jet blast. - Operations for Class B runway for Air Force, Navy and Marine Corps, vertical landing pads may be sited within the runway primary surface, but must remain a distance from the runway edge equal to the distance the runway hold position markings are located.
		Min. 762.00 m (2,500 ft)	IFR using simultaneous operations (depart-depart) (depart-approach).
		Min. 1,310.64 m (4,300 ft)	IFR using simultaneous approaches.
10	Connecting Taxiway Width	**\1** 22.86 m **/1/** (75 ft)	The connecting taxiway must be long enough so that after an aircraft has landed and is on the VL pad, it does not interfere with aircraft operations on the runway, taxiway or apron to which the VLZ is connected.
11	Connecting Taxiway Total Width of shoulders (paved and unpaved)	15 m (50 ft)	
12	Connecting Taxiway Paved Shoulder Width	**\1** 3.05 m **/1/** (10 ft)	
13	Connecting Taxiway Grades	See Table 5-1.	

Table 8-5. Vertical Landing (VL) Pad Airspace Imaginary Surfaces

Table 8-5. Vertical Landing Pad Airspace Imaginary Surfaces				
Item		Legend	Requirement	Remarks
No.	Description			
1	Primary surface width	A	93.5 m (300 ft)	Centered on vertical landing pad. - At US Navy and Marine Corps STOVL facilities where the lateral clearance was established according to previous criterion, that distance may remain.
2	Primary surface length	A	93.5 m (300 ft)	Centered on vertical landing pad. At US Navy and Marine Corps STOVL facilities where the lateral clearance was established according to previous criterion, that distance may remain.
3	Primary surface elevation	A	Elevation of VL pad.	The primary surface elevation is the highest point on a VL pad. The VL Pad primary surface must be at the same elevation or above the primary surface of adjacent runways. The designer will verify that the primary surface of a VL pad does not interfere with the primary surface and other clearances of adjacent runways, aprons, or taxiways.
4	Grade of Clear Zone in any direction	B	5.0% Max.	The clear zone starts at the end of the primary surface and has the same width as the primary surface (93.5 m [300 ft]), with a length of 400 ft. - Clear zones are areas on the ground, located at the ends of the primary surface, centered on the primary approach path to the VL pad. - Areas to be free of obstructions. Rough grade and turf when required. Positive drainage to avoid standing water.
5	Start of Lower approach-departure Surface	C	45.72 m (150 ft)	Measured from the center of the VL Pad along the primary approach path.
6	Length of sloped Lower approach-departure surface	C	365.7 m (1,200 ft)	Measured horizontally along the extended approach path. - This approach length reflects obstacle clearance requirements for STOVL or rotary aircraft to make a straight decelerating transition to the intended point of landing.
7	Slope of Lower approach-departure surface	C	8:1	Slope ratio is horizontal: vertical. Example: 8:1 is 8 m (ft) horizontal to 1 m (ft) vertical.

Table 8-5. Vertical Landing Pad Airspace Imaginary Surfaces

Item No.	Item Description	Legend	Requirement	Remarks
8	Width of Lower approach-departure surface at start of sloped portion	C	91.44 m (300 ft)	- Centered on the extended centerline of the approach path and at the primary surface. - At US Navy and Marine Corps VTSOL facilities where the lateral clearance was established according to previous criterion, that distance may remain.
9	Width of Lower approach-departure surface at end of sloped portion	C	274.3 m (900 ft)	- Perpendicular to the extended centerline of the approach path. - At US Navy and Marine Corps VTSOL facilities where the lateral clearance was established according to previous criterion, that distance may remain.
10	Elevation of Lower approach-departure surface at start of sloped portion	C	Elevation of VL Pad	
11	Elevation of Lower approach-departure surface at end of sloped portion	C	45.7 m (150 ft)	Measured up from the primary surface.
12	Start of Upper approach-departure Surface	D	365.7 m (1,200 ft)	Measured from the center of the VL Pad along the primary approach path. It starts at the top of the Lower Approach Surface.
13	Length of sloped Upper approach-departure surface	D	4,267 m (14,000 ft)	Measured horizontally along the extended approach path. - This approach length reflects obstacle clearance requirements for the STOVL aircraft to make a straight decelerating transition to the intended point of landing. - This is the horizontal distance required to extend from the top of the Lower Approach Surface to 500 ft AGL.

Table 8-5. Vertical Landing Pad Airspace Imaginary Surfaces				
Item		**Legend**	**Requirement**	**Remarks**
No.	**Description**			
14	Slope of Upper approach-departure surface	D	40:1	Slope ratio is horizontal: vertical. Example: 40:1 is 40 m (ft) horizontal to 1 m (ft) vertical.
15	Width of Upper approach-departure surface at start of sloped portion	D	274.3 m (900 ft)	- Centered on the extended centerline of the approach path and starts at the top of the 2:1 transitional slope. This distance spans the full width along the top of the transition surface. - At US Navy and Marine Corps VTSOL facilities where the lateral clearance was established according to previous criterion, that distance may remain.
16	Width of Upper approach-departure surface at end of sloped portion	D	914.4 m (3,000 ft)	- Perpendicular to the extended centerline of the approach path. - The 1000:75 width ratio is horizontal length: horizontal width. This ratio is consistent with class-A VFR runway requirements. - At US Navy and Marine Corps VTSOL facilities where the lateral clearance was established according to previous criterion, that distance may remain.
17	Elevation of Upper approach-departure surface at start of sloped portion	D	45.7 m (150 ft)	- Measured up from the primary surface elevation to the top of the 8:1 approach surface. - This start elevation reflects the requirement for the STOVL aircraft to remain above 150 ft AGL until over the intended point of landing.
18	Elevation of Upper approach-departure surface at end of sloped portion	D	152.4 m (500 ft)	Measured from the edge of VL pad on approach centerline.
19	Radius of inner horizontal surface	E	1,869 m (6,000 ft)	An imaginary surface constructed by scribing a 180-degree (or more for multiple approaches) arc with a radius of 1,869 m (6,000 ft) from the center of the VL pad. -This imaginary surface covers the VFR landing pattern obstacle clearance requirements.

Table 8-5. Vertical Landing Pad Airspace Imaginary Surfaces				
Item		Legend	Requirement	Remarks
No.	Description			
20	Width between outer edges of inner horizontal surface	E	3,738 m (12,000 ft)	
21	Elevation of inner horizontal surface	E	45.72 m (150 ft)	Measured up from the elevation of the VL Pad Primary Surface. Exception: When the VL Pad is adjacent to an airfield, the inner horizontal surface is established to match the adjacent airfield's inner horizontal surface.
22	Start of transitional surface	H	45.72 m (150 ft)	Measured perpendicularly from centerline of the approach path and extended centerline of Vertical Landing pad (coincident with edge of Primary Surface).
23	End of transitional surface	H	Various	The transitional surface ends at the inner horizontal surface, at an elevation of 45.72 m (150 ft). See NOTE 1.
24	Slope of transitional surfaces	H	2:1	Slope ratio is horizontal: vertical. 2:1 is 2 m (ft) horizontal to 1 m (ft) vertical. Vertical height of vegetation and other fixed or mobile obstacles and/or structures will not penetrate the transitional surface. - For Navy and Marine Corps airfields, taxiway pavements are exempt from this requirement. - For the USAF, the air traffic control tower is exempt from this requirement if the height will not affect TERPS criteria.

NOTES:

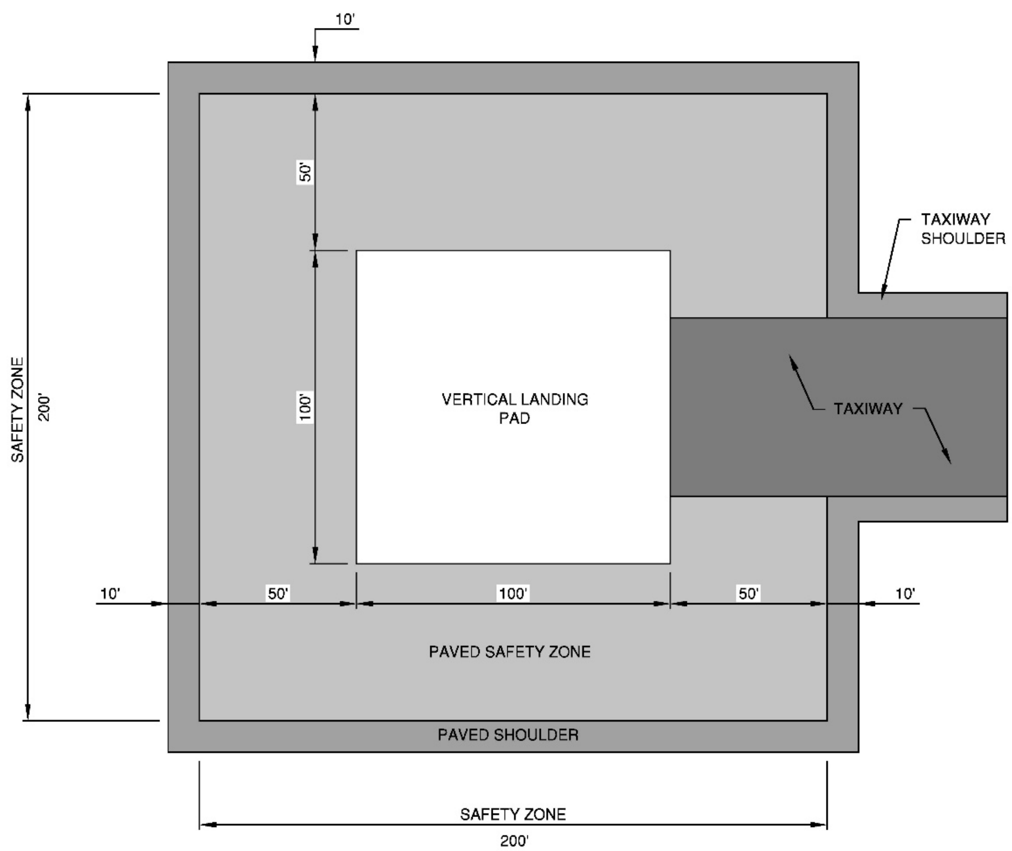
1. When the vertical landing pad is located within the boundaries of an existing DoD airfield and the imaginary surfaces of the two facilities overlap, the vertical landing pad transitional surface elevation will extend to meet the existing inner horizontal surface elevation of the DoD airfield. The vertical landing pad imaginary surface requirements may be waived provided the existing DoD airfield imaginary surfaces meet or exceed the obstacle clearance requirements defined by the imaginary surfaces in Table 8-8.
2. When the vertical landing pad is located within the primary surface of the existing DoD runway, use of the runway approach/departure surface may suffice for the vertical landing pad approach surface provided a visual transition between the path and the vertical landing pad can be conducted while under VMC conditions.

Table 8-6. Vertical Landing (VL) Pad Clear Zone and APZs

Item No.	Item Description	Legend	Requirement	Remarks
1	Clear Zone	B	Length: 121.90m (400 ft) Width: 91.44m (300 ft)	Length measured along the extended primary approach path. Width measured perpendicular to the primary approach path.
2	APZ I	J	Length: 243.83m (800 ft) Width: 91.44m (300 ft)	APZ I starts at the end of the clear zone, and is centered on the primary approach path. Width measured perpendicular to the primary approach path.

\1

Figure 8-23. Vertical Landing (VL) Pad Facility Outline with Safety Zones



/1/

Figure 8-24. Vertical Landing (VL) Pad Facility Cross Section Gradient

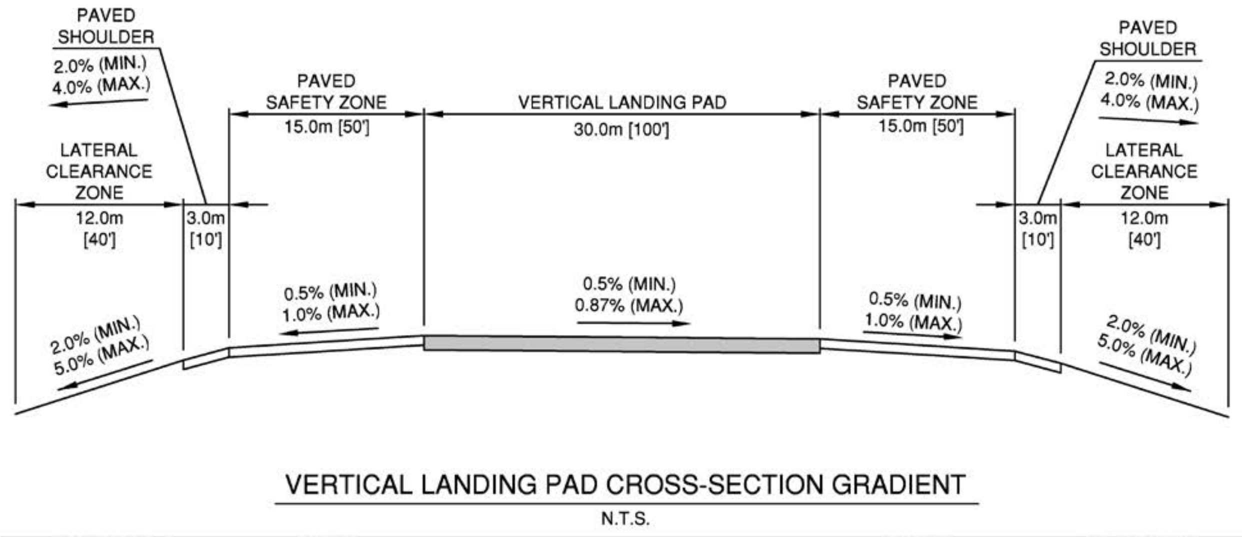


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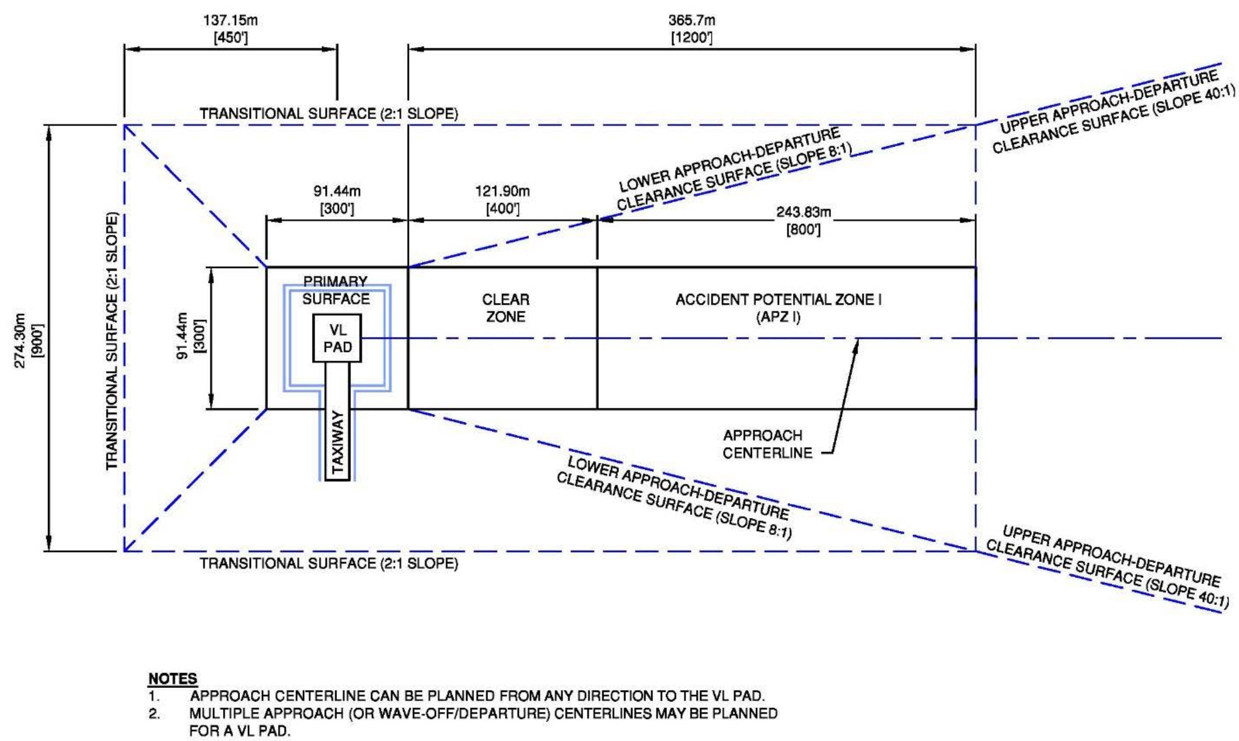
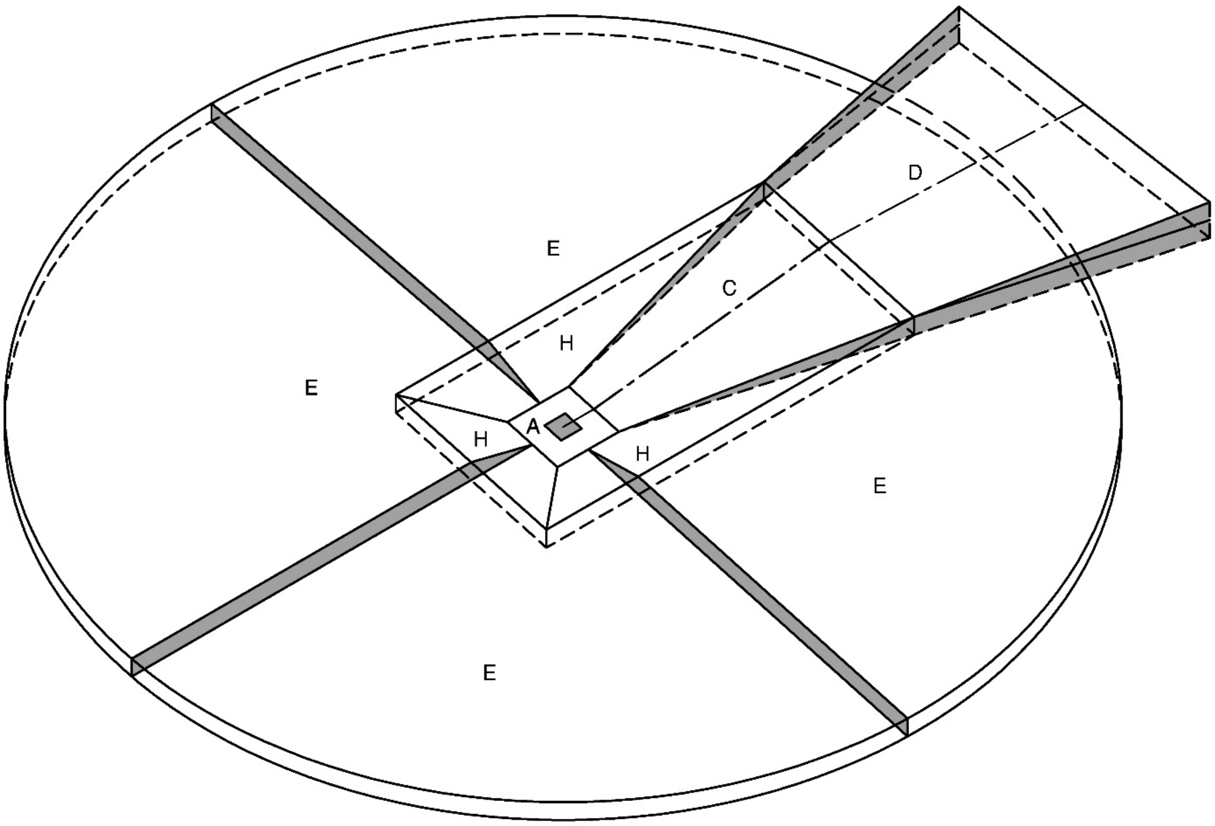
Figure 8-25. Vertical Landing (VL) Pad Facility Clear Zone and Accident Potential Zone for F-35B and Rotary Aircraft



/1/

Figure 8-26. Vertical Landing (VL) Pad Approach Surface Isometric



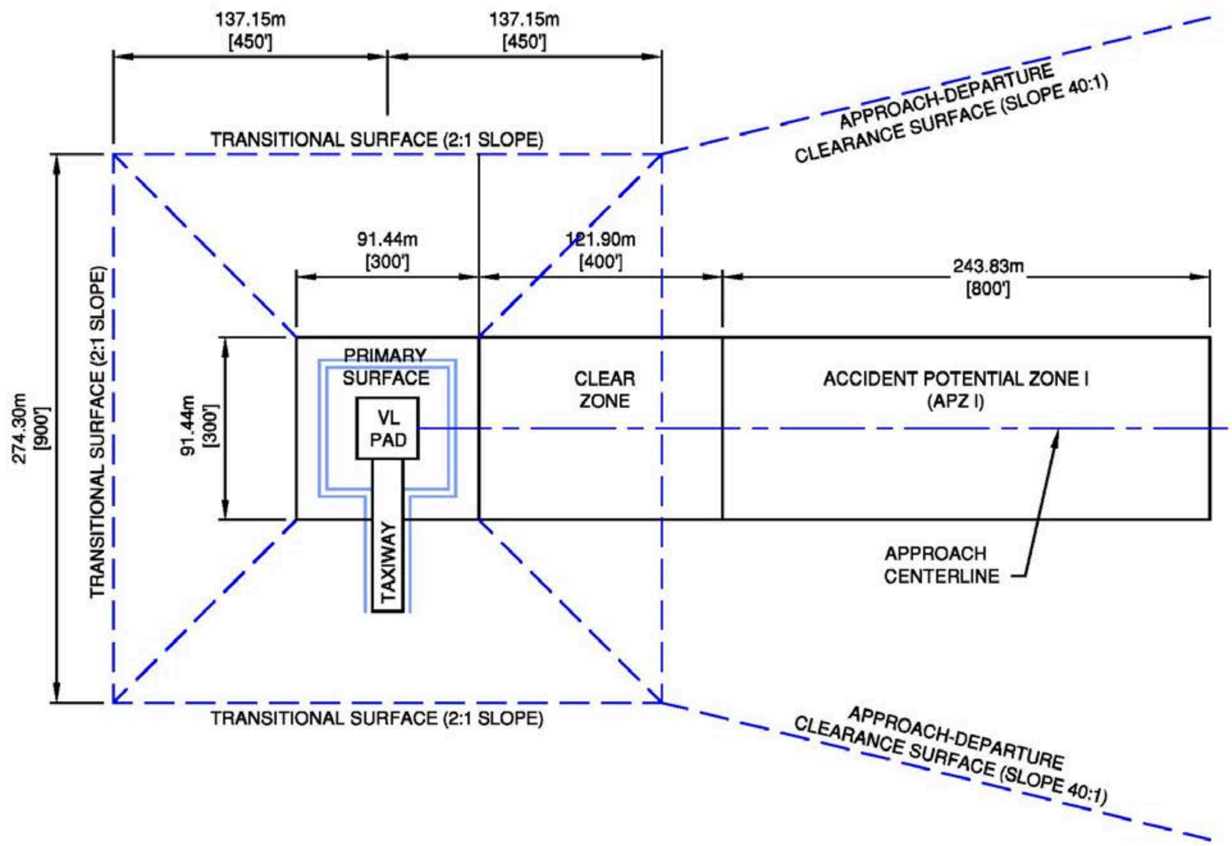
LEGEND

A PRIMARY SURFACE
B CLEAR ZONE SURFACE (NOT SHOWN)
C LOWER APPROACH-DEPARTURE CLEARANCE SURFACE (8:1 SLOPE RATIO)
D UPPER APPROACH-DEPARTURE CLEARANCE SURFACE (40:1 SLOPE RATIO)
E INNER HORIZONTAL SURFACE (45.72m [150'] ELEVATION)
F NOT USED
G NOT USED
H TRANSITIONAL SURFACE (2:1 SLOPE RATIO)
I NOT USED
J ACCIDENT POTENTIAL ZONE (APZ) (NOT SHOWN)

NOTES

1. AIRSPACE IS DEFINED FOR APPROACHES ONLY, NOT DEPARTURES.
2. APPROACH CENTERLINE MAY BE FROM ANY DIRECTION TO THE VL PAD.
3. MULTIPLE APPROACH (OR WAVE-OFF/DEPARTURE) CENTERLINES MAY BE DEFINED.

Figure 8-27. Vertical Landing (VL) Pad Facility Clear Zone and Accident Potential Zone for F-35B Only



NOTES

1. APPROACH CENTERLINE CAN BE PLANNED FROM ANY DIRECTION TO THE VL PAD.
2. MULTIPLE APPROACH (OR WAVE-OFF/DEPARTURE) CENTERLINES MAY BE PLANNED FOR A VL PAD.

Figure 8-28. Vertical Landing (VL) Pad Markings

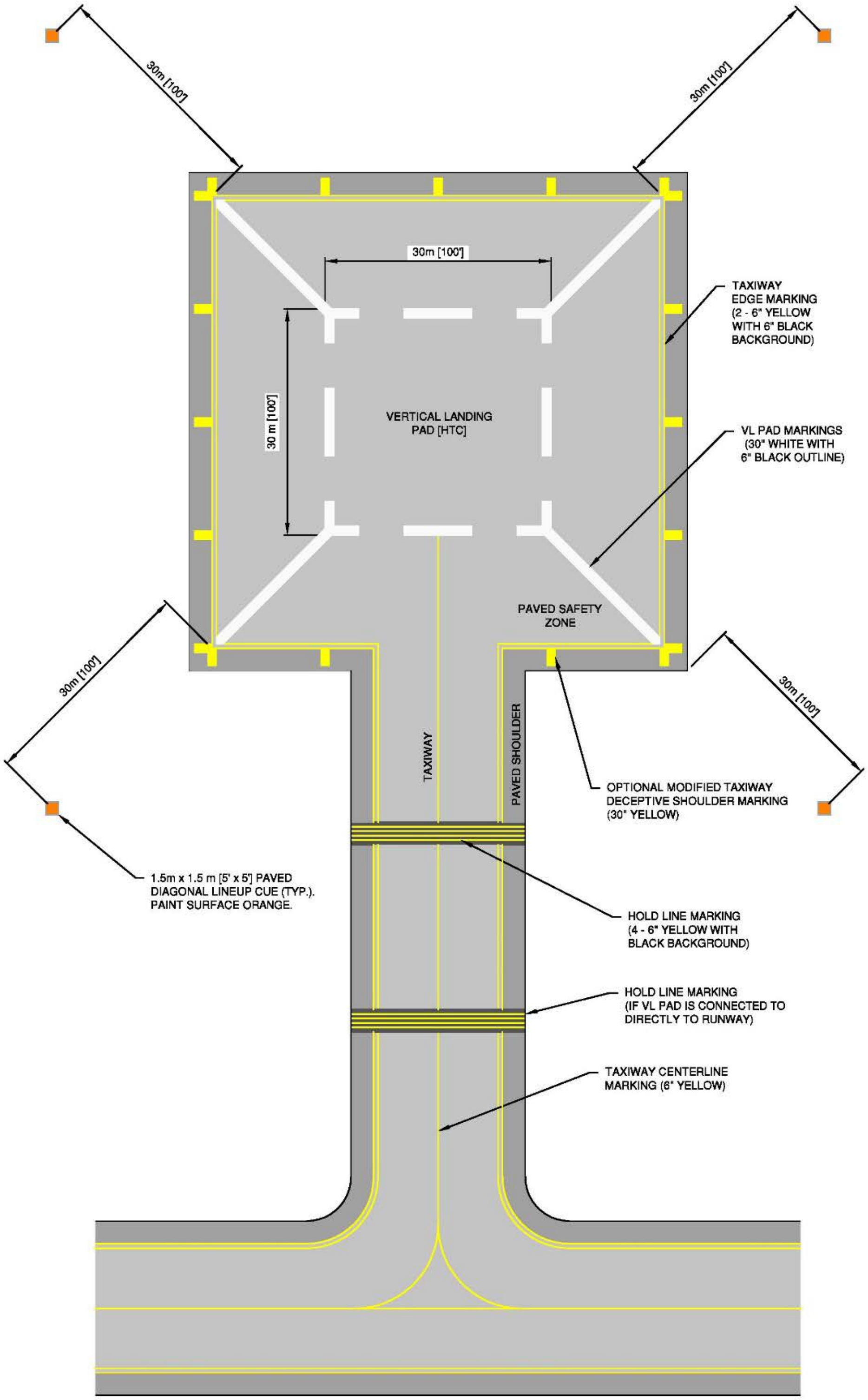


Figure 8-29. Vertical Landing (VL) Pad Lighting

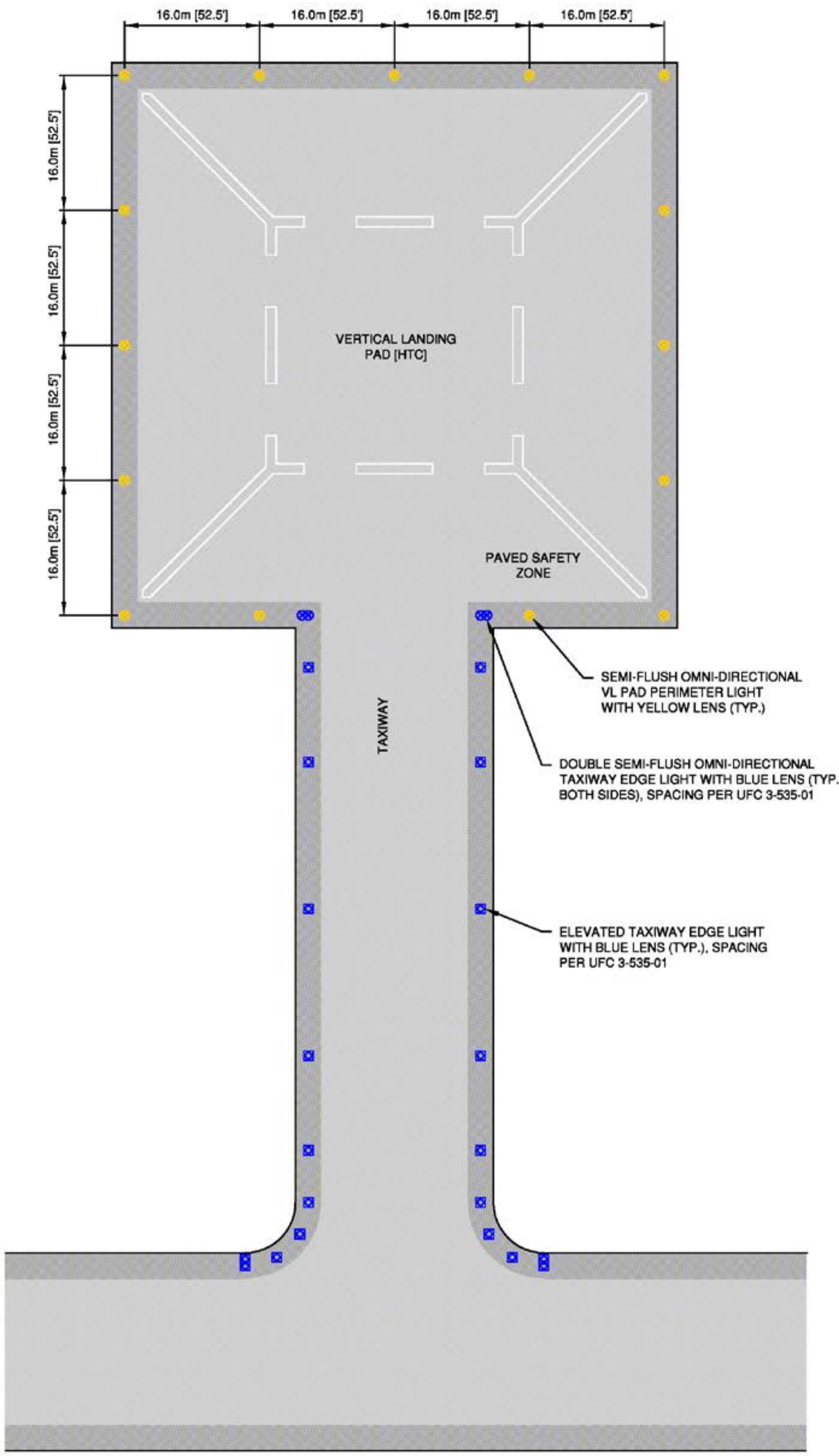
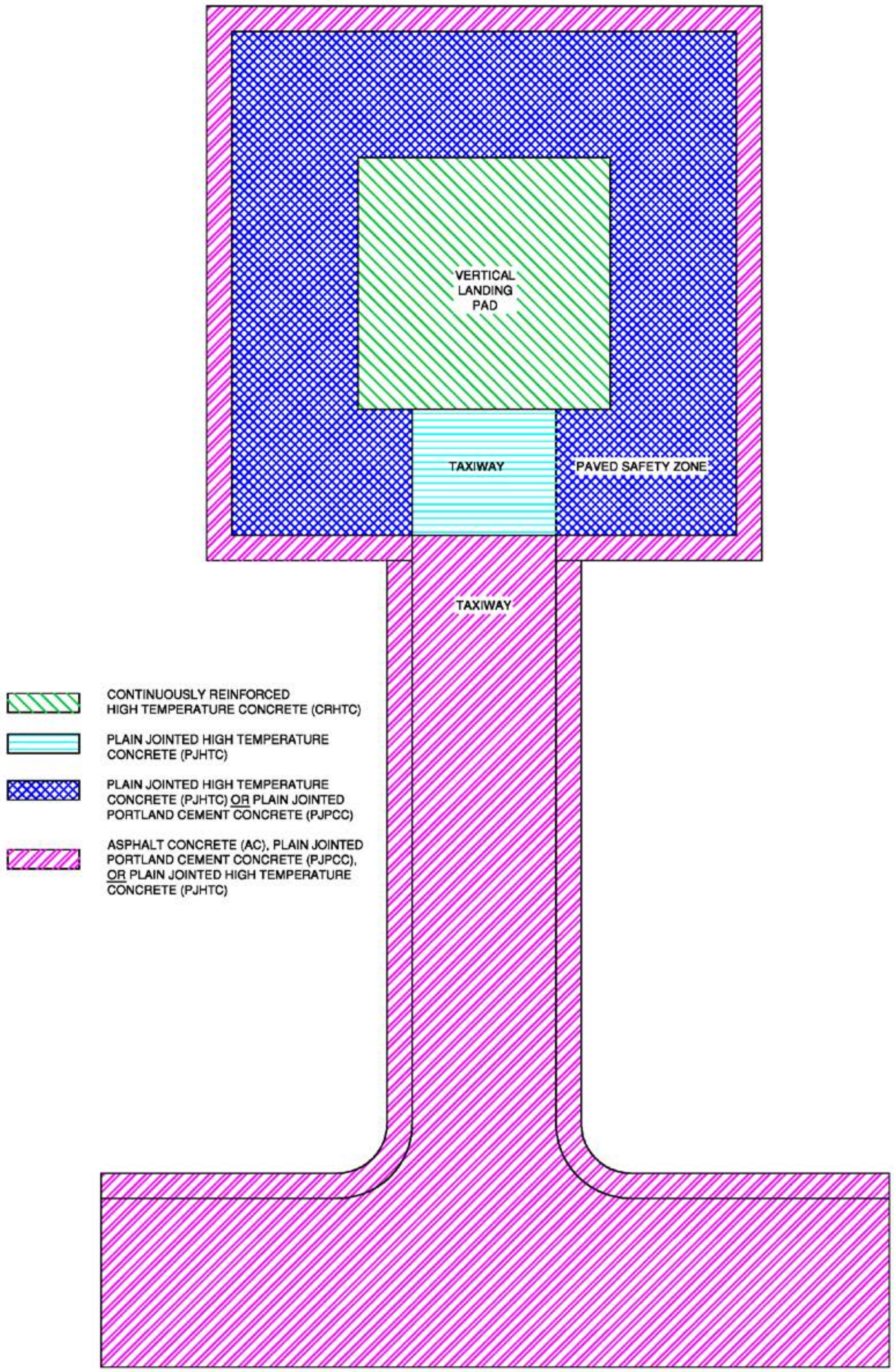


Figure 8-30. VL Pad Pavement Surface Types



8-6 FORWARD OPERATING BASE (FOB) STOVL FACILITY.

8-6.1 FOB Concept.

At some locations, STOVL Forward Operating Base training has incorporated the use of secondary roads or taxiways to support FOB mission Training and Readiness qualification requirements. The size and structure of these facilities varies slightly from location to location; however, in general terms the facility would be narrower and shorter than a standard Class A or B runway. The primary focus of these training evolutions is the training objectives for the pilots and Landing Site Supervisors (LSSs). The primary landing at a FOB in support of those objectives is a precision Rolling Vertical Landing (RVL) with a typical approach speed of 60 knots. The acceptable tolerances for a precision RVL are significantly tighter than the typical RVL flown to a Class B runway. To afford the proper visual cuing and reinforcement of the established tolerances for the FOB training facility the criteria for the C-130 landing zone (60 ft x 3000 ft runway) and similar obstacle clearances are used. The use of these criteria is applicable because the FOB operations will be conducted under Visual Flight Rules and while under the control of a LSS. Use of these accepted criterions has real world applications were FOBs are set up as ground loiter points based on mission necessity and not the availability of host nation airfields. These mission-critical ground loiter points may or may not meet typical obstacle clearance criteria; however, they are robust enough to insure the aviation commander sufficient margin for safe and efficient aircraft operations.

8-6.2 FOB Standard Drawings.

No standard drawings have been developed for FOB facilities. The criteria provided in this chapter must be site-adapted to the proposed location.

8-6.3 FOB Background.

STOVL Forward Operating Base training varies slightly from location to location; however, in general terms the facility would be narrower and shorter than a standard Class A or B runway. The primary focus of these training evolutions is the training objectives for the pilots and Landing Site Supervisors (LSSs). The primary landing at a FOB in support of those objectives is a precision Rolling Vertical Landing (RVL) with a typical approach speed of 150 knots, landing at approximately 60 knots. The acceptable tolerances for a precision RVL are significantly tighter than the typical RVL flown to a Class B runway. To afford the proper visual cuing and reinforcement of the established tolerances for the FOB training facility the criteria for the C-130 landing zone (60 ft x 3000 ft runway) and similar obstacle clearances are used. The use of these criteria is applicable because the FOB operations will be conducted under Visual Meteorological Conditions and while under the control of a landing site supervisor. Use of these accepted criterions has real world applications were FOBs are set up as ground loiter points based on mission necessity and not the availability of host nation airfields. These mission-critical ground loiter points may or may not meet typical obstacle clearance criteria, however are robust enough to insure the aviation commander sufficient margin for safe and efficient aircraft operations.

8-6.3.1 Assumptions.

- Airspace imaginary surfaces are defined for a standalone training facility. When the FOB STOVL facility is collocated with an existing DoD airfield and their respective imaginary surfaces overlap, the most restrictive or lower surface will be utilized to ensure obstacle clearance.
- The imaginary surfaces for the FOB STOVL facility provide obstacle clearance for the F-35B day/night visual pattern. The FOB visual landing pattern altitude defines the inner horizontal surface and transitional area elevations. An overhead entry or straight-in visual approach will be the entry maneuver for the FOB visual pattern, and the obstacle clearance needed for these maneuvers define the approach and departure path requirements. These definitions are presented similar to the existing Class B runway criteria.
- A 300-foot primary surface width is used for the FOB STOVL facility because all recoveries will be conducted under VMC and the close supervision of a Landing Site Supervisor.
- Airspace imaginary surfaces extend 1.5 nm abeam and 3.3 nm approach-departure path to support obstacle clearance for aircraft within the landing pattern or maneuvering to a 3 nm initial.

8-6.4 FOB Geometry.

8-6.4.1 Runway, Overrun, and Safety Zone Descriptions.

Figures 8-31 through 8-41, and Table 8-7 provide dimensional criteria for the layout and design of the FOB runway, overruns, and safety zones. The FOB runway should be considered bi-directional unless specifically limited to a single approach and departure path. Overruns and shoulders are provided as safety zones to prevent erosion of graded surfaces by jet blast from aircraft and surface water runoff, and to provide a smooth transition from paved to unpaved surface. Runway shoulders are not required in cases where the runway width meets or exceeds the combined total widths for the runway and shoulders defined in this document. Each zone or surface contains a brief description of their use and reference to where their specific dimension or graphic is located within the document.

8-6.4.2 Runway Length.

Table 8-7 provides the minimum length for the FOB runway. Training and operational facilities will be of various lengths based on facilities available, elevation, and supported mission.

8-6.4.3 Runway Width.

Table 8-7 provides the minimum width for the FOB runway. Training and operational facilities will be of various widths based on facilities available and supported mission.

8-6.4.4 Gradients of Operational Surfaces.

Gradient constraints are based upon sufficient slope to insure surface water runoff. A uniform transverse slope is preferable to eliminate irregularities between landing gear at touchdown. For this reason, the FOB runway should be centerline crowned or the entire runway sloped in one direction. Either sloping scheme will provide the pilot with a consistent uniform surface adequate for touchdown. See Table 8-7.

8-6.4.5 Overrun Length.

Table 8-7 provides the length of the overrun for both the approach and departure ends. This length is dependent on the STO profile and the distance from the FOB runway where the profile reaches a minimum altitude of 150 ft AGL.

8-6.4.6 Overrun Width.

Table 8-7 provides the width of the overrun. This width, at a minimum, reflects the width of the FOB runway plus any shoulder width and will be centered on the extended runway centerline.

8-6.4.7 Shoulder Length.

Table 8-7 provides the length of the shoulder. This length is dependent on the length of the FOB runway and ties into the overrun on both ends of the FOB runway for one continuous surface.

8-6.4.8 Shoulder Width.

Table 8-7 provides the width of the shoulder. This width is designed to prevent soil erosion from jet blast or surface water runoff and provide a smooth transition to the graded unpaved shoulder areas.

8-6.5 FOB Separation Distances.

Table 8-7 provides the minimum separation distances between permanent runways/helipads and the FOB runway for simultaneous operations. Table 8-7 provides the minimum separation distances between permanent Class A or Class B Runways and FOB runway for non-simultaneous operations.

8-6.6 FOB Clear Zones, Imaginary Surfaces, and APZs.

Figures 8-35 through 8-39 and Tables 8-8 and 8-9 provide applicable clearances and grade controls for a reasonable level of safety. Their description and layout are similar to other airfield types and are not unique to the FOB runway or facility. Each zone or surface contains a brief description of their use and reference to where their specific dimension or graphic is located within the document.

8-6.6.1 Clear Zones.

Runway clear zones are areas on the ground, located at the ends of each runway. The FOB runway should be considered bi-directional unless specifically limited to a single approach and departure path. They possess a high potential for accidents, and their use is restricted to be compatible with aircraft operations. Runway clear zones are required for the runway and should be owned or protected under a long-term lease. See Table 8-9.

8-6.6.2 Imaginary Surfaces.

Surfaces in space established around a STOVL facility in relation to the FOB runway and designed to define the protected airspace around the STOVL facility. The imaginary surfaces for the FOB STOVL facilities are the primary surface, transitional surface, inner horizontal surface, conical surface, outer surface and approach-departure path surfaces. See Table 8-8.

8-6.7 Accident Potential Zones.

Accident Potential Zones of a STOVL facility that possesses a significant potential for accidents, and their use is restricted in accordance with DoDI 4165.57. Their dimensions and layout are listed in Table 8-9. Navy planners will use OPNAVINST 11010.36C/MCO 11010.16 (or latest version) to determine specific AICUZ requirements. For the Air Force, land use guidelines within the clear zone (beyond the graded area) and APZ I and APZ II are provided in AFI 32-7063 and AFH 32-7084.

8-6.8 FOB Pavement Markings.

No pavement markings are <u>required</u> for FOB STOVL Facilities; however, at locations where FOB STOVL facilities will be used for training or long-term operations, it is desirable to apply painted markings to the pavement surface to enhance safety. When needed, apply markings to FOB pavements using reflective airfield marking paint, following the general scheme shown in Figure 8-40.

8-6.8.1 Threshold Bar.

White threshold stripes may be marked at each end of the FOB runway to distinguish between the overrun and the FOB runway surface. The marking will be 1.2 meters (4 feet) wide and extend from edge to edge of the FOB runway surface.

8-6.8.2 Edge Stripes.

White side stripes should be painted when there is no visual distinction between the FOB runway surface and the paved shoulder (e.g. both FOB runway and shoulder are asphalt). Edge stripes will be 0.3 meter (1 foot) wide and extend along the entire length of the FOB runway.

8-6.8.3 Taxiway Centerline.

If the FOB runway has connecting taxiways, the taxiway centerline turn radius will not be extended onto the FOB runway surface.

8-6.8.4 Taxiway, Apron and Turnaround Edge Stripes.

If FOB STOVL facility taxiways, aprons or turnarounds have paved shoulders and there is no visual distinction between the edge of load-bearing pavement and the shoulder, the edge of full-strength pavement will be marked with two 152-millimeter (6-inch) wide yellow stripes separated by a 152-millimeter (6-inch) wide gap.

8-6.8.5 Holding Position Marking.

The holding position is located a minimum of 30.5 meters (100 feet) from the near edge of the FOB runway. This distance is measured perpendicular to the long axis of the runway. For holding position marking dimensions, see Service-specific airfield marking guidance.

8-6.8.6 Touchdown Box Markings (Optional).

When desired by the airfield manager, touchdown box markings may be applied. These markings consist of 0.9-meter (3-foot) -wide white stripes that extend transversely across the entire width of the runway surface. The stripes are located 30.5 meters and 152 meters (100 feet and 500 feet) from the approach end threshold.

8-6.8.7 Runway Designation Markings.

Runway designation markings will not be used on FOB runways.

8-6.8.8 Runway Centerline (Optional).

When desired by the airfield manager, runway centerline stripes may be applied. Stripes are 0.5 meter to 0.9 meter (1.5 feet to 3 feet) wide and 30.5 meters (100 feet) long, with an 18.3-meter (60-foot) gap between stripes.

8-6.9 FOB Lighting.

No airfield lighting is <u>required</u> for FOB STOVL Facilities; however, at locations where FOB STOVL facilities will be used for training or long-term operations, it is desirable to install edge light systems to enhance safety. When needed, install edge lights on the FOB STOVL Facility following the general scheme shown in Figure 8-41. See UFC 3-535-01 for lighting component details. Lighting layout generally follows the Chapter 7 AMP-1 Lighting Layout.

8-6.10 FOB Pavement Surface Types.

Figure 8-42 shows the pavement types needed for FOB Runway Facilities. Pavements on the FOB Runway must be constructed with PJPCC. Life-cycle cost considerations should be used to determine the whether CRPCC is cost effective to reduce the number of pavement joints subjected to high pressures during takeoff operations and thereby reduce future maintenance demands. Shoulder pavements may be constructed with PJPCC or HMA. Overruns will be designed to match the runway pavement. Special design consideration may be needed if the overrun is used as a taxiway or turnaround area.

Table 8-7. Forward Operating Base (FOB) STOVL Runway Criteria

Table 8-7. Forward Operating Base (FOB) STOVL Facility Runway Criteria			
Item		Requirement	Remarks
No.	Description		
1	Length	914 m (3,000 ft)	
2	Width	Min. 10m (32ft)	Typical width is 18.5m (60 ft).
3	Width of shoulders	Min. 3 m (10 ft)	Navy and Marine Corps airfields
4	Paved shoulder width	3 m (10 ft)	Navy and Marine Corps airfields
5	Paved Overrun length	Min 91.44 m (300 ft)	The length of the overrun may be dependent on the approach path length where the aircraft will be below 25 ft AGL.
6	Paved Overrun width	Min.15.85m (52 ft)	The width of the Overrun will match the total width of the runway plus shoulders. Typical width is 24.5m (80 ft).
7	Graded Clear Zone Length	Min. 60.96 m (500 ft)	Measured from the runway threshold. Corresponds to the Clear Zone Area.
8	Graded Clear Zone Width	Min. 91.44 m (300 ft)	Centered on the runway centerline. Corresponds to the Clear Zone area.
9	Longitudinal grades of runway and shoulders	Max 3.0%	Grades may be both positive and negative but must not exceed the limit specified. - Grade restrictions are exclusive of other pavements and shoulders. - Where other pavements tie into runways, comply with grading requirements for towways, taxiways, or aprons as applicable, but hold grade changes to the minimum practicable to facilitate drainage.
10	Longitudinal runway grade change	Max 1.5% per 61m (200 ft)	Where economically feasible, the runway will have a constant centerline gradient from end to end.

Table 8-7. Forward Operating Base (FOB) STOVL Facility Runway Criteria			
Item		Requirement	Remarks
No.	Description		
11	Longitudinal Overrun grade	Max 3.0%	Grades may be both positive and negative but must not exceed the limit specified. Grade restrictions are exclusive of other pavements and shoulders. - Where other pavements tie into runways, comply with grading requirements for towways, taxiways, or aprons as applicable, but hold grade changes to the minimum practicable to facilitate drainage.
12	Graded Clear Zone slope	Max. 10.0%	Does not apply to overrun paved surfaces. Grades may be both positive and negative but must not exceed the limit specified. Applies to both longitudinal and transverse directions.
13	Transverse grade of runway	Min 0.5% Max 3.0%	- New STOVL training facility pavements will be centerline crowned to insure adequate drainage of surface water. - Existing STOVL facility and runway pavements with insufficient transverse gradients for rapid drainage should provide increasing gradients when overlaid or reconstructed.
14	Transverse grade of paved shoulder	Min 1.5% Max 5.0%	Paved portion of shoulder Slope downward from runway pavement. Reversals are not allowed.
15	Transverse grade of Overrun	Min 0.5% Max 3.0%	Slope pavement downwards from the runway with no reversals to insure adequate drainage of surface water. Exception is at or adjacent to intersections where the pavement surfaces must be warped to match abutting pavements.
16	Runway Lateral Clearance Zone (corresponds to half the width of primary surface)	45.72 m (150 ft)	Supports VFR operations - Measured perpendicularly from centerline of STOVL facility. This area is to be clear of fixed and mobile obstacles. - In addition to the lateral clearance criterion, the vertical height restriction on structures and parked aircraft as a result of the transitional slope must be taken into account. - Fixed obstacles include man-made or natural features constituting possible hazards to moving aircraft.
17	Transverse grades within Runway Lateral Clearance Zone	Max 10.0%	- Exclusive of pavement, shoulders, and cover over drainage structures. - Slopes are to be as gradual as practicable. Avoid abrupt changes or sudden reversals. Rough grade to the extent necessary to minimize damage to aircraft.
18	Distance from centerline of fixed-wing runway to the centerline of a parallel	Min 213.36m (700 ft)	Simultaneous VFR operations for Class A runway
		Min 304.80 m (1,000 ft)	Simultaneous VFR operations for Class B runway.

Table 8-7. Forward Operating Base (FOB) STOVL Facility Runway Criteria			
Item		Requirement	Remarks
No.	Description		
	FOB runway	Min 213.36m (700 ft)	Non- simultaneous VFR operations. Distance may be reduced to 60.96m (200ft); however, waiver must be based on wake-turbulence and jet blast. FOB may be sited within the adjacent runway primary surface but must be positioned outside the adjacent runway hold position markings.

Table 8-8. Forward Operating Base (FOB) STOVL Airspace Imaginary Surfaces

Table 8-8. FOB STOVL Airspace Imaginary Surfaces				
Item		Legend	Requirement	Remarks
No.	Description			
1	Primary surface width	A	91.44 m (300 ft)	Centered on FOB runway.
2	Primary surface length	A	Runway length + 60.96 m (200 ft) at each end	Primary surface extends 60.96 m (200 ft) beyond each end of the FOB runway
3	Primary surface elevation	A	See Remarks	The elevation of the primary surface is the same as the elevation of the nearest point on the FOB runway centerline
4	Clear Zone longitudinal and transverse grade of surface	B	Max 10.0%	See Table 8-4, Safety Zone Grades
5	Start of approach-departure Surface	C	60.96 m (200 ft)	Measured from the end of the FOB runway.
6	Length of sloped portion of approach-departure surface	C	Min 5334 m (17,500 ft)	Measured horizontally
7	Slope of approach-departure surface	C	35:1	Slope ratio is horizontal: vertical. Example: 35:1 is 35 m (ft) horizontal to 1 m (ft) vertical.
8	Width of approach-departure surface at start of sloped portion	C	91.44 m (300 ft)	Centered on the extended FOB runway centerline and is the same width as the primary surface.

Table 8-8. FOB STOVL Airspace Imaginary Surfaces				
Item		Legend	Requirement	Remarks
No.	Description			
9	Width of approach-departure surface at end of sloped portion	C	891.5 m (2,925 ft)	- Centered on the extended FOB runway centerline. - The 1000:75 width ratio is horizontal length: horizontal width. This ratio is consistent with class-A VFR runway requirements. - At US Navy and Marine Corps VTSOL facilities where the lateral clearance was established according to previous criterion, that distance may remain.
10	Elevation of approach-departure surface at start of sloped portion	C	0 m (0 ft)	Same as the FOB runway centerline at the threshold.
11	Elevation of approach-departure surface at end of sloped portion	C	152.4 m (500 ft)	Above the established FOB runway elevation.
12	Start of horizontal portion of approach-departure surface	D	Min 5334 m (17,500 ft)	Measured from the end of the primary surface. The end of the primary surface (start of the approach-departure surface) is 60.96 m (200 ft) from the end of the FOB runway.
13	Length of horizontal portion of approach-departure surface	D	Min 4419 m (14,500 ft)	Measured horizontally along the ground. Total approach path length is the same total length as the LZ approach path 9,753 m (32,000 ft).
14	Width of approach-departure surface at start of horizontal portion	D	891.5 m (2,925 ft)	Centered along the FOB runway extended centerline.
15	Width of app-dep surface at end of horizontal portion	D	1,555 m (5,100 ft)	- Centered along the FOB runway extended centerline. - The 1000:75 width ratio is horizontal length: horizontal width. This ratio is consistent with class-A VFR runway requirements.
16	Elevation of horizontal portion of approach-departure surface	D	152.4 m (500 ft)	Above the established FOB runway elevation
17	Radius of inner horizontal surface	E	1,600 m (5,250 ft)	Imaginary surface constructed by scribing an arc with a radius of 1,600m (5,250 ft) about the centerline at each end of the FOB runway and interconnecting these arcs with tangents.

Table 8-8. FOB STOVL Airspace Imaginary Surfaces				
Item		Legend	Requirement	Remarks
No.	Description			
18	Width between outer edges of inner horizontal surface	E	3,200 m (10,500 ft)	
19	Elevation of inner horizontal surface	E	45.72 m (150 ft)	Above the established FOB runway elevation. Exception: When the FOB is adjacent to an airfield, the inner horizontal surface is established to match the adjacent airfield's inner horizontal surface.
20	Horizontal width of conical surface	F	NA	Conical surface not required
21	Slope of conical surface	F	NA	Conical surface not required
22	Elevation of conical surface at start of slope	F	NA	Conical surface not required
23	Elevation of conical surface at the end of slope	F	NA	Conical surface not required
24	Distance to outer edge of conical surface	G	NA	Outer horizontal surface not required
25	Width of outer horizontal surface	G	NA	Outer horizontal surface not required
26	Elevation of outer horizontal surface	G	NA	Outer horizontal surface not required
27	Distance to outer edge of outer horizontal surface	G	NA	Outer horizontal surface not required
28	Start of transitional surface	H	45.72 m (150 ft)	Measured perpendicularly from FOB runway centerline.
29	End of transitional surface	H	Various	The transitional surface ends at the inner horizontal surface, conical surface, or at an elevation of 45.72 m (150 ft). See NOTE 1.

Table 8-8. FOB STOVL Airspace Imaginary Surfaces				
Item		Legend	Requirement	Remarks
No.	Description			
30	Slope of transitional surfaces	H	2:1	- Slope ratio is horizontal: vertical. 2:1 is 2 m (ft) horizontal to 1 m (ft) vertical. - Vertical height of vegetation and other fixed or mobile obstacles and/or structures will not penetrate the transitional surface. Taxiing aircraft are exempt from this requirement. - For Navy and Marine Corps airfields, taxiway pavements are exempt from this requirement. - For the USAF, the air traffic control tower is exempt from this requirement if the height will not affect TERPS criteria.

NOTES:

1. When the FOB STOVL facility is located within the boundaries of an existing DoD airfield and the imaginary surfaces of the two facilities overlap, the FOB STOVL facility transitional surface elevation will extend to meet the existing inner horizontal surface elevation of the DoD airfield. The FOB STOVL facility imaginary surface requirements may be waived provided the existing DoD airfield imaginary surfaces meet or exceed the obstacle clearance requirements defined by the imaginary surfaces in Table 8-8.
2. When the FOB STOVL facility is located parallel with an existing DoD runway use of the runway approach/departure surface may suffice for the FOB STOVL facility approach/departure surface provided a visual transition between the path and the FOB STOVL facility can be conducted while under VMC conditions.

Table 8-9. Forward Operating Base (FOB) STOVL Facility Clear Zone and APZs

Item No.	Item Description	Legend	Requirement	Remarks
1	Clear Zone	B	Length: 152.40m (500 ft) Width: 91.44m (300 ft)	Length measured along the extended runway centerline beginning at the end of the runway. Width measured perpendicular to the extended runway centerline.
2	APZ I	J	Length: 762.00m (2,500 ft) Width: 152.40m (500 ft)	APZ I starts at the end of the clear zone, and is centered and measured on the extended runway centerline. Modification (reduction) from class-A runway requirement is made because all STOVL facility operations will be VMC, and all landings and departures will be under the supervision of a Landing Site Supervisor (LSS).
3	APZ II	J	Length: 762.00m (2,500 ft) Width: 304.80m (1,000 ft)	APZ II starts at the end of the APZ I and is centered and measured on the extended runway centerline. Class A runway criteria are used because all STOVL facility operations will under VMC, and all landings and departures will be under the supervision of a Landing Site Supervisor (LSS).

Figure 8-31. Forward Operating Base STOVL Facility Outline

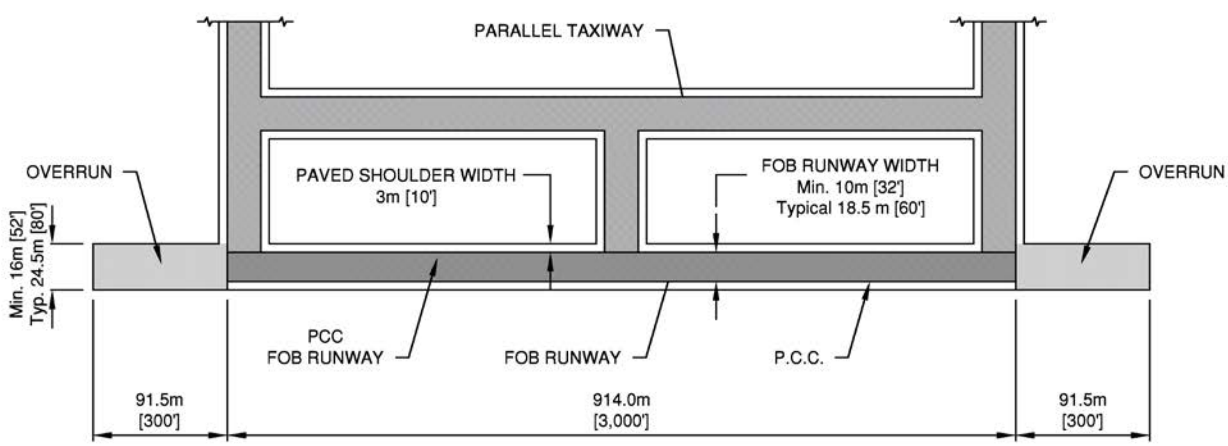


Figure 8-32. Forward Operating Base STOVL Facility with Clearance Zones

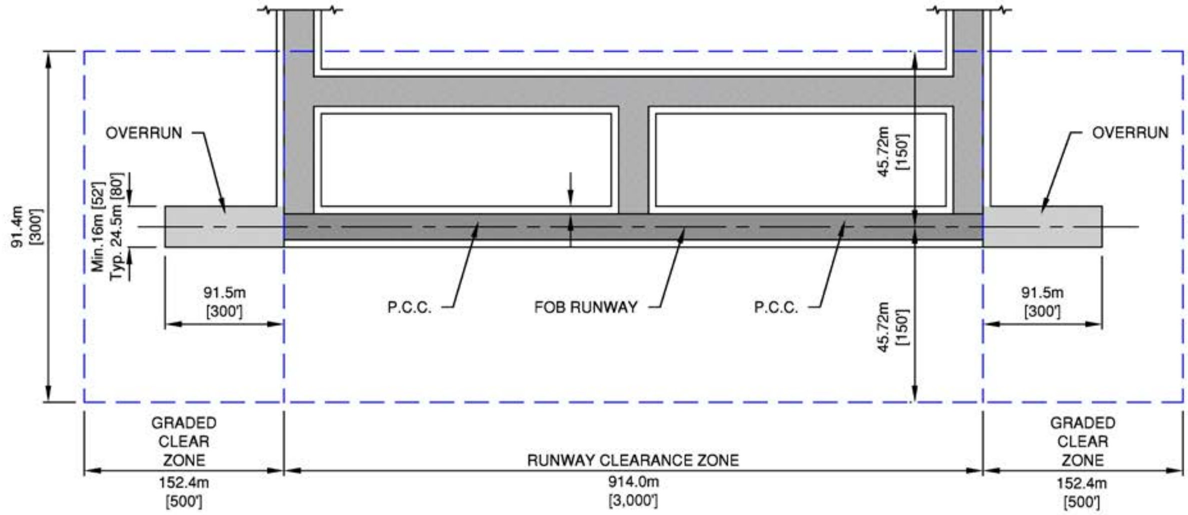


Figure 8-33. Forward Operating Base STOVL Facility Longitudinal Gradient

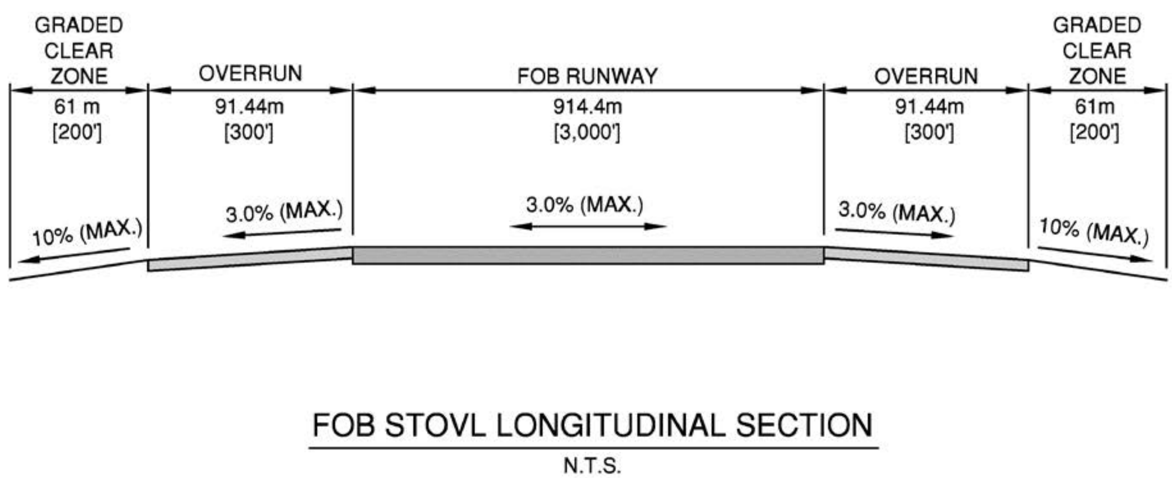


Figure 8-34. Forward Operating Base STOVL Facility Transverse Section

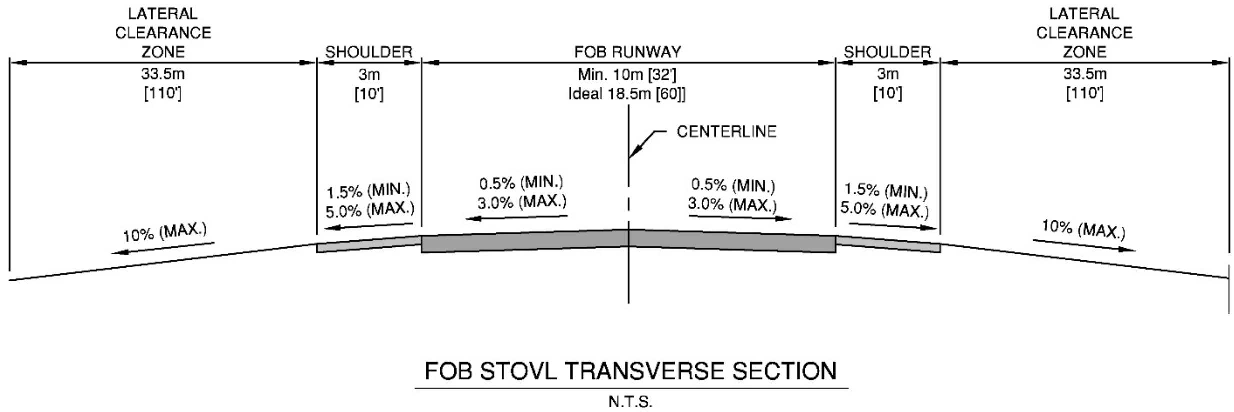


Figure 8-35. Forward Operating Base STOVL Facility Departure Clearance Surface and Clear Zone

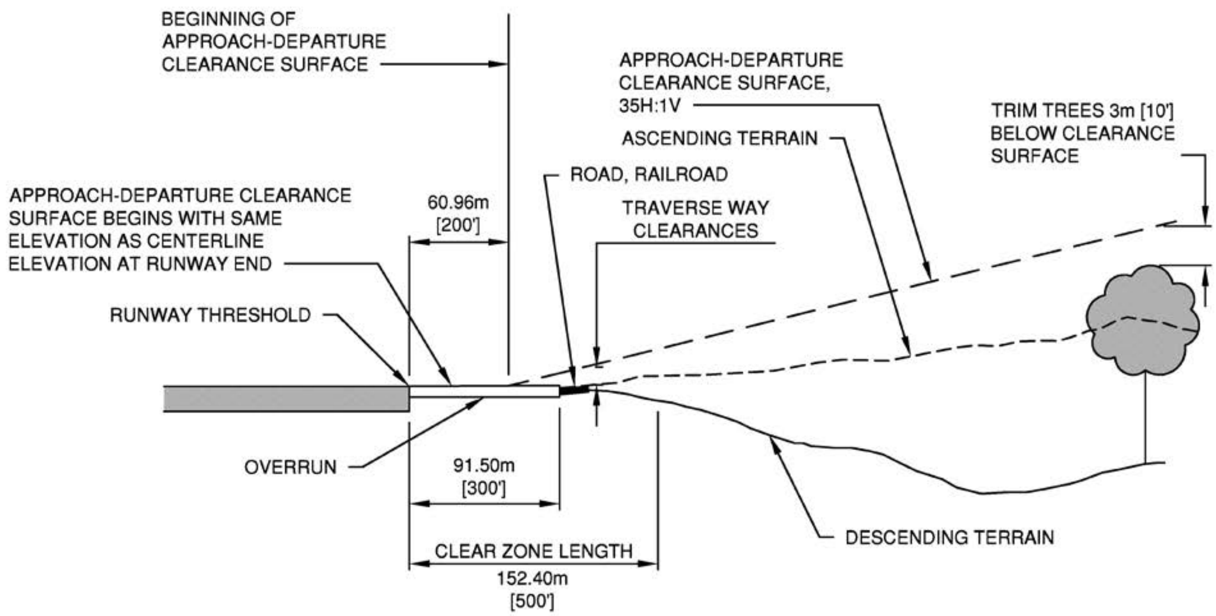


Figure 8-36. Forward Operating Base STOVL Facility Departure Clear Zones and APZs

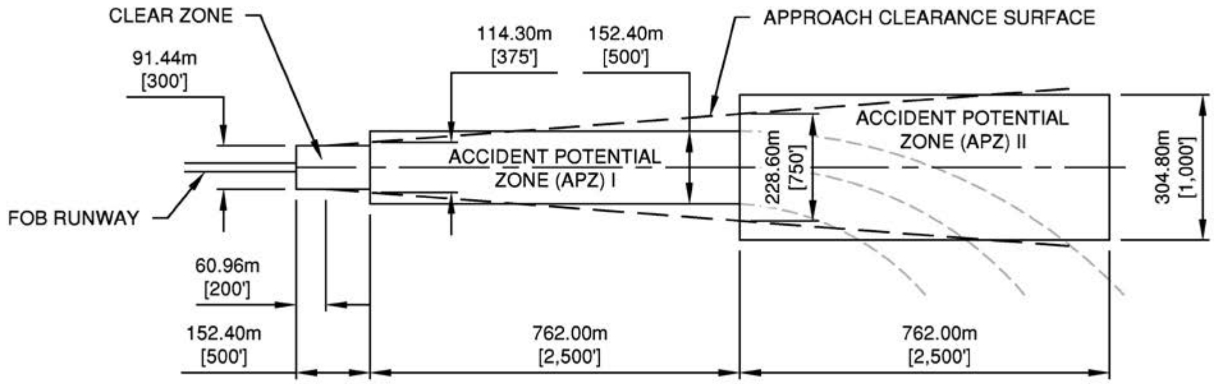


Figure 8-37. Forward Operating Base STOVL Facility Isometric

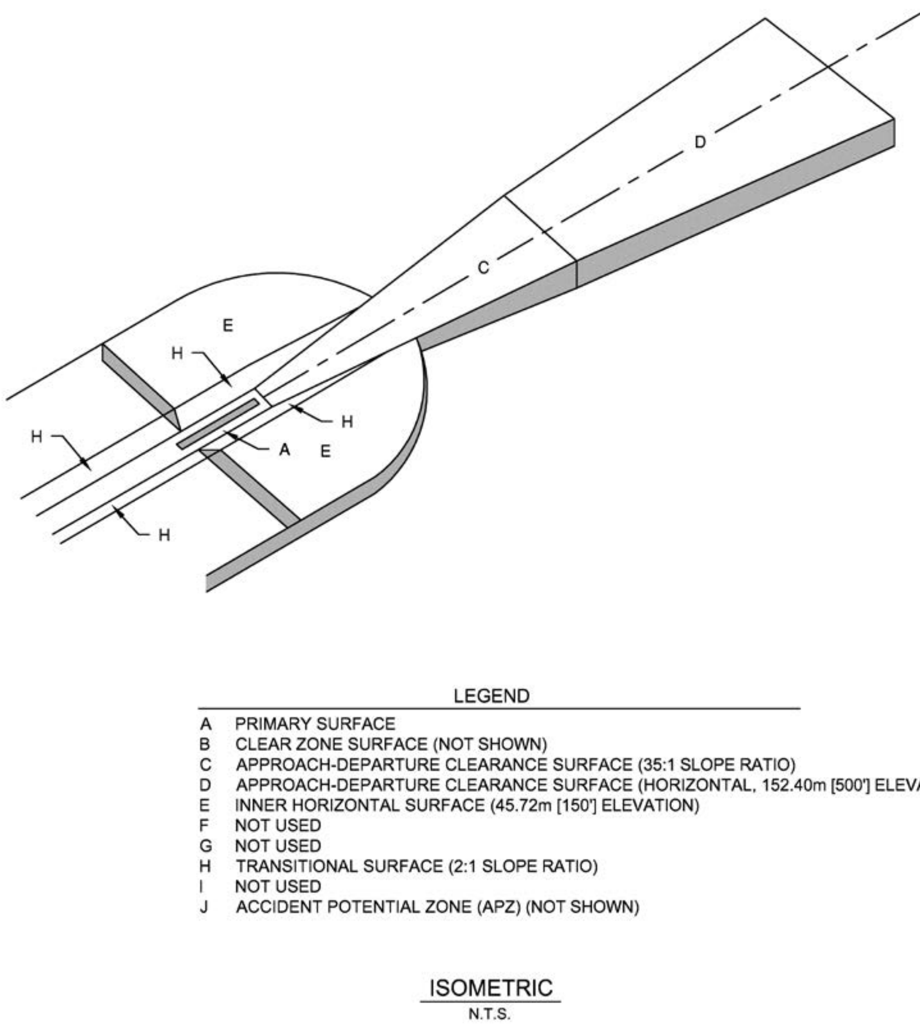


Figure 8-38. Forward Operating Base STOVL Facility Imaginary Surfaces

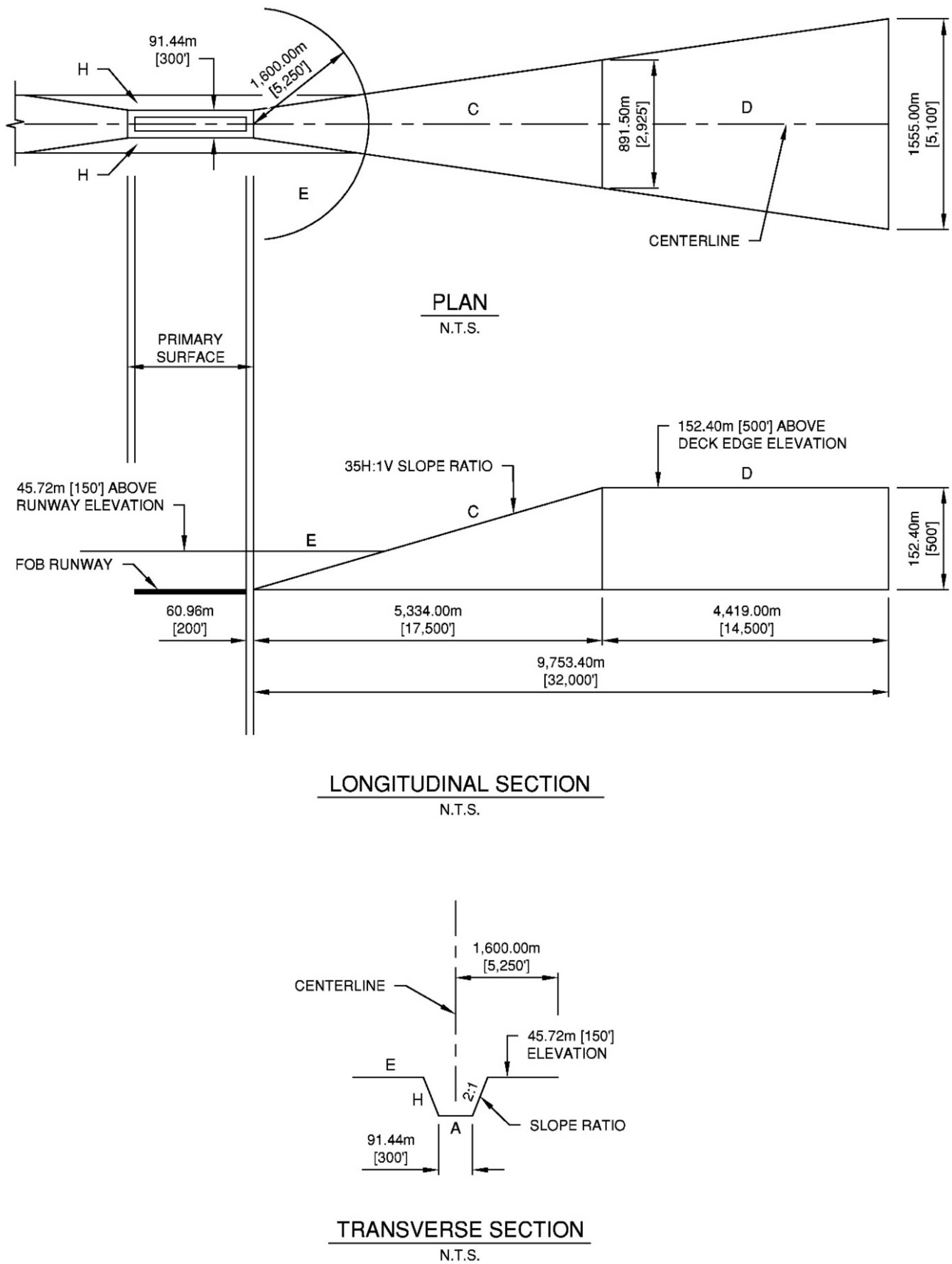


Figure 8-39. Forward Operating Base STOVL Facility Runway End Detail

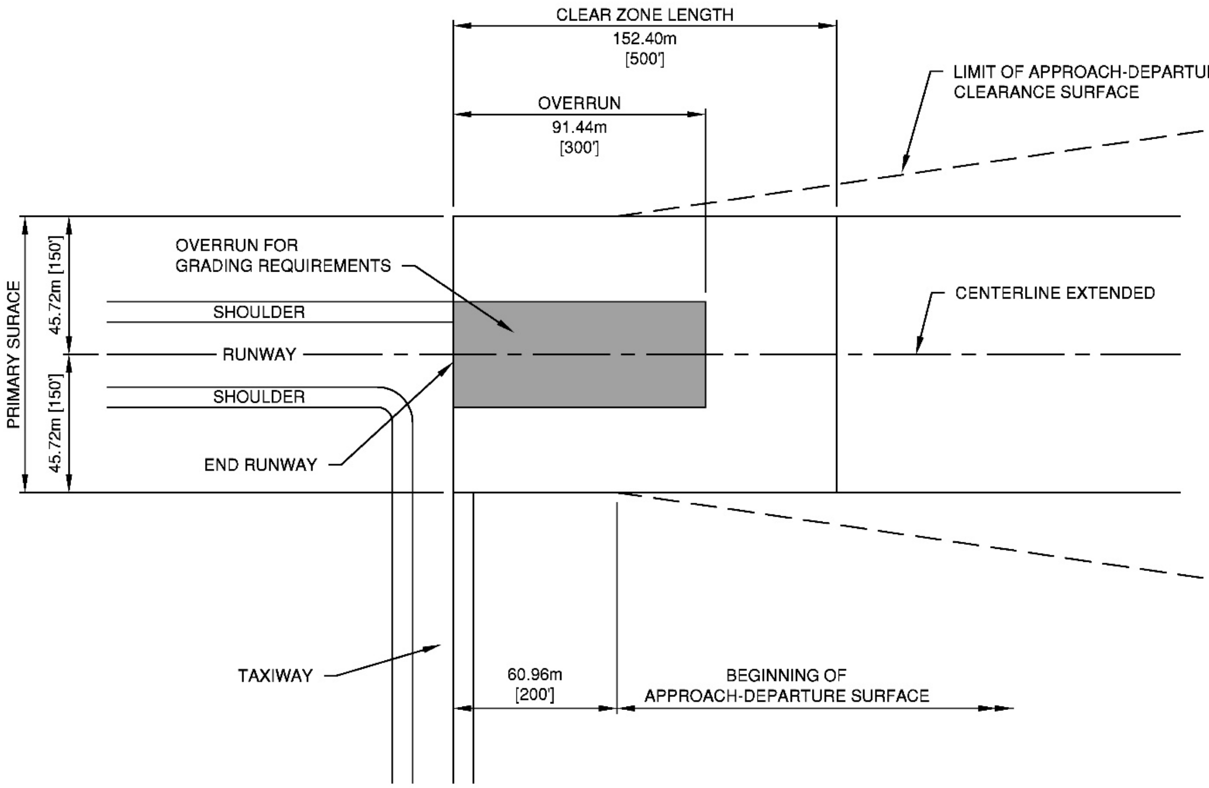


Figure 8-40. Forward Operating Base STOVL Facility Markings

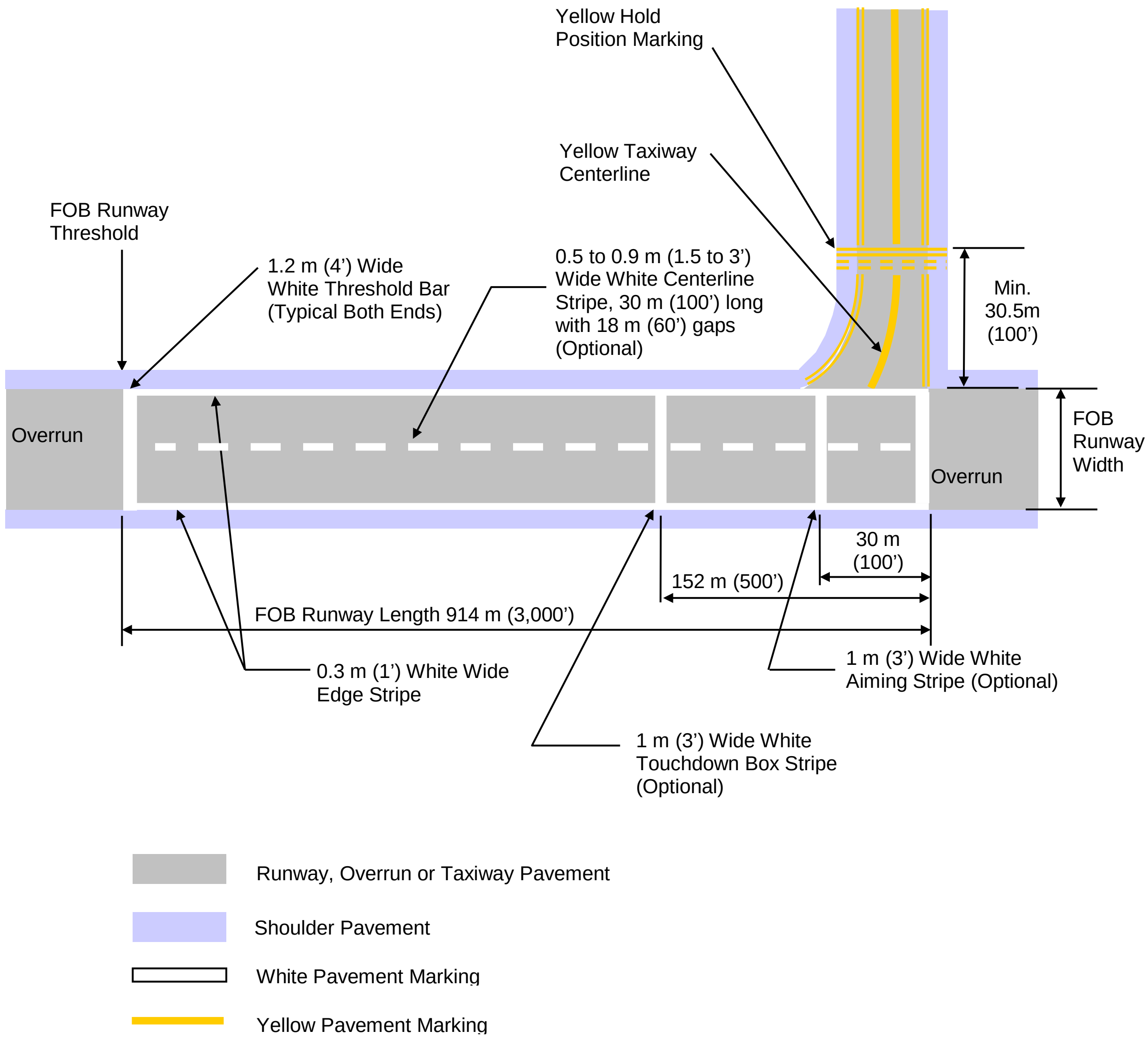


Figure 8-41. Forward Operating Base STOVL Facility Lighting

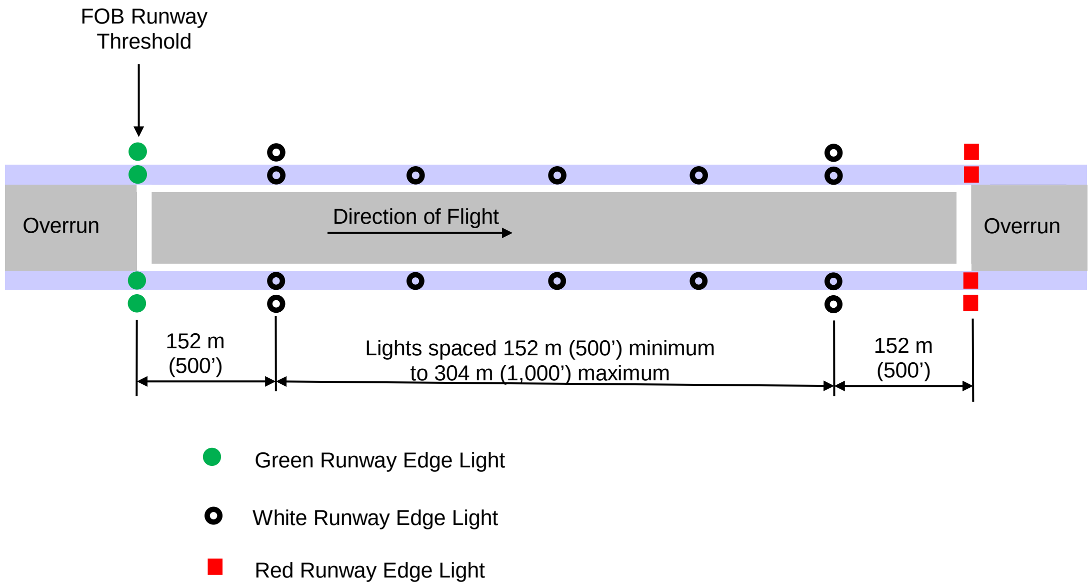
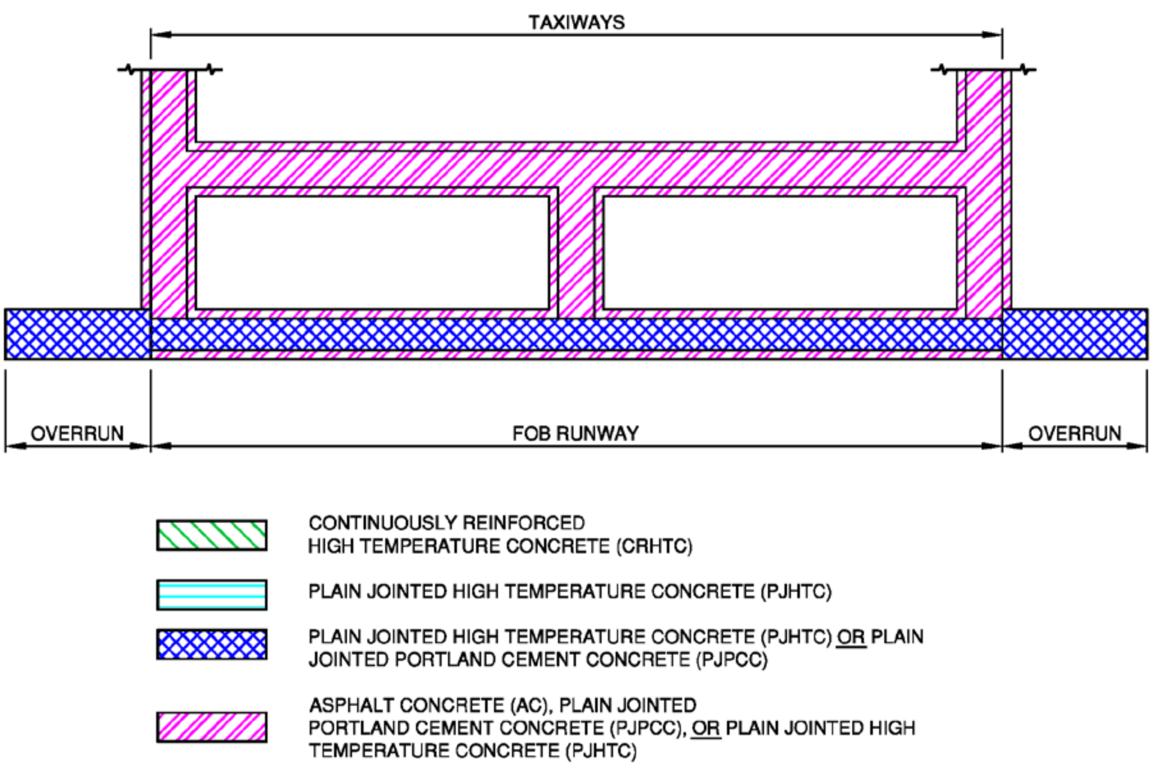


Figure 8-42. STOVL FOB Pavement Surface Types



8-7 V-22 TILT-ROTOR OUTLYING LANDING FIELD (OLF) FACILITY FOR TRAINING.

8-7.1 OLF Concept.

OLFs are auxiliary airfields generally located near and associated with a Naval or Marine Corps Air Station. OLF's have no based units or aircraft and only minimal facilities. They are usually positioned in an area with low aircraft traffic to provide proficiency training and flexibility for degraded aircraft system recovery.

8-7.2 OLF Standard Drawings.

No standard drawings have been developed for OLF facilities. The criteria provided in this chapter must be site-adapted to the proposed location.

8-7.3 OLF Background.

OLF training varies slightly from location to location; however, in general terms the facility would be narrower and shorter than a standard Class A or B runway. OLFs are auxiliary airfields, generally located near and associated with a Naval or Marine Corps Air Station. In most cases, OLF's have no based units or aircraft and only minimal facilities. They are usually positioned in an area with low aircraft traffic for flight training, with reduced risks and distractions of other aircraft traffic.

8-7.3.1 Assumptions.

- Airspace imaginary surfaces are defined for a standalone training facility.
- The imaginary surfaces for the OLF facility provide obstacle clearance for the V-22 visual landing pattern. The OLF visual landing pattern altitude defines the inner horizontal surface and transitional area elevations. An overhead entry or straight-in visual approach will be the entry maneuver for the OLF visual pattern, and the obstacle clearance needed for these maneuvers define the approach and departure surface requirements. These definitions are presented similar to the existing Class B runway criteria.
- A 300 m (1,000-ft) primary surface width is used for the OLF facility.

8-7.4 OLF Geometry.

8-7.4.1 OLF Runway, Overrun, and Safety Zone Descriptions.

Figures 8-43 through 8-46 and Table 8-10 provide dimensional criteria for the layout and design of the OLF runway, overruns, and safety zones. The OLF runway should be considered bi-directional unless specifically limited to a single approach and departure path. Overruns and shoulders are provided as safety zones to prevent erosion of graded surfaces by jet blast from aircraft and surface water runoff, and to provide a smooth transition from paved to unpaved surface. Runway shoulders are not required in cases where the runway width meets or exceeds the combined total widths for the runway and shoulders defined in this document. Each zone or surface contains a brief description of their use and reference to where their specific dimension or graphic is located within the document.

8-7.4.2 Runway Length.

Table 8-10 provides the minimum length for the OLF runway. Training and operational facilities will be of various lengths based on facilities available, elevation, and supported mission.

8-7.4.3 Runway Width.

Table 8-10 provides the minimum width for the OLF runway. Training and operational facilities will be of various widths based on facilities available and supported mission.

8-7.4.4 Gradients of Operational Surfaces.

Gradient constraints are based upon sufficient slope to insure surface water runoff. A uniform transverse slope is preferable to eliminate irregularities between landing gear at touchdown. For this reason, the OLF runway should be centerline crowned or the entire runway sloped in one direction. Either sloping scheme will provide the pilot with a consistent uniform surface adequate for touchdown. See Table 8-10 and Figures 8-45 and 8-46.

8-7.4.5 Overrun Length.

Table 8-10 provides the length of the overrun for both the approach and departure ends.

8-7.4.6 Overrun Width.

Table 8-10 provides the width of the overrun. This width, at a minimum, reflects the width of the OLF runway plus any shoulder width and will be centered on the extended runway centerline.

8-7.4.7 Shoulder Length.

Table 8-10 provides the length of the shoulder. This length is dependent on the length of the OLF runway and ties into the overrun on both ends of the OLF runway for one continuous surface.

8-7.4.8 Shoulder Width.

Table 8-10 provides the width of the shoulder. This width is designed to prevent soil erosion from jet blast or surface water runoff and provide a smooth transition to the graded unpaved shoulder areas.

8-7.5 OLF Separation Distances.

Table 8-10 provides the minimum separation distances between permanent runways/helipads and the OLF runway for simultaneous operations. Table 8-10 provides the minimum separation distances between permanent Class A or Class B Runways and OLF runway for non-simultaneous operations.

8-7.6 OLF Clear Zones, Imaginary Surfaces, and APZs.

Figures 8-47 through 8-50 and Tables 8-11 and 8-12 provide applicable clearances and grade controls for a reasonable level of safety. Their description and layout are similar to other airfield types and are not unique to the OLF runway or facility. Each zone or surface contains a brief description of their use and reference to where their specific dimension or graphic is located within the document.

8-7.6.1 Clear Zones.

Runway clear zones are areas on the ground, located at the ends of each runway. The OLF runway should be considered bi-directional unless specifically limited to a single approach and departure path. They possess a high potential for accidents, and their use is restricted to be compatible with aircraft operations. Runway clear zones are required for the runway and should be owned or protected under a long-term lease and must be cleared and graded. See Table 8-12.

8-7.6.2 Imaginary Surfaces.

Surfaces in space established around a STOVL facility in relation to the OLF runway and designed to define the protected airspace around the STOVL facility. The imaginary surfaces for the OLF facilities are the primary surface, transitional surface, inner horizontal surface and approach-departure path surfaces. See Table 8-11.

8-7.6.3 Accident Potential Zones.

A land use control area beyond the clear zone of a STOVL facility that possesses a significant potential for accidents, and their use is restricted in accordance with DoDI 4165.57. Their dimensions and layout are listed in Table 8-12. Navy planners will use OPNAVINST 11010.36C/MCO 11010.16 (or latest version) to determine specific AICUZ requirements. For the Air Force, land use guidelines within the clear zone (beyond the graded area) and APZ I and APZ II are provided in AFI 32-7063 and AFH 32-7084.

8-7.7 OLF Pavement Markings.

No pavement markings are required for OLF facilities.

8-7.8 OLF Lighting.

No airfield lighting is required for OLF facilities.

8-7.9 OLF Pavement Surface Types.

Figure 8-51 shows the pavement types needed for Tilt-Rotor OLF. The paved operations surfaces used for these facilities will be constructed with HMA or PJPCC. Life-cycle cost considerations should be used to determine whether PJHTC is cost effective to improve the durability of the pavement and reduce future pavement demands, particularly for the first and last 150 m (500 ft). Seal joints in rigid pavement with neoprene.

Table 8-10. Tilt-Rotor Outlying Landing Field (OLF) Facility Criteria

Table 8-10. Tilt-Rotor Outlying Landing Field (OLF) Facility Criteria			
Item		Requirement	Remarks
No.	Description		
1	Runway Length	Min. 490 m (1,600 ft)	Basic length to be corrected for elevation and temperature. Increase 10% for each 300 m (1,000 ft) in elevation above 600 m (2,000 ft) MSL and add 4.0% for each 5 degree Celsius (10 degree Fahrenheit), above 15 degree Celsius (59 degree Fahrenheit) for the average daily maximum temperature for the hottest month. (1) Additional runway length will be provided based on operational and training requirements. Justification will be provided on a case-by-case basis. (2) For special mission or proficiency training such as autorotation operations, the length may be increased up to 300 m (1,000 ft) with no additive corrections.
2	Runway Width	Min. 30m (100ft)	
3	Total Width of shoulders (paved and unpaved) adjacent to all operational pavements	Min. 7.5 m (25 ft)	Minimum of 3.75m (12.5 ft) of shoulder width will be paved o provide a minimum width of 37.5 m (125 ft) of paved surface (30 m + 3.75m + 3.75 m (100 ft + 12.5 ft + 12.5 ft)).
4	Paved shoulder width	3.75 m (12.5 ft)	
5	Overrun length (unpaved)	Min 120 m (400 ft)	
6	Overrun width	Min. 37.5 m (125 ft)	The width of the Overrun will match the total width of the runway plus paved shoulders.
7	Longitudinal grades of OLF Runways, Overruns and Shoulders	Max 1.0%	Grades may be both positive and negative but must not exceed the limit specified. - Grade restrictions are exclusive of other pavements and shoulders. - Where other pavements tie into runways, comply with grading requirements for towways, taxiways, or aprons as applicable, but hold grade changes to the minimum practicable to facilitate drainage.

Table 8-10. Tilt-Rotor Outlying Landing Field (OLF) Facility Criteria			
Item		Requirement	Remarks
No.	Description		
8	Longitudinal grade change on OLF Runways, Overruns and Shoulders	Max 0.167% per 30m (100 ft)	Where economically feasible, the runway will have a constant centerline gradient from end to end. Exceptions: 0.4% per 30 m (100 ft) for edge of runways at runway intersections.
9	Transverse grade of runway	Min 1.0% Max 1.5%	OLF Runway may be centerline crowned or single cross-slope to insure adequate drainage of surface water.
10	Transverse grade of paved shoulder	Min 2.0% Max 4.0%	Slope downward from runway pavement. Reversals are not allowed.
11	Transverse grade of unpaved shoulder (adjacent to paved shoulder)	(a) 40 mm (1.5 inches) drop off at edge of paved shoulder (b) 5% slope first 3 m (10 ft) (c) Primary Surface criteria apply beyond this point	Slope downward from edge of shoulder. See Item 14.
12	Transverse grade of Overrun	Min 2.0% Max 3.0%	Slope pavement downwards from the runway with no reversals to insure adequate drainage of surface water. Exception is at or adjacent to intersections where the pavement surfaces must be warped to match abutting pavements.
13	Runway Lateral Clearance Zone (corresponds to half the width of primary surface)	150 m (500 ft)	Measured perpendicularly from centerline of OLF runway. This area is to be clear of fixed and mobile obstacles. In addition to the lateral clearance criterion, the vertical height restriction on structures and parked aircraft as a result of the transitional slope must be taken into account. (1) Fixed obstacles include man-made or natural features constituting possible hazards to moving aircraft. See Note 1. (2) Mobile obstacles include parked aircraft, parked and moving vehicles, railroad cars and similar equipment. (3) Taxiing aircraft are exempt from this restriction. However, parallel taxiways (exclusive of shoulder width) must be located in excess of the lateral clearance distance.
14	Grades within the Primary Surface (in any direction)	Max 5.0%	- Exclusive of pavement, shoulders, and cover over drainage structures. - Slopes are to be as gradual as practicable. Avoid abrupt changes or sudden reversals. Rough grade to the extent necessary to minimize damage to aircraft.

Table 8-11. Tilt-Rotor Outlying Landing Field (OLF) Airspace Imaginary Surfaces

Table 8-11. Tilt-Rotor OLF Airspace Imaginary Surfaces				
Item		**Legend**	**Requirement**	**Remarks**
No.	**Description**			
1	Primary surface width	A	300 m (1,000 ft)	Centered on OLF runway centerline.
2	Primary surface length	A	Runway length + 61 m (200 ft) at each end	Primary surface extends 61 m (200 ft) beyond each end of the OLF runway
3	Primary surface elevation	A	See Remarks	The elevation of the primary surface is the same as the elevation of the nearest point on the OLF runway centerline
4	Grade of Clear Zone in any direction	B	5.0% Max.	The clear zone starts at the end of the primary surface and has the same width as the primary surface (93.5 m [300 ft]), with a length of 400 ft. - Clear zones are areas on the ground, located at the ends of the primary surface, centered on the primary approach path to the VL pad. - Areas to be free of obstructions. Rough grade and turf when required. Positive drainage to avoid standing water.
5	Start of OLF Approach-Departure Surface	C	61 m (200 ft)	Measured from the end of the OLF runway.
6	Length of sloped portion of OLF Approach-Departure Surface	C	Min 2,400 m (8,000 ft)	Measured horizontally
7	Slope of OLF Approach-Departure Surface	C	20:1	Slope ratio is horizontal: vertical. Example: 20:1 is 20 m (ft) horizontal to 1 m (ft) vertical. For clearances over highway and railroads, see Table 3-8, Imaginary Surfaces Minimum Clearances over Highway, Railroad, Waterway and Trees.
8	Width of OLF Approach-Departure Surface at start of sloped portion	C	300 m (1,000 ft)	Centered on the extended OLF runway centerline, and is the same width as the primary surface.

Table 8-11. Tilt-Rotor OLF Airspace Imaginary Surfaces				
Item		Legend	Requirement	Remarks
No.	Description			
9	Width of OLF Approach-Departure Surface at end of sloped portion	C	1,030 m (3,400 ft)	Centered on the extended OLF runway centerline.
10	Elevation of Approach-Departure Surface at start of sloped portion	C	0 m (0 ft)	Same as the OLF runway centerline at the threshold.
11	Elevation of OLF Approach-Departure Surface at end of sloped portion	C	120 m (400 ft)	Above the established OLF runway elevation.
12	Transitional Surface Slope	—	2:1	Slope ratio is horizontal:vertical. 2:1 is 2 m (ft) horizontal to 1 m (ft) vertical. (1) The transitional surface starts at the lateral edges of the Primary Surface and the Approach-Departure Surface. It continues outward and upward at the prescribed slope to an elevation of 45 m (150 ft) above the established airfield elevation.
13	Inner Horizontal Surface Radius	E	1,400 m (4,600 ft)	An Imaginary surface constructed by scribing an arc with a radius of 1,400 m (4,600 ft) about the centerline at each end of the OLF runway and interconnecting these arcs with tangents.
14	Elevation of Inner Horizontal Surface	E	45 m (150 ft)	Above the established OLF runway elevation. Exception: When the OLF is adjacent to an airfield, the inner horizontal surface is established to match the adjacent airfield's inner horizontal surface.

Table 8-12. Tilt-Rotor Outlying Landing Field (OLF) Clear Zone and APZs

Item No.	Item Description	Legend	Requirement	Remarks
1	Clear Zone	B	Length: 120 m (400 ft) Width: 300 m (1,000 ft)	Length measured along the extended runway centerline beginning at the end of the primary surface. Width of Clear Zone is centered on and measured perpendicular to the extended runway centerline.
2	Clear Zone Grades (any direction)		Min 2.0% Max. 5.0%	Clear Zone only. Area to be free of obstructions. Rough grade and turf when required.
3	APZ I	J	Length: 240 m (800 ft) Width: 300m (1,000 ft)	APZ I starts at the end of the clear zone, and is centered and measured on the extended runway centerline.

Figure 8-43. Tilt-Rotor Outlying Landing Field (OLF) Facility Outline

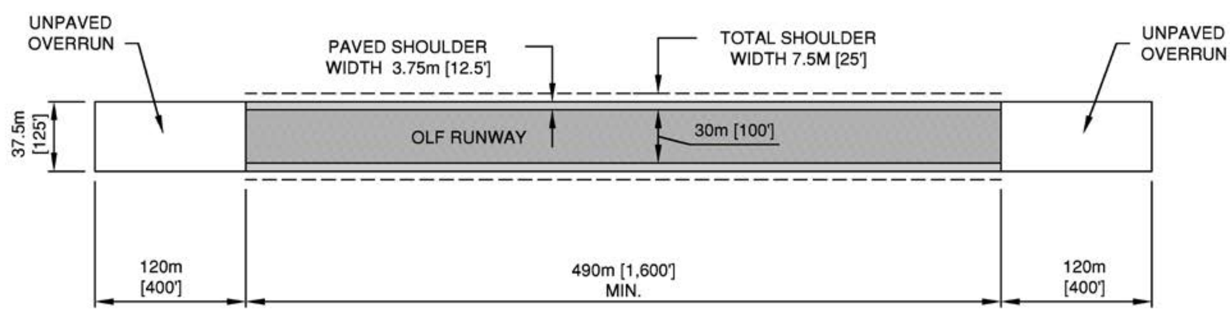


Figure 8-44. OLF Facility with Clear Zones

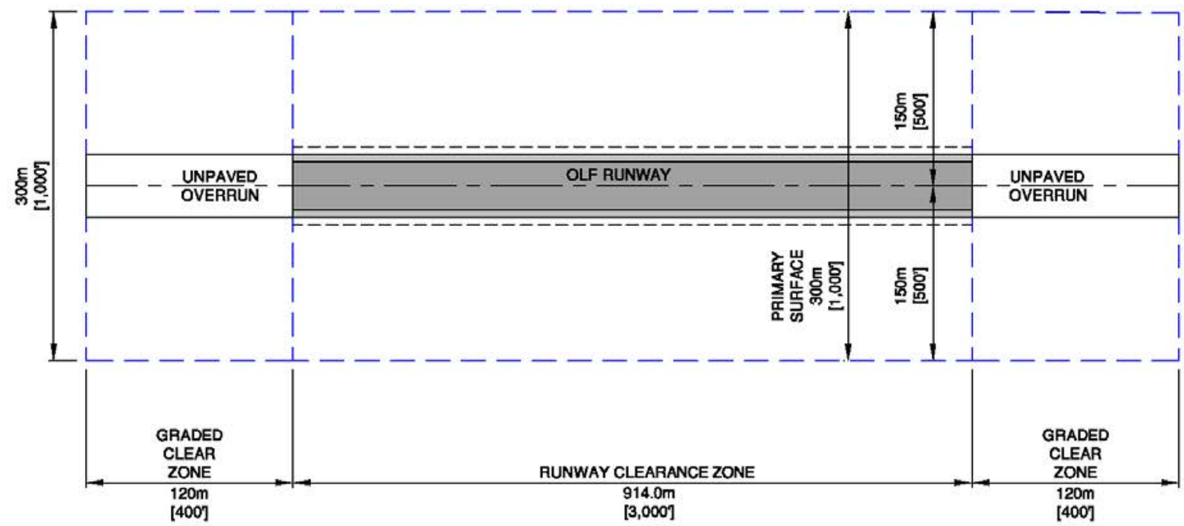


Figure 8-45. OLF Facility Longitudinal Gradient

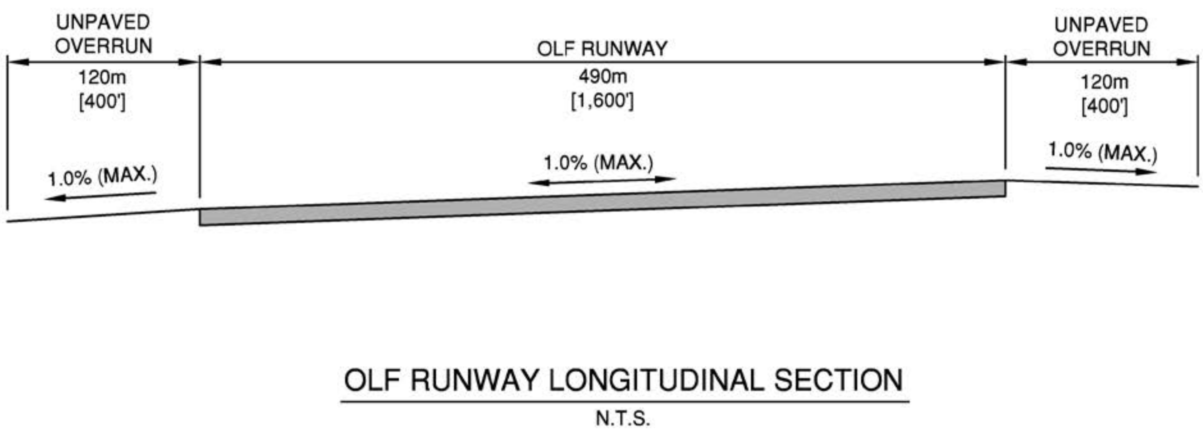


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Figure 8-46. OLF Facility Transverse Section

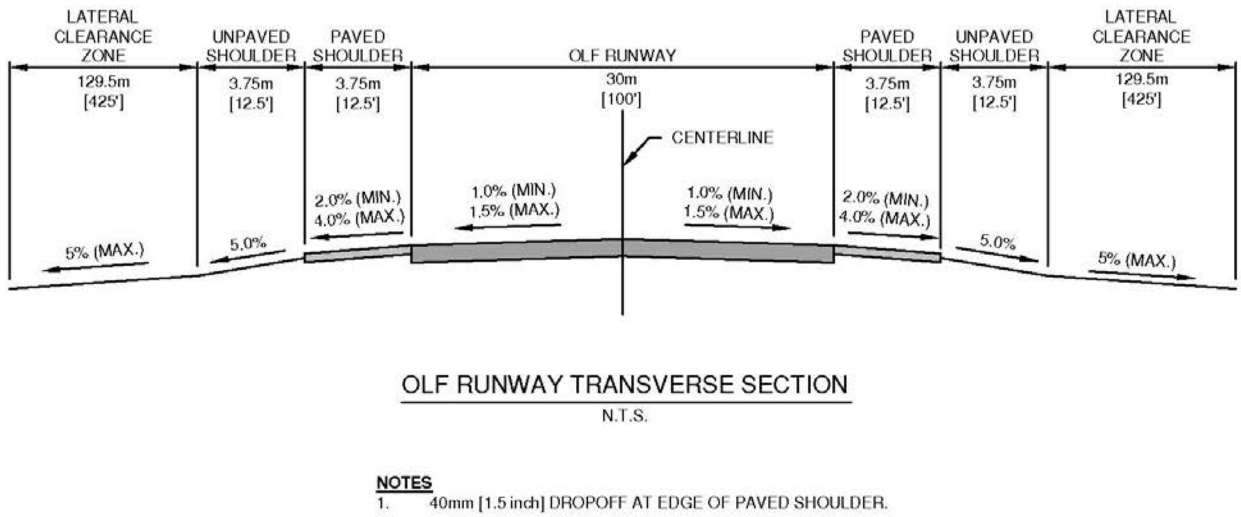

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Figure 8-47. OLF Facility Approach-Departure Clearance Surface and Clear Zone

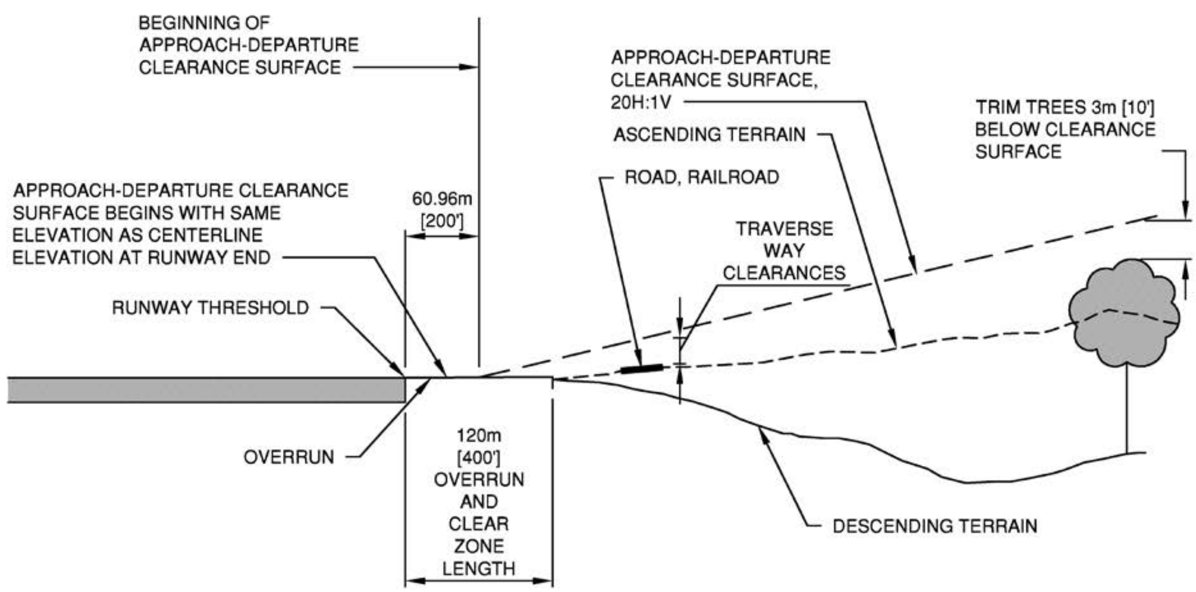


Figure 8-48. OLF Facility Clear Zones and APZs

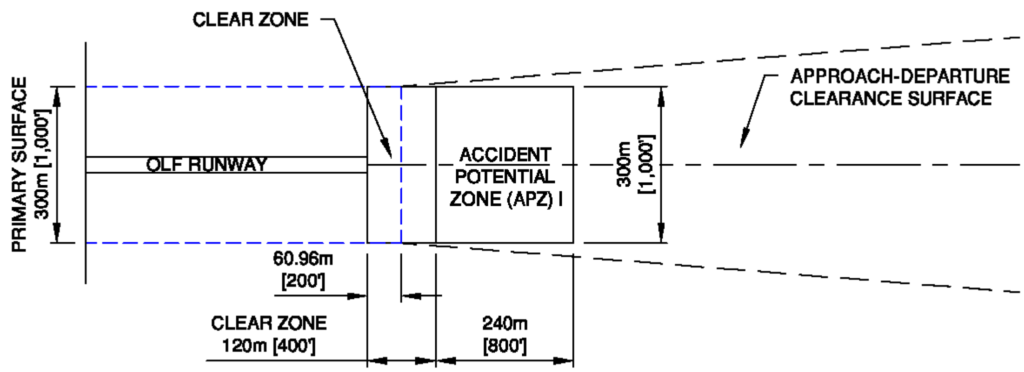


Figure 8-49. OLF Facility Isometric

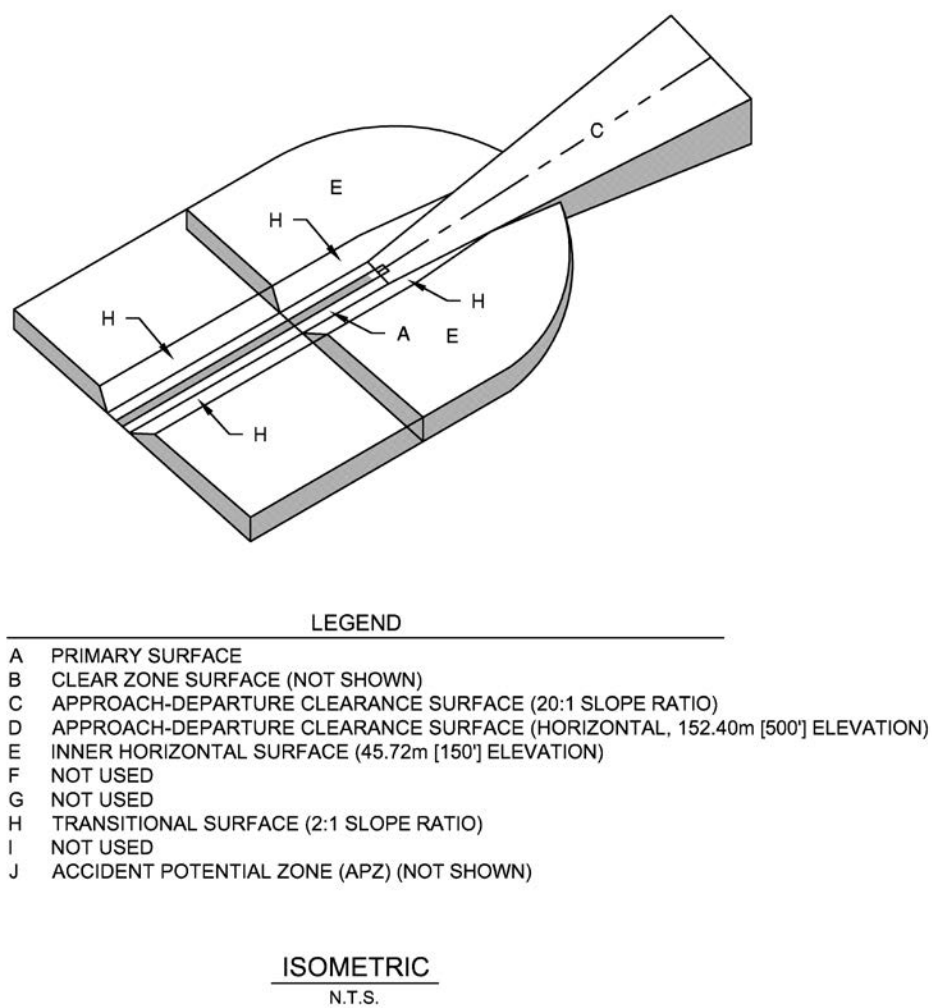


Figure 8-50. OLF Facility Imaginary Surfaces

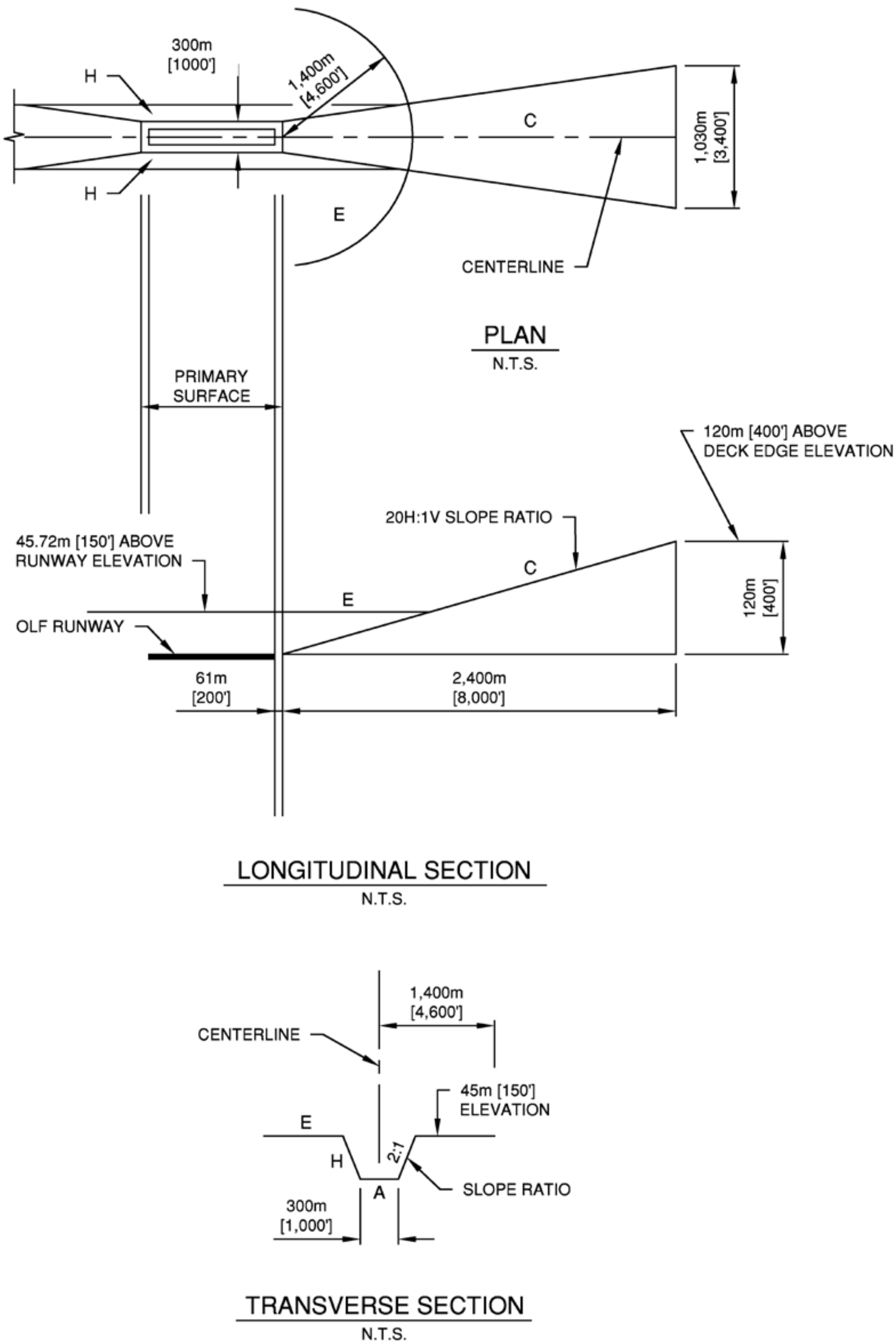
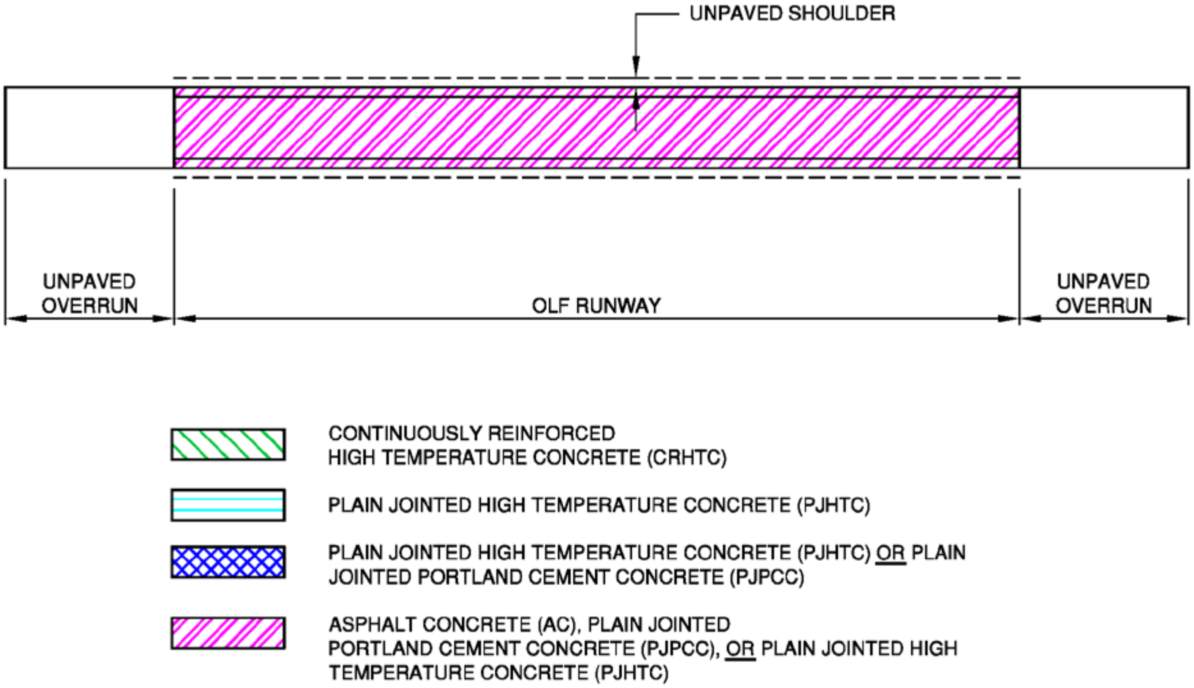


Figure 8-51. Tilt-Rotor OLF Pavement Surface Types



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CHAPTER 9
UNMANNED AIRCRAFT SYSTEMS (UAS)

9-1 CONTENTS.

This chapter presents guidance and criteria for planning and designing runway and ancillary movement areas that support operations of US Army (USA)/US Air Force (USAF)/US Navy wheeled/skid Unmanned Aircraft Systems (UAS).

9-2 REQUIREMENTS. LAND USE AND AIRSPACE APPROVAL.

Public Aircraft Operations are limited by federal statue to certain government operations within U.S. airspace per Federal Aviation Administration (FAA) proposed rules.

9-3 RUNWAY.

Runway location and orientation are paramount to airfield safety for UAS aircraft. Wind direction and velocity is a major consideration for siting runways. With respect to UAS operations, prevailing winds and velocities may actually prevent operations if the runway cannot be aligned with them. To be functional, efficient, and safe, the runway should be oriented in alignment with the prevailing winds, to the greatest extent practical, to provide favorable wind coverage. Wind data, obtained from local sources, for a period of not less than five years, should be used as a basis for developing the wind rose to be shown on the airfield general site plan. Appendix B, Section 4, provides guidance for the research, assessment, and application of wind data. NOTE: For RQ-7Bv2, the term “runway” in this chapter shall be synonymous with “launch/recovery strip” and the term “hangar” shall be synonymous with “shelter.”

9-4 AIRCRAFT COVERED IN THIS CHAPTER.

- MQ-9A Reaper
- MQ-1B Predator
- MQ-1C Gray Eagle
- RQ-4A/B Global Hawk
- MQ-4C Triton
- RQ-7Bv2 Shadow (or earlier versions)
- MQ-8B/C Fire Scout

9-5 AIRCRAFT CHARACTERISTICS.

For aircraft characteristics see USACE Technical Report TSC 13- 2.

9-6 AIRFIELD DIMENSIONAL CRITERIA.

The dimensions for airfield facilities, airfield lateral safety clearances, and airspace imaginary surfaces are provided in this document. Typical layout, sections and profiles for UAS runways and the associated airspace surfaces are shown in Figures 9-1 through 9-6.

9-6.1 Airfields/Heliports Used by Both Manned and Unmanned Aircraft.

Airfields/Heliports, Air Force Bases, Naval Air Stations and Marine Corps Air Stations used by both manned and unmanned aircraft (dual use facilities) will use the geometric criteria contained in this UFC. The most critical criteria **(manned versus unmanned aircraft criteria)** will apply based on the segment use, it may even be a combination of UAS Criteria, i.e. the taxiway to the UAS apron will be designed based on this UFC. The RQ-4A/B and MQ-4 require a Class B runway. New pavements for UAS aircraft at manned aircraft facilities shall be designed in accordance with the requirements in UFC 3-260-02. Chapter 1 of UFC 3-260-02 details which pavements must be rigid pavements and which pavements can be either rigid or flexible pavements. The traffic mix utilized for the installation shall be used for these new UAS pavements (installation traffic mixes are spelled out in UFC 3-260-02 Chapter 2 for Army Class I, II, III, IV and in Chapter 3 for USAF medium, light, heavy, etc.).

9-6.2 Permissible Deviations from Design Criteria.

See paragraph B13-2.16 for deviations from criteria.

9-6.3 UAS Runway Co-located with an Active Army Airfield, Army Heliport, Air Force, Navy or Marine Corps Runway.

9-6.3.1 Separation Criteria.

Table 9-1 lists the separation criteria between manned and unmanned runways. If the UAS facility is planned for dual use, the requirements of this UFC, UFC 3-535-01 and appropriate service marking directives apply.

9-6.3.2 New Pavements.

New pavements for UAS aircraft at collocated facilities shall be designed in accordance with the requirements in UFC 3-260-02. Chapter 1 of UFC 3-260-02 details which pavements must be rigid pavements and which pavements can be either rigid or flexible pavements. The traffic mix used for UAS only pavements shall be, as a minimum, the same as the traffic used for an Army Class II Helipad (20,000 passes of a 22,680kg [50,000lb] CH-47 Aircraft). If other support vehicles (i.e. crash fire trucks, support trucks, forklifts, etc.) utilize these areas that require a thicker pavement design then the thickened design for those vehicles shall govern.

Table 9-1. Separation Distance Between Runways

Table 9-1. Separation Distance Between Runways	
Min. 213.4m [700 ft]	Non-simultaneous Visual Flight Rules (VFR) operations.
Min. 304.8m [1000 ft]	Simultaneous VFR operations
Min. 762m [2500 ft]	Instrument Flight Rules (IFR)/VFR using simultaneous operations (depart-depart) (depart-approach).
Concurrent UAS Ops	The separation distance between multiple runways that are going to be used for UAS aircraft operations will need to be coordinated with the UAS Program Managers (operating multiple TALS in close proximity to each other may create radar signature interferences or conflicts for approaching UAS aircraft).

9-6.4 UAS-only Facilities.

This section presents design considerations for UAS only facilities. See TC 25-8 *Training Ranges* for additional RQ-7Bv2 Shadow facility design criteria, especially expeditionary training and/or semi-improved training facilities.

9-6.4.1 New Pavements.

New pavements for UAS aircraft at these facilities shall be designed in accordance with the requirements in UFC 3-260-02. Chapter 1 of UFC 3-260-02 details which pavements must be rigid pavements and which pavements can be either rigid or flexible pavements. The traffic mix used for UAS only pavements shall be, as a minimum, the same as the traffic used for an Army Class II Helipad (20,000 passes of a 22,680kg [50,000lb] CH-47 Aircraft). If other support vehicles (i.e. crash fire trucks, support trucks, forklifts, etc.) utilize these areas that require a thicker pavement design then the thickened design for those vehicles shall govern.

9-6.4.2 Runway Designation.

For runway designation see UFC 3-260-04. These runways are not built structurally to support standard fixed wing or rotary aircraft operations.

9-6.4.3 Tactical Shadow Facility.

Down range tactical facilities are rudimentary in nature to enable launch/recovery and provide basic shelter to support training operations. These facilities are permanent sites that are constructed on installation range complexes to enable launch and recovery under the veil of installation restricted airspace. Tactical facilities must be configured IAW Operators Manual requirements for tactical use. Building structures should be sited to comply with Table 9-6.

Table 9-2. UAS Runways

Table 9-2. UAS Runways					
	Item	Criteria			Remarks
No.	Description	MQ-1	RQ-7Bv2	MQ-9	
1	Length (min)	1524m [5000']	243.84m [800']	2286m [7500']	MQ-1C: 1371.6m [4500'], at 2743.2m [9000'] elevation runway length is 1676.4m [5500']. For USAF required length shall be determine by the A2, but not less than stated except for lengths in Appendix B. For RQ-7, length of runway will depend on the number of TALs touch down points. 243.84m [800'] is only adequate for one touch point. Increase runway length to 304.8m [1,000'] for two or more platoons.
2	Width	22.86m [75']	15.24m [50']	22.86m [75']	MQ-1C 30.48m [100']
3	Width of shoulder	3.05m [10']	1.52m [5']	3.05m [10']	Shoulder may be paved or unpaved.
4	Longitudinal grades of runway and shoulders	Grades may be both positive and negative but must not exceed the limit specified in this UFC. Shadow can operate on a max grade of 1.7%. Grade restrictions are exclusive of other pavements and shoulders. Where other pavements tie into runways, comply with grading requirements for towways, taxiways, or aprons as applicable, but hold grade changes to the minimum practicable to facilitate drainage.			
5	Longitudinal runway grade changes	No grade change is to occur less than 304.8m [1,000'] from the runway end	No grade change is to occur less than 30.48m [100'] from the runway end	No grade change is to occur less than 304.8m [1,000'] from the runway end	Where economically feasible, the runway will have a constant centerline gradient from end to end. Where terrain dictates the need for centerline grade changes, the distance between two successive points of intersection (PI) will be not less than 304.8m [1,000'] (MQ-1 and MQ-9), 30.48m [100'] (RQ-7A/B) and two successive distances between PIs will not be the same.
6	Rate of longitudinal runway grade changes	Maximum rate of longitudinal grade change is produced by vertical curves having 180-m [600-ft] lengths for each percent of algebraic difference between the two grades.			
7	Longitudinal sight distance	Any two points 2.44m [8'] above the pavement must be mutually visible (visible by each other) for 1524m [5000']. Proportionally reduce height above runway for runways shorter than 1524m [5,000'].			
8	Transverse grade of runway	Min 1.0% Max 1.5%	Max 0.5%	Min 1.0% Max 1.5%	Runway pavements will be centerline crowned. Slope pavement downwards

Table 9-2. UAS Runways

	Item	Criteria			Remarks
No.	Description	MQ-1	RQ-7Bv2	MQ-9	
					from centerline of runway. 1.5% slope is optimum transverse grade of runway.
9	Transverse grade of paved shoulder	Slope downward from runway pavement. Reversals are not allowed.			
10	Runway lateral clearance zone width (from centerline)	76.2m [250']	18.29m [60']	76.2m [250']	The runway lateral clearance limits coincide with the limits of the primary surface. The ends of the lateral clearance zone coincide with the runway ends plus overruns. The ground surface within this area must be clear of fixed or mobile objects, and graded to the requirements in Table 3-2, items 13 and 14, Chapter 3. The zone width is measured perpendicularly from the centerline of the runway and begins at the runway centerline. (1) Fixed obstacles include man-made or natural features such as buildings, trees, rocks, terrain irregularities and any other features constituting possible hazards to moving aircraft. (2) Mobile obstacles include parked aircraft, parked and moving vehicles, railroad cars, and similar equipment. Taxiing aircraft, emergency vehicles, and authorized maintenance vehicles are exempt. (3) Parallel taxiway (exclusive of shoulder width) will be located in excess of the lateral clearance distances (primary surface). (4) Above ground drainage structures, including headwall, are not permitted within 45.72m [150'] (24.38m [80'] for RQ-7) of the runway centerline.
11	Longitudinal grades within runway lateral clearance zone	Exclusive of pavement, shoulders, and cover over drainage structures. Slopes are to be as gradual as practicable. Avoid abrupt changes or sudden reversals. Rough grade to the extent necessary to minimize damage to aircraft.			

Table 9-2. UAS Runways					
	Item	Criteria			Remarks
No.	Description	MQ-1	RQ-7Bv2	MQ-9	
12	Transverse grades within runway lateral clearance zone (in direction of surface drainage)	Exclusive of pavement, shoulders, and cover over drainage structures. Slopes are to be as gradual as practicable. Avoid abrupt changes or sudden reversals. Rough grade to the extent necessary to minimize damage to aircraft. Grades may need to be adjusted as necessary to accommodate siting of RQ-7 TALS, but shall be done in accordance with these requirements.			
13	Width of mandatory frangibility zone (MFZ)	91.44m [300']	NA*	91.44m [300']	Centered on the runway centerline. All items sited within this area must be frangible. (See Appendix B, Section 13.).
14	Length of MFZ	Extends the entire length of the runway plus clear zone. Items that must be sited there due to their function must be made frangible to the maximum extent possible.(See Appendix B, Section 13)*			

***** For the RQ-7 runways no objects except for the arresting system and barrier net may be placed within the primary surface.

Figure 9-1. MQ-1/9 Predator/Gray Eagle/Reaper Primary Surface End Details

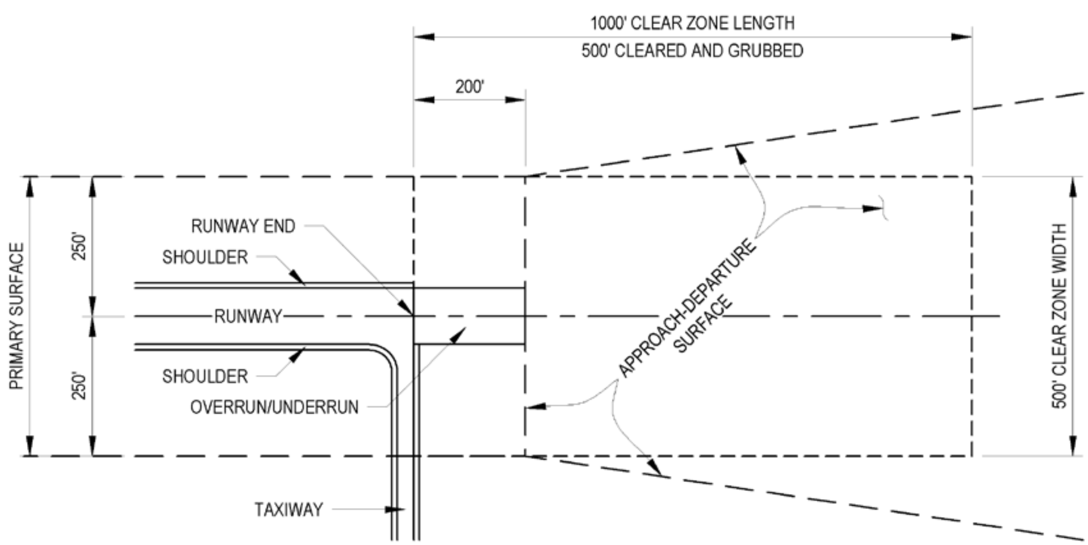


Figure 9-2. RQ-7Bv2 Shadow Primary Surface End Details

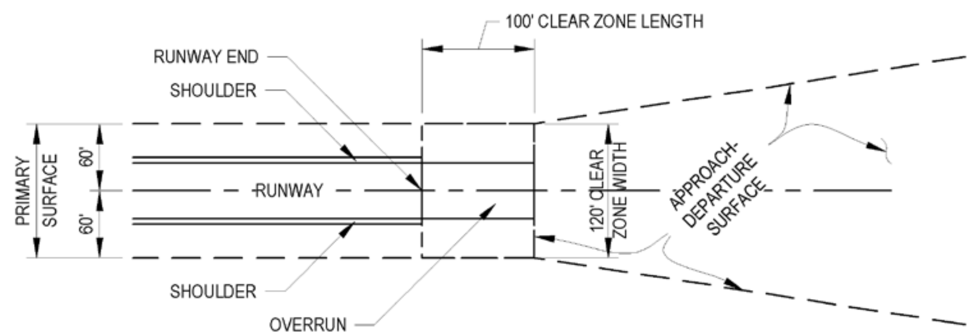
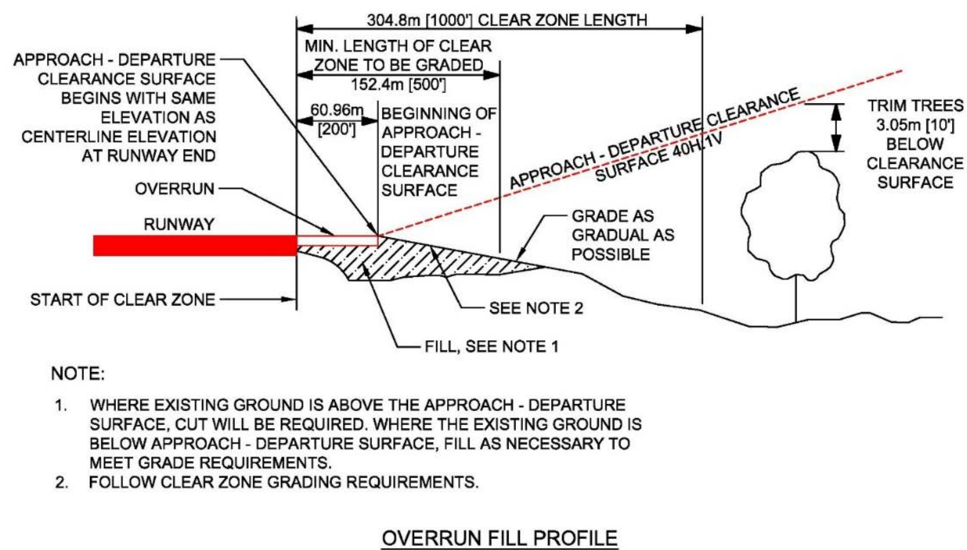


Figure 9-3. MQ-1/9 Predator/Gray Eagle/Reaper Approach-Departure Clearance Surface Profile



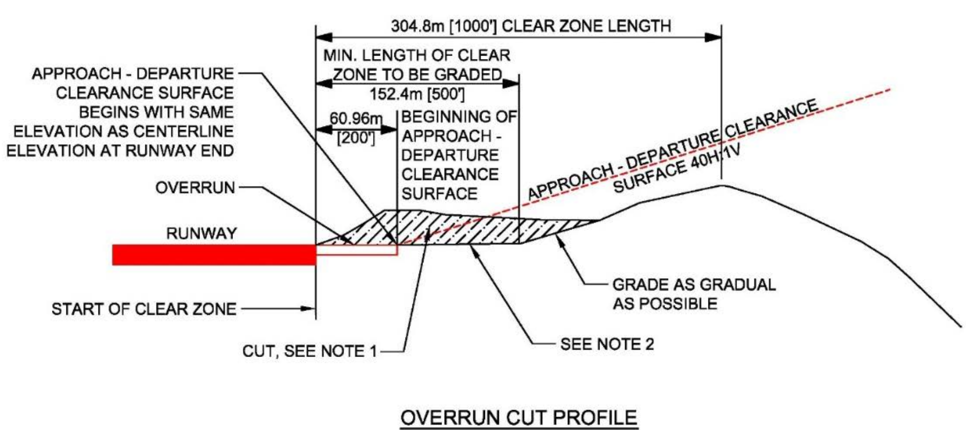
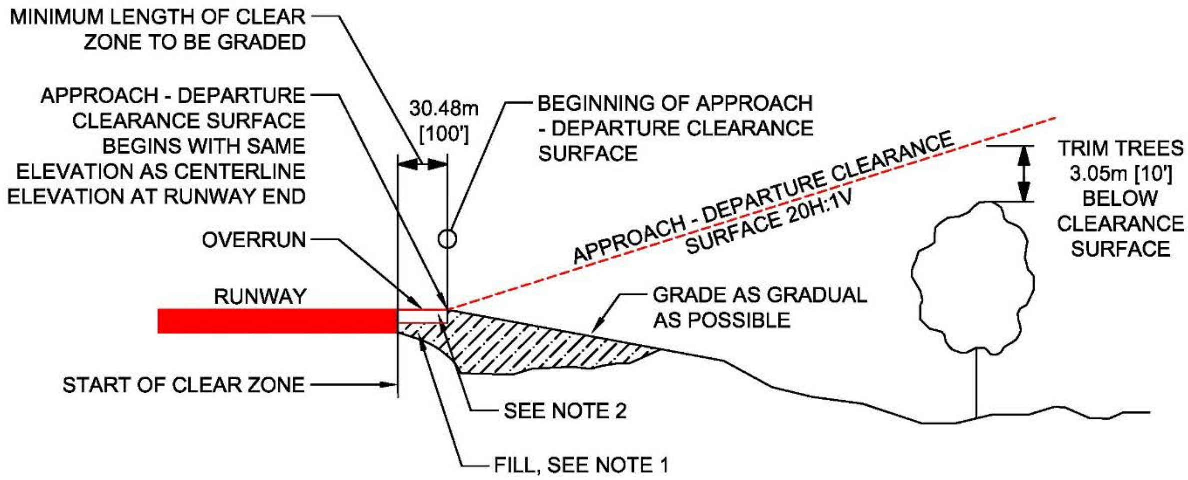


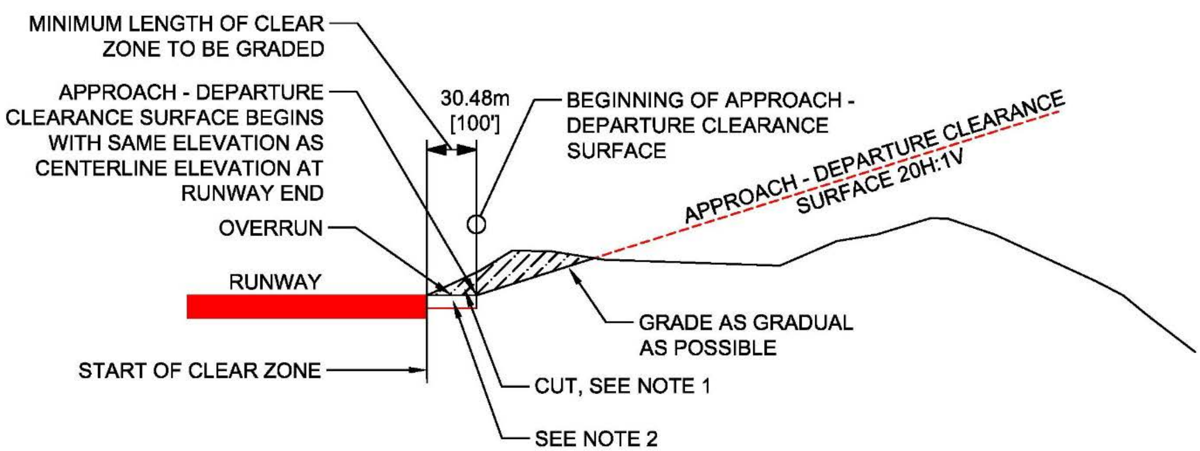
Figure 9-4. RQ-7Bv2 Shadow Approach-Departure Clearance Surface Profile



NOTE:

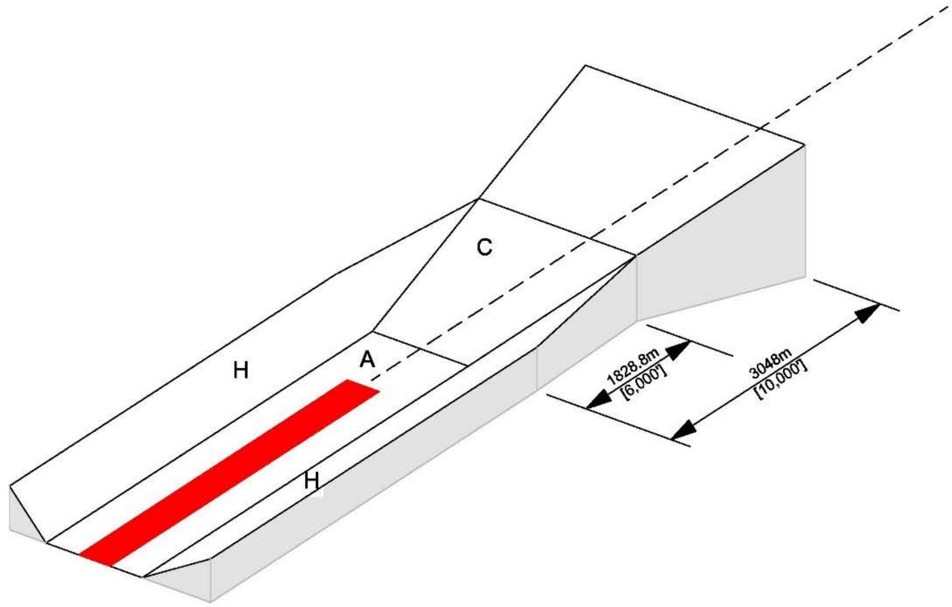
1. WHERE EXISTING GROUND IS ABOVE THE APPROACH - DEPARTURE SURFACE, CUT WILL BE REQUIRED. WHERE THE EXISTING GROUND IS BELOW APPROACH - DEPARTURE SURFACE, FILL AS NECESSARY TO MEET GRADE REQUIREMENTS.
2. FOLLOW CLEAR ZONE GRADING REQUIREMENTS.

OVERRUN FILL PROFILE



OVERRUN CUT PROFILE

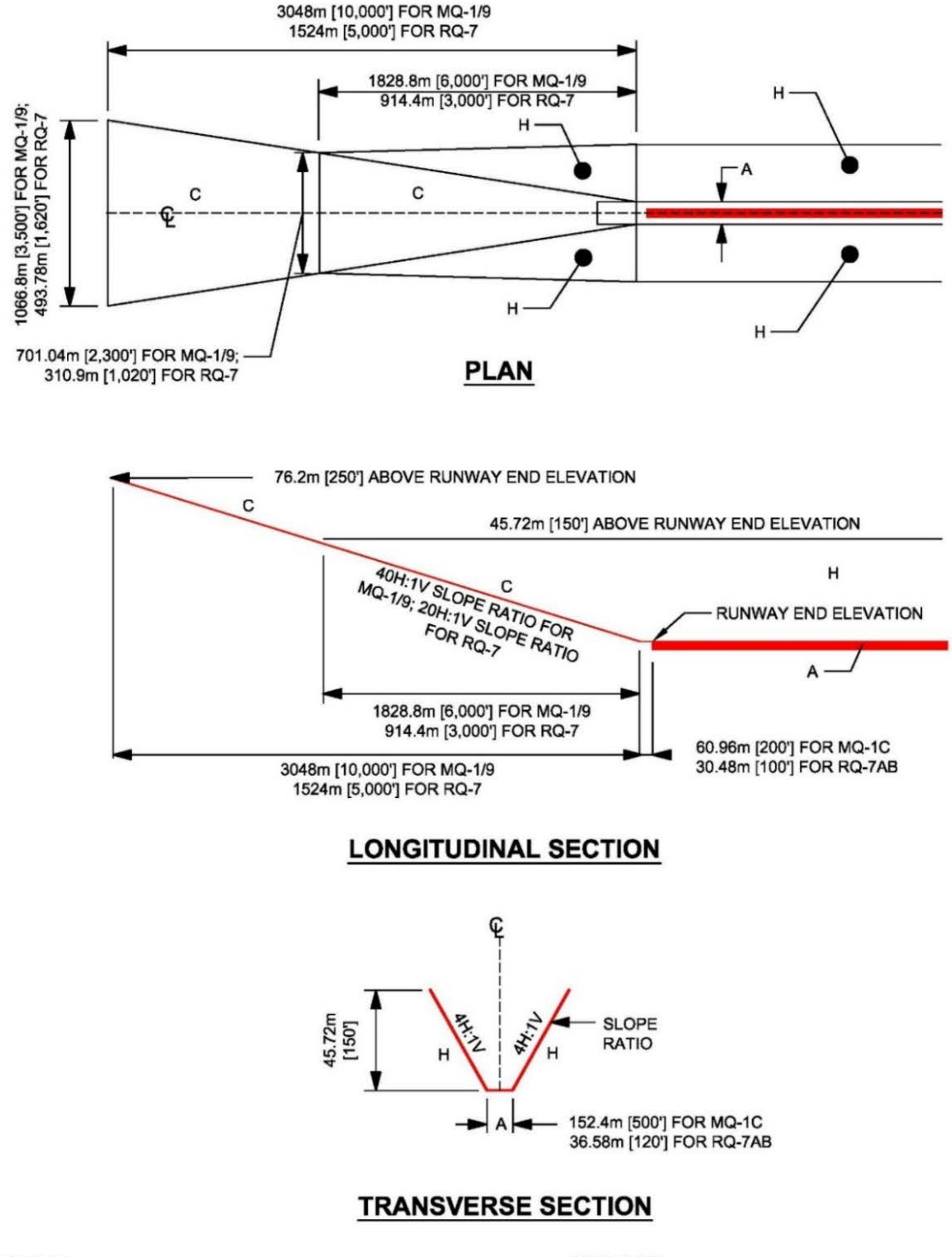
Figure 9-5. MQ-1/9 Predator/Gray Eagle/Reaper Runway Isometric Airspace Imaginary Surfaces



LEGEND

A. PRIMARY SURFACE.
B. CLEAR ZONE SURFACE (NOT SHOWN).
C. APPROACH-DEPARTURE CLEARANCE SURFACE (40H:1V SLOPE RATIO).
D. APPROACH-DEPARTURE CLEARANCE SURFACE (HORIZONTAL, NOT REQUIRED).
E. INNER HORIZONTAL SURFACE (NOT REQUIRED).
F. CONICAL SURFACE (NOT REQUIRED).
G. OUTER HORIZONTAL SURFACE (NOT REQUIRED).
H. TRANSITIONAL SURFACE (4H:1V SLOPE RATIO).
I. NOT USED.

Figure 9-6. MQ-1/9 & RQ-7Bv2 Runway Plan and Profile Airspace Imaginary Surfaces



LEGEND:

A - PRIMARY SURFACE.
B - CLEAR ZONE SURFACE.
C - APPROACH-DEPARTURE CLEARANCE SURFACE (40H:1V FOR MQ-1/9 & 20H:1V FOR RQ-7).
H - TRANSITIONAL SURFACE (4H:1V SLOPE RATIO).

NOTES:

1. DATUM ELEVATION FOR SURFACE C IS THE RUNWAY CENTERLINE ELEVATION AT THE THRESHOLD. SURFACE H VARIES AT EACH POINT.

9-6.5 Runway Overruns.

Runway overruns keep the probability of serious damage to an aircraft to a minimum in the event that the aircraft runs off the runway end during a takeoff or landing, or lands short during a landing. Overruns are required for the landing and takeoff area.

Table 9-3. UAS Overruns

Table 9-3. Overruns					
Item		MQ-1	RQ-7Bv2	MQ-9	Remarks
No.	Description	Requirement			
1	Length	60.96m [200']	30.48m [100']	60.96m [200'	
2	Paved Length	60.96m [200']	30.48m [100']	60.96m [200']	If runway is paved, overrun will be paved.
3	Total width of overrun (paved and unpaved)	Sum of runway and shoulders			The outside edges of the overrun, equal in width to the runway shoulder, are graded but not paved.
4	Paved overrun width	Same as width of runway			Center on runway centerline extended.
5	Longitudinal centerline grade	Same as last 304.8m [1,000'] of runway	Same as last 30.48m [100'] of runway	Same as last 304.8m [1,000'] of runway	To avoid abrupt changes in grade between the first 91.44m [300'] and remainder of overrun the maximum change of grade is 2.0% (1.7% for RQ-7) per 30.48 linear meter [100 linear ft.]
6	Transverse grade	Min 2.0% Max 3.0% (1.7% max for RQ-7) 1.5 in drop-off at edge of paved overrun +/- 0.5 in			From centerline of overrun. Transition from the runway and runway shoulder grades to the overrun grades to be made within the first 15.24m [50'] of overrun.

9-6.6 Runway Clear Zones.

Runway clear zones are areas on the ground, located at the ends of each runway. They possess a high potential for accidents, and their use is restricted to be compatible with aircraft operations. Hence, they are treated as “exclusion zones” and not merely restricted access. Runway clear zones are required for the runway and should be owned or protected under a long-term lease.

9-6.6.1 Treatment of Clear Zones.

The purpose of the clear zone is to protect the safety of flight and safety of people on the ground. The entire clear zone area is a land use control area intended to protect people both flight safety and property on the ground. Land use for the clear zone area for UAS facilities corresponds to the clear zone land use criteria for fixed-wing airfields as defined for DoD AICUZ and Service-specific standard and as discussed in Chapter 3.

9-6.6.2 Clear Zone Mandatory Frangibility Zone (MFZ).

The MFZ extends through the graded area. Items that must be sited there due to their function must be made frangible to the maximum extent possible (Appendix B, Section 13).

9-6.6.3 Prohibited Land Uses.

Criteria prohibits certain land uses within the clear zone and APZs (APZ I and APZ II). These land uses include storage and handling of munitions and hazardous materials, and live fire weapons ranges (See DoDI 4165.57 and individual service component directives and DA PAM 385-63 for more information on compatible land use).

Table 9-4. UAS Clear Zones

Table 9-4. UAS Clear Zones					
Item No.	Description	MQ-1	RQ-7Bv2	MQ-9	Remarks
		Requirement			
1	Length	304.8m [1000’]	30.48m [100’]	304.8m [1000’]	Measured along the extended runway centerline beginning at the runway end. For grading requirements, see items 4 and 5.
2	Width at start of clear zone (adjacent to the runway)	152.4m [500’]	36.58m [120’]	152.4m [500’]	Centered on the runway center line extended.
3	Length of Graded Clear zone surface (graded area)	152.4m [500’]	30.48m [100’]	152.4m [500’]	Graded area only. For land use outside the graded area of the clear zone, apply AICUZ standards.
4	Width at end of clear zone	152.4m [500’]	36.58m [120’]	152.4m [500’]	Centered on the runway center line extended.
5	Longitudinal grade of area to be graded	Max 10.0%	Max 1.7%	Max 10.0%	The area to be graded is 152.4m [500’] (MQ-1, MQ-9), and 30.48m [100’] (RQ-7) in length by the established width of the primary surface. Grades are exclusive of the overrun, but are to be shaped into the overrun grade. The maximum longitudinal grade change cannot exceed + 2.0% per 30.48m [100’]. Grade restrictions are also exclusive of other pavements and shoulders. Where other pavements cross the graded area, comply with grading requirements for the specific pavement design (towways, taxiways, or aprons as applicable), but hold grade changes to the minimum practicable to facilitate drainage. The graded area is to be cleared and grubbed of stumps and free of abrupt surface irregularities, ditches, and ponding

Table 9-4. UAS Clear Zones					
Item No.	Description	MQ-1	RQ-7Bv2	MQ-9	Remarks
		Requirement			
					areas. No aboveground structures, objects, or roadways (except air traffic control controlled service roads to arresting gear are permitted in the area to be graded, but gentle swales, subsurface drainage, covered culverts and underground structures are permissible. The transition from the graded area to the remainder of the clear zone is to be as gradual as feasible. For policy regarding permissible facilities, geographical features, and land use in the remainder of the clear zone, refer to guidance furnished by the DoD AICUZ guidelines for clear zones and accident potential zones. (See Appendix B, Section 3.).
6	Transverse grade of area to be graded (in direction of surface drain-age prior to channelization)	Min 2.0% Max 10.0%			For RQ-7 Max 1.7%
7	Width of MFZ	91.44m [300']	NA	91.44m [300']	Centered on the extended runway centerline. All items sited within the MFZ in the graded area of the clear zone must be frangible. Items located beyond the Graded Area of the clear zone but within the MFZ must be constructed to be frangible, low impact resistant structures, or semi-frangible (see Appendix B, Section 13).
8	Length of MFZ	152.4m [500']	NA	152.4m [500']	Extends the full length of the runway plus the clear zone.

Table 9-5. UAS Accident Potential Zones

Table 9-5. UAS Accident Potential Zones					
Item		MQ-1	RQ-7Bv2	MQ-9	Remarks
No.	Description	Requirement			
1	APZ I length	457.2m [1500']			APZ I starts at the end of the clear zone, and is centered and measured on the extended centerline. Modifications will be considered if: - The runway is infrequently used. - Prevailing wind conditions are such that a large percentage (that is, over 80%) of the operations are in one direction. - Local accident history indicates consideration of different areas. - Most aircraft do not overfly an APZ area as defined here during normal flight operations (modifications may be made to alter these zones and adjust them to conform to the line of flight). - Other unusual conditions exist.
2	APZ I width	152.4m [500']	36.58m [120']	152.4m [500']	
3	APZ II length	304.8m [1000']			APZ II starts at the end of the APZ I and is centered and measured on the extended runway centerline. Modifications will be considered if: - The runway is infrequently used. - Prevailing wind conditions are such that a large percentage (that is, over 80 percent) of the operations are in one direction. - Local accident history indicates consideration of different areas. - Most aircraft do not overfly an APZ area as defined here during normal flight operations (modifications may be made to alter these zones and adjust them to conform to the line of flight). - Other unusual conditions exist.
4	APZ II width	152.4m [500']	36.58m [120']	152.4m [500']	

Table 9-6. UAS Airspace Imaginary Surfaces

Table 9-6. Airspace Imaginary Surfaces (See Figures 9-1 thru 9-6)						
Item		Legend	UAS Runway			Remarks
No.	Description		MQ-1	RQ-7Bv2	MQ-9	
1	Primary surface width	A	152.4m [500’]	36.58m [120’]	152.4m [500’]	Centered on the runway centerline.
2	Primary surface length	A	60.96m [200’]	36.58m [100’]	60.96m [200’]	Runway length plus value indicated on each end of the runway (extends beyond each end of the runway).
3	Primary surface elevation	A	The elevation of any point on the primary surface is the same as the elevation of the nearest point on the runway centerline.			
4	Clear zone surface (graded area)	B	152.4m [500’]	30.48m [100’]	152.4m [500’]	For land use outside the graded area of the clear zone, apply AICUZ standards.
5	Start of approach-departure surface	C	60.96m [200’]	30.48m [100’]	60.96m [200’]	Measured from the end of the runway.
6	Length of sloped portion of approach-departure surface	C	3048m [10,000’]	1524m [5,000’]	3048m [10,000’]	Measured horizontally. For MQ-1C the length can be reduced to 1851.96m [6,076’].
7	Slope of approach-departure surface	C	40:1	20:1	40:1	Slope ratio is horizontal: vertical. Example: 40:1 is 12.19m [40’] horizontal to 0.30m [1’] vertical. For clearances over highway and railroads, see Table 3-8.
8	Width of approach-departure surface at start of sloped portion	C	152.4m [500’]	36.58m [120’]	152.4m [500’]	Centered on the extended runway centerline, and is the same width as the Primary Surface.
9	Width of approach-departure surface at end of sloped portion	C	1066.8m [3500’]	493.78m [1620’]	1066.8m [3500’]	Centered on the extended runway centerline. For MQ-1C the width can be reduced to 354m [1,161.4’]
10	Elevation of approach-departure	C	Same as the runway centerline elevation at the threshold.			

Table 9-6. Airspace Imaginary Surfaces (See Figures 9-1 thru 9-6)						
Item		Legend	UAS Runway			Remarks
No.	Description		MQ-1	RQ-7Bv2	MQ-9	
	surface at start of sloped portion					
11	Elevation of approach-departure surface at end of sloped portion	C	76.2m [250’]			Above the established airfield elevation.
12	Start of transitional surface	H	76.2m [250’]	18.29m [60’]	76.2m [250’]	Measured from runway centerline.
13	End of transitional surface	H	See Remarks			The transitional surface ends at the inner horizontal surface, conical surface, outer horizontal surface, or at an elevation of 45.72m [150’].
14	Slope of transitional surfaces	H	4:1			Slope ratio is horizontal:vertical. 4:1 is 1.22m [4’] horizontal to 0.30m [1’] vertical. Vertical height of vegetation and other fixed or mobile obstacles and/or structures will not penetrate the transitional surface. Taxiing aircraft are exempt from this requirement.

NOTE: See Figures 9-1 & 9-6

9-7 TAXIWAYS.

Taxiways provide for ground movement of aircraft. Taxiways connect the runway(s) of the airfield with the parking and maintenance areas and provide access to hangars, docks, and various parking aprons and pads. Taxiways are designated alphabetically, avoiding the use of I, O, (could be mistaken for runway numbers) and X (closure marking). Alphanumeric designations may be used when necessary, for example, A1, B3. RQ-7A/B do not require taxiways, however do require paved towways for wing walkers.

9-7.1 Basic.

The basic airfield layout consists of a taxiway connecting the center of the runway with the hangar access apron. This system limits the number of aircraft operations at an airfield. Departing aircraft must taxi on the runway to reach the runway threshold. When aircraft are taxiing on the runway, no other aircraft is allowed to use the runway. If runway operations are minimal or capacity is low, the basic airfield layout with one taxiway may be an acceptable layout.

9-7.2 Parallel Taxiway.

A taxiway parallel for the length of the runway, with connectors to the end of the runway and hangar access apron, is the most efficient taxiway system. Aircraft movement is not hindered by taxiing operations on the runway, and the connectors permit rapid entrance and exit of traffic.

9-7.3 Taxiway Intersection Criteria.

To prevent the main gear of an aircraft from coming dangerously close to the outside edge of the taxiway during a turn, fillets are provided at taxiway intersections. When an aircraft turns at an intersection, the nose gear of the aircraft usually follows the painted centerline marking. The main gears, located to the rear of the nose gear, do not remain a constant distance from the centerline stripe during the turn due to the physical design of the aircraft. The main gears pivot on a shorter radius than does the nose gear during a turn. Intersections should be designed to ensure that the main gear wheels stay a minimum of 5 feet from the pavement edge.

9-7.4 Hangar Access Taxiways.

Hangar access taxiways are provided for aircraft access onto a hangar access apron. The apron access taxiways should be located to enhance the aircraft's departing sequence and route.

9-7.5 Shoulders.

Shoulders are provided along a taxiway to allow aircraft to recover if they leave the paved taxiway. Paved shoulders prevent erosion caused by prop wash, support an occasional aircraft that wanders off the taxiway, support vehicular traffic, and reduce maintenance of unpaved shoulder areas. Criteria for UAS taxiway shoulders, including widths and grading requirements to prevent the ponding of storm water, are presented in Table 9-7. Manholes, hand holes, and drainage structures constructed within these areas should, at a minimum, be designed as provided in this section. Beyond the paved or unpaved shoulders, sub-grade structures are not designed to support aircraft wheel loads. The top surface of foundations, manhole covers, hand hole covers, and frames should be flush with the grade. Maintenance action is required if the drop-off at the edge of the structure or foundation exceeds three inches.

Table 9-7. UAS Taxiways

Table 9-7. UAS Taxiways				
Item		MQ-1/9	RQ-7Bv2	Remarks
No.	Description	Requirement		
1	Width (ft)	15.24m [50']	4.57m [15']	9.14m [30'] for MQ-1C
2	Total width of shoulders (paved and unpaved) (ft)	3.05m [10']	NA	Any or all of the shoulders may be paved or unpaved. For unpaved shoulders turfed/grassed shoulders are recommended except in desert locations where gravel surfacing is also acceptable.
3	Longitudinal grade of taxiway and shoulders	Max 3.0%		Grades may be positive or negative but must not exceed the limits specified.
4	Rate of longitudinal taxiway grade change	Max 2.0% per 30.48m [100']	NA	The minimum distance between two successive points of intersection (PI) is 152.4m [500']. Changes are to be accomplished by means of vertical curves. Up to a 0.4% change in grade is allowed without a vertical curve. A vertical curve is not necessary where a taxiway crosses a runway or taxiway crown..
5	Transverse grade of taxiway	Min 1.0% Max 1.5%	NA	Taxiway pavements will be centerline crowned. Slope pavement downward from the centerline of the taxiway. When existing taxiway pavements have insufficient transverse gradients for rapid drainage, provide for increased gradients when the pavements are overlaid or reconstructed. The transverse gradients requirements are not applicable at or adjacent to intersections where pavements must be warped to match abutting pavements.
6	Transverse grade of optional paved shoulders	Min 2.0% Max 4.0%	NA	
7	Transverse grade of unpaved shoulders	40mm [1.5"] drop-off at edge of pavement +/- 13mm [0.5"] 2.0% min, 4.0% max	NA	Unpaved shoulders shall be graded to provide positive surface drainage away from paved surfaces.

Table 9-7. UAS Taxiways				
Item		MQ-1/9	RQ-7Bv2	Remarks
No.	Description	Requirement		
8	Taxiway turning radius (ft)	19.81m [65']	NA	
9	Fillet radius at intersections (ft)	15.24m [50']	NA	
10	Clearance from edge of access apron to other taxiways and aprons (ft)	30.48m [100']	NA	Where hover taxi is involved the minimum distance is 60.96m [200']
11	Clearance from taxiway centerline to fixed or mobile obstacles (taxiway clearance line) (ft)	30.48m [100']	NA	
12	Distance between taxiway centerline and parallel taxiway/taxilane centerline (ft)	38.1m [125']	NA	
13	Grade of area between taxiway shoulder and taxiway clearance line	Min of 2.0% prior to channelization Max 10.0%		Unpaved areas shall be graded to provide positive surface drainage away from paved surfaces. 40mm [1.5"] drop-off at pavement edge, +/- 13mm [0.5"]

9-7.6 Towways.

A towway is used to tow aircraft from one location to another or from the runway/taxiway to a hangar/storage facility.

9-7.6.1 Dimensions.

Table 9-8 presents the criteria for towway layout and design, including clearances, slopes, and grading dimensions. When designing for access to a hangar, flare the pavement to the width of the hangar door from a distance beyond the hangar sufficient to allow maintenance personnel to turn the aircraft around.

Table 9-8. UAS Towways

Table 9-8. UAS Towways				
Item		MQ-1/9	RQ-7A/B	Remarks
No.	Description	Requirement		
1	Width (ft)	9.14m [30']	4.57m [15']	RQ-7 requires a paved towway.
2	Total width of shoulders (ft)	3.05m [10']	3.05m [10']	Any or all of the shoulders may be paved or unpaved. For unpaved shoulders turfed/grassed shoulders are recommended except in dessert locations where gravel surfacing is also acceptable.
3	Longitudinal grade of towway	Max 3.0%		Grades may be both positive and negative but must not exceed the limit specified.
4	Rate of longitudinal grade change per 30 m (100 ft)	Max 2.0%		The minimum distance between two successive PI is 150 m (500 ft). Changes are to be accomplished by means of vertical curves. For the Air Force and Army, up to a 0.4% change in grade is allowed without a vertical curve. A vertical curve is not necessary where a taxiway crosses a runway or taxiway crown.
5	Longitudinal sight distance	N/A (See note 1.)		
6	Transverse grade	Min 1.0% Max 3.0%		Pavement crowned at towway centerline. Slope pavement downward from centerline of towway.
7	Towway turning radius (ft)	27.43m [90']	15.24m [50']	Criteria presented here are for straight sections of towway. Pavement width and horizontal clearance lines may need to be increased at horizontal curve locations, based on aircraft alignment on the horizontal curve.
8	Fillet radius at intersections (ft)	15.24m [50']	9.14m [30']	
9	Transverse grade of shoulder	(a) 40 mm (1.5 in) drop-off at edge of pavement, +/- 13 mm (0.5 in). (b) 2.0% min, 4.0% max.		
10	Horizontal clearance from towway centerline to fixed or mobile obstacles	The greater of: ½ the wing width of the towed +25 ft.; or the minimum of 18.29m [60'].		
11	Vertical clearance from towway pavement surface to fixed or mobile obstacles	(Height of towed mission aircraft) + 3 m (10 ft)		

12	Grade (area between towway shoulder and towway clearance line)	Min of 2.0% prior to channelization Max 10%. (See note 2.)	

NOTES:
1. N/A = not applicable
2. Bed of channel may be flat.

9-8 APRONS AND OTHER PAVEMENTS.

9-8.1 Apron Requirements.

Aprons should be sized to allow safe movement of towed aircraft or aircraft operating under their own power.

9-8.1.1 Location.

Aprons should be located contiguous to maintenance and hangar facilities. Do not locate them within runway and taxiway lateral clearance distances. A typical access apron is illustrated in Figure 9-9. (For Army, based on Vice Chief of Staff of the Army (VCSA) approval of concept, there is no aircraft parking apron authorized for Army UAS.)

9-8.1.2 Size.

As a general rule, there are no standard sizes for aircraft aprons. Aprons are individually designed to support aircraft and missions at specific facilities. The actual dimensions of an apron are based on the number of authorized aircraft, the maneuvering space, and the type of activity that the apron serves. The ideal apron size affords the maximum parking capacity with a minimum amount of paving.

9-8.2 Types of Aprons and Other Pavements.

Listed here are types of aprons and other aviation facilities:

- Parking Apron (RQ-1/4)
- Hangar access apron/Warm up pad (MQ-1/9, RQ-7Bv2)
- Arm/Dearm pad

9-8.3 RQ-4A/B Global Hawk Parking Apron.

Parking areas for the RQ-4A Global Hawk and the RQ-4B Global Hawk should be designed with dimensions shown in Figure 9-8. Locations for tie-downs on the RQ-4A are shown in Figure 9-7. Tie-downs should be designed to resist an uplift force equal to the rated capacity of the tie down chain (i.e., typically 44,482N [10,000 pounds]). Special apron areas for hot refueling or arming/dearming are not required for the Global Hawk.

9-8.3.1 Location.

Aprons should be located contiguous to maintenance and hangar facilities. Do not locate them within runway and taxiway lateral clearance distances. A typical access apron is illustrated in Figure 9-9 (For US Army based on Vice Chief of Staff of the Army (VCSA) approval of concept, there is no aircraft parking apron authorized for UAS.)

9-8.3.2 Size.

As a general rule, there are no standard sizes for aircraft aprons. Aprons are individually designed to support aircraft and missions at specific facilities. The actual dimensions of an apron are based on the number of authorized aircraft, the maneuvering space, and the type of activity that the apron serves. The ideal apron size affords the maximum parking capacity with a minimum amount of paving.

9-8.4 Hangar Access Apron.

The pavement that allows access from the taxiway/towway to the hangar is referred to as a “hangar access apron” and is discussed in more detail below based on Army usage.

9-8.4.1 MQ-1C.

For USA the MQ-1C parking space width is 19.81m [65’], and the parking space length is 12.19m [40’].

9-8.4.2 Specific Aircraft.

If the assigned aircraft are predominantly one type, the access apron will be based on the specific dimensions of that aircraft, i.e. an RQ-7Bv2 parking space is 9.45m [31’] in width and 6.71m [22’] in length.

9-8.4.3 Layout.

The hangar access/ parking apron will be sized to accommodate a minimum of two UAS’s with an area for one UAS to be towed by.

Table 9-9. UAS Hangar Access Apron

<table>
<tr><th colspan="5">Table 9-9. UAS Hangar Access Apron</th></tr>
<tr><th colspan="2">Item</th><th>MQ-1/9</th><th>RQ-7A/B</th><th rowspan="2">Remarks</th></tr>
<tr><th>No.</th><th>Description</th><th colspan="2">Requirement</th></tr>
<tr><td rowspan="2">1</td><td rowspan="2">Length (ft)</td><td>60.96m [200’]</td><td>4.57m [15’]</td><td>For Army MQ-1 hangars the standard length is 30.48m [100’].</td></tr>
<tr><td colspan="3">Access aprons are located between the taxiway/towway and the front of the hangar. The hangar cannot be located within the taxiway/towway clearance distance.</td></tr>
<tr><td>2</td><td>Width (ft)</td><td>121.92m [400’]</td><td>9.75m [32’]</td><td>Pavement should be sized for type of aircraft, number of hangar bays, and location of hangar bays. For Army MQ-1 hangars, the standard width is 48.77m [160’].</td></tr>
<tr><td rowspan="2">3</td><td rowspan="2">Grades in direction of drainage</td><td colspan="2">Min +0.5%
Max +1.5%</td><td></td></tr>
<tr><td>Min -1.0% first 15.24m [50’] from hangar</td><td></td><td>NFPA 415 requires aircraft fueling ramps to slope away from terminal buildings, aircraft hangars, aircraft loading walkways, or other structures.</td></tr>
<tr><td>4</td><td>Width of shoulders (total width including paved and unpaved) (ft)</td><td>3.05m [10’]</td><td>1.52m [5’]</td><td>For unpaved shoulders turfed/grassed shoulders are recommended except in desert locations where gravel surfacing is also acceptable.</td></tr>
<tr><td>5</td><td>Width of paved shoulders</td><td colspan="2">Not required</td><td></td></tr>
<tr><td>6</td><td>Transverse grade of unpaved shoulder</td><td colspan="2">(a) 40mm [1.5”] drop-off at edge of pavement.
(b) 2.0% min,
4.0% max.</td><td></td></tr>
<tr><td>7</td><td>Wingtip clearance to fixed or mobile obstacles (ft)</td><td>7.62m [25’]</td><td>3.05m [10’] with wing walkers</td><td>Along length of access apron. Wingtip clearance at entrance to hangar may be reduced to 3.05m [10’] either side of the door for RQ-4, MQ-1/9, 1.52m [5’] either side for RQ-7.</td></tr>
<tr><td>8</td><td>Grade
(area between access apron shoulder and wingtip clearance line)</td><td colspan="2">Max 10.0%</td><td>If the wingtip clearance line falls within the access apron shoulder, no grading is required beyond the access apron shoulder.</td></tr>
</table>

9-9 MOORING AND GROUNDING POINTS.

9-9.1 Layout.

The mooring points are located five feet fore and aft or left and right of the grounding point.

- Mooring point Layout for RQ-1/4 USAF/USN. See Figure 9-7.
- Mooring point Layout for UAS hangar access apron. See Figure 9-9.
- See Appendix B, Section 11 for typical mooring point details and testing procedures.

Figure 9-7. Mooring Layout for the RQ-4A Global Hawk

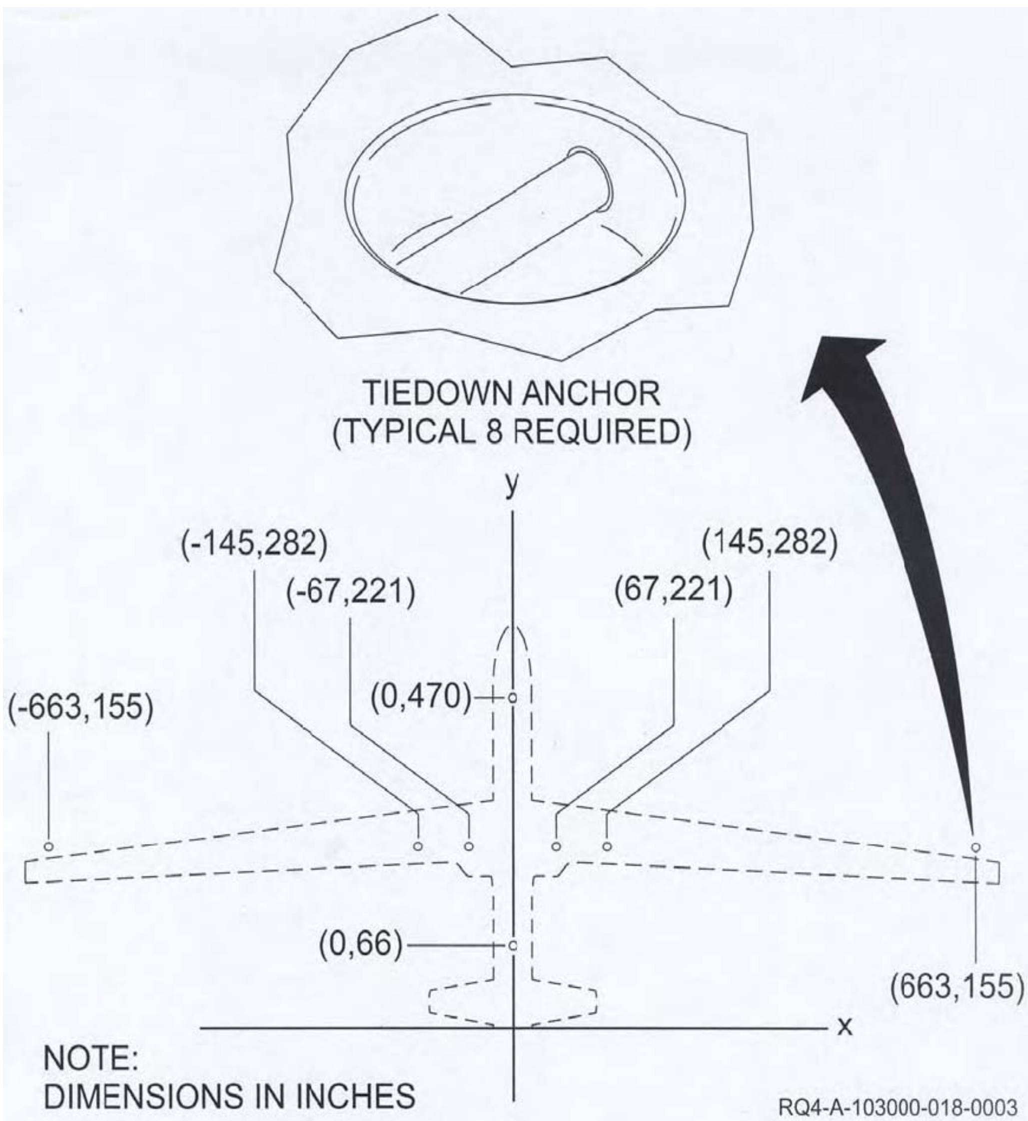


Figure 9-8. Parking Area Dimensions for RQ-4A and RQ-4B Global Hawk

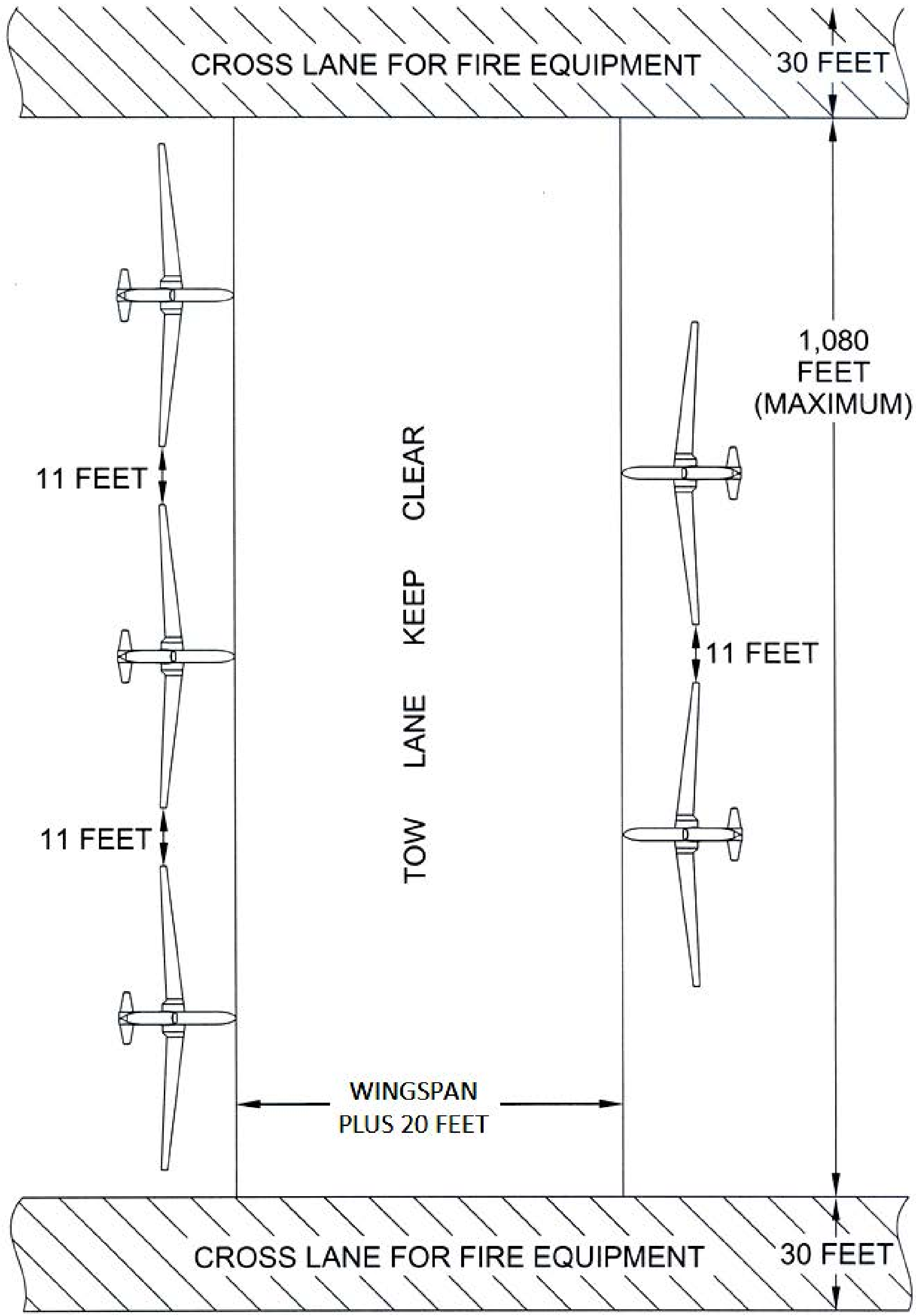


Figure 9-9. Standard Army MQ-1C Hangar Access Apron

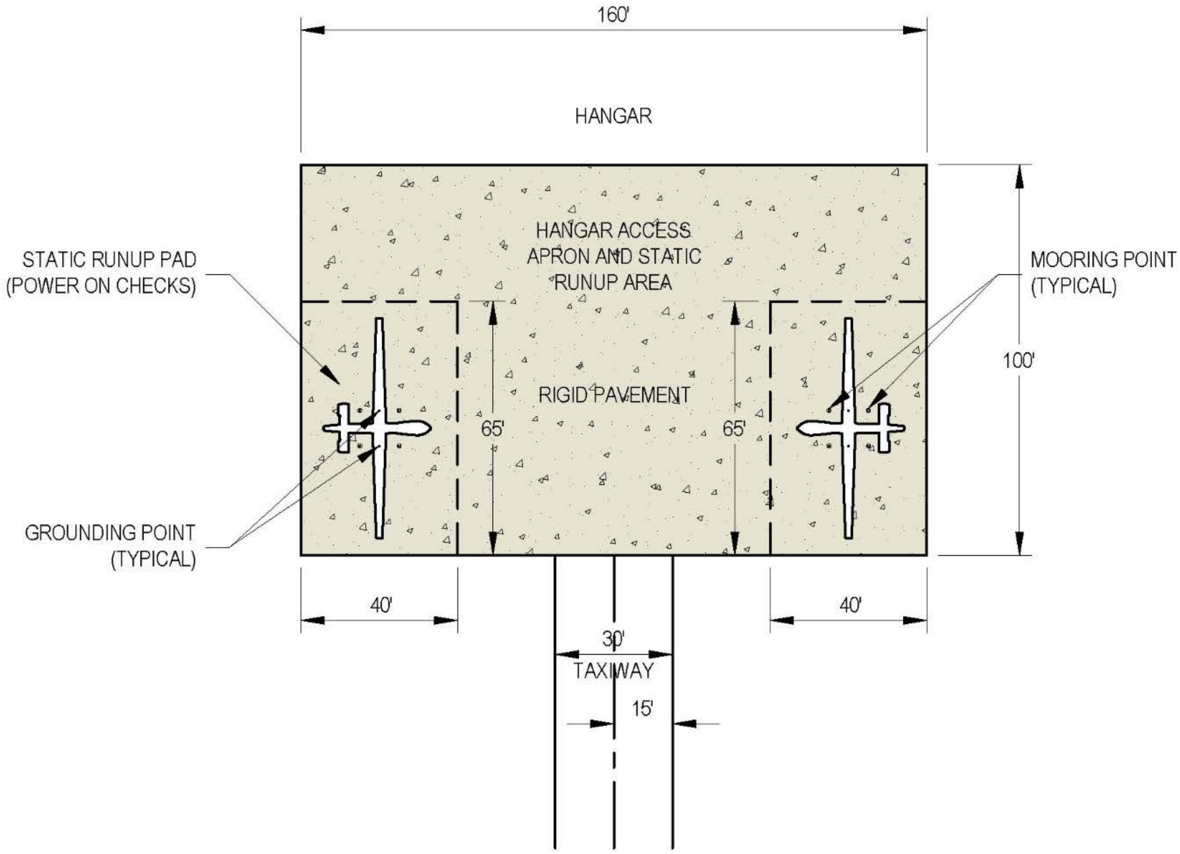
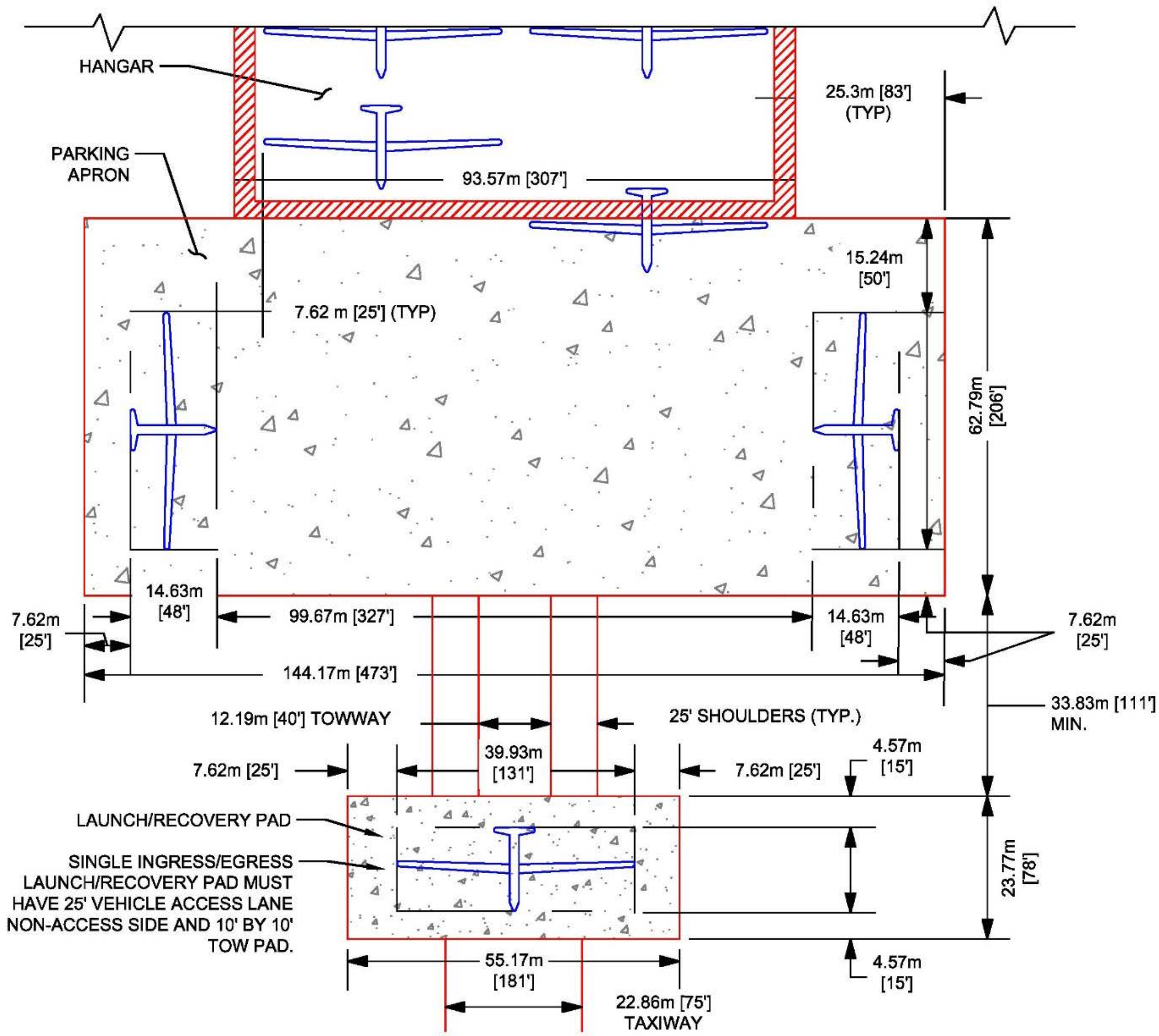


Figure 9-10. Navy MQ-4C Triton Hangar Access Apron

Note: The Triton unmanned aircraft system (UAS) requires a dedicated launch location to allow the Global Positioning System codes to be incorporated into the aircraft's mission plan for airfield ground taxi operations. The aircraft will utilize the UAS launch point for all programmed start and stop airfield operations. UAS dedicated aprons do not require peripheral taxiways.



NOTES:

1. THIS IS A BASIC APRON LAYOUT AND MAY BE SITE ADAPTED TO MEET ADDITIONAL CUSTOMER REQUIREMENTS.
2. LAYOUT OF PARKING APRON AND LAUNCH/RECOVERY PAD ALLOWS FOR SIMULTANEOUS OPERATIONS. AN OFFSET OF 111' IS REQUIRED.
3. AN OFFSET OF 25' IS REQUIRED BETWEEN PAVEMENT EDGE AND WINGTIP CLEARANCES FOR MAINTENANCE AND SAFETY.
4. WINGTIP CLEARANCE RADII ARE BASED ON A 45 DEGREE TURN.

9-10 LIGHTING.

Lighting will be IAW UFC 3-535-01.

9-11 MARKING.

Markings will be IAW UFC 3-260-04.

APPENDIX A REFERENCES

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APPENDIX B
SECTION 1
WAIVER PROCESSING PROCEDURES

B1-1 ARMY.

B1-1.1 Waivers to Criteria and Standards.

Waivers are processed when compliance with criteria cannot be achieved, the obstruction poses little or no risk to flying safety, and there are no other alternatives. When proposed objects or facilities will violate airfield imaginary surfaces, safe clearance, or other design criteria established in this manual, they must be analyzed to determine potential impact and risks to aircraft operations, personnel, and infrastructure.

B1-1.1.1 Permanent Waivers.

Established for violations that cannot be reasonably corrected and either pose little to no threat to flight operations and personnel or risks have been accepted at the appropriate level. Permanent waivers are issued where no further mitigative actions are intended or necessary.

B1-1.1.2 Temporary Waivers.

Established for a specified period during which additional actions to mitigate the situation must be initiated to fully comply with criteria or to obtain a permanent waiver. Routine follow-up inspections are required to evaluate the effectiveness of implemented risk mitigation actions, control measures, and identification of new risks for each temporary waiver granted.

B1-1.1.3 Operational Waivers.

Establish operational waivers when a particular aircraft operation is required to operate on existing facilities that do not meet current airfield design criteria listed in this manual. Ensure a risk assessment is performed on all proposed operational waiver requests prior to submitting to the approval authority. All operational waiver requests must have the aviation mission commander’s endorsement.

B1-1.1.4 Construction Waivers.

A construction waiver (sometimes referred to as temporary construction waivers) is obtained when one or more elements of a construction project (equipment, facilities, personnel, etc.) violate airfield and airspace criteria in this manual. Construction waivers should only be planned for the duration of the construction project unless circumstances dictate otherwise. An FAA Form 7460-1 Notice of Proposed Construction or Alteration, must be submitted to the DAR prior to sending the request to the Installation/Garrison commander for approval. Temporary waiver requests for construction projects must be prepared in accordance with paragraphs B1-1.1 and B1-1.2.

NOTE: Emergency maintenance and repair requirements and routine maintenance activities, such as mowing and maintenance of airfield systems, are exempt from this requirement; however, the DPW Airfield Manager will ensure implementation of appropriate safety measures, including Notices to Airmen (NOTAM) or Local NOTAMs.

B1-1.1.5 Permissible Deviations.

Permissible deviations to airfield and airspace criteria which do not require waivers if properly sited are listed in Section 13 of this appendix, beginning at paragraph B13-2.

B1-1.1.6 Exemptions.

Existing airfield facilities (See paragraph 1-3.1) built under previous design standards should be documented as exemptions and programmed for replacement away from the airfield environment at the end of their useful life or when mission needs dictate earlier replacement. If improvements are proposed that would extend the useful life of the airfield facilities, a temporary/permanent waiver must be requested. If the exempted facility is demolished, any use of that site should conform to the criteria in this UFC.

Airfield managers will identify and document all airfield facilities built under previous design standards and not requiring a waiver and submit the following information to the ACOM/ASCC/DRU or ARNG for validation:

- Description of exempt facility. (e.g. fixed-wing runway lacks overruns, taxiway lacks shoulders).
- Pictures, diagrams or charts that clearly illustrate the current exempt condition.
- Original mission supported (e.g. runway designed for Air Force B-52, taxiways designed for rotary-wing aircraft, etc.) and current mission supported.
- Year built. (Supporting documentation that confirms when the facility was built or a previous determination was made).
- Previous design criteria used (regulation number, criteria and date if known).
- Current criteria required and description of violation. (e.g., Table 3-2., runway lateral clearance zone, 500 ft. requirement, Taxiway B is 400 ft. from centerline/100 ft. violation).
- Safety of operations (risk management). Use DD Form 2977 Deliberate Risk Assessment Worksheet. Include risk description of each risk level associated with the non-compliant condition and what mitigation actions will be taken. See DA PAM 385-30 and ATP 5-19 for guidance.
- Estimated cost to remove/relocate or correct condition.

The ACOM/ASCC/DRU or ARNG will determine whether documented facilities should be classified as an exemption, or should have a temporary or permanent waiver.

B1-1.2 Responsibilities.

B1-1.2.1 Installation.

The installation's design agent, aviation representative (safety officer, Airfield Manager, operations officer, and/or air traffic and airspace [AT&A] officer), Department of Public Works (DPW) and/or Construction Facilities Management Office (CFMO) master planner will:

- Jointly with DPW prepare/initiate all waiver requests. Project Designers must immediately notify the Airfield Manager when project designs will not meet design criteria listed in this manual.
- Submit requests through the installation to the ACOM/ASCC/DRU/or ARNG.
- Maintain a complete record of all waivers requested and their disposition (approved or disapproved). A list of waivers to be requested and those approved for a project should also be included in the project design analysis prepared by the design agent, aviation/airfield representative, or DPW/CFMO master planner.
- Annual review. All airfield waivers will be annually reviewed to validate if a requirement for the waiver still exists, and all appropriate safety precautions, mitigative measures, and conditions of approval are being effectively implemented. Waivers no longer required will be cancelled through the ACOM/ASCC/DRU/ or ARNG.

B1-1.2.2 The ACOM/ASCC/DRU or ARNG will:

- Ensure all required coordination has been accomplished.
- Ensure the type of waiver requested is clearly identified as either temporary or permanent.
- Review all command supported waiver requests and forward to USAASA for action.
- Provide a command level endorsement of the waiver request.

B1-1.2.3 USAASA.

USAASA is responsible for coordinating reviews for the waiver request with the following agencies:

- Air traffic control assessment by Air Traffic Services Command (ATSCOM).

- Safety and risk assessment by the U.S. Army Combat Readiness/Safety Center (USACRC).
- Technical engineering review by the Transportation Systems Center (TSC).
- Waivers that affect instrument flight procedures by the USAASA Instrument Procedures Branch.
- From these reviews, USAASA formulates a consolidated position and makes the final determination on all waiver requests.

B1-1.3 Waiver Process Procedures.

B1-1.3.1 Contents of Waiver Requests.

Each request must contain the following information:

- Reference by publication, paragraph, and page to the specific standard(s) and/or criterion to be waived. Include all applicable design criteria that is non-compliant.
- Complete justification for noncompliance with the airfield/airspace criteria and/or design standards. Demonstrate that noncompliance will provide an acceptable level of safety, economics, durability and quality for meeting the Army mission. This would include reference to special studies made to support the decision. For manmade obstacles, the date of construction needs to be stated/indicated. Specific justification for waivers to criteria and allowances must be included as follows:

a. When specific site conditions (physical and functional constraints) make compliance with existing criteria impractical and/or unsafe. For example, the need to provide hangar space for all aircraft because of recurring adverse weather conditions; the need to expand hangar space closer to and within the runway clearances due to lack of land; maintaining fixed-wing Class A clearances when support of Class B fixed-wing aircraft operations are over 10 percent of the airfield operations.

b. When deviation(s) from criteria fall within a reasonable margin of safety as determined by a documented risk assessment based on assigned and known future missions of airfield/heliport that are determined will not impair construction of long-range facility requirements. For example, locating security fencing around and within established clearance areas.

c. When construction that does not conform to criteria is the only alternative to meet mission requirements. Evidence of analysis and efforts taken to follow criteria and standards must be documented and referenced. Copies of this analysis will be included in the final designs and maintained by DPW real estate offices.

- The rationale for the waiver request, including specific impacts upon assigned mission, safety, and/or environment.
- Temporary waiver requests shall include the action planned to correct the violation, risk assessment, project/work order number, and estimated completion date.
- Safety of operations (risk management). Use DD Form 2977 Deliberate Risk Assessment Worksheet. Include risk description of each risk level associated with the non-compliant condition and what mitigation actions will be taken. See DA PAM 385-30 and ATP 5-19 for guidance.
- Pictures, diagrams, and charts that clearly illustrate condition, distances, etc.

B1-1.3.2 Additional Requirements.

B1-1.3.2.1 Operational Factors.

Include information on the following existing and/or proposed operational factors used in the assessment:

- Mission urgency.
- All aircraft by type and operational characteristics.
- Density of aircraft operations at each air operational facility.
- Facility capability (visual flight rules [VFR] or instrument flight rules [IFR]).
- Use of self-powered parking versus manual parking.
- Existing navigational aids (NAVAID).

B1-1.3.2.2 Documentation.

Record all alternatives considered, their consequences, necessary mitigative efforts, and evidence of coordination. The Garrison/Installation Commander will sign all requests for waivers regardless of level of residual risk determined.

B1-2 AIR FORCE.

B1-2.1 Waivers to Criteria.

B1-2.1.1 Waivers, Permissible Deviations, Exemptions and Non-Conforming Facilities/Structures/Objects.

Waivers are required when compliance with criteria cannot be achieved. The waiver process is designed to ensure leadership is aware of potential risk and to ensure that all alternatives have been considered. Approval of a waiver is an acknowledgment of the associated risk (it is not project approval). A thorough examination of potential alternatives must be completed and documented prior to installation site approval, and before a waiver is requested from the MAJCOM/CD. When requesting a waiver, consider grouping adjacent supporting items with a controlling obstruction or grouping related items, such as a series of drainage structures, as one waiver. UFC 3-260-01 waivers do not apply to off installation development or obstructions to airspace off-installation (TERPS are the data steward for obstructions to air space criteria for off installation as outlined in AFI 32-7062). The only exception would be building a new airfield in an area with existing development (e.g. AFCENT, AFRICOM, EUCOM, PACOM). Under most circumstances, funding or budgetary constraints are not adequate justification for granting a waiver. Criteria violations caused by terrain located on Air Force controlled property will be classified as a non-conforming object, exemption or temporary waiver, not a permanent waiver. Criteria violations located on property not controlled by the Air Force will be classified as non-conforming facilities/structures or objects (see B1-2.1.8). There are four types of waivers (permanent, temporary, construction, and airshow) that are described below.

NOTE: Projects may be part of a larger NEPA action (in compliance with 32 CFR 989) which requires consideration of alternatives. The waiver request package should be provided in the environmental analysis.

NOTE: Clear Zones. Additionally, waivers to criteria in this UFC should be pursued for violations located within the graded area of the clear zone. A land use variance should be pursued if the proposal creates an incompatible land use violation in the remaining area of Air Force controlled clear zones, (See AFI 32-7063, Air Installations Compatibility Use Zone Program, AICUZ). In some circumstances, a proposal may require a waiver from this UFC and an AICUZ clear zone variance, if the proposal creates an incompatible land use, and violates criteria in this UFC (i.e. penetration into an imaginary surface).

NOTE: Operational Waivers. Certain existing facilities may require the supported aircraft activity to have an operational waiver in order to operate, such as taking off and landing on a shorter runway or inadequate wingtip clearance inside existing hangars and sunshades. These are operational waivers and not UFC 3-260-01 waivers. See AFI 11-218, Flying Operations, for additional information (This note applies to wing tip clearance in sunshades).

B1-2.1.2 Permanent Waivers.

Permanent waivers are established for criteria violations that cannot be reasonably met. If the criteria to be waived under this UFC would also result in a violation of UFC 3-535-01 Visual Air Navigation Facilities then consult with the Air Force Flight Standards Agency (AFFSA) and/or the Air Force Safety Center. The waiver request should be initiated by the Base Civil Engineer's (BCE) designated representative as soon as it is determined criteria can't be met, and be approved before siting, programming, and/or design is finalized. Permanent waivers are appropriate for violations associated with development of facilities on overseas installations where the U.S. has no authority to implement Air Force standards. See Section B1-2.2 for waiver package content. These waivers are approved/disapproved by the owning MAJCOM Deputy Commander.

Approval of a waiver constitutes acceptance of the risk associated with criteria violations. The MAJCOM/CD may delegate approval/disapproval authority to another organization within the MAJCOM Headquarters.

B1-2.1.3 Temporary Waivers.

Temporary waivers are established for criteria violations that can be corrected within eight years. During the two years following waiver approval, CE will develop/program an action to correct the violation, including a description of the proposed action, project number, and cost estimate. The remaining six years will be used to implement the corrective action. If the violation cannot be brought into compliance within eight years, the violation should be reclassified as a permanent waiver (Reclassification requests to permanent status will require MAJCOM/CD approval). See Section B1-2.2 for waiver package content. These waivers are approved/disapproved by the owning MAJCOM Deputy Commander. Approval of a waiver constitutes acceptance of the risk associated with criteria violations. The MAJCOM/CD may delegate approval/disapproval authority to another organization within the MAJCOM Headquarters.

B1-2.1.4 Construction Waivers.

A construction waiver (sometimes referred to as temporary construction waiver) is obtained when one or more elements of a construction project (equipment, facilities, personnel, etc.) violates criteria in this UFC. Construction waivers should only be planned for the duration of the construction project unless circumstances dictate otherwise. An FAA Form 7460-1 Notice of Proposed Construction or Alteration, must be included in request package to Installation Commander for approval. See Section 14 of this appendix, “Construction Phasing Plan and Operational Safety on Airfields during Construction” for additional guidance. Construction waivers **\1** must **/1/** be approved before construction activities begin. The Installation Commander is the approval authority for construction waivers. See Section B1-2.2 for waiver package.

NOTE: Emergency maintenance and repair requirements, as well as routine maintenance activities (mowing, snow removal, rubber removal and maintenance of airfield systems), are exempt from this requirement; however, the BCE will coordinate with the airfield management, flight safety, and flight operations offices to ensure implementation of appropriate safety measures, including Notices to Airmen (NOTAM).

B1-2.1.5 Air Show Waivers.

Air Show waivers are processed for events that will temporarily create criteria violations. The Installation Commander is the approval authority for Air Show Waivers. See Section B1-2.2 for waiver package content. Event waivers other than airshows require MAJCOM/CD approval.

B1-2.1.6 Permissible Deviations.

Permissible deviations are for airfield support facilities or equipment that are not required to meet airfield criteria, however, they must meet siting criteria specified in Appendix B, Section 13, of this UFC. The MAJCOM Deputy Commander (MAJCOM/CD) may grant permissible deviation status for other airfield-related facilities or systems that are unique to the MAJCOM, but must provide acceptable construction standards, siting criteria, and aircraft clearance requirements for such items.

B1-2.1.7 Exemptions.

Facilities constructed under previous standards should be documented as exemptions and programmed for replacement away from the airfield environment at the end of their useful life or when mission needs dictate earlier replacement. If improvements are proposed that would extend the useful life of the facility, a waiver must be requested. If the exempted facility is demolished any use of that site should conform to the criteria in this UFC. Exception is allowed for facilities located beyond and beneath the Building Restriction Lines (BRL). These exempted facilities may remain without waiver for an indefinite period, and may be renovated to extend their life-cycle if the intended use of the facility fits within the approved category groups listed as appropriate for siting within the boundaries of the BRL. See Appendix B, Section 17 for guidelines provided to establish these areas and facilities approved for construction or renovation within this area.

B1-2.1.8 Non-Conforming Facilities/Structures/Objects.

Existing facilities, structures, or objects (which could include equipment or terrain features) identified as not meeting criteria in this UFC, and are not exempted or have an existing waiver, will be classified as Non-Conforming until they are evaluated to determine whether they should be classified as an exemption, or should have a permanent or temporary waiver. These may be identified during annual airfield inspections, special inspections, survey efforts, or while conducting day to day observations. The BCE will coordinate with airfield management, flight safety, and flight operations offices (and others as appropriate) to ensure implementation of appropriate safety measures.

B1-2.1.9 Amendment of Waivers.

Amendments to existing waivers (temporary and permanent) will be developed when there are proposed changes to the scope of the original violation. This may include increasing/decreasing criteria violations included in the original waiver request (e.g. lights, sunshades, improving grade, etc.). When the number/extent of criteria violations is reduced, note the improvement on the annual review. If the number/extent of criteria violations is increased, MAJCOM/CD approval is required.

B1-2.2 Contents of Waiver Request Package.

Each request must contain the following information unless otherwise noted:

- Criteria to be waived. Reference publication, paragraph, and page number of the specific criteria to be waived.
- Alternatives Courses of Action (COA) Considered. Describe any alternative courses of actions that were considered when developing the solution proposal and why they were not acceptable for meeting the purpose and need of the proposal/action.
- Rationale/Justification of Selected COA. Explain the rationale for the selected COA and why the approving official should accept the risks associated with the proposal.
- Risk Assessment. Complete the AF Form 4437 Deliberate Risk Assessment Worksheet. Utilize a cross functional team to complete the risk assessment. Contributing organizations may include civil engineering, safety, airfield operations and others as appropriate. See AFI 90-802 for additional information. The risk analysis should include a detailed explanation of the methodology used, data considered, and rationale for determining the risk (see Attachment 8 of AFPAM 90-803).
- Graphics. Pictures, diagrams, and charts must clearly illustrate condition, distances, imaginary surfaces, clear zones, etc.
- Federal Aviation Administration (FAA) Notification. Include if required per Title 14, Code of Federal Regulations (CFR), Part 77.
- Proof of Coordination. The waiver preparer documents installation coordination from the appropriate stakeholders, for example: Safety, Operations Support, Maintenance, terminal instrument procedures (TERPS), Security Forces, Communications, Civil Engineering (and any other organizations that the installation feels should coordinate on the waiver request) before requesting approval from the installation commander. At the MAJCOM level, Temporary and Permanent waiver requests should be coordinated with the same functional offices as at installation level in addition to any additional offices deemed necessary.

NOTE: Ensure any packages to support reclassification of waivers will include all the information above.

B1-2.3 Processing Waiver Requests.

Obtain current waiver processing procedures from AFCEC/CP. Waivers being reclassified will be accomplished through the standard waiver request process.

B1-2.4 Review of Waivers.

Installation review of all approved Permanent and Temporary airfield waivers will be conducted by a cross functional team to include Operations, Safety, and other appropriate stakeholders. The results are to be briefed to the Facilities Board with a copy sent to AFCEC/CP. Include the following in the review:

- A list of all waivers by waiver number.
- Waiver currency, accuracy and classification evaluation (any proposed reclassification of a waiver identified in the review will be accomplished through the waiver approval process). Note the rationale for any proposed reclassification in the summary presentation to the Facilities Board.
- Evaluate the effectiveness of implemented risk mitigation actions, control measures, and identification of any new risks for each temporary waiver.
- A summary of the number of waivers approved and/or cancelled within the last year.
- An update of the status of action/projects associated with each temporary waiver.

B1-2.5 Responsibilities.

B1-2.5.1 AFCEC/CO.

Develops and maintains United Facilities Criteria for Airfield and Heliport Planning and design and provides secondary technical support on the airfield waiver program.

B1-2.5.2 AFCEC/CP.

Provides policy direction on the airfield waiver and waiver review programs. Determines technical sufficiency of permanent and temporary airfield waiver requests. Maintains completed airfield waivers and waiver reviews on its website. Forwards a record copy of installation waiver review summary to the MAJCOM for information.

B1-2.5.3 HQ AFFSA.

- Reviews all policy changes to airfield planning and design criteria before implementation to determine operational impact on airfield and aircraft operations.
- Reviews all requests for waivers to instrument procedure criteria.
- Processes requests for waivers to instrument procedure design criteria in accordance with guidance outlined in AFI 11-230.
- Provides documentation to AFCEC/CO to justify adding any new permissible deviations (such as newer navigational aids or weather equipment) in B13-2 Permissible Deviations. Documentation would

include siting diagrams and signed Risk Assessment by AFFSA/CC or AFFSA/CD recommending the item and associated siting requirements be added to UFC 3-260-01 for the new permissible deviation.

B1-2.5.4 Base Civil Engineer (BCE).

- Coordinates with airfield management, flying and ground safety, flight operations, logistics, TERPS (typically at MAJCOM), security forces, and communications during waiver package preparation.
- **Establishes and updates (at least annually) geospatial data sets of approved waivered items in accordance with AFI 32-7062, Comprehensive Planning, in conjunction with the latest published Installation Development Plan (IDP) GIS guidance. Also see AFI 11-230, *Instrument Procedures*.**
- Develops a military construction (MILCON) program or other project to systematically correct violations noted in temporary waivers. Project listing should include (by waiver) facilities board priority, facility investment metric (FIM) rating, integrated priority list (IPL) rating (or other installation or AFIMSC prioritization rating system), risk assessment rating, funds type required (e.g., O&M, MILCON, 3080), and projected fiscal year.
- Record, review, and process waiver requests (see paragraph B1-2.3 and B1-2.4) and maintain (for record) one copy of all pertinent documents relative to each waiver, including a record of staff coordination on actions at base, AFCEC/CP and MAJCOM levels.
- Lead the annual review of Permanent and Temporary waivers and brief the Facilities Board per paragraph B 1-2.4 above.
- Participates in an annual assessment of the airfield/airspace criteria using the Air Force Airfield Certification/Safety Inspection Checklist (see AFI 13-213).

B1-2.5.5 NGB/A7CP (for ANG facilities).

- Develops policy on waivers and manages the ANG waiver program.
- Processes and coordinates inquiries and actions for deviations to criteria and standards.
- ANG tenant units on active duty installations must use AFCEC/CP waiver processing guidelines.

B1-2.5.6 HQ AFRC/A4C (for AFRC facilities).

- Develops policy on waivers and manages the AFRC waiver program.
- Processes and coordinates inquiries and actions for deviations to criteria and standards.

- AFRC tenant units on active duty installations must use AFCEC/CP waiver processing guidelines.

B1-3 NAVY AND MARINE CORPS.

B1-3.1 Applicability.

See Chapter 1 for Scope and Applicability of criteria.

B1-3.1.1 Use of Criteria.

The criteria in this UFC apply to Navy and Marine Corps aviation facilities located in the United States, its territories, trusts, and possessions. Where a Navy or Marine Corps aviation facility is a tenant on a civil airport, use these criteria to the extent practicable; otherwise, FAA criteria apply. Where a Navy or Marine Corps aviation facility is host to a civilian airport, these criteria will apply. Apply these standards to the extent practical at overseas locations where the Navy and Marine Corps have vested base rights. While the criteria in this UFC are not intended for use in a theater-of-operations situation, they may be used as a guideline where prolonged use is anticipated and no other standard has been designated.

B1-3.1.2 Criteria at Existing Facilities.

See Chapter 1, Paragraph 1-3 for additional guidance and requirements for existing facilities where mission has changed. The criteria will be used for planning new aviation facilities and new airfield pavements at existing aviation facilities (exception: primary surface width for Class B runway). Existing aviation facilities have been developed using previous standards which may not conform to the criteria herein. Safety clearances at existing aviation facilities need not be upgraded solely for the purpose of conforming to these criteria. However, at existing aviation facilities where few structures have been constructed in accordance with previous safety clearances, it may be feasible to apply the revised standards herein.

B1-3.2 Navy/Marine Corps Design and Airfield Safety Waiver Processes.

Waivers can be temporary or permanent in nature and various NAVY, NAVFAC, NAVAIR and USMC documents may use different terminology for their respective purposes. The primary purpose of this UFC is to offer criteria for new facilities. Mil-STD 3007 contains NAVFAC waiver and exemption requirements. However, waivers may be required from multiple authorities.

B1-3.2.1 NAVFAC UFC Waivers.

NAVFAC UFC Waivers are waivers or exemptions to criteria (per Mil-STD 3007) addressing design considerations of new facilities. The need for such waiver may arise during the planning site approval process or during project design. The site approval process and resources are documented in NAVFACINST 11010.45A, Site Approval Request (SAR) Process. Generally, if criteria is not being met during the planning or design phase, both NAVFAC UFC and NAVAIR Airfield Safety Waivers are required if another site avoiding violations cannot be selected. All waivers to the NAVFAC UFC program are contained in MIL-STD 3007. However, a joint process using the NAVAIR IBONS system has been developed to satisfy the NAVFAC Mil-STD process and the NAVAIR process since it will also be necessary to seek a NAVAIR Airfield Safety Waiver to support the NAVFAC UFC Waiver (see Paragraph B1-3.2.2).

For additional information about the NAVFAC Site Approval Request (SAR) process, copies of policies, Asset Management Bulletins, and latest Installation Site Approval Request Team (ISART) Resource, in addition to links to relevant NAVFAC Business Management Systems (e.g. Standard BMS, Airfield Safety BMS), and Points of Contact (POCs), etc., visit the SAR process website on the NAVFAC portal, at:

https://hub.navfac.navy.mil/webcenter/portal/am/page1848/

NOTE: Authorized DOD personnel must have a CAC card. When prompted, you may utilize the name and email address of the NAVFAC SAR Process program manager to obtain access to the HQ NAVFAC website.

B1-3.2.2 NAVAIR Airfield Safety Waivers.

NAVAIR Airfield Safety Waivers are temporary or permanent waivers to criteria which incorporate air operations safety and risk considerations and operational mitigations. It is acknowledged that NAVAIR is the authority for Airfield Safety and shares this UFC for the purposes of managing the NAVAIR Airfield Safety Waiver Program. Generally, it is necessary to seek NAVAIR waivers during the site planning/approval, design, and construction phases or for existing facilities and other situations as defined by CNIC (per NAVAIR 00-80T-124 NATOPS Air Operations Manual) and other NAVAIR policies. The NAVAIR IBONS system can be used to request both a NAVFAC and NAVAIR waiver or just a NAVAIR waiver depending on the situation.

The joint NAVFAC/NAVAIR process is under development and if not available, separate waivers using separate processes must be sought. For IBONS Access: Go to the following link : https://ibons.navair.navy.mil/ibons

Must have CAC and utilize your CAC for log in.

Go to "Get an entry URL"

Complete the information and submit.

Access will be granted within 24 hours.

B1-3.3 Exceptions from Waivers.

See Chapter 2 for Navy and Marine Corps facilities excepted from waivers.

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APPENDIX B
SECTION 2
LAND USE AND FACILITY SPACE -- ALLOWANCES

B2-1 APPLICABILITY.

B2-1.1 Army.

For Army facility space allowances, see DAPAM 415-28, *Guide to Army Real Property Category Codes*.

B2-1.2 Air Force.

For Air Force facility space allowances, see AFI 32-1024, *Standard Facility Requirements* and AFH 32-1084, *Facility Requirements*.

B2-1.3 Navy and Marine Corps.

This section does not apply to the Navy and Marine Corps. For Navy and Marine Corps facility space allowances, see UFC 2-000-05N, *Facility Planning for Navy and Marine Corps Shore Installations*.

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APPENDIX B
SECTION 3
DOD AIR INSTALLATIONS COMPATIBLE USE ZONES

B3-1 REFERENCES.

Refer to the following documents for the latest guidance on air installation land use compatibility guidelines. Also, refer to paragraph 3-12 and Table 3-5 for additional information on the graded area of clear zones.

B3-1.1 DoD.

DoDI 4165.57 provides the DoD policy for Service AICUZ program management.

B3-1.2 Air Force.

Air Force land use guidelines are provided in AFI 32-7063 and AFH 32-7084.

B3-1.3 Navy and Marine Corps.

For Navy and Marine Corps installations, see OPNAVINST 11010.36C/MCO 11010.16 (or latest version).

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APPENDIX B
SECTION 4
WIND COVERAGE STUDIES

B4-1 APPLICABILITY.

B4-1.1 Army.

One factor in the determination of the runway and helipad orientation is wind coverage, as discussed in Chapter 3. Runway and helipad orientation based on wind coverage for Army airfields will be determined in accordance with the methodology presented in FAA AC 150/5300-13, Appendix 1, "Wind Analysis." The runway or helipad orientation should obtain 95 percent wind coverage with a 19.5 kilometer-per-hour (10.5 knot) crosswind. If this coverage cannot be attained, a crosswind runway would be desirable.

B4-1.2 Air Force.

One factor in the determination of the runway orientation is wind coverage, as discussed in Chapter 3. Runway orientation based on wind coverage for Air Force airfields will be determined in accordance with the methodology presented in FAA AC 150/5300-13, Appendix 1, "Wind Analysis." Criteria for crosswind runway authorization will be in accordance with criteria presented in AFH 32-1084. AF/A3O, Director of Operations, must approve authorization for crosswind runways.

B4-1.3 Navy and Marine Corps.

Runway orientation for Navy and Marine Corps airfields will be determined in accordance with this section. Criteria for the crosswind runways are found in paragraph B4-6.

B4-2 OBJECTIVE.

This section provides guidance on the assembly and analysis of wind data to prepare a wind coverage study to determine runway and helipad orientation. It also provides guidance on analyzing the operational impact of winds on existing runways and helipads.

B4-3 GENERAL.

A factor influencing runway and helipad orientation is wind. Ideally, a runway or helipad should be aligned with the prevailing wind. Wind conditions affect all airplanes in varying degrees. Generally, the smaller the airplane, the more it is affected by wind, particularly crosswind components.

B4-3.1 Basic Conditions.

The most desirable runway or helipad orientation based on wind is the one which has the largest wind coverage and minimum crosswind components. Wind coverage is that percent of time crosswind components are below an acceptable velocity. The desirable wind coverage for an airport is 95 percent, based on the total number of weather observations.

B4-3.2 Meteorological Conditions.

The latest and best wind information should be used to carry out a wind coverage study. A record which covers the last five consecutive years of wind observations is preferred. Ascertain frequency of occurrence, singly and in combination, for wind (direction and velocity), temperature, humidity, barometric pressure, clouds (type and amount), visibility (ceiling), precipitation (type and amount), thunderstorms, and any other unusual weather conditions peculiar to the area.

B4-3.2.1 Usable Data.

Use only data which give representative average values. For example, do not consider extremes of wind velocity during infrequent thunderstorms of short duration.

B4-3.2.2 Source of Data.

Obtain meteorological data from one or more of the following sources:

- National Oceanic and Atmospheric Administration, Environmental Data Service
- National Weather Service
- Bureau of Reclamation
- Forest Service
- Soil Conservation Service
- Federal Aviation Administration
- Army Corps of Engineers
- Navy Oceanographic Office
- Geological Survey
- US Air Force

B4-4 WIND VELOCITY AND DIRECTION.

The following are the most important meteorological factors determining runway and helipad orientation:

B4-4.1 Composite Windrose.

When weather recording stations are located near a proposed site and intervening terrain is level or slightly rolling, prepare a composite windrose from data of surrounding stations.

B4-4.2 Terrain.

If intervening terrain is mountainous or contains lakes or large rivers, allow for their effects on wind velocities and directions by judgment, after study of topographical information and available meteorological data.

B4-4.3 Additional Weather Data.

Consider wind directions and velocities in conjunction with visibility, precipitation, and other pertinent weather information.

B4-4.4 Wind Distribution.

Determine wind distribution to accompany instrument flight rule (IFR) conditions when considering orientation of an instrument runway.

B4-5 USE OF WINDROSE DIAGRAMS.

Prepare a windrose diagram for each new runway or helipad in the planning stage or to analyze the operational impact of wind on existing runways or helipads.

B4-5.1 Drawing the Windrose.

The standard windrose (Figures B4-1 and B4-2) consists of a series of concentric circles cut by radial lines. The perimeter of each concentric circle represents the division between successive wind speed groupings. Radial lines are drawn so that the area between each successive pair is centered on the direction of the reported wind.

B4-5.2 Special Conditions.

Windrose diagrams for special meteorological conditions, such as wind velocities and directions during IFR conditions, should be prepared when necessary for local airfield needs.

B4-5.2.1 Wind Direction.

Use radial lines to represent compass directions based on true north, and concentric circles, drawn to scale, to represent wind velocities measured from the center of the circle.

B4-5.2.2 Calm Wind.

Use the innermost circle to encompass calm periods and wind velocities up to the allowable crosswind component for the airfield under consideration.

B4-5.2.3 Computations.

Compute percentages of time that winds of indicated velocities and directions occur, and insert them in the segments bounded by the appropriate radial direction lines and concentric wind velocity circles. Express percentages to the nearest tenth, which is adequate and consistent with wind data accuracy. Figure B4-3 displays a completed windrose.

Figure B4-1. Windrose Blank Showing Direction and Divisions (16-Sector [22.5°] Windrose)

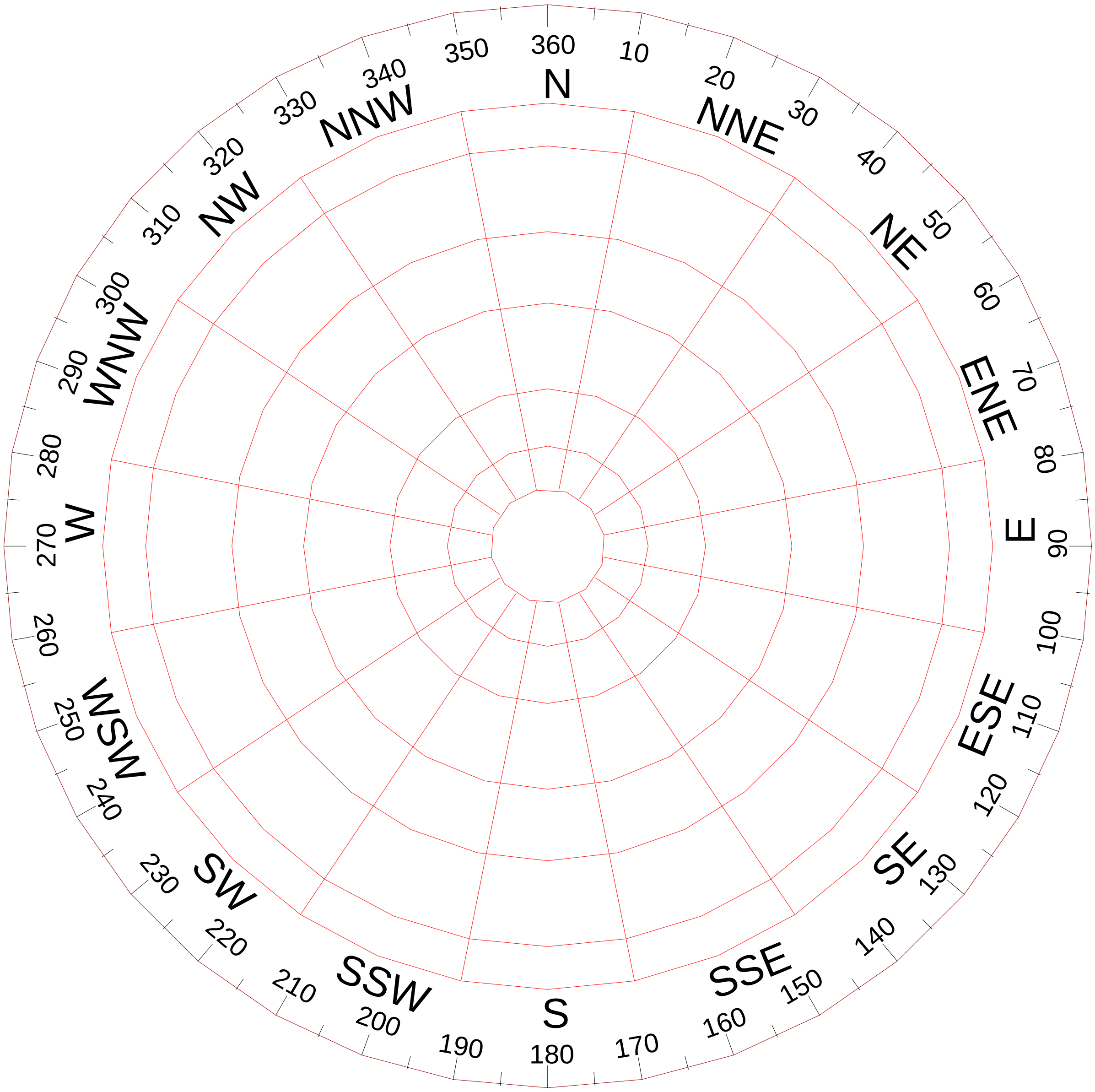


Figure B4-2. Windrose Blank Showing Direction and Divisions (36-Sector [10°] Windrose)

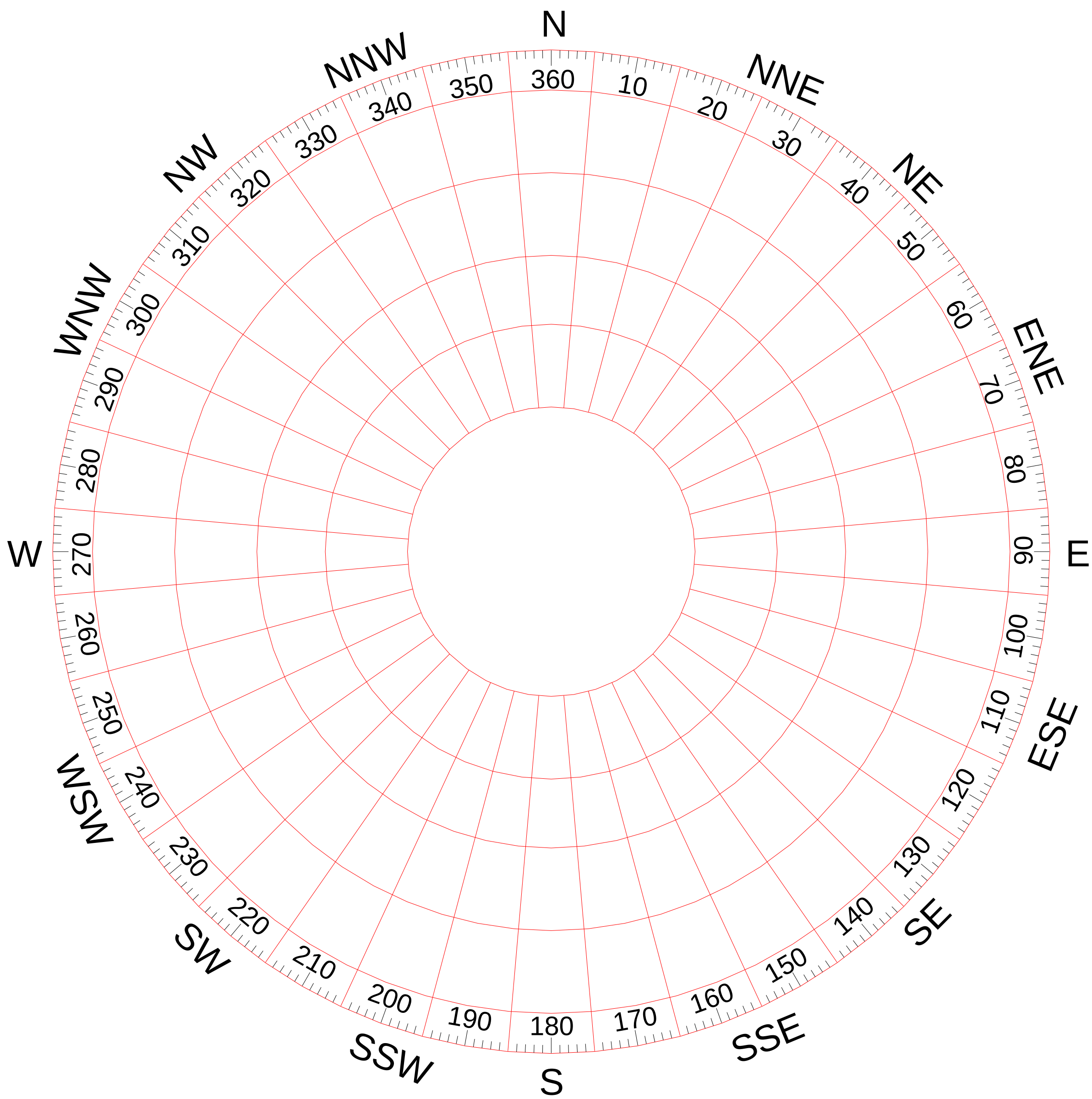
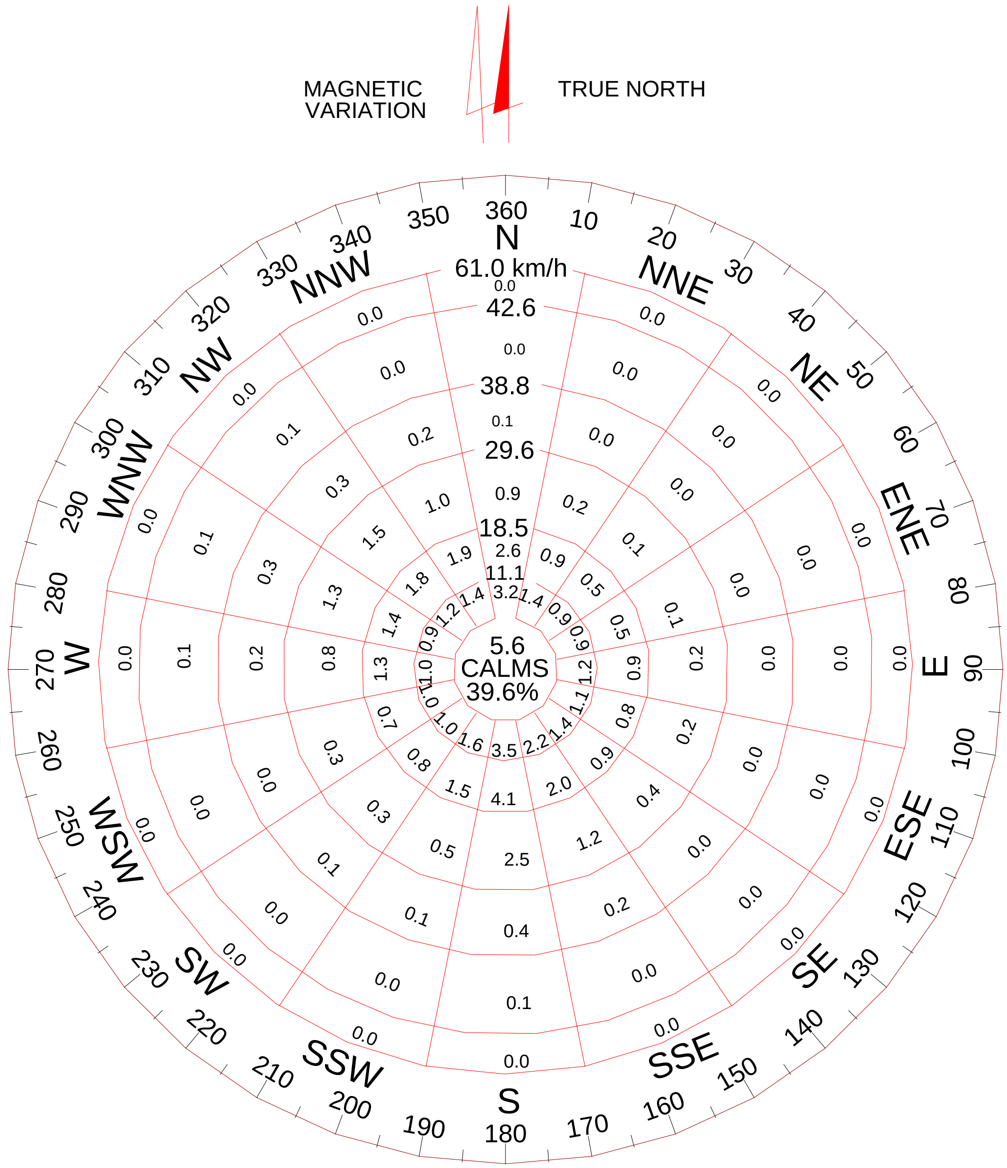


Figure B4-3. Completed Windrose and Wind Velocity Equivalents (16-Sector [22.5°] Windrose)



WIND VELOCITY EQUIVALENTS		
KNOTS	KM/H	MPH
3	5.6	3.5
6	11.1	6.9
10	18.5	11.5
16	29.6	18.4
21	38.8	24.2
23	42.6	26.5
33	61.0	37.9

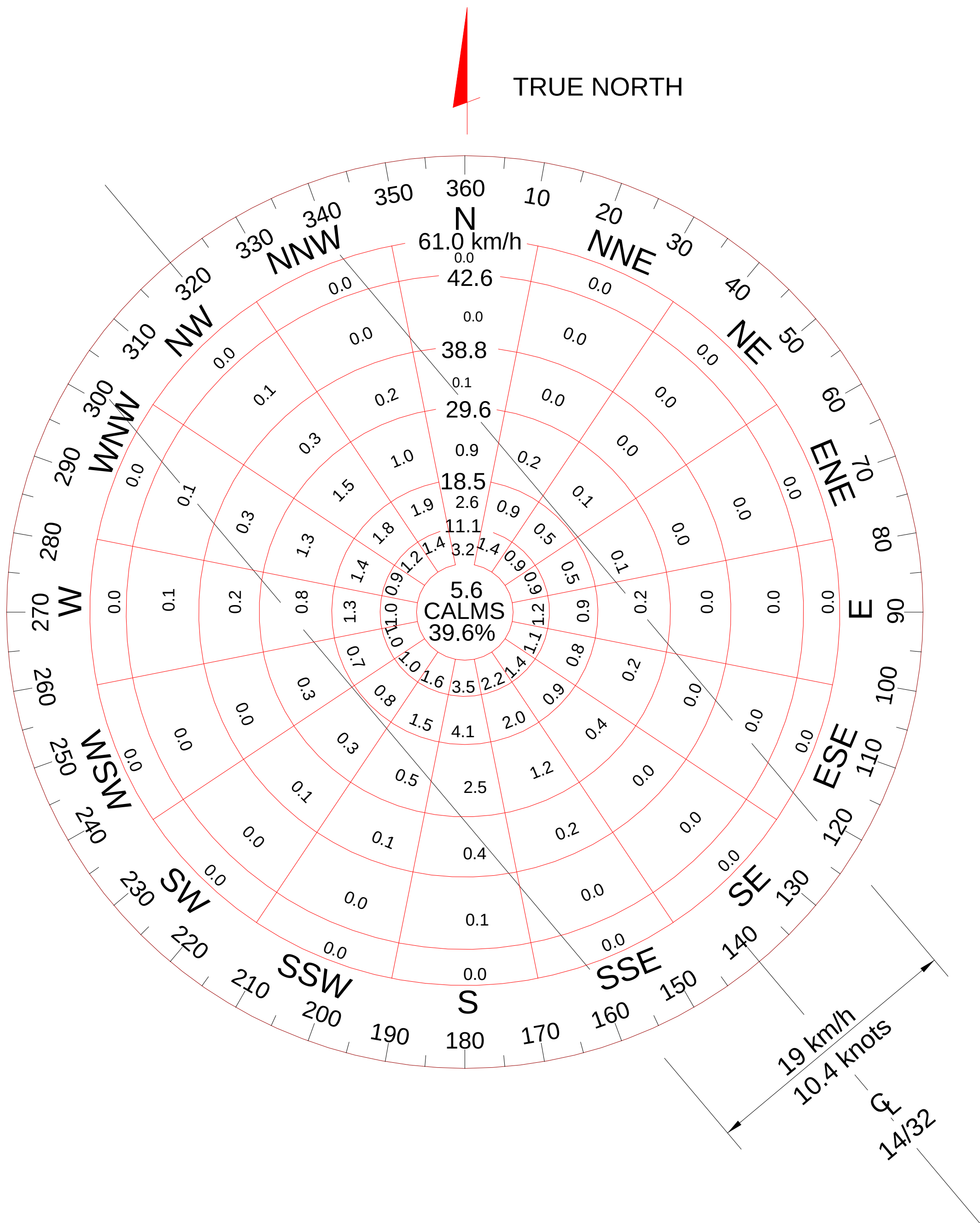
B4-5.2.4 Crosswind Template.

A transparent crosswind template is a useful aid in carrying out the windrose analysis. The template is essentially a series of three parallel lines drawn to the same scale as the windrose circles. The allowable crosswind for the runway width establishes the physical distance between the outer parallel lines and the centerline.

B4-5.3 Desired Runway or Helipad Orientation.

For the use of windrose diagrams and crosswind templates in determining desirable runway or helipad orientations with respect to wind coverage, see Figure B4-4.

Figure B4-4. Windrose Analysis



NOTE: A runway oriented 140° to 320° (true) would have 3.1 percent of winds exceeding the design crosswind component of 19 km/h.

B4-6 WIND COVERAGE REQUIREMENTS FOR RUNWAYS.

Determine the runway orientation which provides the greatest wind coverage within the allowable crosswind limits. Place runways to obtain at least 95 percent wind coverage of the maximum allowable crosswind components, as discussed in paragraph B4-6.3. It is accepted practice to total the percentages of the segments appearing outside the limit lines and to subtract this number from 100. For analysis purposes, winds are assumed to be uniformly distributed throughout each of the individual segments. The larger the area or segment, the less accurate this presumption.

B4-6.1 Primary Runways or Helipads.

Orient a primary runway or helipad for the maximum possible wind coverage. See Figure B4-4 for the method of determining wind coverage.

B4-6.2 Secondary Runways.

Where wind coverage of the primary runway is less than 95 percent, or in the case of some localities where during periods of restricted visibility the wind is from a direction other than the direction of the primary runway, a secondary (crosswind) runway is required. Normally, secondary runways will not be planned without prior authorization from Naval Air Systems Command. The secondary runway will be oriented so that the angle between the primary and secondary runway centerline is as near 90 degrees as is feasible, considering local site conditions and the need to provide maximum crosswind coverage.

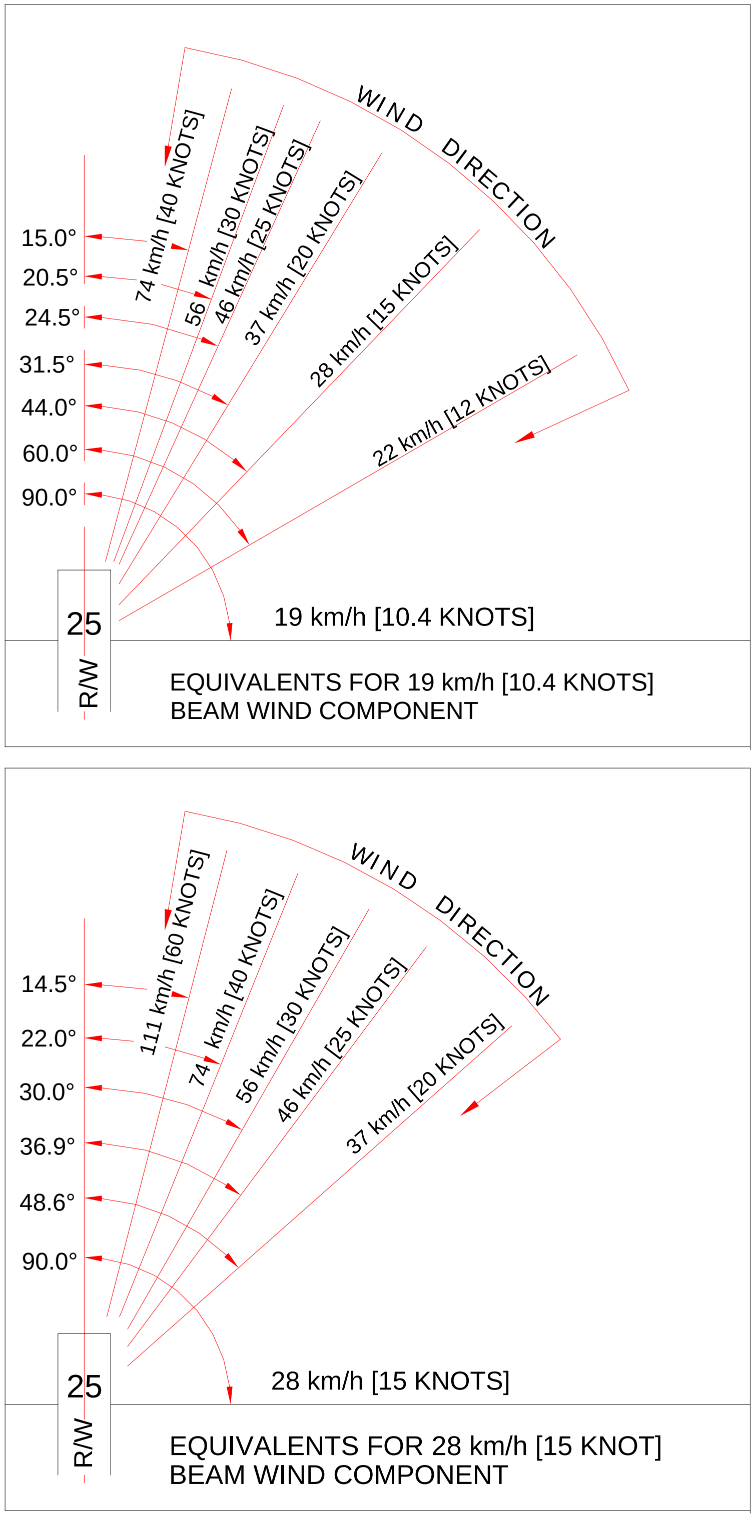
B4-6.3 Maximum Allowable Crosswind Components (Navy Only).

Select these components according to type of aircraft, as follows: (1) tricycle gear aircraft, 28.0 kilometers per hour (15.0 knots); and (2) conventional gear aircraft, 19.5 kilometers per hour (10.5 knots).

B4-6.4 Allowable Variations of Wind Direction.

See Figure B4-5 for allowable wind directions.

Figure B4-5. Allowable Wind Variation for 19 Kilometer-per-Hour (10.4 Knot) and 28 Kilometer-per-Hour (15 Knot) Beam Wind Components



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APPENDIX B
section 5
federal aviation regulation part 77, objects affecting navigable airspace

***note**: far part 77 is periodically updated. check https://www.gpo.gov/fdsys/pkg/cfr-2012-title14-vol2/xml/cfr-2012-title14-vol2-part77.xml#seqnum77.5 for the most current version of the regulation.*

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APPENDIX B
SECTION 6
AIRCRAFT CHARACTERISTICS FOR AIRFIELD-HELIPORT DESIGN AND EVALUATION

B6-1 GENERAL.

Aircraft characteristics, including aircraft dimensions, weights, and other information for Military Aircraft are available in Technical Report TSC 13-2, and for Selective Commercial Aircraft are available in Technical Report TSC 13-3. Both documents are available at https://transportation.erdc.dren.mil/tsmcx/criteria.aspx. This ETL is not all-inclusive. Refer to the Mission Design Series (MDS) Facilities Requirements Document (FRD) for late model aircraft characteristics.

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APPENDIX B
SECTION 7
JET BLAST EFFECTS

B7-1 CONTENTS.

Jet blast affects various operational areas at an airport. Personnel safety is a major concern in terminal, maintenance, and cargo areas.

B7-2 CONSIDERATIONS.

The effects of jet blast are far more serious than those of prop wash and must be considered when designing aircraft parking configurations for all military and civil aircraft. These high velocities are capable of causing bodily injury to personnel, damage to airport equipment, or damage to certain pavements and other erodible surfaces.

B7-2.1 Blast Temperatures.

High temperatures are also a by-product of jet exhaust. The area exposed to hazardous high temperatures is typically smaller than the area subjected to hazardous blast velocities.

B7-2.2 Blast Velocities.

Blast velocities greater than 48 kilometers per hour (30 miles per hour) can cause loose objects on the pavement to become airborne and injure personnel who may be a considerable distance behind the aircraft. The layout of aviation facilities must protect personnel from projectiles.

B7-2.3 Minimum Clearances.

The minimum clearance from the rear of a jet operating at military power to dissipate the temperature and velocity to levels that will not endanger aircraft personnel and damage other aircraft is referred to as the safe distance. Safe distances are discussed in paragraph B7-5.

B7-2.4 Engine Blast Relationship.

Each jet engine has its own footprint of temperature and velocity versus distance. Jet blast relationships for Army, Air Force, and selected civil aircraft may be obtained from the source listed in Appendix B, Section 6, or from the Facilities Requirements Document (FRD) for the specific Mission Design Series (MDS). The relationships are in graphical format showing velocity versus distance and temperature versus distance at various power settings. The planner/designer should obtain the jet blast relationship when the effects of jet blast could create a hazardous condition for personnel and equipment.

B7-3 PROTECTION FROM JET BLAST EFFECTS.

B7-3.1 Blast Deflectors.

Equipment such as blast deflectors may be required at locations where continued jet engine run-up interferes with the parking or taxiing of aircraft, the movement of vehicles, and the activities of maintenance or aircraft personnel. Additional information on jet blast deflectors is presented in Appendix B, Section 8.

B7-3.2 Unprotected Areas.

Unprotected areas of the airfield which receive continued exposure to jet blast can erode and cause release of soil, stones, and other debris that can be ingested into jet engines and cause engine damage.

B7-3.3 Minimum Distances for Run-Up.

See Appendix B, Section 12 for minimum distances from the rear of jet aircraft to the edge of adjacent asphalt pavements. Run-up pads must be sized to provide a minimum of 7.62 meters (25 feet) of Portland cement concrete (PCC) aft of the aircraft fuselage to prevent damage to the aircraft in the event the pavement fails due to jet blast.

B7-4 NOISE CONSIDERATIONS.

Protection against noise exposure is required whenever the sound level exceeds 85 dB(A) continuous, or 140 dB(A) impulse, regardless of the duration of exposure.

B7-5 JET BLAST REQUIREMENTS.

B7-5.1 Parked Aircraft.

A minimum clearance (safe distance) is needed to the rear of an engine to dissipate jet blast to less than 56 kilometers per hour (35 miles per hour) and jet exhaust temperatures to 38 degrees Celsius (100 degrees Fahrenheit) or ambient, whichever is more—otherwise, a jet blast deflector is needed. Velocities of 48 kilometers per hour (30 miles per hour) to 56 kilometers per hour (35 miles per hour) can occur over 490 meters (1,600 feet) to the rear of certain aircraft with engines operating at takeoff thrust. However, these velocities decrease rapidly with distance behind the jet engine.

B7-5.2 Taxiing Aircraft.

The distance from the rear of the aircraft engine to the wingtip of other aircraft will be:

- A distance such that jet blast temperature will not exceed 38 degrees Celsius (100 degrees Fahrenheit);
- A distance such that jet blast velocity will not exceed 56 kilometers per hour (35 miles per hour).

APPENDIX B
SECTION 8
JET BLAST DEFLECTOR

B8-1 OVERVIEW.

Jet blast deflectors can substantially reduce the damaging effects of jet blast on structures, equipment, and personnel. Jet blast deflectors can also reduce the effects of noise and fumes associated with jet engine operation. Erosion of shoulders not protected by asphaltic concrete surfacing can be mitigated by blast deflectors. Blast deflectors consist of a concave corrugated sheet metal surface, with or without baffles, fastened and braced to a concrete base to withstand the force of the jet blast and deflect it upward.

B8-1.1 Location.

The deflector is usually located 21 meters (70 feet) to 37 meters (120 feet) aft of the jet engine nozzle, but not less than 15 meters (50 feet) from the tail of the aircraft.

B8-1.2 Size and Configuration.

Size and configuration of jet blast deflectors are based on jet blast velocity and location and elevation of nozzles. Commercially available jet blast deflectors should be considered when designing jet blast protection.

B8-1.3 Paved Shoulders.

For blast deflectors placed off the edge of a paved apron, a paved shoulder is required between the blast deflector and the edge of the paved apron.

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APPENDIX B
SECTION 9
EXPLOSIVES ON OR NEAR AIRFIELDS

B9-1 CONTENTS.

All explosives locations, including locations where aircraft loaded with explosives are parked, must be sited in accordance with DoD Standard 6055.09-M and applicable Service explosives safety regulations. Explosives site plans, approved through command channels to DoD, ensure that minimal acceptable risk exists between explosives and other airfield resources. To prevent inadvertent ignition of Electrically Initiated Devises (EID), separation between sources of electromagnetic radiation is required. Separation distances must be according to safe separation distance criteria. Grounding requirements, lightning protection, and further considerations for explosives on aircraft are presented below.

B9-2 SEPARATION DISTANCE REQUIREMENTS.

See Chapter 1, Paragraph 1-4.1 for explosive safety criteria requirements and other facility design criteria.

B9-3 PROHIBITED ZONES.

Explosives, explosive facilities, and parked explosives-loaded aircraft (or those being loaded or unloaded) are prohibited from being located in Accident Potential Zones (APZ) I and II and clear zones as set forth in AR 385-10; DAPAM 385-64, Chapter 5; AFMAN 91-201; and AFI 32-7063.

B9-4 HAZARDS OF ELECTROMAGNETIC RADIATION TO EID.

EID on aircraft are initiated electrically. The accidental firing of EID carried on aircraft initiated by stray electromagnetic energy is a possible hazard on an airfield. A large number of these devices are initiated by low levels of electrical energy and are susceptible to unintentional ignition by many forms of direct or induced stray electrical energy, such as radio frequency (RF) energy from ground and airborne emitters (transmitters). Additional sources of stray electrical energy are lightning discharges, static electricity or triboelectric (friction-generated) effects, and the operation of electrical and electronic subsystem onboard weapon systems. AFMAN 91-201 should be used as a guide in setting up safe separation between aircraft loaded with EID.

B9-5 LIGHTNING PROTECTION.

Lightning protection must be installed on open pads used for manufacturing, processing, handling, or storing explosives and ammunition. Lightning protection systems must comply with DoD 6055.09-M; AFM 88-9CH3/TM 5-811-3; AFI 32-1065; and National Fire Protection Association (NFPA) 780.

B9-6 GROUNDING OF AIRCRAFT.

Aircraft that are being loaded with explosives must be grounded at all times. Air Force grounding of aircraft will be in accordance with AFMAN 91-201 and applicable weapons systems technical orders (T.O.).

B9-7 HOT REFUELING.

Hot refueling is the transfer of fuel into an aircraft with one or more engines running. The purpose of hot refueling is to reduce aircraft ground time, personnel and support equipment requirements, and increase system reliability and effectiveness by eliminating system shut-down and restart. All hot refueling locations must be sited in accordance with DoD 6055.09-M and applicable Service explosives safety criteria.

APPENDIX B
SECTION 10
COMPASS CALIBRATION PAD MAGNETIC SURVEY

B10-1 CONTENTS.

This section describes the procedures for performing a magnetic survey for new or existing compass calibration pad (CCP) by a state-registered land surveyor. These surveys will determine the following:

- Suitability of a particular site for use as a CCP.
- Variations of the magnetic field within the surveyed area.
- Magnetic declination of the area at the time of the survey.

B10-2 AIR FORCE REQUIREMENTS.

Air Force designers may use these criteria or the criteria given in Appendix 4 of FAA Advisory Circular (AC) 150/5300-13 (see paragraph 6-11.2).

B10-3 CCP SURVEY AUTHORITIES AND RESOURCES.

Many resources are available to perform CCP surveys including Registered Land Surveyors. However, additional government resources exist including:

U.S. Geological Survey

The U.S. Geological Survey (USGS) of the Department of Interior is available to provide information to airports and others on the necessary surveys and equipment to certify a compass rose. In addition, the USGS is available to calibrate magnetometers and other suitable instruments used to measure the magnetic field. The instruments are necessary to determine the difference between true and magnetic north and the uniformity of the magnetic field in the area of a compass calibration pad and must be regularly calibrated to make accurate measurements. The cost for calibration service is only that necessary to cover the cost. Requests for this service should be made to the following:

U.S. Geological Survey
Geomagnetism Group
Box 25046, MS 966
Denver, CO 80225
website: https://www.geomag.usgs.gov

National Geospatial-Intelligence Agency (NGA)

The NGA has capabilities to perform CCP surveys as well as other services. Each DoD branch of service must contact their respective representative to request compete their project need.

Navy Contact in NGA:
GI&S Officer
OPNAV N2N6E4 PNT
Pentagon, 1D479
571-256-8222

For the Navy, additional technical resources may be available from Naval Air Technical Data and Engineering Services Center (NATEC). See additional guidance in NAVAIR 05-15C-2 OPERATION, ORGANIZATIONAL AND INTERMEDIATE MAINTENANCE WITH ILLUSTRATED PARTS BREAKDOWN: A/E36T-2 MAGNETIC COMPASS CALIBRATOR SET or contact Naval Air Technical Data and Engineering Services Center (NATEC).

B10-4 CCP SURVEY ACCURACY REQUIREMENTS.

For the purpose of this survey, final calculations should be reported to the nearest one minute (1') of arc with an accuracy of ±10 minutes (10'). Typically, magnetic variations can be determined to the nearest 30 minutes (30') of arc by using a conventional transit with a compass. The finer precision needed for these surveys may be obtained by taking a minimum of three readings at each site and then reporting their average. All azimuths must be established by the Global Positioning System (GPS) or Second Order Class II conventional control survey referenced to known positions within the North American Datum of 1983 (NAD83) adjustment network, or convert host nation datum to World Geodetic System 1984 (WGS-84).

B10-5 PRELIMINARY SURVEY REQUIREMENTS.

Preliminary surveys are conducted for proposed sites to determine that the areas are magnetically quiet and thus suitable for a CCP. They are also used to determine if newly constructed items within the influence zone (see paragraph B10-10.1) of an existing CCP are causing magnetic interference. When siting a new CCP, the location should be chosen such that all separation distances, as defined in paragraph B10-10.1, are allowed for to the greatest extent practical. A preliminary magnetic survey will then be conducted to determine if the area is magnetically quiet with no natural or manmade magnetic disturbances. When conducting the preliminary survey, the surveyor must immediately notify the agency requesting the survey of any areas they find that are causing magnetic interferences so they can try to identify and remove the interference and also determine if the survey should continue any further. The location of the anomaly can be pinpointed by taking readings at additional points around the disturbed area and finding the location with the highest disturbance. If the magnetic anomaly cannot be removed and the site made magnetically quiet, then a new site will need to be chosen. One of the following methods is suggested for a preliminary survey.

B10-5.1 Proton Magnetometer Method.

A proton magnetometer can be used by walking over the area and making observations approximately every 6 meters (20 feet) in a grid pattern covering the site. If the values measured do not vary from any other reading by more than 25 gammas for the whole area, then the site can be considered magnetically quiet.

B10-5.2 Distant Object Method.

A distant landmark is selected for siting from the various points, 6-meter (20-foot) grid pattern, of the area being checked. A second distant object at approximately 90 degrees (90º) can also be chosen to increase accuracy. The further away the distant object is, the wider an area of points that can be compared to each other and still obtain the accuracy needed. An 8-kilometer (5-mile) -distant object will allow a comparison of magnetic declinations of points within a 24-meter (80-foot) -wide path in the direction of the distant object; while a 24-kilometer (15-mile) -distant object will allow a comparison of points within a 73-meter (240-foot) width, or effectively, the whole CCP site. If the magnetic declinations of the different points vary by more than 12 minutes (12') of arc then the site is not magnetically quiet.

B10-5.3 Reciprocal Observation Method.

Several scattered points are selected and marked in the area to be tested. The transit is set up over one central point and the magnetic azimuth to all of the other points is determined and recorded. Then the transit is set up over all the other points and a back azimuth to the central point is determined and recorded. If there are no magnetic disturbances then the original azimuth and the back azimuth should be the same for each of the points checked. If there is a difference between the azimuth and back azimuth of any of the points which is greater than 12 minutes (12') of arc, then the site is not magnetically quiet.

B10-6 MAGNETIC SURVEY REQUIREMENTS.

See paragraph 6-11 for CCP initial, re-surveying, and re-marking requirements.

B10-7 MAGNETIC SURVEY PROCEDURES.

These procedures consist of the magnetic field survey used to determine the magnetic declination of a site and the magnetic direction survey used to lay out the CCP markings. Both a magnetic field survey and a magnetic direction survey of the CCP will be performed at the frequency defined in Chapter 6 and when magnetic influences have occurred within or adjacent to the CCP. Magnetic influences are considered to be additions of power lines, installation of items containing ferrous metals, or similar activities within an influencing distance of the CCP as defined in paragraph B10-10.1.

B10-7.1 Magnetic Field Survey.

This survey is to measure the magnetic declination within the CCP area. The surveyor will be required to certify that the variations of the magnetic field are within the allowable range and to provide the average magnetic declination of the area. The direction of the horizontal component of the Earth's magnetic field (magnetic declination) measured at any point within a space between 0.6 meter (2 feet) and 1.8 meters (6 feet) above the surface of the CCP and extending over the entire area of the CCP must not differ by more than 12 minutes (12') of arc from the direction measured at any other point within this area. All raw data, intermediate computations, and final results shall be submitted in a clear, neat, and concise format. The surveyor shall accurately lay out a 6-meter by 6-meter (20-foot by 20-foot) grid with its center point coincident with the center point of the CCP. The grid will be laid out so the entire area of the CCP plus a minimum of 6 meters (20 feet) outside each edge of the CCP is covered. The grid may be laid out in any direction, but a true north or a magnetic north direction is preferred since it will simplify the azimuth calculations and allow immediate recognition of points outside the allowable declination limits. In any case, the surveyor shall determine the true azimuth of the grid layout by standard surveying procedures so the azimuth and declination of each point can be determined. After the grid is laid out, the surveyor shall check the declination of all the grid points by one of the following methods:

B10-7.1.1 Distant Object Method.

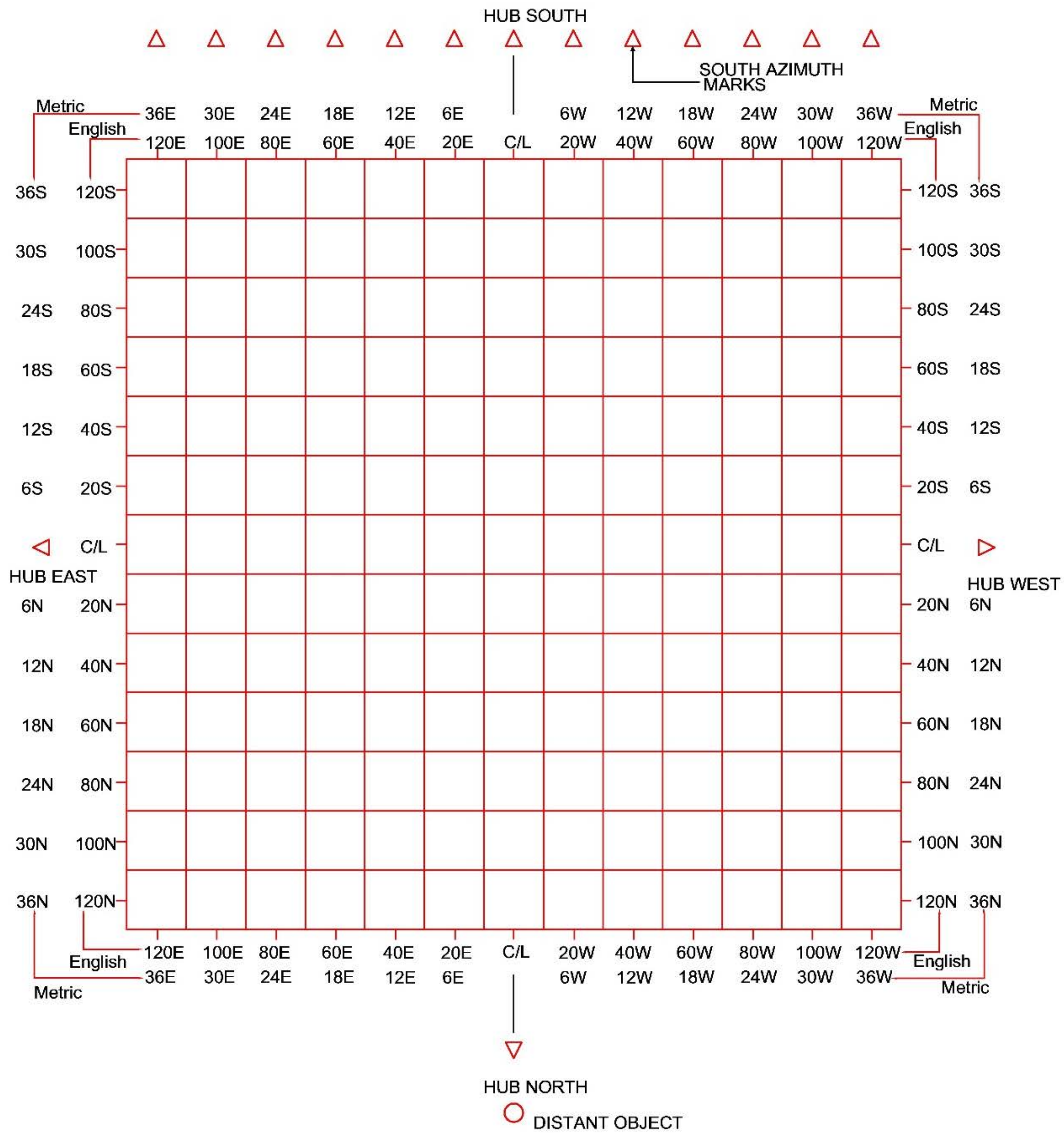
A distant landmark is selected for siting from the various points of the area being checked. A second distant object at approximately 90 degrees (90º) can also be chosen to increase accuracy. The further away the distant object is, the wider an area of points that can be compared to each other and still obtain the accuracy needed. An 8-kilometer (5-mile) -distant object will allow a comparison of magnetic declinations of points that are within a 24-meter (80-foot) -wide path in the direction of the distant object; while a 24-kilometer (15-mile) -distant object will allow a comparison of points within a 73-meter (240-foot) width, or effectively, the whole CCP site. If a distant object cannot be chosen far enough away to accurately compare the whole sight (at no time will a distant object be closer than 8 kilometers [5 miles]), then corrections for the eccentricity would have to be made. If the grid were laid out so its center was in line with the distant object and an equal number of points were laid out on either side of this centerline, then this eccentricity would automatically be corrected when the azimuths are averaged. But the points can only be compared to other points within the allowable path width when checking for disturbances in the declinations, unless corrections for the eccentricities are allowed for. The average value is then computed, adjusting for eccentricities if necessary, and reported as the site declination.

B10-7.1.2 Distant Hub Method.

After the grid is laid out, lay out additional hubs a minimum of 90 meters (300 feet) in all four directions from the center point of the grid and designated as "Hub N," "Hub S," "Hub E," and "Hub W." "South Azimuth Marks" are placed perpendicular to the "Hub S," 6 meters (20 feet) apart, and coincident to the grid layout, as shown in Figure B10-1.

Use these azimuth marks for sighting and taking declination readings. After the grid and azimuth marks are accurately set, the surveyor shall set up and level the transit over the center point and sight it on the "Hub S" mark and zero the vernier. The surveyor then must release the compass needle and turn the transit to center it on the compass needle while all the time tapping the compass to minimize friction effects. Take a reading here (to the nearest one minute [1']) then deflect the compass needle with a small magnet, realign the transit with the compass and take a third reading. Average these three readings to provide the declination for this spot. The surveyor shall accurately record the time to the nearest minute for the first and third reading. After the readings are completed for the center point (which will be used for reference), the surveyor shall then set up the transit over the other points of the grid and follow the same steps as above while sighting at the appropriate "Azimuth Mark" and determine the declination of each of these grid points. Approximately every 20 to 30 minutes, or any time a reading turns out to be outside the allowable 12 minutes (12') of arc, the surveyor must re-setup over the center point and take new readings to check for diurnal changes in the declination. If readings are found to be outside the allowable 12 minutes (12') of arc, after making corrections for diurnal changes, the surveyor shall set up at the bad point and re-check it to see if the results are repeatable. If all the readings are within the required 12 minutes (12') after the surveyor has made diurnal corrections, then average these readings and determine the site declination.

Figure B10-1. Magnetic Field Survey Sheet



B10-7.2 Magnetic Direction Survey.

A magnetic direction survey is an engineering survey used to establish and verify the location of control points and to layout and verify the markings for a CCP.

B10-8 CCP CONTROL POINTS.

CCP control points shall be located and verified using a magnetic direction survey.

B10-8.1 New CCP Control Points.

For new CCP, the surveyor shall determine the center of the pad and mark it with a bronze surveying marker accurately grouted in place. Stamp this point "Center of Calibration Pad." After the center point is located and set, the surveyor shall accurately locate and set the following control points and pavement markings in a similar manner. See Figures B10-2 and B10-3 for greater detail of the control point layout.

B10-8.1.1 True North and South Control Points.

Set a north and south control point on a "true north-south" line established through the center of the calibration pad marker. The north-south control points must be located radially from the center of the compass calibration pad at a distance of 9 meters (30 feet). Stamp these points "N_T" for the north point and "S_T" for the south point. Stamp the markers with "True North (South) - Established 'Day' 'Month' 'Year. ' "

B10-8.1.2 Magnetic North Control Point.

Set a magnetic north control point on the "magnetic north azimuth" as determined by the magnetic survey. The magnetic north control point must be located radially from the center of the compass calibration pad at a distance of 12 meters (40 feet). Mark this point on the pavement with a "Nm" above the point at 12.3 meters (41 feet) radially from the center point and " 'Month' 'Year' " below the point at 11.7 meters (39 feet) radially from the centerpoint. The date shall reflect when the magnetic north was established by a field magnetic survey. The markings shall consist of 300-millimeter (12-inch) -high block numerals with 75-millimeter (3-inch) -wide orange paint stripes. Stamp the bronze marker with "Magnetic North - Established 'Day' 'Month' 'Year'" and "Declination - 'Degrees' 'Minutes.' " True North-South.

B10-8.2 Type I CCP Control Points.

Type I CCPs require the Center, True North, True South, and Magnetic North Control Points described in paragraph B10-8.1. Figure B10-2 shows the control point layout for Type I CCPs.

B10-8.3 Type II CCP Control Points.

Type II CCPs require the Center, True North, True South, and Magnetic North Control Points described in paragraph B10-8.1. In addition, provide twenty-four (24) control points at 7.5 meters (25 feet) radially from the centerpoint beginning at true north and then every 15 degrees (15°). These points shall consist of bronze markers accurately grouted in place. Stamp each of these points with their true azimuth (for example, 15NT). Figure B10-3 shows the control point layout for Type II CCPs.

B10-8.4 Existing CCPs.

For existing CCP, the surveyor will be required to check the alignment of the magnetic north control point and adjust it if necessary. If the average magnetic declination, as determined by a magnetic field survey as described in paragraph B10-7.1, differs by more than 0.5 degree (30 arc-min) from what is marked on the CCP then the CCP must be re-calibrated (see Chapter 6, Paragraph 6-11). First, all magnetic markings must be removed from the pavement. Then the magnetic north control point marker must be removed and reset to the correct position as described above for a new CCP. The CCP markings are then laid out and marked as described in Paragraph B10-9.

Figure B10-2. Typical Type I Compass Rose Control Point and Marking Layout

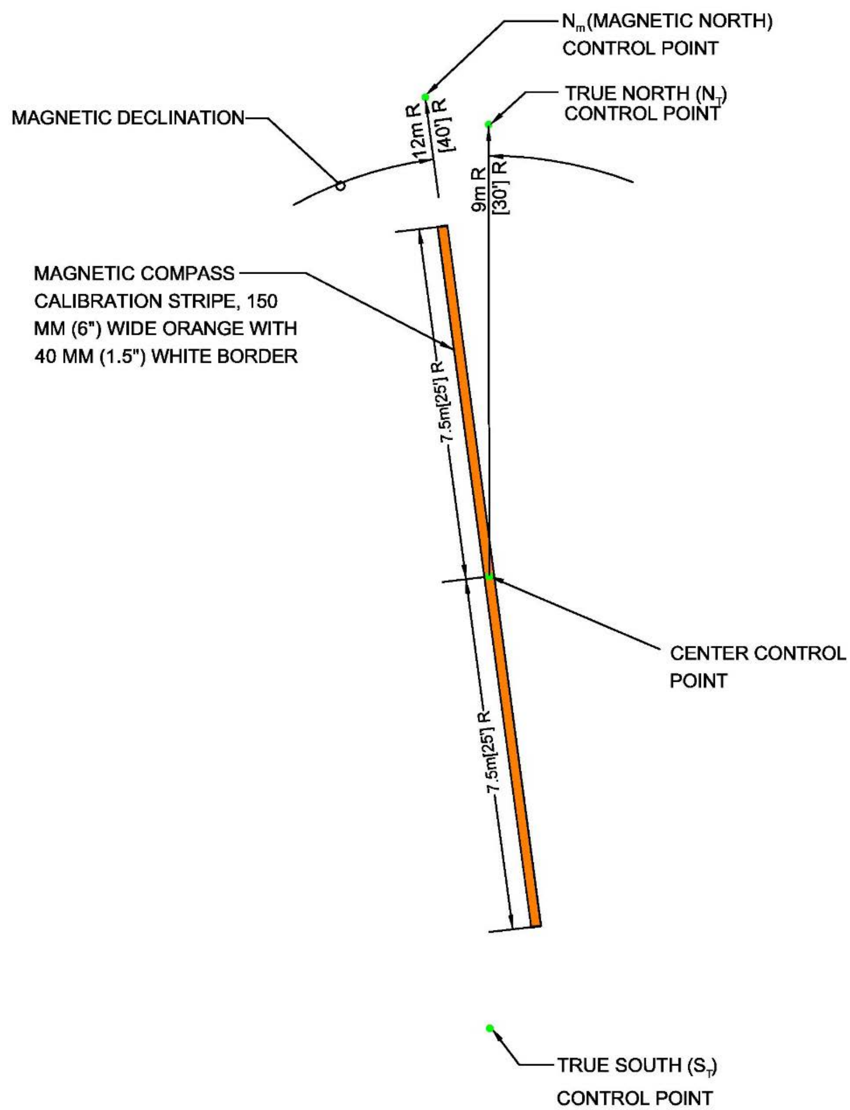
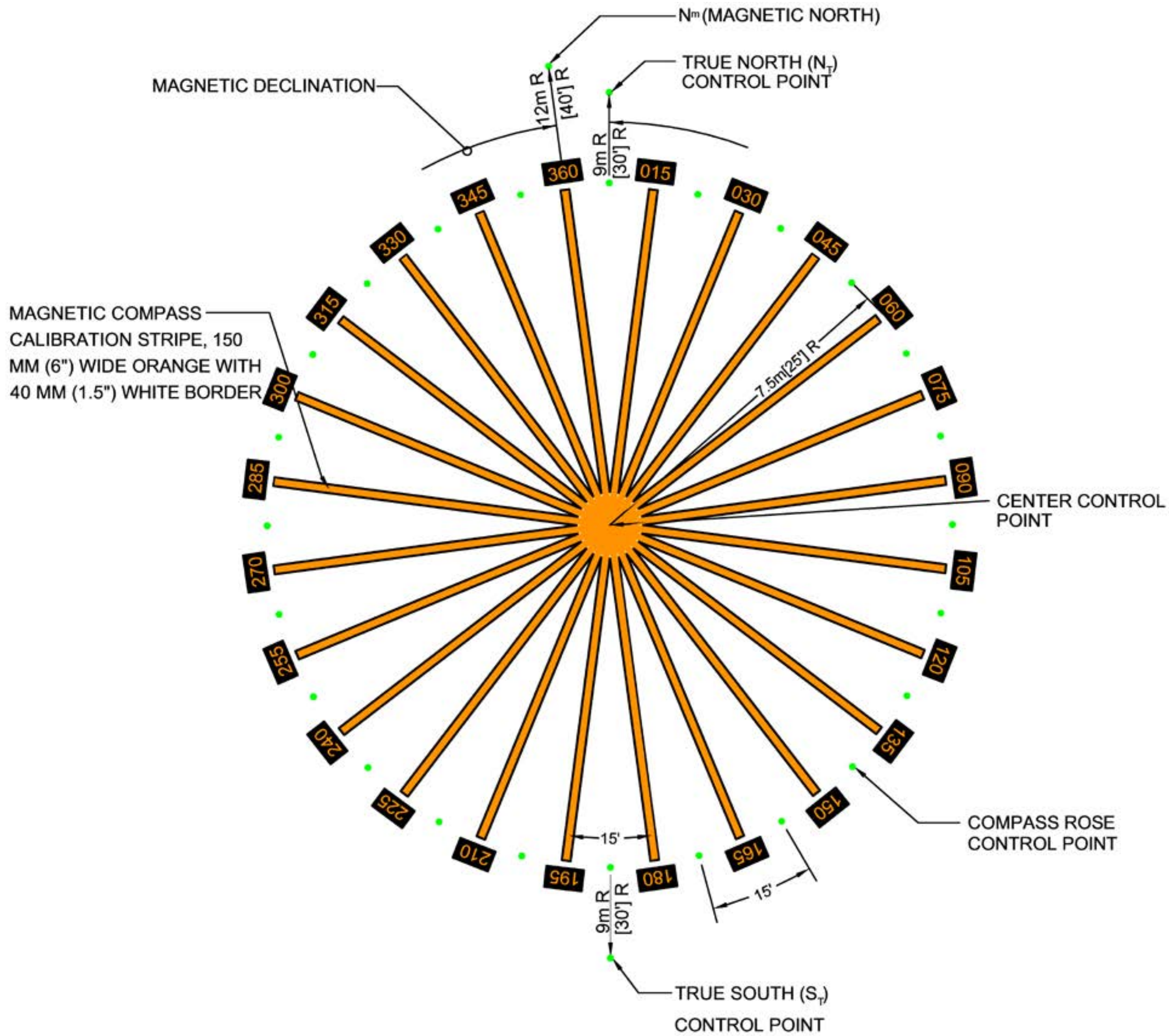


Figure B10-3. Type II Compass Rose Control Point and Marking Layout



B10-9 CCP MARKINGS.

B10-9.1 Magnetic Compass Calibration Pad Type I Markings.

Type I marking should be determined by the controlling aircraft technical manual (coordinate with aircraft maintenance group to determine specific requirements). The number of lines and locations of the lines relative to each other is determined by the number of compass systems and their installation location relative to the aircraft centerline. Some aircraft types may need only 1 line, others may need 3 lines. Typical lines are 150-millimeter (6-inch) -wide orange stripes. These stripes begin at the center of the pad and extend outward for a minimum length of 7.5 meters (25 feet), aligned on the magnetic north and south control points. Border each stripe with a 40-millimeter

(1.5-inch) -wide white stripe. Where Type I and Type II pads overlap, select line colors and layout to deconflict the markings as much as possible.

B10-9.2 Magnetic Compass Calibration Pad Type II Markings.

Type II markings are set at magnetic directions from the corresponding true compass rose control point at every 15 degrees (15°). A 150-millimeter (6-inch) -wide orange stripe will be painted for each of the 24 compass rose control points. These stripes begin at the center of the pad and extend outward for a minimum length of 7.5 meters (25 feet). Border each stripe with a 40-millimeter (1.5-inch) -wide white stripe. At a distance of 8.2 meters (27 feet) from the center of the pad, identify the azimuth of each stripe as measured from magnetic north with 600-millimeter (24-inch) -high by 381-millimeter (15-inch) -wide orange block numerals. All azimuth numbers will contain 3 numerals (e.g., 045). The stroke of each numeral is a minimum of 90 millimeters (3.5 inches) wide. Each azimuth number will be painted on a solid white background formed from a rectangle 660 millimeters (26 inches) in height by 1,295 millimeters (51 inches) in width. The layout of the compass rose is detailed in Figure B10-3.

B10-9.3 Calibration Survey Data Markings.

Mark the latest survey information on the CCP pavement using black letters on a white background as shown in Figure B10-4. Update the survey data after every re-calibration.

Figure B10-4. Compass Calibration Pad Survey Data Marking

COMPASS ROSE
SURVEY DATA
SURVEY DATE: MONTH YEAR
SURVEY DUE: MONTH YEAR
EQUIPMENT
A/E36T-2
DECLINATION
DEG, # MIN WEST

B10-10 SITING CONSIDERATIONS.

B10-10.1 Separation Distances.

To meet the magnetically quiet zone requirements and prevent outside magnetic fields from influencing the aircraft compass calibration, all efforts possible will be taken to make sure the center of the pad meets the minimum separation distance guidelines.

The minimum recommended separation distances are as follows:

- 70 meters (230 feet) to underground metal conduits, metal piping (including reinforced concrete pipes), or similar items.
- 85 meters (280 feet) from the edge of any pavement that is not specifically designed and built for CCP operations.
- 150 meters (500 feet) to underground alternating current (AC) power lines (including runway/taxiway edge lighting).
- 185 meters (600 feet) to overhead steam lines; overhead conduits or metal piping; overhead AC power lines; any AC equipment; the nearest edge of any railroad track; the nearest fire hydrant; and the nearest portion of any building.
- 300 meters (1,000 feet) to any direct current (DC) power lines or equipment (including any underground or aboveground telephone lines).

B10-10.2 Checking Site.

Each proposed site for a CCP must be checked for magnetic influence to ensure the area is magnetically quiet, regardless of adherence to separation distances.

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APPENDIX B
SECTION 11
TIEDOWNS, MOORING, AND GROUNDING POINTS

B11-1 TYPES OF EQUIPMENT.

B11-1.1 Mooring and Grounding Point.

A mooring and grounding point is a mooring casting with a grounding rod attached. Aircraft mooring and grounding points are used to secure parked aircraft and also serve as electrodes for grounding connectors for aircraft. Combined mooring and grounding points have previously been used by the Army but are not currently used as they do not meet mooring and grounding design loads required by TM 1-1500-250-23.

B11-1.2 Mooring Point.

A mooring point is a mooring casting without a grounding rod attached, used to secure parked aircraft. Mooring points are used by the Army.

B11-1.3 Static Grounding Point.

A static grounding point is a ground rod attached to a casting. The casting protects the ground rod but does not provide mooring capability. Static grounding points are used by the Army in aprons and hangars.

B11-1.4 Static Ground.

A static ground is a 3-meter (10-foot) rod with a closed-eye bend. The static ground is not intended to secure parked aircraft but may serve as an electrode connection for static grounding of aircraft. Static ground are installed at many Air Force installations.

B11-1.5 Tiedown Mooring Eye.

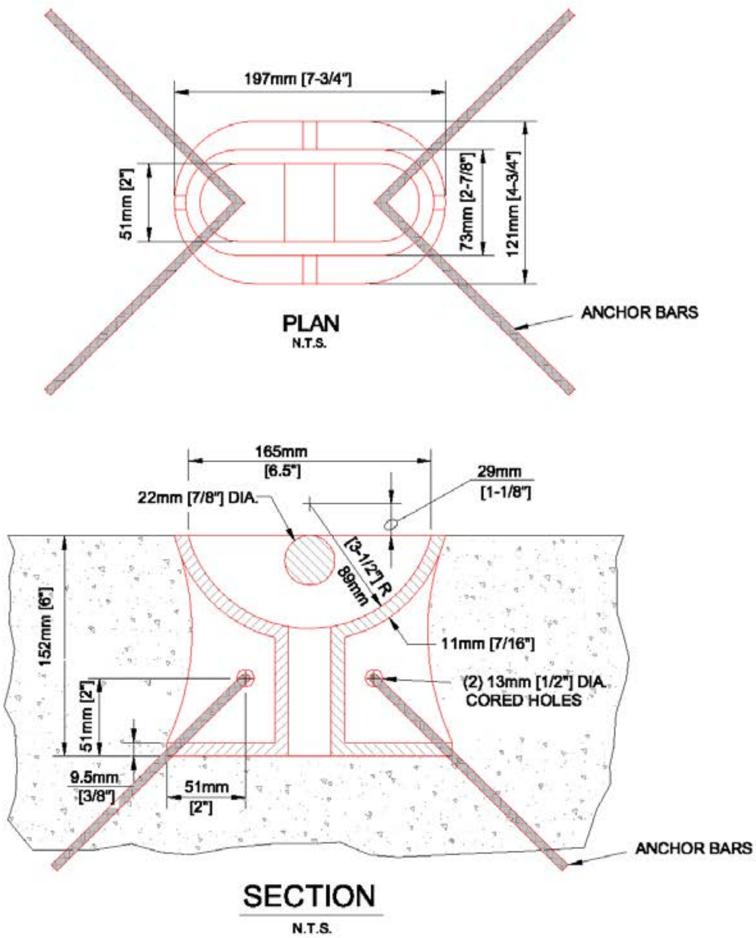
A tiedown mooring eye is a mooring casting with a grounding rod attached. They are similar to the mooring and grounding point discussed above. Tiedown mooring eyes are used by the Navy and Marine Corps.

B11-2 MOORING POINTS FOR ARMY FIXED- AND ROTARY-WING AIRCRAFT.

B11-2.1 Type.

A mooring point consists of a ductile iron casting, as shown in Figure B11-1. The mooring casting is an oval-shaped casting with a cross-rod to which mooring hooks are attached.

Figure B11-1. Army Mooring Point



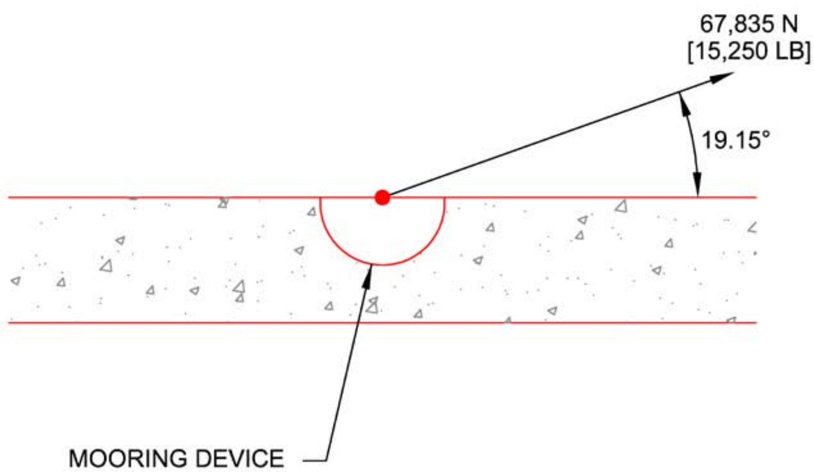
NOTES

1. MOORING DEVICE TO BE CAST IN DUCTILE IRON 80-55-06 OR EQUAL
2. ANCHOR RODS SHALL BE #3 DEFORMED REBAR, 380 mm (15") LONG AND BENT DOWNWARD AT 45 DEGREES. TWO ANCHOR BARS PER MOORING DEVICE.

B11-2.2 Design Load.

Unless specifically waived in writing by the facility commander, all new construction of Army aircraft parking aprons will include aircraft mooring points designed for a 67,800-Newton (15,250-pound) load, as specified in TM 1-1500-250-23 and applied at 19.15 degrees (19.15°) from the pavement surface, as illustrated in Figure B11-2. Testing of new mooring point installations is not required; however, follow Figure B11-2 if testing is performed.

Figure B11-2. Army Load Testing of Mooring Points



NOTES

1. MOORING TESTS SHALL BE ACCOMPLISHED USING A HYDRAULIC RAM OR SIMILAR DEVICE AND AN APPROPRIATE REACTION (HEAVY VEHICLE, ETC.) THAT IS CAPABLE OF APPLYING A TENSILE LOAD OF 71,172 N [16,000 LB]
2. THE LENGTH OF MOORING CHAIN AND CONNECTING SHACKLE SHALL BE SELECTED IN SUCH A WAY THAT AN ANGLE OF 19.15° FROM THE PAVEMENT SURFACE (SEE ABOVE FIGURE) CAN BE MAINTAINED DURING LOAD TESTING.
3. APPROPRIATE SAFETY PRECAUTIONS SHALL BE TAKEN AT ALL TIMES DURING LOAD TESTING OPERATIONS.
4. THE MOORING POINTS SHALL BE LOADED IN 1,130 kg [2,500 LB] INCREMENTS UP TO 44,482 N [10,000 LB] AND IN 4,448 N [1000 LB] INCREMENTS UP TO 71,172 N [16,000 LB] WITH EACH LOAD INCREMENT HELD FOR AT LEAST 60 SECONDS.
5. TO PASS TEST REQUIREMENTS, MOORING POINTS SHALL NOT DEFORM PERMANENTLY UNDER 71,172 N [16,000 LB] LOAD.

B11-2.3 Layout.

B11-2.3.1 Fixed-Wing Aprons.

Mooring points should be located as recommended by the aircraft manufacturer or as required by the base.

B11-2.3.2 Rotary-Wing Aprons.

B11-2.3.2.1 Number of Moored Parking Spaces.

All exterior aircraft parking spaces will be provided with mooring points.

B11-2.3.2.2 Number of Mooring Points at Each Parking Space.

Each rotary-wing aircraft parking space location will have six mooring points. Although some rotary-wing aircraft only require four mooring points, six will be installed to provide greater flexibility for the types of rotary-wing aircraft that can be moored at each parking space. The largest diameter rotor blade of the facilities' assigned aircraft will be used for locating the mooring points within the parking space. The allowable spacing and layout of the six mooring points is illustrated in Figure B11-3. Parking space width and length dimensions are presented in Table 6-2 of Chapter 6.

B11-2.3.2.3 Mooring Points on a Grid Pattern.

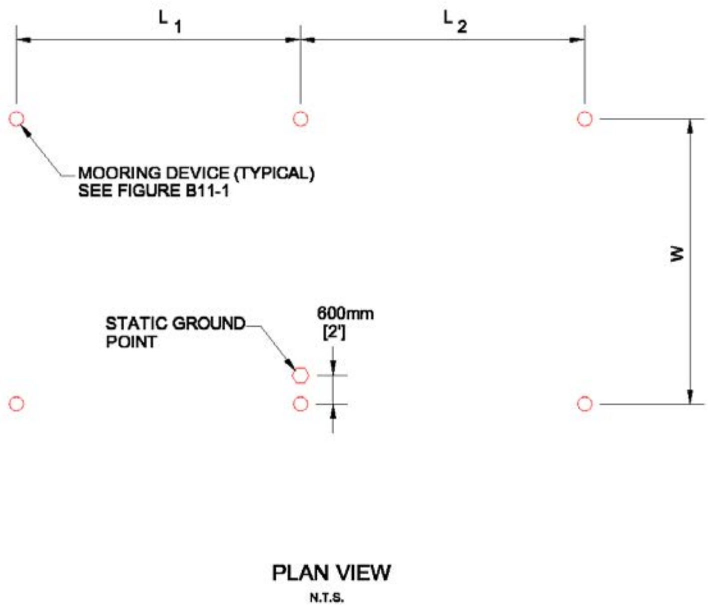
A 6-meter by 6-meter [20-foot by 20-foot] mooring point grid pattern throughout the apron for mass aircraft parking aprons will not be authorized unless economically and operationally justified in writing by the installation commander. Figure B11-4 provides the recommended pavement joint and mooring point spacing should grid pattern mooring be utilized.

B11-2.4 Installation.

B11-2.4.1 Mooring Points for New Rigid Pavement Equal to or Greater Than 150 Millimeters (6 Inches) Thick.

Mooring points for new rigid pavements will be provided by embedding the mooring devices in fresh Portland cement concrete (PCC). The layout of points is shown in Figure B11-3 with mooring points at least 600 millimeters (2 feet) from the new pavement joints. This spacing will require close coordination between the parking plan and the jointing plan. Mooring points should be located a minimum of 600 millimeters (2 feet) from any pavement edge or joint and should provide proper cover for the reinforcing steel. Reinforcing bars should be placed around the mooring points as illustrated in Figure B11-5.

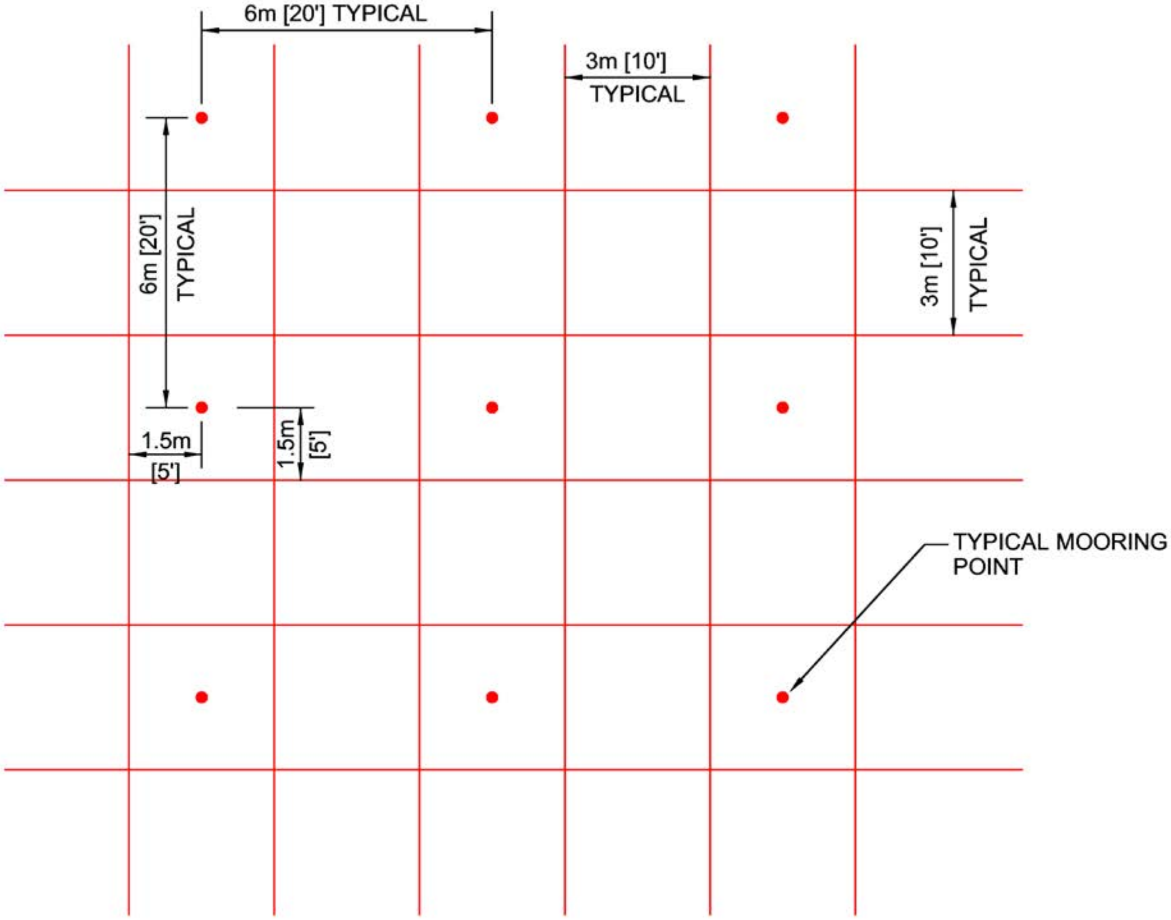
Figure B11-3. Army Rotary-Wing Allowable Mooring Point Spacing



NOTES

1. THE PREFERRED MOORING POINT SPACING FOR EACH AIRCRAFT PARKING POSITION IS L_1=L_2 = W = 6m [20.0']
2. IN NEW OR EXISTING RIGID PAVEMENT, THE MOORING POINTS SHALL BE AT LEAST 600mm [2'] AWAY FROM ANY PAVEMENT JOINT OR EDGE. TO MISS THE PAVING JOINTS, THE SPACING OF THE MOORING POINTS MAY BE VARIED AS FOLLOWS:
   A. W, L_1 AND L_2 MAY VARY FROM 5 TO 6m [17 TO 20'].
   B. W, L_1 AND l_2 NEED NOT BE EQUAL.
3. THE CONSTRUCTION TOLERANCE ON MOORING POINT LOCATION SHALL BE 50mm [±2"]

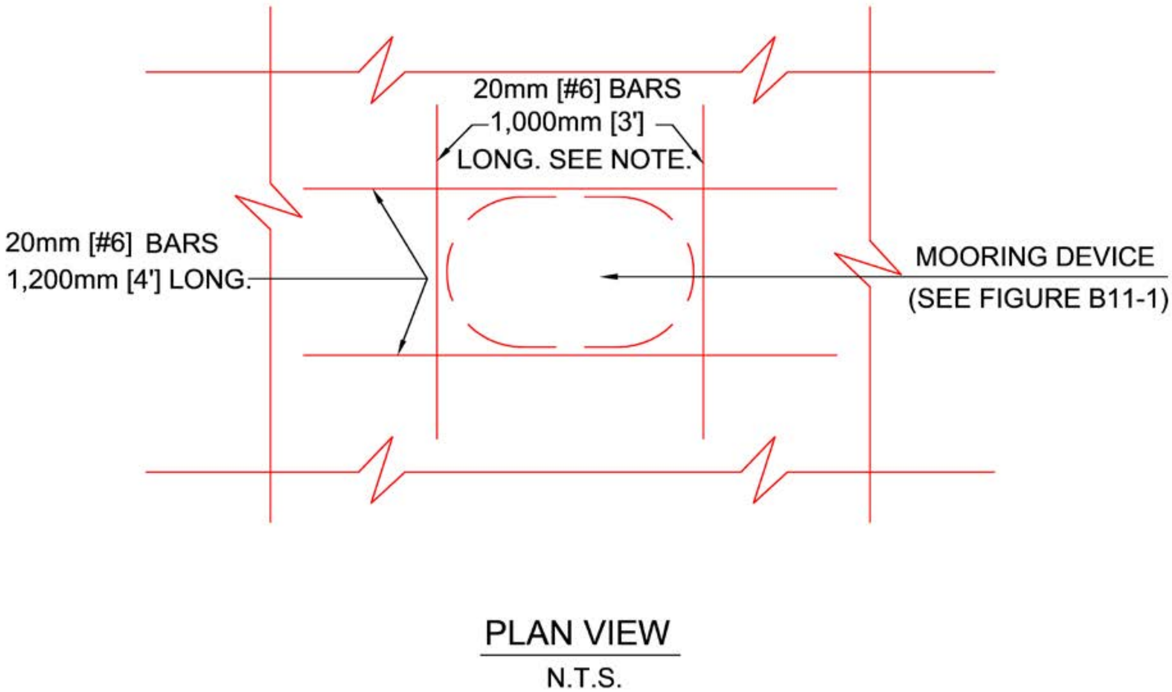
Figure B11-4. Army Rotary-Wing Mooring Points Layout



NOTE

THIS IS THE RECOMMENDED JOINT SPACING FOR NEW CONCRETE PAVEMENT WHERE MOORING DEVICES ARE JUSTIFIED AND AUTHORIZED THROUGHOUT THE APRON. OTHER JOINT SPACINGS MAY BE USED AS LONG AS MOORING DEVICES ARE SPACED AS SHOWN IN FIGURE B11-3.

Figure B11-5. Slab Reinforcement for Army Mooring Point



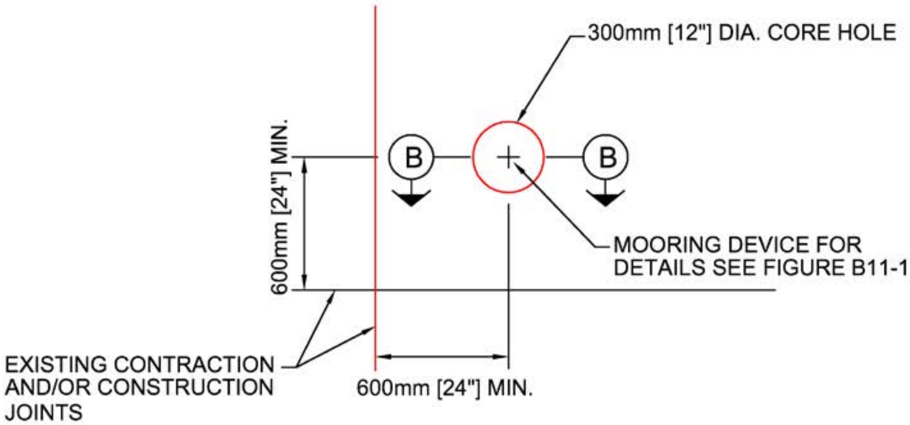
NOTES

1. #6 REINFORCING BARS SHALL BE PLACED 75mm [3"] FROM MOORING DEVICE AND 75mm [3"] BELOW PAVEMENT SURFACE.
2. ENDS OF REINFORCING BARS SHALL BE PLACED 75mm [3"] FROM PAVING JOINTS TO PROVIDE COVER.

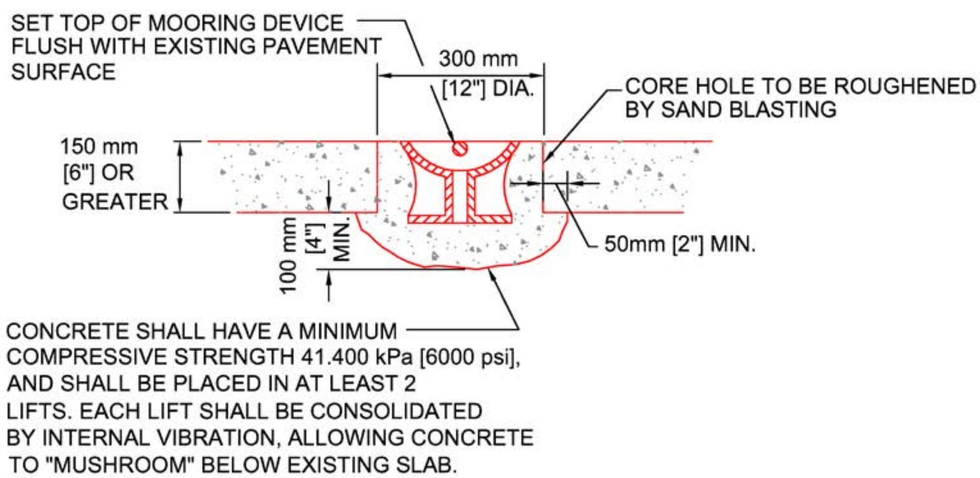
B11-2.4.2 Mooring Points for Existing Rigid Pavement Equal to or Greater Than 150 Millimeters (6 Inches) Thick and in Uncracked Condition.

The following method should be used to provide mooring points for existing rigid pavement in an uncracked condition. The pavement should have only a few slabs with random cracks and must not exhibit "D" cracking. Mooring points should be provided by core-drilling a 300-millimeter (12-inch) -diameter hole through the pavement and installing a mooring point as illustrated in Figure B11-6.

Figure B11-6. Mooring Point for Existing Rigid Pavement for Pavement Thickness Greater Than 150 Millimeters (6 Inches)



PLAN VIEW
N.T.S.



SECTION B
N.T.S.

NOTE

EXISTING CONCRETE SHOULD HAVE ONLY A FEW SLABS WITH CRACKS IF THIS OPTION IS TO BE USED.

B11-2.4.3 Mooring Points for Areas Not Covered Above.

The following installation options should be used to provide mooring points for rotary-wing aircraft parked on the following pavements: existing rigid pavement less than 150 millimeters (6 inches) thick; existing rigid pavement in a cracked or deteriorated condition; new or existing flexible pavement; turfed areas; and other areas where appropriate.

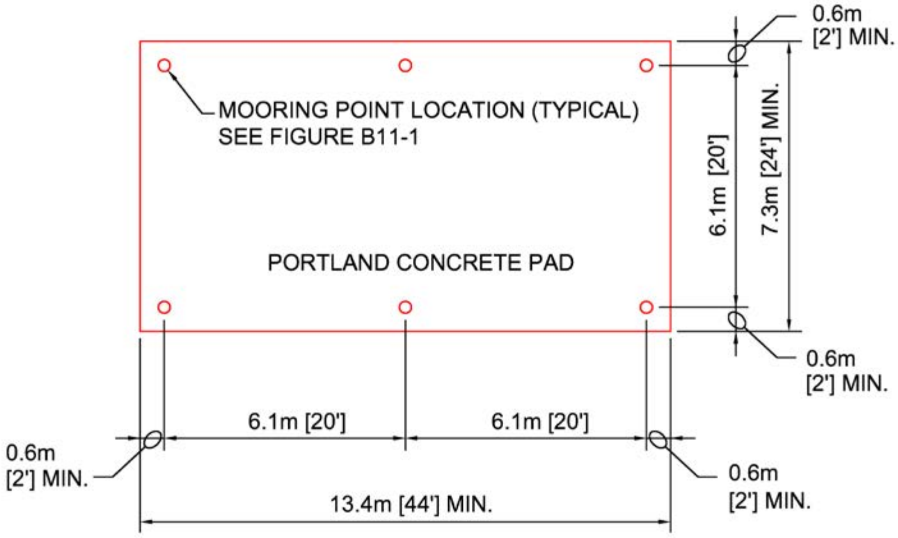
B11-2.4.3.1 Installation Option 1, Mooring Pad.

This option is the preferred installation method and allows for placement of a new concrete pad with a minimum thickness of 200 millimeters (8 inches). The size of the pad should be a minimum of 7.3 meters (24 feet) wide by 13.4 meters (44 feet) long. The length and width may be increased to match the existing concrete joint pattern. The mooring pad, with six mooring points, is illustrated in Figure B11-7. The mooring devices should be installed as illustrated in Figure B11-1 and the concrete reinforced as illustrated in Figure B11-5.

B11-2.4.3.2 Installation Option 2, Piers.

This option allows the use of individual concrete piers for each mooring point, as shown in Figure B11-8. The diameter and length of the pier must be based on the strength of the soil, as presented in Table B11-1.

Figure B11-7. Army Rotary-Wing Mooring Pad Detail

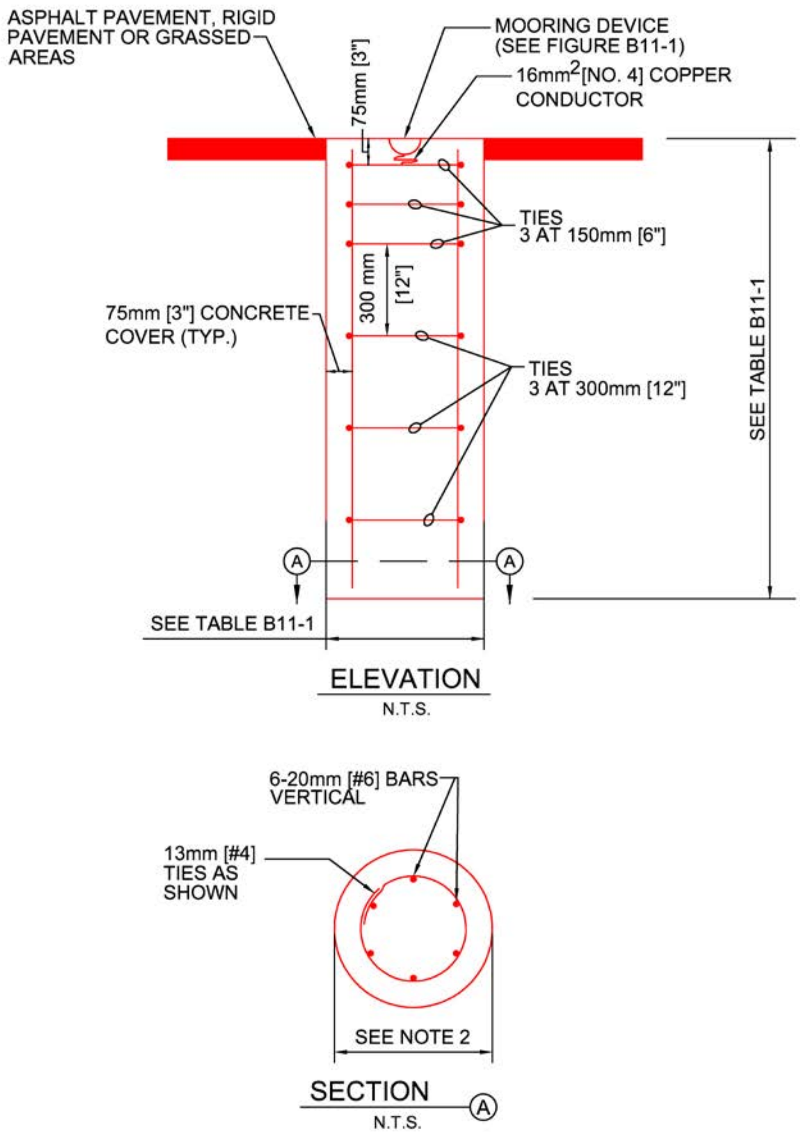


PLAN VIEW
N.T.S.

NOTES

1. THIS MOORING PAD IS THE PREFERRED METHOD OF PROVIDING MOORING POINTS IN GRASSED AREAS AND IN FLEXIBLE PAVEMENTS. FOR RIGID PAVEMENT APPLICATIONS, THE SIZE OF THE PAD SHOULD BE INCREASED TO MATCH THE EXISTING JOINT PATTERN.
2. THICKNESS OF THE PAD SHALL BE DESIGNED TO CARRY THE EXPECTED AIRCRAFT LOADS, BUT NOT LESS THAN 200mm [8"] THICK.
3. THE SLAB SHOULD BE DESIGNED AS A REINFORCED SLAB SO THAT PAVEMENT JOINTING WILL NOT BE REQUIRED. IF JOINTED PAVEMENT IS DESIRED, JOINT SPACING SHOULD BE ADJUSTED SO THAT MOORING POINTS ARE A MINIMUM OF 0.6m [2'] FROM PAVEMENT JOINTS.
4. SEE FIGURE B11-6 FOR REINFORCING ADJACENT TO MOORING DEVICE.
5. TYPICAL PREFERRED SPACING BETWEEN MOORING DEVICES IS 6.1m [20']. SEE FIGURE B11-3 FOR ALLOWABLE MOORING AND STATIC GROUND POINT SPACING.

Figure B11-8. Army Mooring Point for Grassed Areas, Flexible Pavement, or Rigid Pavement - Thickness Less Than 150 millimeters (6 inches)



NOTES

1. CORE DRILL ASPHALT PAVEMENT. FOR PIER LENGTH AND DIAMETER, SEE TABLE B11-1
2. SPIRAL REINFORCEMENT EQUIVALENT TO THE 13mm [#4] TIES MAY BE USED.
3. SEE FIGURE B11-3 FOR ALLOWABLE MOORING AND STATIC GROUND POINT SPACING

Table B11-1. Army Pier Length and Depths for Tiedowns

Cohesive Soils				
	Pier Diameter		Pier Length	
Unconfined Compressive Strength (q_u in kg/m^2 [lb/ft^2])	m	ft	m	ft
q_u < 5,000 kg/m^2 (q_u < 1,000 lb/ft^2)	600 mm	2.0 ft	1,800 mm	6.0 ft
5,000< q_u <19,500 kg/m^2 (1,000< q_u <4,000 lb/ft^2)	500 mm	1.5 ft	1,800 mm	6.0 ft
q_u >18,500 kg/m^2 (q_u >4,000 lb/ft^2)	500 mm	1.5 ft	1,200 mm	4.0 ft
Cohesionless Soils				
	Pier Diameter		Pier Length	
Friction Angle ∅ in Degrees	m	ft	m	ft
Φ < 20°	600 mm	2.0 ft	2,100 mm	7.0 ft
20° ≤ Φ ≤ 30°	600 mm	2.0 ft	1,800 mm	6.0 ft
Φ > 30°	500 mm	1.5 ft	1,800 mm	6.0 ft

B11-3 EXISTING MOORING POINTS FOR ARMY.

Existing mooring points will be tested for structural integrity and strength as detailed in Figure B11-2. If the existing mooring fails to meet the structural requirements listed herein, replacement of the mooring structure is required. If the existing mooring point has an attached ground rod, its electrical resistance value must be measured. If it fails to meet resistivity requirements, a new static ground rod is required.

B11-3.1 Evaluation of Existing Mooring Points for Structural Adequacy.

B11-3.1.1 Adequate Mooring Points.

Existing 19-millimeter (0.75-inch) -diameter bimetallic, copper-covered steel rods, 1,800 millimeters (6 feet) long are considered adequate for immediate aircraft protection, provided the following conditions are met:

- The existing rods are installed in rigid pavement.
- The existing rods do not show signs of deformation or corrosion.
- The existing rods are inspected for deformation and corrosion at least once a year and after each storm event with winds greater than 90 kilometers per hour (50 knots).

B11-3.1.2 Inadequate Mooring Points.

At Army facilities, any existing rods that exhibit deformation or corrosion will be considered inadequate and require replacement. All existing 19-millimeter (0.75-inch) -diameter, 1,800-millimeter (6-foot) -long rods in flexible (asphalt) pavement, including those with a Portland cement concrete (PCC) block at the surface, require replacement.

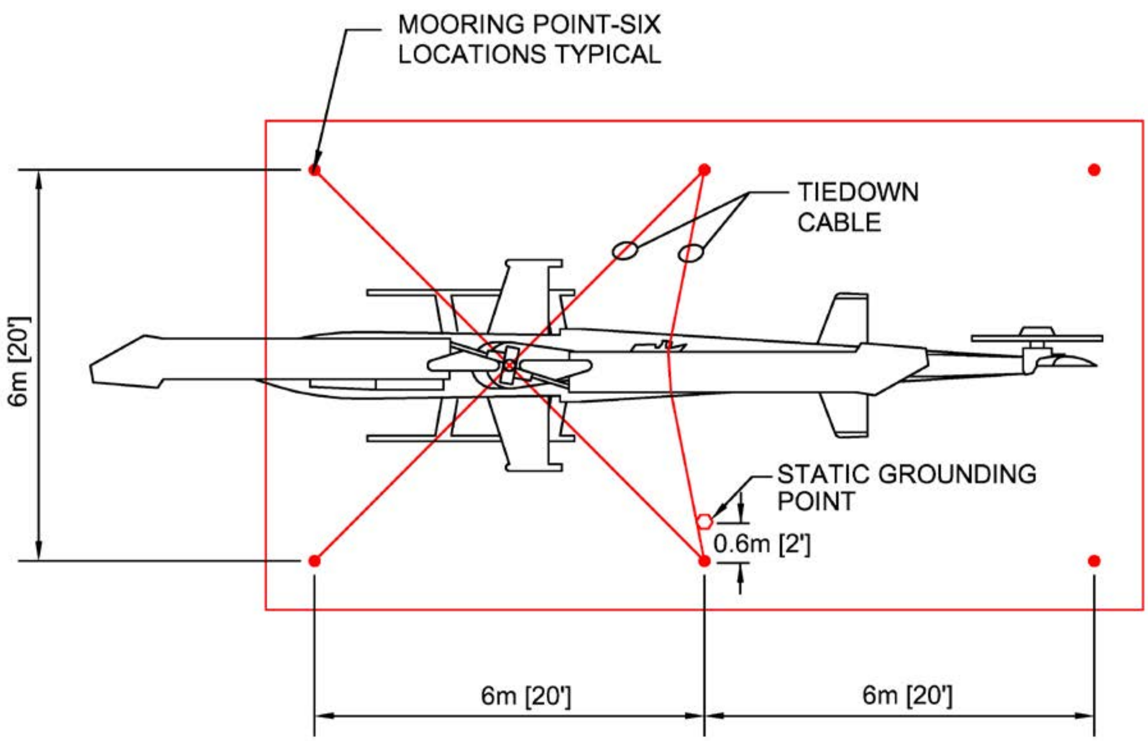
B11-3.2 Evaluation of Existing Mooring Points for Resistance.

The maximum resistance measured, in accordance with IEEE Standard 142, of existing grounding points, will not exceed 10,000 ohms under normally dry conditions. If this resistance cannot be obtained, an alternative grounding system will be designed.

B11-4 STATIC GROUNDING POINTS FOR ARMY AND AIR FORCE FIXED- AND ROTARY-WING FACILITIES.

See UFC 3-575-01 for static ground requirements. One static ground point shall be provided at each rotary-wing parking position, as shown in Figure B11-9.

Figure B11-9. Mooring and Ground Point Layout for Rotary-Wing Parking Space



B11-5 AIR FORCE TIEDOWNS.

B11-5.1 General.

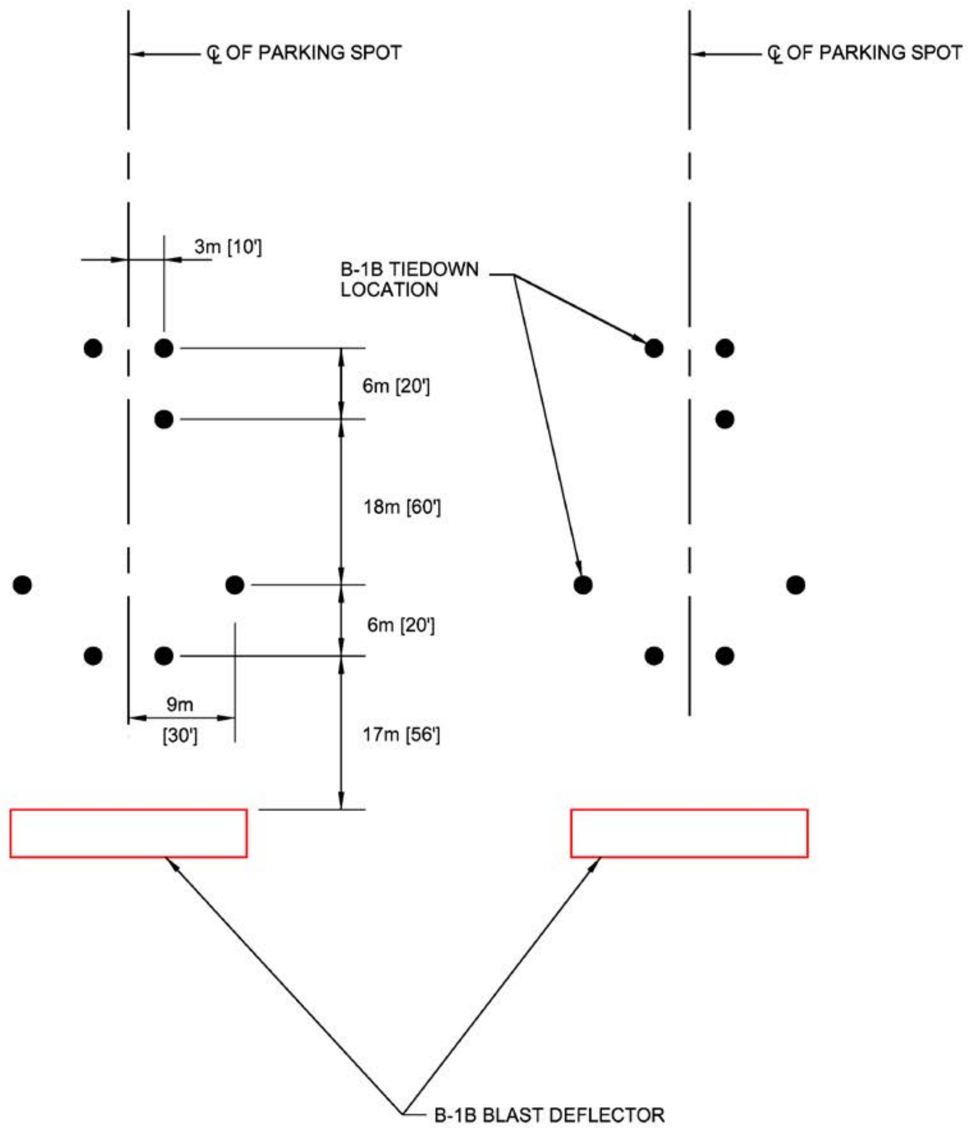
For the Air Force, tiedowns will be constructed in accordance with Figures B11-11 and B11-12 and may be used as a static ground provided they meet the requirements given in UFC 3-575-01. For maximum flexibility, they may be installed in 4.6-meter (15-foot), 6.1-meter (20-foot), or 9.1-meter (30-foot) grids, or offset grids. At minimum, place tiedowns as indicated in aircraft Technical Orders or Facility Requirements Documents. Ideally, tiedowns will be centered in slabs, but, at minimum, shall not be located less than **\1** 533 millimeters (21 inches) **/1/** from any joint.

- B11-5.1.1 If tiedowns are intended to also be used as static grounds, soil conditions may require that a ground rod be installed. When a ground rod is included, bond it to the tiedown bar.
- B11-5.1.2 See UFC 3-575-01 for static ground requirements.

B11-5.2 Layout.

Tiedowns shall be configured and spaced in accordance with the requirements of the mission aircraft and will vary from aircraft to aircraft. An example of a multiple fixed-wing aircraft tiedown layout is shown in Figure B11-10.

Figure B11-10. Example of Air Force Multiple Tiedown Layout for Fixed-Wing Aircraft



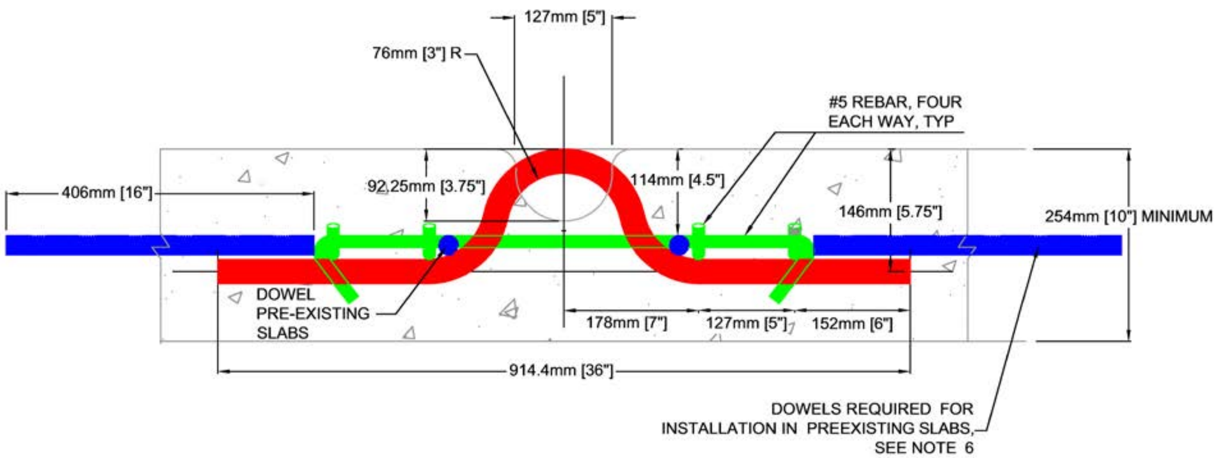
NOTE:
THIS IS AN EXAMPLE FOR ONE AIRCRAFT (B-1B). FOR SPECIFIC AIRCRAFT DIMENSIONS REFERENCE THE AIRCRAFT TECHNICAL ORDER (T.O.) (AVAILABLE FROM MAINTENANCE ASSISTANCE PROGRAM OFFICE).

B11-5.3 Installation.

B11-5.3.1 Pavement Recess Design.

The top of the static ground will be set at pavement grade or not more than 6 millimeters (0.25 inch) below grade. A smooth, rounded-edge recess 75 millimeters (3 inches) wide and not more than 150 millimeters (6 inches) long will be provided in the pavement around the eye for accessibility and attachment of grounding cables. This is shown in Figure B11-12.

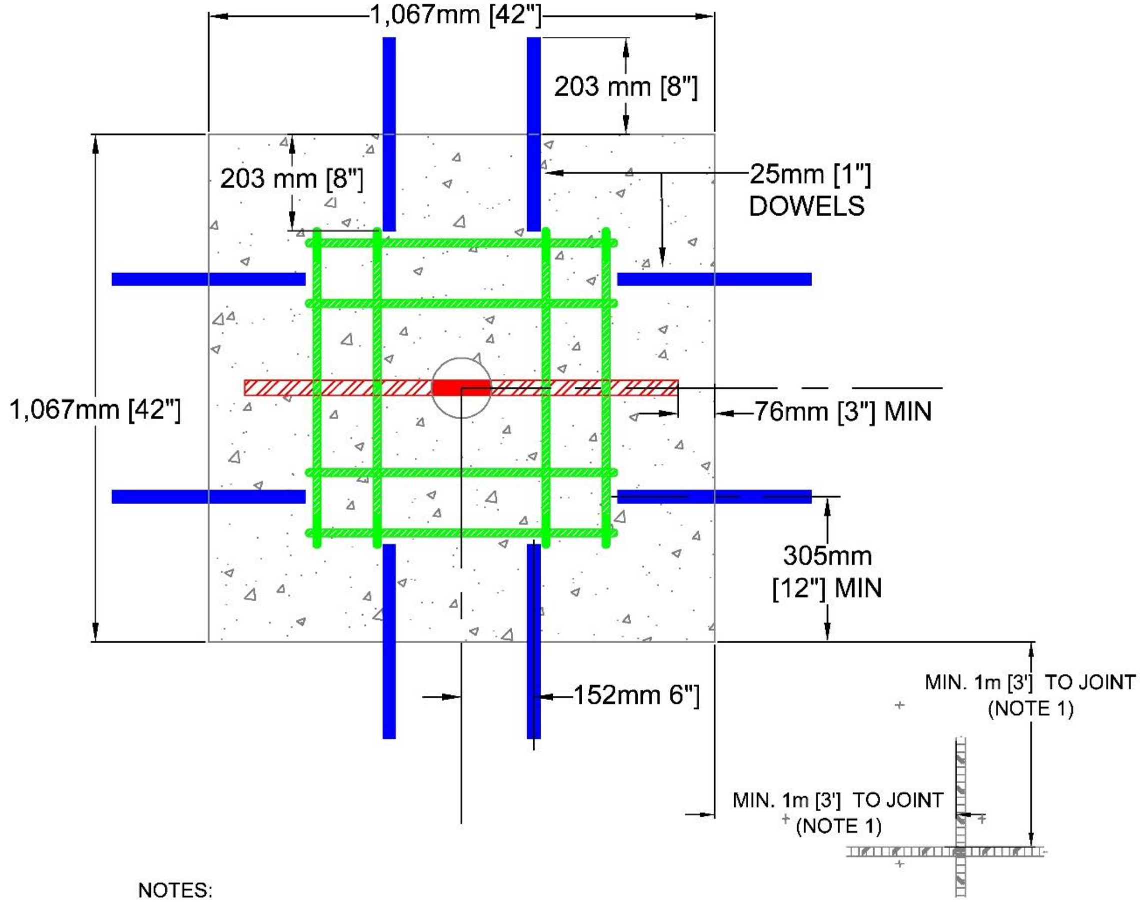
Figure B11-11. Air Force Aircraft Tiedown, Profile



NOTES:

1. PLACE TIE DOWNS AS INDICATED IN AIRCRAFT TECHNICAL ORDER OR FACILITY REQUIREMENTS DOCUMENT. IF THE TIEDOWN IS INTENDED TO ALSO BE USED AS A STATIC GROUND, SOIL CONDITIONS MAY REQUIRE THAT A GROUND ROD BE INSTALLED. WHEN A GROUND ROD IS INCLUDED, BOND IT TO THE TIEDOWN BAR.
2. MINIMUM DISTANCE FROM TIEDOWN CENTER POINT TO AN UNDOWELED JOINT IS 914 mm (3'). WHEN TIE DOWNS OCCUR 914mm [3 '] FROM A SINGLE JOINT, ORIENT BAR PARALLEL WITH THE JOINT. IF CENTER POINT OCCURS 914mm (3') FROM ADJACENT JOINTS, ORIENT BAR PARALLEL WITH EITHER JOINT.
3. BAR WILL BE NUMBER 7 (0.875") NON-DEFORMED AISI 8620H STEEL.
4. MINIMUM SLAB THICKNESS IS 254mm [10"].
5. PIER DIMENSIONS FOR ASPHALT PAVEMENTS MUST BE DESIGNED TO ACCOMMODATE ANTICIPATED UPLIFT FORCES. FOR 17,100 kg (37,700 LBS) MINIMUM PIER DIMENSIONS ARE 1.83m x 1.83m x 2.13m (6' x 6' x 7').
6. FOR INSTALLATION IN PREEXISTING SLABS, INSTALL 1" Ø x 16" DOWEL RODS CENTERED AT HALF SLAB DEPTH , ALL FOUR SIDES AS SHOWN IN THE PLAN VIEW. MINIMUM ANCHOR BLOCK DIMENSIONS IN THIS CASE ARE 254mm [10"] x 1,067mm [42"] x 1,067mm [42"].

Figure B11-12. Air Force Aircraft Tiedown, Plan



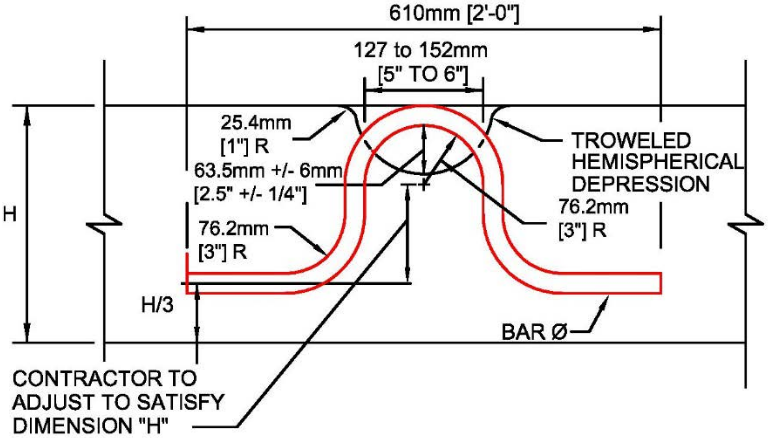
NOTES:

1. EDGE OF RETROFIT PATCH WILL BE MINIMUM 1m (3') FROM NEAREST JOINT IN BOTH DIRECTIONS TO REDUCE RISK FOR SYMPATHETIC CRACKS IN EXISTING SLAB. IF TIEDOWN MUST BE CLOSER TO JOINT, THEN EXPAND RETROFIT PATCH TO THE NEAREST JOINT.

B11-6 TIEDOWN MOORING EYES FOR NAVY AND MARINE CORPS.

Requirements, layout, and installation details for Navy and Marine Corps tiedown mooring eyes are found in Figures B11-13, B11-14 and B11-15. Requirements, layout, and installation details for Navy and Marine Corps grounding arrangements are found in UFC 3-575-01. A tiedown mooring eye must be placed at the center of every parking apron slab. For PCC with a thickness greater or equal to 254 mm (10"), the allowable uplift capacity of a T-56 tiedown is 167,698 Newtons (37,700 lbs). For PCC with a thickness greater or equal to 178 mm (7"), but less than 254 mm (10"), the allowable uplift capacity of a T-56 tiedown is 111,206 Newtons (25,000 lbs). These allowable uplift capacities assume a minimum of 40% load transfer efficiency across all doweled and non-doweled joints.

Figure B11-13. Navy and Marine Corps T-56 Mooring Eye/Tiedown Detail



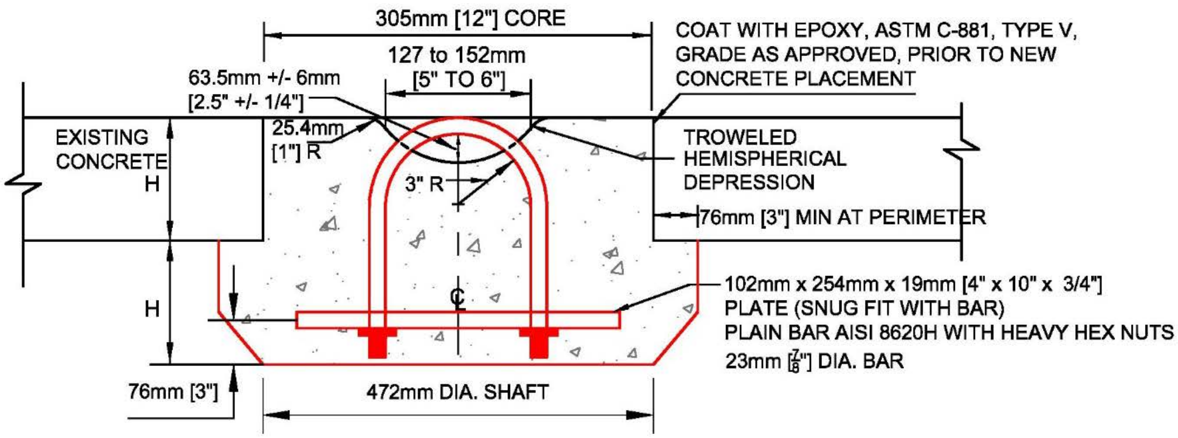
TIEDOWN/MOORING EYE-TYPE A

NOT TO SCALE

NOTES

1. PLACE MOORING EYES AS INDICATED ON PLANS.
2. WHEN REBAR FOR EYE OCCURS WITHIN 610mm (2') OF JOINT, ORIENT REBAR PARALLEL TO JOINT.
3. BAR MUST BE 23MM ($\frac{7}{8}$") NON-DEFORMED AISI 8620H STEEL (SINGLE QUENCHED AND TEMPERED (230° C (450° F)), CARBURIZED).

Figure B11-14. Navy and Marine Corps T-56 Retrofit Detail Option 1



TIEDOWN/MOORING EYE (RETROFIT) DETAIL

NOT TO SCALE

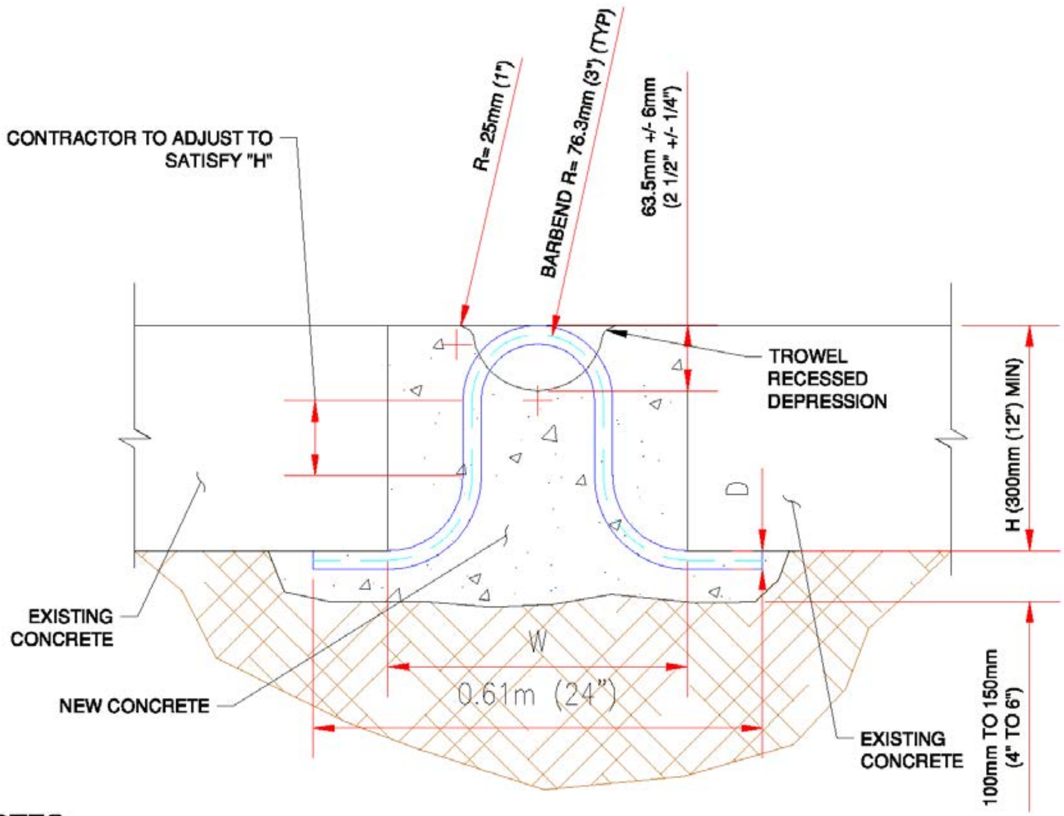
NOTES

1. PLACE MOORING EYES AS INDICATED ON PLANS.
2. DO NOT PLACE MOORING EYE WITHIN 1M [3'] OF ANY CRACK OR JOINT.
3. TIEDOWNS MUST NOT BE PLACED WITHIN 1M (3') OF ANY CONTRACTION OR CONSTRUCTION JOINT AND MUST BE ORIENTED PARALLEL TO NEAREST JOINT.
4. BAR MUST BE 23MM (7/8") NON-DEFORMED AISI 8620H STEEL (SINGLE QUENCHED AND TEMPERED (230° C (450° F)), CARBURIZED).

SEQUENCE

1. CORE PAVEMENT.
2. EXTEND SHAFT TO A MINIMUM DEPTH AND 76mm [3"] MINIMUM UNDERCUT SHOWN.
3. MAINTAIN SHAFT UNTIL PCC PLACEMENT.
4. PLACE BAR ASSEMBLY AND NEW CONCRETE (4,000 PSI MIN).

Figure B11-15. Navy and Marine Corps T-56 Retrofit Detail Option 2



NOTES

1. THIS DETAIL IS NOT INTENDED FOR USE IN PAVEMENTS LESS THAN 300mm (12") THICK.
2. SAWCUT EXISTING CONCRETE. DIMENSIONS OF SAWCUT SHALL BE 300mm (12") WIDE ("W") BY 685mm (27") LONG.
3. EXCAVATE 100mm to 150 mm (4" TO 6") BELOW BASE OF SLAB WITH HAND TOOLS AS REQUIRED TO ROTATE HAT-SHAPED BAR 90 DEGREES.
4. PLACE HAT SHAPED BAR INTO HOLE.
5. ROTATE HAT-SHAPED BAR 90 DEGREES.
6. SUSPEND TOP OF HAT-SHAPED BAR SO THAT THE TOP OF BAR IS RECESSED APPROXIMATELY 6mm (¼") BELOW TOP OF CONCRETE SLAB.
7. PLACE CONCRETE AND HAND TROWEL RECESSED DEPRESSION.
8. BAR MUST BE 23mm (⅞") NON-DEFORMED AISI 8620H STEEL (SINGLE QUENCHED AND TEMPERED (230° C (450° F)), CARBURIZED).
9. TIEDOWNS MUST NOT BE PLACED WITHIN 1m (3') OF ANY CONTRACTION OR CONSTRUCTION JOINT AND MUST BE ORIENTED PARALLEL TO NEAREST JOINT.

APPENDIX B
SECTION 12
JET ENGINE THRUST STANDOFF REQUIREMENTS FOR AIRFIELD ASPHALT EDGE PAVEMENTS

B12-1 PURPOSE.

This section presents the standoff distances from jet aircraft during engine run-up required to prevent uplift forces from causing catastrophic failure of asphalt edge pavements. This Section supersedes ETL 07-3, *Jet Engine Thrust Standoff Requirements for Airfield Asphalt Edge Pavements*.

B12-2 APPLICATION.

The requirements of this section are mandatory for Air Force Installations.

B12-2.1 Authority.

Air Force policy directive (AFPD) 32-10, *Air Force Installations and Facilities*, and Air Force instruction (AFI) 32-1023, *Design and Construction Standards and Execution of Facility Construction Projects*.

B12-2.2 Intended Users.

- Air Force MAJCOM engineers.
- Base Civil Engineers (BCE), RED HORSE (Rapid Engineers Deployable - Heavy Operations Repair Squadron Engineers) squadrons, and other units responsible for design, construction, maintenance, and repair of airfield pavements.
- U.S. Army Corps of Engineers (USACE) and Navy offices responsible for Air Force design and construction.

B12-2.3 Referenced Publications.

B12-2.3.1 Air Force.

- AFPD 32-10, *Air Force Installations and Facilities*, available at http://www.e-publishing.af.mil/2
- AFI 32-1023, *Designing and Constructing Military Projects*
- **\1** AFMAN 32-1040, *Civil Engineer Airfield Infrastructure Systems* **/1/**, available at http://www.e-publishing.af.mil/

B12-2.3.2 Army.

- USACE TSC Report 13-2 *Aircraft Characteristics for Airfield Pavement Design and Evaluation, May 2015, available at* https://transportation.wes.army.mil/tsmcx/criteria.aspx (CAC required for access).

B12-2.3.3 Joint.

- Unified Facilities Criteria 3-260-04, *Airfield Pavement Markings.*

B12-2.3.4 Industry.

- Boeing Document D6-58329 Rev C, 777 200/300 Airplane Characteristics for Airport Planning, July 2002, available at http://www.boeing.com/commercial/airports/777.htm

B12-2.4 Background.

Catastrophic failure of airfield edge pavement due to uplift forces from jet engine thrust has occurred at multiple locations, resulting in damage to aircraft, vehicles, and real property. The criteria in this Section are being issued due to tangible life safety and financial concerns. This phenomenon has been observed and studied in the past. In 1988, the Air Force Engineering and Services Center (AFESC) responded to MAJCOMs' requests for engineering data on this subject by providing safe standoff distances to edge pavements for numerous aircraft. This Section encompasses and updates previous guidance.

B12-2.5 Analysis.

Past guidance was based on both mechanistic air velocity–air pressure relationships, as defined by the Bernoulli equation, and empirical observation. Based on the following Bernoulli model, the critical air velocity would be limited to 218 kilometers per hour (kph) (136 miles per hour [mph] or 199.8 feet per second [fps])

$$V = \sqrt{\frac{2g\Delta p}{\rho}}$$

$$\rho = \frac{p}{RT}$$

where:

V	=	velocity
Δp	=	1197 pascals (25 pounds per square foot [psf]) (51-millimeter [2-inch] thick asphalt mass)
g	=	9.81 meters (32.2 feet) per second•second

ρ	=	101.3 kilopascals (14.7 pounds per square inch absolute [psia]) at sea level
R	=	53.3 (ft-lb/lb) / °Rankine (°R) (gas constant, air)
T	=	985 °R (typical exhaust temperature at expected velocity and distance of interest)

However, empirical observation has indicated that the typical 51-millimeter (2-inch)-thick edge pavement can withstand velocities up to 362 kph (225 mph). This higher observed velocity was accepted as a valid basis for criteria development because the simple Bernoulli model ignored other forces which are difficult to model, such as friction, shear, and adhesion. Without being able to further refine the mechanistic model, guidance was issued based on empirical observations, with a safety factor of two applied. The active uplift force is a function of the velocity squared. Dividing the observed velocity of 362 kph (225 mph) by the square root of this safety factor yielded a threshold velocity of 257 kph (160 mph). This velocity was issued as criteria for establishing standoff distances.

B12-2.6 Standoff Distances.

Aircraft should be positioned so that jet blast velocities are below 257 kph (160 mph) at the edge of a typical 51-mm (2-in) -thick asphalt shoulder pavement. Table B12-1 lists the standoff distance aft of the aircraft tail where data indicates the engine exhaust velocity is reduced to 257 kph (160 mph). Where data indicates that the actual velocity would be lower than this threshold velocity value, a minimum standoff distance of 8 meters (m) (25 feet [ft]) is recommended. In locations where the Aircraft Tail Standoff Distance cannot be met, increasing the asphalt thickness can counteract the uplift force caused by jet blast; however, asphalt lifts must be well-bonded to each other and free of cracking to ensure jet blast cannot separate the top lift from the underlying lift(s).

Table B12-1. Safe Standoff Distances Aft of Aircraft Tail (Based on 51-mm [2-in] Asphalt Shoulder Pavement Thickness)

Table B12-1. Safe Standoff Distances Aft of Aircraft Tail			
Aircraft	**Aircraft Tail Standoff Distance**	**Jet Blast Velocity Data Source**	**Remarks**
B-1B	88 m (290 ft)	ETL 1110-3-394	
B-52H	8 m (25 ft)	ETL 1110-3-394	See Note 3
C-5A/B	23 m (75 ft)	ETL 1110-3-394	
C-9A	20 m (65 ft)	ETL 1110-3-394	
C-17	18m (60 ft)	ETL 1110-3-394	
C-20B	18m (60 ft)	ETL 1110-3-394	See Note 6
C-21A	9 m (30 ft)	ETL 1110-3-394	
C-32 (Boeing 757-200)	55 m (180 ft)	ETL 1110-3-394	
C-37A	18 m (60 ft)	ETL 1110-3-394	See Note 6
C-40 (Boeing 737-700)	26 m (85 ft)	Boeing	
C-130	8 m (25 ft)	ETL 1110-3-394	See Note 3
KC-10	61 m (200 ft)	ETL 1110-3-394	3 engines
KC-135E/R EC-135A/G/L RC-135	32 m (105 ft)	ETL 1110-3-394	
KC-46	43 m (140 ft)	Boeing FRD	
VC-25A (Boeing 747-200)	26 m (85 ft)	Boeing	
F-15E	43 m (140 ft)	ETL 13-2	
F-16C/D	55 m (180 ft)	ETL 13-2	
F-22			
F-35A	71 m (232 ft)	FRD	
F-35B			
F-35C	71 m (232 ft)	FRD	
Boeing 707	35 m (115 ft)	Boeing	
Boeing 727	34 m (110 ft)	Boeing	

Table B12-1. Safe Standoff Distances Aft of Aircraft Tail

Aircraft	Aircraft Tail Standoff Distance	Jet Blast Velocity Data Source	Remarks
Boeing 737	26 m (85 ft)	Boeing	
Boeing 747	35 m (115 ft)	Boeing	
Boeing 757	49 m (160 ft)	Boeing	
Boeing 767	46 m (150 ft)	Boeing	
Boeing 777	94 m (310 ft)	Boeing	
DC-9	23 m (75 ft)	Boeing	
DC-10	73 m (240 ft)	Boeing	
MD-80	37 m (120 ft)	Boeing	
Airbus A300F4-600	30 m (100 ft)	Airbus	
Airbus A318-100	12 m (40 ft)	Airbus	
Airbus A319	8 m (25 ft)	Airbus	See Note 3
Airbus A320	26 m (85 ft)	Airbus	
Airbus A321	8 m (25 ft)	Airbus	See Note 3
Airbus A330	76 m (250 ft)	Airbus	
Airbus A340	No jet blast data available for >102 mph		
Airbus A380	107 m (305 ft)	Airbus	
AN-124	No jet blast data available		
IL-76	No jet blast data available		

NOTES

1. If the design aircraft is not listed in Table B12-1, bases should contact their MAJCOM pavement engineer for additional guidance.
2. The information listed in the table is derived from the best information available at the time of publication. However, aircraft models and engines can change, resulting in changes to jet blast characteristics. Therefore, when designing or evaluating a site for a particular aircraft, always check for updated jet blast characteristics.
3. Data indicates jet blast velocities are less than 257 kph (160 mph) at the back of the aircraft tail. In such instances, it is recommended that a minimum 8 m (25 ft) standoff should be applied.
4. All reported distances are for maximum or takeoff engine power settings.
5. Where no specific aircraft model is listed, listed standoff distance is for the aircraft model with highest jet blast velocity.
6. Standoff distance is based on Gulfstream II jet blast data.

B12-2.7 Run-Up Pad Design.

When designing new or checking existing engine run-up pads, the following criteria should be applied:

- New and existing run-up pads should be designed/modified to provide the full standoff distance behind the tail of the aircraft, as listed in Table B12-1.
- When it is not possible or practical to meet the distances listed in Table B12-1, then a minimum 8 m (25 ft) of Portland cement concrete (PCC) pavement must be provided between the tail of the aircraft and the edge of the apron. However, be aware that damage to the asphalt shoulder pavement can be expected. To mitigate damage, PCC may be constructed in lieu of asphalt in the areas affected by jet blast.
- Consideration must be given to other objects in the jet blast wake (e.g., roads, parking lots, hangars, lights, cargo). Precautions should be taken to eliminate the potential for damage caused by flying debris.

B12-2.8 Run-Up Pad Markings.

Proper marking of engine run-up pads is critical to ensure aircraft positioning complies with required standoff distances. All markings should comply with service-specific instructions and UFC 3-260-04, *Airfield Pavement Marking*. The following guidance shall be followed on current and future run-up pad locations:

- Provide a centerline marking that runs parallel to the prevailing wind direction specific to the run-up pad.
- Provide a nose wheel stop-block marking for the primary assigned aircraft that will be using the run-up pad. If several different aircraft are assigned to the installation, provide a nose wheel stop-block marking for the most demanding aircraft. Aircraft may be parked on nose wheel stop-block markings that provide more standoff distance than required. However, aircraft must not be parked on nose wheel stop-block markings that provide less standoff distance.
- Label each nose wheel stop-block marking for the aircraft that are intended to use it. Only mark blocks for primary assigned aircraft. Transient aircraft requiring use of the run-up pad should be evaluated on a case-by-case basis.

APPENDIX B
SECTION 13
DEVIATIONS FROM CRITERIA FOR AIR FORCE AND ARMY AIRFIELD SUPPORT FACILITIES

B13-1 WAIVERABLE AIRFIELD SUPPORT FACILITIES

B13-1.1 Contents.

This section provides information for selected airfield support systems and facilities that are authorized to deviate from criteria presented in this UFC with a specific waiver from the IMSC Detachment or USAASA (USA) as applicable. See Appendix B, Section 1 for waiver processing procedures. The standard designs for these facilities and systems are not considered frangible and therefore must not be sited within the frangibility zones described within paragraph B13-2.2 and Chapter 3. See Air Force Technical Order (T.O.) 31Z3-822-2. When airfield NAVAIDs, support equipment, or weather systems are decommissioned, become obsolete, or are deactivated for other reasons, the systems and all related equipment, structures, and foundations must also be removed from the airfield environment and the grades restored to comply with criteria provided in this UFC. Unless otherwise specified, the criteria (distances) referenced in the paragraphs below are applicable to Class A and B fixed-wing runways.

B13-1.2 Navy and Marine Corps Requirements.

This section does not apply to the Navy, and Marine Corps.

B13-1.3 Fixed Base Airport Surveillance Radar (ASR) or Fixed Base Digital Airport Surveillance Radar (DASR).

Radar that displays range and azimuth typically is used in a terminal area as an aid to approach and departure control. Normally, ASR and DASR are used to identify and control air traffic within 60 nautical miles of the airfield. The antenna scans through 360 degrees to give the air traffic controller information on the location of all aircraft within line-of-sight range. The antenna, located adjacent to the transmitter or receiver shelter, is elevated to obtain the required line-of-sight distance. Fixed radar siting in the continental United States (CONUS) will be accomplished in accordance with FAA Order 6310.6.

B13-1.4 Airport Rotating Beacon.

Airport rotating beacons are devices that project beams of light, indicating the location of an air base/airfield/heliport/helipad. Detailed siting guidance is found in UFC 3-535-01.

B13-1.5 Nondirectional Radio Beacon Facilities.

Radio beacon facilities are nondirectional aids used to provide homing, fixing, and air navigation assistance to aircraft with suitable automated direction-finding equipment.

They consist of two categories: a medium-power, low-frequency beacon and a medium-power, ultrahigh-frequency beacon.

B13-1.6 Air Traffic Control Tower (ATCT).

The ATCT Control Cab must be correctly oriented so that the area to be controlled is visible from the cab. Air traffic controllers must have proper depth perception of the area under surveillance and there can be no electronic interference with equipment in the cab or with navigational equipment on the ground. A site survey must be conducted to determine the best siting. For these and other operational and technical aspects and considerations for selecting a site, consult Service-specific requirements in the early stages of planning. For Air Force installations, contact Air Force Flight Standards Agency (AFFSA), Requirements and Sustainment Directorate, HQ AFFSA/XR; or for Army installations, contact the United States Army Air Traffic Services Command (ATSCOM), Fixed Base Systems Division (AFAT-ATS-CB), Building 50301 Nevin Street, Cairns Army Airfield, Ft. Rucker, AL 36362-5265. Specific architectural, structural, mechanical, and electrical systems design requirements may be found in UFC 4-133-01, *Air Traffic Control and Air Operations Facilities*. Also, see paragraph B13-2.21.3.6 and Appendix B, Section 16, paragraph B16-4.3.

B13-2 PERMISSIBLE DEVIATIONS FROM DESIGN CRITERIA.

B13-2.1 Contents.

This section furnishes siting information for airfield support facilities that may not conform to the airfield clearance and airspace surface criteria elsewhere in this UFC. This list is not all-inclusive. Siting and design for airfield facilities and equipment must conform to these design and siting criteria, and must be necessary for support of assigned mission aircraft, or a waiver from the MAJCOM or USAASA is required. If the equipment renders satisfactory service at locations not requiring a clearance deviation, such locations should be selected to enhance the overall efficiency and safety of airfield operations. When airfield NAVAIDs, support equipment, or weather systems are decommissioned, become obsolete, or are deactivated for other reasons, the systems and all related equipment, structures, and foundations must also be removed from the airfield environment and the grades restored to comply with criteria provided in this UFC.

a. Any facilities in this chapter installed on rotary-wing runways (IFR/VFR) cannot violate the lateral clearance criteria, but is permissible within the transitional surface.

b. Clear zones are comprised of two separate areas that are treated differently. This is because initially the area known as the clear zone was defined as "the areas immediately adjacent to the ends of a runway, which have been cleared of all above ground obstructions and graded to minimize damage to aircraft that undershoot or overrun the runway." In 1974, DoD implemented a requirement for the Services to control development near military airfields to protect the safety, health and welfare of personnel on base and in the surrounding communities. This action was also intended to preserve maximum mission flexibility. To accommodate these needs, the clear zone size was expanded and the allowable uses were published within the Air Installation Compatible Use Zone (AICUZ) Program guidance, DoDI 4165.57. It is important to understand that all objects located within the expanded area of clear zones are not necessarily obstructions and there are no specific grading requirements for this area. Review current AICUZ criteria for land uses in this area before initiating development.

NOTE: For Air Force operated airfields (including those at Joint Bases): AFI 32-7063, Air Installations Compatible Use Zones (AICUZ) Program, directs that Air Force facility sitings, construction and land use must be consistent with the land use recommendations in the AFI and provides specific guidance on what is and is not allowed in the Clear Zone. Essential navigation aids and operational facilities can be located in the clear zone if there are no feasible alternatives. Due to the high potential for accidents in the CZ, facilities/equip listed in this section that are not required to be located in this area, especially those with personnel/people (i.e. facilities with classrooms or offices) should be considered for locations outside the clear zone. If they must be located within the clear zone to support the safe operation of the airfield, documents supporting the need to locate these facilities/equipment within the clear zone should be kept on file (including other locations evaluated and found unsuitable in order to communicate the decision to locate these objects within Air Force controlled areas of the Clear Zone. Any other uses within the clear zone will require a clear zone variance be completed (see AFI 32-7063).

B13-2.2 Frangibility Requirements.

All structures placed or constructed within the airfield environment must be made frangible (to the maximum extent practicable) or placed below grade unless otherwise noted in the definitions that follow or unless specifically described as exempt from frangibility requirements using the siting criteria in this UFC. This applies for any above ground construction within 76 meters (250 feet) of a fixed wing runway centerline and an extension of that dimension for 914 meters (3,000 feet) beyond the ends of the runway thresholds and within the taxiway clearance line (see Table 5-1, Item 10), but is limited to structures owned or controlled by DoD. For VFR helicopter runways/helipads (except limited use facilities) frangibility requirements apply within 30 meters (100 feet) of centerline/center of helipad and an extension of that dimension beyond the ends of the runway threshold/ approach/departure surface for 120 meters (400 feet) and within the rotary-wing taxiway clearance line (see Table 5-2, Item 5). For IFR helicopter runways/helipads (except limited use facilities) frangibility requirements apply within 53 meters (175 feet) of centerline/center of helipad. Frangibility implies that an object will collapse or fall over after being struck by a moving aircraft with minimal damage to the aircraft to the maximum extent practicable. The constructed object must not impede the motion or radically alter the path of the aircraft. Foundations for frangible structures shall be constructed flush with finished grade and the surrounding soil shall be compacted. Corrective action is required if more than 76 millimeters (3 inches) of the vertical surface of any foundation is exposed above finish grade. All structures shall be designed to allow performance of the structure to withstand wind loads less than 112 kilometers per hour (70 miles per hour). At wind speeds and icing conditions above permissible airfield operations conditions, deflections shall remain within the elastic performance of the structure. **\1** This concept does not include structures intended to house people or perimeter fencing within the MFZ. **/1/** Integral fuel tanks should be used for necessary emergency power generator sets. If auxiliary fuel tanks are required for emergency generators, or integral fuel tanks are not available, place the fuel supply system below grade with other supporting utilities.

B13-2.2.1 Types of Frangible Devices and Structures.

Essentially, there are three types of frangible devices and structures. These are normally related to the height of the structure. They are described below.

B13-2.2.1.1 Frangible Support.

A support for elevated fixtures or other devices composed of a supporting element with a fracture mechanism at its base. It is designed to present a minimum of mass and to break at the base when impacted. It is typically used when the mounting height is 2 meters (6 feet) or less above the mounting surface.

B13-2.2.1.2 Low-Impact Resistant Support.

A support for elevated fixtures or other devices designed to present a minimum mass and to break with a minimum resistance when impacted. Normally used for supporting lights or other devices between 2 meters and 12 meters (6 feet and 40 feet) above the mounting surface.

B13-2.2.1.3 Semi-Frangible Support.

A two-element support for light fixtures or other devices designed for use in applications where the mounting height is over 12 meters (40 feet) above the ground or the facility, or the device is constructed over a body of water. These type supports are comprised of a rigid base or foundation with a frangible or low-impact-resistant support used for the upper portion of the structure. The rigid portion of the structure must be no higher than required to allow performance and maintenance of the apparatus and the frangible or low-impact-resistant support.

B13-2.2.2 Frangibility Requirements.

New designs for airfield equipment, systems, and other facilities must meet the design and testing criteria given in ICAO Document 9157, *Aerodrome Design Manual*, Part 6, "Frangibility," First Edition, 2006, as well as the following guidelines for acceptance as a permissible deviation. Siting criteria provided within this UFC shall be used in lieu of the siting standards provided within Part 6 of the *Aerodrome Design Manual*. These requirements do not apply to facilities that house people.

B13-2.2.2.1 Frangible Structures.

Construction above the ground surface that will collapse or shatter upon impact. The structure must be designed using materials of minimum mass that will either break into segments or shatter without impaling the aircraft skin or becoming an obstacle to the continued movement of the aircraft.

B13-2.2.2.2 Frangible Support.

Used for mounting fixtures or equipment items less than 2 meters (6 feet) in height. The structure will be of minimum mass and will separate at the base connection when struck by a moving aircraft. Upon separation of the base connection, the support must not alter the path or impede flight of the aircraft if a segment of the structure wraps around the aircraft. The structure also must not impale the aircraft.

B13-2.2.2.3 Low-Impact-Resistant Support.

Used for supporting elevated fixtures or equipment items more than 2 meters but less than 12 meters (6 to 40 feet) above the ground surface, typically towers or poles. Upon impact by aircraft, the structure will be designed to break away at or below the impact location and collapse without wrapping around the aircraft, impaling the aircraft, or causing significant structural damage to the aircraft. If the design is such that potential exists for a portion of the structure to wrap around the aircraft, it shall not significantly alter the path or flight trajectory, nor prevent the aircraft from completing a successful takeoff or landing. Collapse of the structure may occur at a single point of failure or may be a segmented collapse. The structure shall be designed such that service of the equipment must be accomplished by lowering the equipment. The design shall not include elements that permit climbing by means of a built-in ladder or other scaling devices.

B13-2.2.2.4 Semi-Frangible Support.

Semi-frangible supports are used for those elevated fixtures or equipment items that must be higher than 12 meters (40 feet) or constructed over a body of water. The foundation shall be no higher above grade or the surface of the water than necessary to allow performance and maintenance of the apparatus and the frangible or low-impact-resistant support. The upper portion of the structure will be constructed of multiple elements of low-impact-resistant supports. The supports may be in pairs that provide directional stability or groups that provide stability to the grouping as an element. Upon impact by aircraft, each of the supporting elements will be designed to collapse as a unit or in segments independent of the grouping. The elements of the supporting structure will not impale the aircraft, wrap around the aircraft, or significantly change aircraft direction of travel upon impact. If the design is such that potential exists for a portion of the structure to wrap around the aircraft, it shall not significantly alter the path or flight trajectory, nor prevent the aircraft from completing a successful takeoff or landing. The group of elements may incorporate climb-to-service devices such as ladders, provided they comply with applicable safety criteria.

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B13-2.2.2.5 Airfield Perimeter Fencing within the Mandatory Frangibility Zone (MFZ).

a. The chain-link fencing within the MFZ must meet the requirements of UFC 4-022-03.

b. Fence posts must be thin wall steel, aluminum, or fiberglass composite material. Do not brace posts in the direction parallel to the direction of the runway. Gates, gate posts, corner posts, and pull posts are prohibited in the MFZ. Frangible connections at the bottom of fence posts are not required. Ensure posts are not filled with concrete or reinforced in any way. **/1/**

B13-2.3 Visual Air Navigational Facilities.

This term identifies, as a type of facility, all lights, signs and other devices located on, and in the vicinity of, an airfield that provide a visual reference to pilots for guidance when operating aircraft in the air and on the ground. These facilities supplement guidance provided by electronic aids, such as tactical air navigation (TACAN) and precision approach radar (PAR). When constructed and sited in accordance with Air Force/Army standards, these components and systems are frangible. Systems and components not designed and constructed in accordance with Air Force/Army standards must be programmed for replacement. For detailed construction and siting criteria, see **\1** AFMAN 32-1040 **/1/** and UFC 3-535-01.

B13-2.4 Radar Facilities.

Services use various fixed-base radar facilities, such as Ground Control Approach (GCA), Radar Approach Control (RAPCON) (USAF), Army Radar Approach Control (ARAC) (Army) to support local radar air traffic control operations. The radar sets are situated for the best possible coverage of air traffic operations. The radar data may be relayed many miles between the radar set and the radar facility, so the site is very often separated from the operations facility. These facilities provide air traffic controllers information on aircraft alignment, rate of descent, and relative position in the approach. See paragraph B13-1.3 for fixed airport surveillance radar (ASR) and digital airport surveillance radar (DASR) siting guidance.

B13-2.4.1 Permanent GCA/RAPCON/ARAC Facilities.

Permanent GCA/RAPCON/ARAC facilities house the radar operations center, radar equipment room, training facilities, office spaces, emergency and standby power services, and telecommunications service connections. The fixed GCA/ RAPCON/ARAC facilities are sited outside the airspace boundaries required for safe air traffic control operations.

B13-2.4.2 Mobile GCA and Mobile RAPCON Systems.

Mobile GCA and mobile RAPCON systems are designed to set up at remote deployed locations or stateside in garrison or at temporary training locations.

B13-2.4.2.1 Mobile GCA.

The GCA usually consists of two equipment shelters, one containing the precision approach and ASR and the other shelter containing the air traffic control operations center. Both shelters come with support generators, environmental control units, and remote communications equipment. The radar and operations shelters may be separated by up to 30 meters (100 feet). These units are non-frangible.

B13-2.4.2.2 Mobile RAPCON.

The mobile RAPCON usually consists of mobile ASR, mobile PAR, and one or two mobile operations shelters. The mobile ASR and the mobile PAR may be remotely located from the operations center by several miles via fiber optic cable. The siting of the mobile RAPCON system is dependent upon several factors and is determined before deployment by a survey team from the deploying unit. Each of the mobile RAPCON shelters comes with support generators, environmental control units, and communications remoting equipment. The footprint of the deployed systems is determined during pre-survey coordination meetings between the deploying unit and local airfield manager. These units are non-frangible.

B13-2.4.3 GPM-22 PAR Units.

PAR systems (AN/GPN-22) must be sited not less than 156 meters (512 feet) from the centerline of a runway to the near edge of the equipment. The reference reflector must be positioned so that the reflector and the radar antenna are parallel with runway centerline (± 0.005°), be in clear and unobstructed view of the radar antenna, and be located in an area where there are no large reflecting objects. Specific siting criteria for this system is provided in Air Force T.O. 31P5-2GPN22-12. When it is necessary to place units between parallel runways with insufficient distance to allow a 156-meter (512-foot) clearance to each runway centerline, the system shall be sited to provide the minimum distance to the centerline of the primary instrument runway and the lesser clearance to the centerline of the other runway. While it is desirable, from a safety standpoint, to keep these units as low as possible, the final elevation for the units will be determined by AFFSA ATCALS. The elevation is dependent on the necessary lines of sight between the unit and calibration reflectors and the touchdown areas of the runways. If it is necessary to change the existing ground elevation to provide a proper height for these units, follow grading requirements discussed in Chapter 3. These systems are non-frangible.

B13-2.4.4 AN/TPN-31 or ATNAVICS (Air Traffic Navigation, Integration, and Coordination System).

ATNAVICS is a highly mobile ground-controlled approach system that provides air traffic services where no operational airport control and landing system exists. It consists of an Airport Surveillance Radar (ASR), Precision Approach Radar (PAR), and Secondary Surveillance Radar (SSR).

The ATNAVICS system includes a sensor vehicle, sensor trailer with mounted generator, operations shelter, and an operations trailer with mounted generator. The near edge of the sensor vehicle and sensor trailer with mounted generator will be sited no less than 300 feet from the runway centerline. The operations shelter and operations trailer with mounted generator will be sited no less than 500 feet from the runway centerline. See B13-2.7.2 for siting of reflectors.

B13-2.4.5 AN/FPN-67 or FBPAR (Fixed Base Precision Approach Radar).

The AN/FPN-67 is a modern, solid-state, reliable, ground-based, precision approach radar in a fixed-shelter (or integrated with the ATNAVICS system). AN/FPN-67 systems must be sited not less than 156 meters (512 feet) from the centerline of a runway to the near edge of the equipment. See B13-2.7.2 for siting of reflectors.

B13-2.5 Emergency Generators, Maintenance and Personnel Facilities (Non-Frangible).

These facilities may be collocated with GCA facilities and mobile RAPCON vans as follows:

a. Trailers of standard mobile home construction or pre-engineered construction may be used for maintenance and personnel facilities. (Non-frangible)

b. The entire GCA or RAPCON complex consisting of radar vans, emergency generators, maintenance and personnel trailers must be confined to a site not to exceed 45.7 meters long by 30.5 meters wide (150 feet by 100 feet), with the long side perpendicular to the main runway. The elevation of antennas and other projections will be held to the minimum essential for proper operation. Make every effort to keep the site as small as possible and to maintain the greatest possible distance from the runway. The perimeter of the site must be clearly marked and all future requirements contained within the area. Integral fuel tanks should be used for necessary mobile emergency power generator sets. If additional tanks are required or integral fuel tanks are not available, place the fuel supply system below grade with other supporting utilities.

B13-2.6 Remote Microwave Link (Non-Frangible).

This equipment provides remote operation and control of PAR and GCA facilities and must be sited adjacent to them. In siting the antenna, make sure that the increase in size of the total complex does not exceed the specified size of the area previously given for the GCA facility and RAPCON facility.

B13-2.7 PAR Reflectors (Frangible and Non-Frangible).

B13-2.7.1 Air Force.

For the Air Force, moving target indicator (MTI) reflectors, or “target simulators,” may not be sited less than 45.7 meters (150 feet) from the near edge of a runway nor less than 38.1 meters (125 feet) from the near edge of a taxiway or apron boundary marking to the centerline of the equipment. For the Army, MTI reflectors may not be sited less than 76.2 meters (250 feet) from the near edge of a runway nor less than 38.1 meters (125 feet) from the near edge of a taxiway or apron boundary marking to the centerline of the equipment. The height of these reflectors must be held to a minimum consistent with the operational requirements of the system. MTI reflectors sited less than 152.4 meters (500 feet) from the centerline of any runway must be of frangible construction, using breakaway sections in reflector masts. Tracking reference reflectors must not be installed closer than 152.4 meters (500 feet) to the centerline of any runway, nor exceed 18.3 meters (60 feet) in height above the centerline elevation of the nearest runway at the intersection of the equipment centerline perpendicular with the runway centerline.

B13-2.7.2 Army.

For Army, at least one reflector must be located within the AN/FPN67/AN/TPN-31 PAR azimuth angle coverage area in order to provide a horizontal reference point. Reflectors may not be sited less than 45.7 meters (150 feet) from the near edge of a runway nor less than 38.1 meters (125 feet) from the near edge of a taxiway or apron boundary marking to the centerline of the equipment. Reflectors sited less than 76.2 meters (250 feet) from the runway centerline must be of frangible construction, using breakaway sections of reflector masts, nor exceed 3 meters (10 feet) in height above the centerline elevation of the nearest runway at the intersection of the equipment centerline perpendicular with the runway centerline.

B13-2.8 Airborne Radar Approach Reflectors (Non-Frangible).

Airborne radar approach reflectors may be placed not less than 99.1 meters (325 feet) from the runway edge and not less than 121.9 meters (400 feet) nor more than 228.6 meters (750 feet) from the runway centerline to the edge of the equipment in a pattern parallel to the runway.

B13-2.8.1 Army.

For Army, at least one reflector must be located within the AN/FPN67/AN/TPN-31 PAR azimuth angle coverage area in order to provide a horizontal reference point. It can be sited within 250 feet of the runway centerline with an approved waiver. Reflectors sited less than 76.2 meters (250 feet) from the runway centerline must be of frangible construction, using breakaway sections of reflector masts, nor exceed 3 meters (10 feet) in height above the centerline elevation of the nearest runway at the intersection of the equipment centerline perpendicular with the runway centerline.

B13-2.9 Instrument Landing System (ILS).

Reference FAA Order 6750.16 for siting criteria for the ILS.

B13-2.9.1 ILS Localizer Antennas (Frangible).

The localizer array should be located between 304.8 meters (1,000 feet) and 609.6 meters (2,000 feet) beyond the stop end of the runway. As a rule, siting must conform to approach-departure clearance surface criteria discussed in Chapters 3 and 4. Refer to FAA order 6750.16 if standard localizer antenna placement is not an option.

B13-2.9.1.1 Far Field Monitor (FFM) (Frangible if Mounted on Low-Impact-Resistant Supports, Non-Frangible if Mounted on Utility Poles).

The FFM is not required for CAT I ILS systems; however, it is required for CAT II and above systems. The FFM is considered part of the localizer system. However, it is sited at the opposite end of the runway from the localizer antenna array. Typical locations are 365.8 meters (1,200 feet) to 914.4 meters (3,000 feet) prior to the landing threshold. FFM antenna height is determined by line of sight to the localizer antenna array. The line of sight requirement can be relaxed if satisfactory localizer signal reception is proven with a portable ILS receiver at the proposed lower height of the FFM site. Just as with the localizer antenna array, the FFM antenna shall not penetrate the approach-departure clearance surface criteria discussed in Chapters 3 and 4. Army siting requirements are contained in FAA Order 6750.16.

B13-2.9.1.2 ILS Localizer Transmitter (Non-Frangible).

The ILS localizer transmitter is sited adjacent to the localizer antenna array. It must be located at least 76.2 meters (250 feet) from the extended runway centerline or a waiver is required. Emergency power generators must be as close to the facilities they support as practical.

B13-2.9.2 ILS Glide Slope Antenna (Non-Frangible).

The antenna mast or monitor should be located a minimum distance of 121.9 meters (400 feet) from the runway centerline to the centerline of the antenna, and should not exceed 16.7 meters (55 feet) in height above the nearest runway centerline elevation. A mast height of over 16.7 meters (55 feet) is permitted if the minimum distance from the runway centerline is increased by 3.1 meters (10 feet) for each 305 millimeters (1 foot) the mast exceeds 16.7 meters (55 feet). When the mast cannot, for technical or economic reasons, be located at a minimum distance of 121.9 meters (400 feet) from the runway centerline, the minimum distance may be reduced to not less than 76.2 meters (250 feet) from the centerline, provided the basic mast height of 16.7 meters (55 feet) is reduced 305 millimeters (1 foot) for each 1.5 meters (5 feet) it is moved toward the runway from the 121.9-meter (400-foot) point. Glide slope monitor units are considered part of the parent equipment. Emergency power generators must be as close to the facilities they support as practical, but no closer than the glideslope main facility.

B13-2.9.2.1 ILS End Fire Glide Slope Antenna (Frangible).

Site in accordance with FAA Order 6750.16. For the end-fire glide slope, the antenna array typically extends to 25 feet from the runway edge. This is allowed due to antenna frangibility.

B13-2.9.3 Marker Beacons (Non-Frangible).

Marker beacons support instrument approach procedures. They are located on the runway centerline extended as noted.

B13-2.9.3.1 Outer Marker (OM) Beacon.

The OM beacon marks the point where the aircraft should intercept the glide slope. When the OM beacon cannot be located at this point, it is located between this point and the landing threshold, as close to this point as possible.

B13-2.9.3.2 Middle Marker (MM) Beacon.

B13-2.9.3.3 The MM beacon is located from 609.6 meters to 1,828.8 meters (2,000 to 6,000 feet) from the instrument runway threshold. Inner Marker (IM) Beacon.

The IM beacon is located to mark the point where the glide slope angle intersects the DH point of a CAT II ILS. An inner marker beacon is not used on a CAT I ILS. Marker beacons must not penetrate airspace clearance surfaces defined in this UFC.

B13-2.10 Microwave Landing System (MLS) and Mobile Microwave Landing System (MMLS) (Non-Frangible).

Use FAA Order 6830.5 for selecting MLS sites. Criteria for siting MMLS are provided within AFI 11-230. All installations should be sited the maximum distance from the runway centerline allowed by operational requirements but not less than 60.96 meters (200 feet). MMLS may be required to be sited as near as 45.72 meters (150 feet). Additionally, if the MMLS will be required to remain in service for more than 30 days, the antenna and associated operational equipment should be removed from the trailer and installed on a small foundation that is placed so that the surface is no higher than 76 millimeters (3 inches) above grade. The anchors used to secure the equipment should be the minimum size required to meet local requirements.

B13-2.11 Mobile Navigational Aids and Communication Facilities (Non-Frangible).

These units (including UAS TALS) follow the same general siting criteria as their fixed facility counterpart and the same deviations from standard clearance criteria are permissible. Power generators for these facilities will be located as close to the equipment and in as small a site configuration as possible.

B13-2.12 Mobile Air Traffic Control Towers (MATCT)/Mobile Tower System (MOTS) (Non-Frangible).

At least a 152.4-meter (500-foot) distance must be maintained between the centerline of any runway and the near edge of the tower. Power generators may be located in positions adjacent to the MATCT/MOTS. Communication antennas to be used with these towers, which are not mounted on the facility, require the same separation from the runway centerline as the parent equipment, fixed or mobile.

B13-2.13 Terminal Very High Frequency Omnirange (TVOR) Facility and Very High Frequency Omnirange (VOR) Facility (Non-Frangible).

TVOR and VOR facilities may be located not less than 152.4 meters (500 feet) for Air Force (76.2 m or 250 ft for Army) from the centerline of any runway to the edge of the facility, nor less than 61 meters (200 feet) for Air Force (45.72 m or 150 ft for Army) from the centerline of a taxiway.

B13-2.14 Tactical Air Navigation (TACAN) Facility and Very High Frequency Omnidirectional Radio Range (VORTAC) Facility (Non-Frangible).

When used as terminal navigational aids, the TACAN, VOR, and VORTAC facilities may be sited not less than 152.4 meters (500 feet) from the centerline of any runway to the edge of the facilities, provided the elevation of the antenna does not exceed 15.2 meters (50 feet) above the highest point of the adjacent runway centerline. For an on-base installation, the maximum angle of convergence between the final approach course and the runway centerline is 30 degrees (30°). The final approach course should be aligned to intersect the extended runway centerline 3,000 feet (914.4 meters) outward from the runway threshold. When an operational advantage can be achieved, this point of intersect may be established at any point between the threshold and a point 5,200 feet (1584.96 meters) outward from the runway threshold. Also, where an operational advantage can be achieved, a final approach course which does not intersect the runway centerline or intersects at a point greater than 5,200 feet (1,584.96 meters) outward from the runway threshold may be established, provided that such a course lies within 500 feet (152.4 meters) laterally of the extended runway centerline at a point 3,000 feet (914.4 meters) outward from the runway threshold.

B13-2.15 Non-Directional Beacon (NDB) (Non-Frangible).

When used as terminal navigational aid for the Army, the facility may be sited not less than 76.2 meters (250 feet) from the centerline of any runway to the edge of the facilities, provided the elevation of the antenna does not exceed 7.62 meters (25 feet) above the highest point of the adjacent runway centerline.

B13-2.16 Tactical Automated Landing System (TALS) (Non-Frangible).

This paragraph provides siting information for UAS support facilities that do not conform to the airfield clearance and airspace surface criteria elsewhere in this document. The MQ-1C Tactical Automated Landing System (TALS) and supporting equipment shall be sited at a maximum distance from the runway centerline allowed by operational requirements but not less than 250 feet. When the TALS is required to be sited within 250 feet it must meet frangibility requirements and have an approved waiver IAW Appendix B, Section 1. All other supporting equipment shall be sited not less than 250 feet from the runway centerline. Under no conditions will the TALS be sited closer than 150 feet from the runway centerline. If line-of-sight is the basis of the waiver request then the waiver request will have a line-of-sight analysis justifying the operational distance from the runway centerline. Additionally, if the Tactical Automated Landing System-Tracking System (TALS-TS) will be required to remain in service for more than 30 days, the equipment should be installed on a small concrete foundation. No part of the TALS-TS foundation and any remaining structure attached to it will extend three inches or more above grade after the frangible connections fail.

B13-2.17 Runway Supervisory Unit (RSU) (Non-Frangible) (USAF Only).

An RSU is a transportable or permanent all-weather, control tower type facility used to control or monitor aircraft movement. The RSU complex, consisting of the facility and all support equipment, must be confined to a site not to exceed 15.2 meters (50 feet) long by
15.2 meters (50 feet) wide. A minimum distance of 76.2 meters (250 feet) must be maintained between the runway centerline and the RSU facility and support equipment. Integral fuel tanks should be used for necessary mobile emergency power generator sets. If additional tanks are required or integral fuel tanks are not available, place the fuel supply system below grade with other supporting utilities.

B13-2.18 Fixed Base Weather Observing Systems (Non-Frangible).

A permanently installed automated FBWOS (e.g., AN/FMQ-19, AN/FMQ-22, AN/FMQ-23, or ASOS) consists of a suite of weather sensors and processors capable of collecting, measuring or calculating and reporting a myriad of weather elements. These elements include, but are not limited to, wind direction and speed, prevailing visibility, present weather and visibility obstructions, cloud coverage and cloud base height, temperature, dew point, atmospheric pressure, lightning, and precipitation amounts. The observing system's primary sensor suite contains the majority of the sensors. Many locations also have additional discontinuity sensor suites. The discontinuity suite contains fewer sensors than the primary suite and is sited at the runway's roll out, midfield, or in the case of a multi-runway configuration, at an adjacent site along a parallel or intersecting runway in order to provide critical weather element readings that are representative of the respective location. Selecting appropriate locations to install sensor groups is a critical consideration for flight operations safety as well as to ensure the weather elements collected are representative of the meteorological conditions affecting flight operations. The primary and discontinuity sensor groups will be aligned parallel to the runway and must be not less than 300 feet (Class A/Rotary-Wing Runways) or 400 feet (Class B) from centerline of the runway as close as possible to the touchdown point (between 1000 and 3000 feet down from the runway threshold). Fixed base weather systems are mounted on concrete footings or foundations and may vary in dimension depending on type of system suite. The top surface of these concrete structures will be flush with the surrounding surface grade. For siting criteria of a FBWOS near taxiways and parking aprons on airfields and heliports, use Tables 5-1, 5-2, and 6-1 in this manual. In cases where real-estate and/or terrain do not permit siting according to the UFC's direction, a waiver with supporting justification is required by Air Force IMSC Detachment or Garrison Commander at Army locations.

B13-2.19 Wind Direction Indicators (Frangible and Non-Frangible).

B13-2.19.1 Wind Cones.

See UFC 3-535-01 for appropriate siting.

B13-2.19.2 Landing Direction Indicator (Landing “T” or Tetrahedron) (Non-Frangible).

A landing “T” or tetrahedron must be located at least 83.82 meters (275 feet) from the edge of a runway to the centerline of the equipment.

B13-2.20 UAS Support Equipment (Frangible and Non-Frangible).

UAS support equipment is mobile and moved around the base to meet mission requirements. Equipment must be frangible whenever feasible. Acceptable runway centerline offset for support equipment is 250 ft. Acceptable taxiway centerline offset is 100 ft. Minimum 50 ft taxiway wingtip clearance is required for any non-local aircraft.

B13-2.20.1 Ground Data Terminal (GDT).

Line of Sight (LOS) Antenna that controls aircraft within LOS. The GDT must be elevated to avoid LOS signal interruption.

B13-2.20.2 GDT Towers.

Towers (mobile and fixed) that elevate the GDT above potential LOS interference.

B13-2.20.3 Ground Control Station (GCS).

Container/facility from where the Pilot and Sensor Operator control aircraft

B13-2.20.4 Satellite Antenna (PPSL).

Satellite antenna dish that controls aircraft beyond LOS.

B13-2.20.5 HVAC.

Equipment for cooling.

B13-2.20.6 UHF/VHF Antennas.

radio antenna to communicate with Tower and Crew Chiefs.

B13-2.20.7 Concrete Pads.

Concrete pads set in the turf or pavement for parking mobile equipment. Pads must be constructed flush with the surrounding grade.

B13-2.21 General Information for Operational and Maintenance Support Facilities.

Detailed siting information is furnished in this section, where appropriate.

B13-2.21.1 Operational Facilities.

B13-2.21.1.1 Aircraft Arresting Systems and Barriers (Net Engaging Systems) (Non-Frangible).

A series of components used to engage an aircraft and absorb the forward momentum of a routine or emergency landing (or aborted take-off). See **\1** AFMAN 32-1040 **/1/** or NAVAIR 51-5-31 for detailed siting criteria and other information and requirements.

a. Current aircraft arresting systems installed under previous criteria and standards may continue in service without waiver if they do not impair operational safety. The BCE's representative should identify such systems to flight safety and operations through the airfield manager, determine the proper risk mitigation, and program these systems for replacement. This should be done annually in conjunction with the annual waiver review. Such systems are: BAK-12 with two-roller deck sheave-type runway edge sheaves; BAK-12 systems with two-roller fairlead beam runway edge sheaves; on-grade BAK-12 systems installed before 1 July 1977 that are sited less than 76.2 meters (250 feet) from runway centerline (see grandfather allowance in **\1** AFMAN 32-1040 **/1/**); BAK-9 systems with two-roller deck-sheave runway edge sheaves; and BAK-13 systems; E-28 Arresting Gear Systems for Navy runways.

b. BAK-12 energy absorbers installed on-grade may not be sited less than 83.82 meters (275 feet) from runway centerline. Slopes over tape tubes for all types of installations must comply with criteria for shoulder grading provided in Chapter 3. Fairlead and three-roller deck sheave foundations must be constructed in accordance with Air Force Typical Installation Drawings 67F2013A, applicable to three-roller fairlead beams (e.g., sloped 30H to 1V). Protective shelters constructed for on-grade installations must be constructed from lightweight framing materials and sheathing using connections that will allow the structure to break away and collapse if struck by an aircraft wing. The overall height of the structure must be kept to the absolute minimum to meet mission requirements. See Typical Installation Drawing 67F2013A for suggested sources. For structures that must be constructed to resist high wind or snow loads, consider internal bracing that can be quickly and easily installed when such weather events are forecast, rather than concrete masonry or heavy steel designs.

c. BAK-15 barrier masts and hydraulic system components may be sited within 3 meters (10 feet) of the overrun edge. This is necessary to minimize the mast height needed to maintain the centerline height of the net. Foundations must be constructed flush with grade or grading surrounding the foundations shall be shaped to comply with the grading allowances provided for shoulders in Chapter 3, Table 3-4, Items 5 and 6.

d. Textile brake aircraft arresting systems may be sited adjacent to the runway or overrun edges, whether in a paved or unpaved surface. Cable pretensioning devices should be sited as far from the overrun or runway edge as possible. All foundations shall be flush with grade except the leading edge of the module foundations which have a 76.2-millimeter (3-inch) or less vertical drop to provide jet blast protection for the modules. Unidirectional models of this system, such as the MB 60.9.9, are not sited between the thresholds.

e. When aircraft arresting systems are decommissioned and removed from the airfield environment with no intent of replacement in the existing location, all related structures and foundations must be demolished and removed from the airfield. Grades in the area must be restored to comply with criteria provided in this UFC, as appropriate.

B13-2.21.1.2 Warm-up or Holding Pad.

The warm-up or holding pad is a paved area adjacent to the taxiway and the runway end. It provides a means of bypassing aircraft being held at the runway end for various reasons. For detailed design and siting criteria, see Chapter 6.

B13-2.21.1.3 Arm/Disarm Pad.

Arm/disarm pads are used for arming aircraft just before takeoff and for disarming weapons retained or not expended upon the aircraft's return. For detailed siting criteria and other information, see Chapter 6. When a personnel shelter is required, it is considered a part of the arm/disarm complex and must be sited to provide minimum wingtip/rotor clearance for the adjacent pavement type (taxiway or taxilane) and according to explosives quantity-distance criteria as discussed in Appendix B, Section 9 and AFMAN 91-201/DA PAM 385-64 for Air Force and Army respectively. Also see paragraph B13-2.21.2.8.

B13-2.21.1.4 Helicopter Autorotation Lanes (Also Called "Slide Areas" or Skid Pads").

Such lanes may be sited on or between active runways without a waiver. Ensure they are sited to prevent conflicts in operations (safety clearance zones must not overlap operational areas that will be used simultaneously).

B13-2.21.1.5 Vehicle Control Signs and Traffic Lights (Frangible and Non-Frangible).

These signs and lights provide drivers with guidance on traffic routes, service yard areas, and similar places. They provide warning information at runway and taxiway crossings and other hazardous points. Vehicle control signs and traffic lights may be located on the airfield movement area (including apron) without a waiver to criteria. However, a traffic engineering study should be accomplished and coordinated with civil engineers, airfield management, and safety before traffic control devices are selected and installed. (Refer to Army Military Traffic Management Command [MTMC] Pamphlet 55-14 for information on obtaining assistance with traffic engineering studies.) In siting vehicle controls signs and traffic lights, make sure that they do not obstruct taxiing or towed aircraft. Incorporate frangibility into existing designs to the maximum extent practicable by saw-cutting wood posts on opposing sides to a depth of approximately one-third the cross-section of the post, or chain-drilling metal posts to provide an intended break point near the base. Modifications of this type must be made at a point no more than 76.2 millimeters (3 inches) above grade. Incorporate more precise frangible designs as these devices are replaced. See paragraph B13-2.2.2 for further guidance.

B13-2.21.1.6 Runway Distance Remaining (RDR) Signs (Frangible).

These signs are required for runways used by jet aircraft and are recommended for runways used by propeller-type aircraft. For detailed siting and design guidance, see **\1** AFMAN 32-1040 **/1/** and UFC 3-535-01.

B13-2.21.1.7 Aircraft Security System (Frangible and Non-Frangible).

If a security system or fence is approved by the Air Force for airfield security, such as the microwave fence sensor or similar system as required by AFI 31-101, approval of the siting by the AFIMSC Detachment operation and safety offices will allow siting the system without waiver. No fence shall be allowed to penetrate the primary or approach-departure clearance surfaces without a waiver.

a. Flightline security sensor supports originally developed for the tactical area security system (TAAS) were tested and qualified as acceptable frangible mounting supports for various types of security sensors. These supports may be used over the entire airfield if sited to comply with the following guidelines.

- **Taxiways.** Conformance with criteria for taxiway signs must be met (distance and height).
- **Aprons.** TAAS security sensor mounts will be allowed on aprons, provided minimum taxilane wingtip clearance (as described in Chapter 6 for peripheral, through, and interior taxilanes) is maintained. There is no height restriction for supports up to 3 meters (10 feet) tall.
- **Runway/Overrun.** The closest distance from runway and paved overrun edge will be 30 meters (100 feet); closest distance to threshold (longitudinally) within the CZ will be 300 meters (1,000 feet). No penetrations of the approach-departure clearance surface will be allowed.

B13-2.21.1.8 Defensive Fighting Positions (Non-Frangible).

Although primarily used at deployed locations, base defense plans may require temporary defensive fighting positions (DFP) during base operational readiness exercises or increased force protection levels. DFPs are allowed to be sited within the primary surface and land use control area of the clear zone; however, they must not penetrate the approach-departure clearance surface or the runway/taxiway mandatory zone of frangibility. When temporary DFPs are not in use or are no longer required, they must be removed from the airfield and grades restored.

B13-2.21.2 Maintenance Facilities.

B13-2.21.2.1 Jet Blast Deflectors (Non-Frangible).

Jet blast deflectors are installed where continual jet engine run-up interferes with the parking or taxiing of aircraft, the movement of vehicles, the activities of maintenance personnel, or where it causes the erosion of pavement shoulders. To provide maximum efficiency, jet blast deflectors must be positioned at their optimum distance from the aircraft. They should be located to maintain nominal aircraft taxiing clearance distance as described in Table 6-1.

B13-2.21.2.2 Floodlights (Non-Frangible).

Floodlights illuminate aprons, alert stubs, specialized pads and other paved areas used for aircraft maintenance, loading/unloading, area security, and other reasons. Floodlights may be located on or near the apron, but must provide the minimum aircraft wingtip clearance in Table 6-1. They are not, however, exempt from the vertical restriction imposed by the transitional surface. Any deviation from this restriction must be waived, as discussed in Appendix B, Section 1.

B13-2.21.2.3 Fire Hydrants (Non-Frangible).

Fire hydrants may be installed within the apron clearance distances discussed in Chapter 6, provided the height is no more than 762 millimeters (30 inches) above the ground, and not more than 610 millimeters (24 inches) above the elevation of the adjacent load-bearing pavement. Hydrants must also be sited at least 25.6 meters (84 feet) from taxilane centerline. This is to provide the minimum clearance required by AFI 11-218 and is based on the geometry of a KC-135 aircraft positioned off taxilane centerline toward the hydrant, but with the outermost main gear still on the load-bearing pavement. Fire hydrants that violate the apron or taxiway lateral clearances will be completely painted with reflective paint or have a minimum 4" wide retro-reflective tape or paint surrounding stripe to ensure visibility during night operations. Normally bollards are not required for hydrants located adjacent to aprons. Per UFC 3-600-01, they are required only for hydrants located near roads, streets, and parking lots. If unique circumstances dictate that bollards be installed to protect hydrants located adjacent to the apron, they must be sited at the minimum distance and maximum height provided above. For aprons not intended to support the KC-135, this distance must be computed for the most critical aircraft that will use the apron taxilane. In cases where hydrants were sited prior to the date of publication of this UFC and are found to be sited too close to the peripheral taxilane centerline, the painted taxilane centerline and apron boundary marking or the fire hydrant locations should be adjusted to provide a minimum of 3 meters (10 feet) from the hydrant or bollard to the nearest point on the most demanding aircraft that will use the apron, with the outermost main gear positioned at the edge of the load-bearing pavement. For additional siting criteria and other information on the location of fire hydrants, see UFC 3-600-01.

B13-2.21.2.4 Explosives Safety Barricades (Non-Frangible).

When barricades are an element in an aircraft alert complex, they may be located on or near the apron, but must be sited to provide minimum wingtip clearance distances in Table 6-1. For information on explosives safety standards, see AFMAN 91-201/DA PAM 385-64 for Air Force and Army respectively.

B13-2.21.2.5 Ground Support Equipment (Mobile) (Non-Frangible).

Mobile ground support equipment may be located on aprons, but must be positioned to provide minimum wingtip clearance distances prescribed in Table 6-1 for all aircraft other than those being serviced with the equipment. Examples of ground support equipment exempt under this category are: aerospace ground equipment; electrical carts; forklifts; tow bar trailers; fire extinguisher carts; material-handling equipment; flightline maintenance stands; stair trucks; and portable floodlights. Similar equipment may be included in this category. When such equipment is not in use, it must be removed from the aircraft parking area and stored in areas that do not violate aircraft clearance requirements for normal operating routes (marked taxilanes or taxiways) or other imaginary surfaces. For the purpose of this UFC, equipment in use is defined as support equipment in place not more than three hours before aircraft arrival or three hours after aircraft departure. Support equipment may remain on the ramp in an Ops Group approved location indefinitely. These locations should be marked on the pavement to ensure equipment is stored to meet aircraft wingtip clearance and any other operational criteria to provide for safe operations.

B13-2.21.2.6 Flightline Vehicles (Non-Frangible).

Motor vehicles are allowed, based on approved operational/mission requirements, to operate on or near the flight line, including runways, taxiways, aprons, and service roads, in accordance with the provisions of TC 21-305-20, Chapter 20, *Operation of Motor Vehicles on Flight Lines*, and applicable Service airfield/flightline driving regulations/guidelines. When not required, these vehicles are relocated away from the vicinity of the parked aircraft.

B13-2.21.2.7 Ground Support Equipment (Stationary) (Non-Frangible).

Stationary ground support equipment and the associated safety and security components are necessarily sited on and near aprons, but must be sited to provide the minimum wingtip clearance prescribed in Table 6-1, defined by the wingtip trace of the most demanding aircraft that will use the apron. This type of equipment should not be sited in a way that will require any part of the aircraft to overhang the equipment unless the components are located below grade and the access points meet applicable grading criteria and are designed to withstand wheel loads and jet blast as defined within Chapter 6 of this UFC and Appendix B, Section 7. Fuel safety shut-off switches may be sited in accordance with the siting criteria for fire hydrants or in accordance with siting criteria for airfield signs if they incorporate a frangible coupling at the base (see UFC 3-535-01). Examples of stationary ground support equipment are centralized aircraft support systems and pantograph refueling systems. This also includes markers for petroleum, oil, and lubricant (POL) supply lines, communications and utility lines, and property demarcation. Ensure proper lighting and fire safety features are included.

B13-2.21.2.8 Crew Chief Shack (Non-Frangible).

This facility, sometimes identified as an airfield maintenance unit, is a trailer or permanent prefabricated structure that may be located at the end of the runway, close to the arm/disarm pad or the apron edge. It may also be located on the apron, but must meet wingtip clearance requirements provided in Table 6-1. Although these shelters are allowed in the graded area of the clear zone, no shelter shall penetrate the approach-departure clearance surface, nor the runway or taxiway mandatory zone of frangibility.

Explosive quantity distance criteria in AFMAN 91-201/DA PAM 385-64 applies to Air Force and Army respectively.

B13-2.21.2.9 Service Roads.

Service roads may be located on the perimeter of alert aprons, around specialized aircraft parking pads, or for access to NAVAIDs, aircraft arresting systems, weather sensors, and other similar areas on the airfield. Service roads are not permitted in the runway (graded) clear zones, unless access is controlled by air traffic control (Tower). In locating these roads, the wing overhang and appropriate safe clearance distance for the largest aircraft using the facility must be taken into account, and they must be marked or signed to identify VFR and instrument holding positions, to prevent encroachment into NAVAID critical areas or violation of the approach-departure clearance surface. The distance from the peripheral taxilane on an apron to the edge of the road is computed from the centerline of the aircraft's path, plus the minimum wingtip clearance given in Table 6-1, items 4, 5, and 6 (except at intersections with operational pavement). See UFC 3-260-04 for placement of runway holding positions and instrument landing system (ILS) or precision approach radar (PAR) critical areas. Ensure service roads are appropriately marked to control vehicular movement along and within the roadway. Markings shall be in accordance with **\1** AFMAN 32-1040 **/1/** and the *Manual on Uniform Traffic Control Devices* (MUTCD), published by the Department of Transportation, Federal Highway Administration.

B13-2.21.2.10 Fencing and Barricades (Jersey Barriers) (Frangible and Non-Frangible, respectively).

Fencing and barricades are erected on airfields for a variety of purposes. They may be located on the perimeter of alert aprons, around specialized aircraft parking pads or NAVAIDs, and other similar areas on the airfield when necessary for security or force protection. When siting fences or barricades, the wing overhang and appropriate safe clearance distance for the largest aircraft using the facility must be taken into account. The distance from the nearest taxilane on an apron to the fence or barricade is computed from the centerline of the aircraft's path, plus the minimum wingtip clearance given in Table 6-1, items 4, 5, and 6. **\1\ Exception:** Barricades may not be located within the Mandatory Zone of Frangibility for runways or taxiways without a waiver and fences constructed within these areas must meet wingtip clearance requirements and the requirements of paragraph 13-2.2.2.5. No fence or barricade shall penetrate the primary or approach-departure clearance surfaces or the graded area of the Clear Zone. Installation perimeter fencing shall not be sited within the graded area of the Clear Zone (305 meters [1000 feet]) but may be sited outside of it in the land-use area of the Clear Zone/Mandatory Zone of Frangibility to comply with required installation boundary security/force protection requirements. Fencing within the MFZ must meet the requirements of paragraph 13-2.2.2.5 or it requires a waiver. **/1/** Penetrations to the 7:1 transitional surface are allowed without waiver for base boundary (property line) fences if they have no impact to existing or planned instrument procedures (TERPS). Barricades located on aprons within the primary surface must be marked and lighted as obstructions unless they are shielded by other obstructions that are marked and lighted, or are located on the outer periphery of the apron away from the runway, behind an aircraft parking area with an exempt status or approved waiver.

a. **Snow Fencing**. This type of structure may be installed within the Runway Primary Surface or Transitional Surface(s) however it must be located outside of the Mandatory Frangibility Zone. Fencing will be of a sturdy yet non-permanent construction, of a height not exceed 6 feet tall and all fencing components will be removed during the season(s) when snow is not probable. Snow fencing location(s) will be selected in coordination with the installation Flight Safety and Airfield Management office concurrence. Snow fencing is not permitted in any location that will violate aircraft wing-tip clearances criteria or that will interfere with NAVAIDs or METNAV devices

B13-2.21.2.11 Wildlife Control Devices.

Various devices such as propane cannons, sirens, and traps may require siting within the airfield environment for wildlife control. Ensure these devices are sited at least 30.5 meters (100 feet) from the near edge of runways and overruns. When sited along taxiways and aprons, ensure these devices do not pose a hazard to taxiing or towed aircraft and, as a minimum, conform to distance and height criteria for airfield signs (see UFC 3-535-01). For guidelines on wildlife control fences, see paragraph B13-2.21.2.10 above.

B13-2.21.2.12 Bird Aircraft Strike Hazard (BASH) Radar Systems.

Aircraft bird-strike avoidance radar systems should be sited off the airfield when possible. However, when no alternatives exist, these facilities are authorized as permissible deviations to airfield criteria, provided they are sited so they do not impact existing or planned instrument procedures (TERPS). They also must not be sited within 122 meters (400 feet) of runway centerline, the graded area of the clear zone, as a penetration to the approach-departure clearance surface, nor within any of the mandatory frangibility zones (see Tables 3-2 and 3-5). These areas include taxiway clearance distances and taxilane wingtip clearance distances (see Tables 5-1 and 6-1). Care must also be taken to ensure they are sited so they will not interfere with NAVAID critical areas or other airfield radar systems. Coordinate with the METNAV shop and communications to ensure these requirements are met.

B13-2.21.2.13 Fuel Hydrants.

Fuel hydrants may be installed within the apron clearance distances discussed in Chapter 6, provided the height is no more than 762 millimeters (30 inches) above the ground, and not more than 610 millimeters
(24 inches) above the elevation of the adjacent load-bearing pavement. Fuel Hydrants must also be sited at least 25.6 meters (84 feet) from taxilane centerline. This is to provide the minimum clearance required by AFI 11-218 and is based on the geometry of a KC-135 aircraft positioned off taxilane centerline toward the hydrant, but with the

outermost main gear still on the load-bearing pavement. Normally bollards are not required for hydrants located adjacent to aprons. If unique circumstances dictate that bollards be installed to protect hydrants located adjacent to the apron, they must be sited at the minimum distance and maximum height provided above. For aprons not intended to support the KC-135, this distance must be computed for the most critical aircraft that will use the apron taxilane. In cases where hydrants were sited prior to the date of publication of this UFC and are found to be sited too close to the peripheral taxilane centerline, the painted taxilane centerline and apron boundary marking or the fuel hydrant locations should be adjusted to provide a minimum of 3 meters (10 feet) from the hydrant or bollard to the nearest point on the most demanding aircraft that will use the apron, with the outermost main gear positioned at the edge of the load-bearing pavement.

B13-2.21.3 Miscellaneous.

B13-2.21.3.1 Telephone and Fire Alarm Systems.

Telephone and fire alarm system boxes may be located on or in the vicinity of aprons, provided the height of the structure does not constitute an obstruction to the most demanding aircraft that will use the apron.

B13-2.21.3.2 Trash Collection Containers.

Dumpsters and similar equipment may be located in the vicinity of an apron, provided appropriate wingtip clearance requirements given in Table 6-1, items 4, 5, and 6 are provided, and the location does not constitute a hazard to pedestrian or vehicular traffic from the debris.

B13-2.21.3.3 Landscaping Around Flightline Facilities.

Shrubs and other landscaping should conform to the height restriction discussed in paragraph B13-2.21.3.1 or must be located to provide the minimum wingtip clearances provided in Chapter 6.

B13-2.21.3.4 Other Apron Facilities.

Facilities other than those previously mentioned within this section may require siting near or on aprons due to their function and purpose. In these cases, ensure wingtip clearance shown in Table 6-1 is provided. Some examples of these type facilities are hangars, aircraft sunshades, wash racks, taxi-through alert shelters, air passenger terminals, movable passenger access platforms (jetways), base operations facilities, squadron operations facilities, airfield maintenance unit facilities, fire stations, fuel or groundwater recovery systems, material-handling equipment storage facilities, airfreight terminals, and weather shelters for sentries. Facilities must not penetrate imaginary surfaces without an approved waiver.

B13-2.21.3.5 Utility Access Points.

Utility handholes and manholes should be constructed flush with grade. These utility access points do not require a waiver if the drop-off at the edge of the top surface is 76 millimeters (3 inches) or less.

B13-2.21.3.6 Air Traffic Control Towers.

Air Traffic Control Towers may be considered permissible deviations to the transitional surface if it meets the siting criteria given in Appendix B, Section 16. For Army, Air Traffic Control Towers are not considered permissible deviations.

B13-2.21.3.7 Runway Ice Detection System (RIDS).

RIDS consists of four functional elements: in-pavement sensors; supporting power supply/signal processor units; terminal data processing units; and data display units/printers. The components sited within the airfield environment are authorized as a permissible deviation to airfield criteria provided in this UFC when sited as follows:

a. The in-pavement sensors are installed in the runway pavement flush with and in the plane of the pavement surface. The head surface texture shall be similar to that of the surrounding pavement surface and approximate the flow and pooling characteristics of water on the surrounding pavement. The remote field units that provide power to the in-pavement sensor head, processes raw surface condition input data, collect air temperature and related atmospheric data, and transmit the processed data to the terminal data processing unit are fixed by function and must be sited on the airfield.

b. Where practical, these units should be collocated with other air navigational aids outside the mandatory frangibility zone (MFZ) so they do not conflict with other electronic and visual air navigational aids. If collocation is not possible, the units must be equipped with obstruction lights and shall be sited along the runway and taxiway, outside the MFZ but not within the last 304 meters (1,000 feet) of the runway. The height must be kept to the minimum practicable and the units must be equipped with a frangible coupling at the base. See FAA AC 150/5220-13 for more detailed information on these systems.

B13-2.21.3.8 Utility Risers.

Utility risers located near runways, taxiways and aprons supporting facilities listed as permissible deviations in this Section are authorized. Utility risers within the MFZ must be frangible. Utility riser must be lower than 4-ft tall. Utility riser shall have obstruction light installed when required per UFC 3-535-01.

APPENDIX B
SECTION 14
CONSTRUCTION PHASING PLAN AND OPERATIONAL SAFETY ON AIRFIELDS DURING CONSTRUCTION

B14-1 CONTENTS.

A construction phasing plan must be included in the contract documents. The purpose of a phasing plan is to establish guidelines and constraints the contractor must follow during construction. It is recommended that the construction phasing plan be submitted for coordination and review at the concept and design stage. At minimum, the plan must be coordinated with airfield management, airfield operations, communications, ground and flight safety, environmental, security forces, contracting and logistics.

B14-2 NAVY AND MARINE CORPS REQUIREMENTS.

This section does not apply to the Navy and Marine Corps.

B14-3 INFORMATION TO BE SHOWN ON THE CONSTRUCTION PHASING PLAN.

The phasing plan will include, but is not necessarily limited to, the following:

B14-3.1 Phasing.

All construction activities will be separated into phases. The phasing plan will show or describe the sequence of construction activity for each phase. The phasing plan will be incorporated into the contractor's management plan and reflected in the progress schedule. The work area limits (to define required aircraft and worker safety and security clearances), barricades, maximum equipment height, and temporary fencing requirements will be clearly delineated for each phase. The work area limits will include identification of restricted areas requiring escorts and free zones with secure areas.

B14-3.2 Aircraft Operational Areas.

The phasing plan will identify active aircraft operational areas and closed pavement areas for each phase.

B14-3.3 Additional Requirements.

If required, the location of flagmen, security guards, and other personnel should be shown. These locations should be supplemented in the specifications.

B14-3.4 Temporary Displaced Thresholds.

Temporary displaced thresholds and temporary displaced threshold lighting requirements should be shown. These details will be presented in the drawings and supplemented in the specifications.

B14-3.5 Access.

Construction vehicle access roads, including access gates and haul routes, will be shown.

B14-3.6 Temporary Marking and Lighting.

Temporary pavement marking and lighting details will be presented on the phasing plan. Marking and lighting details are presented in UFC 3-260-04, UFC 3-535-01, and applicable FAA guidance.

B14-3.7 Safety Requirements and Procedures.

The construction phasing plan must include a section outlining safety requirements and procedures for activities on the airfield during the planned period of construction.

B14-3.8 FOD Checkpoints.

Location of foreign object debris (FOD) checkpoints, when required, should be included in the phasing plan.

B14-4 OTHER ITEMS TO BE SHOWN IN THE CONTRACT DRAWINGS.

The following items are not necessarily a part of the phasing plan, but will be included in the contract documents.

B14-4.1 Storage.

The contractor's equipment and material storage locations.

B14-4.2 Parking.

The contractor's personnel vehicle parking area and access routes to the work area.

B14-4.3 Buildings.

Location of the contractor's offices and plants.

B14-4.4 Designated Waste and Disposal Areas.

Off-site disposal should be included in the specifications.

B14-5 MAXIMUM EQUIPMENT HEIGHT.

The maximum height of construction equipment expected to be in use during construction must be included in the contract documents, the work order project requirements checklist, or other project guidance documents. This information must also be included on FAA Form 7460-1, *Notice of Proposed Construction or Alteration*. This form must be submitted to the FAA 30 days before the start of construction if the maximum equipment height penetrates any of the surfaces described in FAR Part 77.

B14-6 OPERATIONAL SAFETY ON THE AIRFIELD DURING CONSTRUCTION.

This section provides the minimum risk mitigation standards for Army and Air Force airfield construction projects and guidelines concerning operational safety on airfields during construction. This information is intended to assist civil engineers, airfield management, and safety personnel in maintenance of a safe operating environment. The principal guidelines provided here were taken from FAA AC 150/5370-2, latest version, but have been modified to better relate to Army and Air Force needs and terminology. Construction activity is defined as the presence and movement of personnel, equipment, and materials in any location that could infringe upon the movement of aircraft. Normal maintenance activities are exempt from these requirements. Some examples of exempt maintenance activities are grass cutting, minor pavement repairs, inspection, calibration, and repair of NAVAIDs and weather equipment, aircraft arresting systems maintenance, and snow removal operations.

B14-6.1 General Requirements.

Construction activities on the airfield, in proximity to, or affecting aircraft operational areas or navigable airspace, must be coordinated with all airfield users before initiating such activities. In addition, basic responsibilities must be identified and assigned and procedures developed and disseminated to instruct construction personnel in airport procedures and for monitoring construction activities for conformance with safety requirements. These and other safety considerations must be addressed in the earliest stages of project formulation and incorporated in the contract specifications, the work order project requirements checklist, and/or other project guidance documents developed for in-house construction projects. Construction areas located within the aircraft movement area requiring special attention by the contractor or in-house construction activity must be clearly delineated on the project plans. The quality assurance personnel, airfield manager, and contract administrator should closely monitor construction activity throughout its duration to ensure continual compliance with safety requirements. At minimum, comply with the requirements in paragraphs B14-6.1.1 through B14-6.1.4. Otherwise, alternative safety mitigation plans must be developed and included in the construction waiver request for the installation commander's approval.

B14-6.1.1 Runways.

Activities within the graded areas of the clear zone will require threshold displacement sufficient to protect the approach-departure clearance surface, and adjustment to the departure runway end location to provide a minimum 305-meter (1,000-foot) safety area between the stop end of the runway and construction activities. Construction activities must not be conducted within a distance equal to the normal VFR holding position distance from the near edge of any active segment of a runway.

B14-6.1.2 Taxiways, Taxilanes and Aprons.

Construction activity setback lines must be located at a distance to provide the minimum wingtip clearance required in Table 6-1, items 5 or 6, as appropriate, for the largest aircraft that will use the taxiway, taxilane or apron.

B14-6.1.3 Jet Blast.

You must also consider jet blast effects on personnel, equipment, facilities, and other aircraft. Maintain a distance behind aircraft sufficient to dissipate jet blast to 56 kilometers per hour (35 miles per hour) and temperatures to a maximum of 38 degrees Celsius (100 degrees Fahrenheit), or ambient, whichever is more, or provide jet blast protection with a deflector.

B14-6.1.4 Marking and Lighting.

Threshold displacements and runway end relocation must be marked and lighted in accordance with UFC 3-260-04, and UFC 3-535-01. Additionally, alternate temporary taxi routes on taxiways or aprons must be marked either with temporary paint markings or with frangible edge markers. They must also be lighted if they will be used during periods of darkness or during instrument flight rule operations. Closed taxiways or taxilanes on aprons must be marked or barricaded and normal lighting circuits disabled. Temporary obstructions, such as cranes, must be marked and lighted in accordance with FAA AC 70/7460-1. All hazardous areas (such as excavations or stockpiled materials) on the airfield must be delineated with lighted barricades on all exposed (visible or accessible) sides.

B14-6.2 Formal Notification of Construction Activities.

Any entity, including the military, proposing any kind of construction or alteration of objects that may affect navigable airspace, including military airspace, as defined in FAR Part 77, is required to notify the FAA. FAA Form 7460-1 is used for this purpose.

B14-6.3 Safety Considerations.

The following is a partial list of safety considerations which experience indicates will need attention during airport construction.

a. Minimum disruption of standard operating procedures for aeronautical activity.

b. Clear routes from firefighting and rescue stations to active airport operations areas.

c. Chain of notification and authority to change safety-oriented aspects of the construction plan.

d. Initiation, currency, and cancellation of Notice to Airmen (NOTAM).

e. Suspension or restriction of aircraft activity on affected airport operations areas.

f. Threshold displacement and appropriate temporary lighting and marking.

g. Installation and maintenance of temporary lighting and marking for closed or diverted aircraft routes and disabling the normal lighting circuits for closed runways, taxiways, and taxilanes.

h. Revised vehicular control procedures or additional equipment and manpower.

i. Marking/lighting of construction equipment.

j. Storage of construction equipment and materials when not in use.

k. Designation of responsible representatives of all involved parties and their availability.

l. Location of construction personnel parking and transportation to and from the work site.

m. Marking/lighting of construction areas.

n. Location of construction offices.

o. Location of contractor's plants.

p. Designation of waste areas and disposal.

q. Debris cleanup responsibilities and schedule.

r. Identification of construction personnel and equipment.

s. Location of haul roads.

t. Security control on temporary gates and relocated fencing.

u. Noise pollution.

v. Blasting regulation and control.

w. Dust control.

x. Location of utilities.

y. Provision for temporary utilities and/or immediate repairs in the event of disruption.

z. Location of power and control lines for electronic/visual navigational aids.

aa. Additional security measures required if AFI 31-101 is impacted (relocation or reconstruction of fences or security sensors).

bb. Marking and lighting of closed airfield pavement areas.

cc. Coordination of winter construction activities with the snow removal plan.

dd. Phasing of work.

ee. Shutdown, relocation and/or protection of airport electronic and or visual navigational aids.

ff. Smoke, steam, vapor, and extraneous light controls.

gg. Notification to crash/fire/rescue and maintenance personnel when working on water lines.

hh. Provide traffic directors/wing walkers, etc., as needed to assure clearance in construction areas.

B14-6.4 Examples of Hazardous and Marginal Conditions.

Analyses of past accidents and incidents identified many contributory hazards and conditions. A representative list follows:

a. Excavation adjacent to runways, taxiways, and aprons.

b. Mounds or stockpiles of earth, construction material, temporary structures, and other obstacles near airport operations areas and approach zones.

c. Runway surfacing projects resulting in excessive lips greater than 25.4 millimeters (1 inch) for runways and 76.2 millimeters (3 inches) for edges between old and new surfaces at runway edges and ends.

d. Heavy equipment, stationary or mobile, operating or idle near airport operations areas or in apron, taxiway, or runway clearance areas.

e. Proximity of equipment or material which may degrade radiated signals or impair monitoring of navigational aids.

f. Tall but relatively low-visibility units such as cranes, drills, and the like in critical areas such as aprons, taxiways, or runway clearance areas and approach zones.

g. Improper or malfunctioning lights or unlighted airport hazards.

h. Holes, obstacles, loose pavement, trash, and other debris on or near airport operations areas.

i. Failure to maintain fencing during construction to deter human and animal intrusions into the airport operation areas.

j. Open trenches alongside operational pavements.

k. Improper marking or lighting of runways, taxiways, and displaced thresholds.

l. Attractions for birds such as trash, grass seeding, or ponded water on or near the airfield.

m. Inadequate or improper methods of marking temporarily closed airport operations areas, including improper and unsecured barricades.

n. Obliterated markings on active operational areas.

o. Encroachments to apron, taxiway, or runway clearance areas, improper ground vehicle operations, and unmarked or uncovered holes and trenches in the vicinity of aircraft operating surfaces are the three most recurring threats to safety during construction.

B14-6.5 Vehicles on the Airfield.

Vehicular activity on the airfield movement areas should be kept to a minimum. Where vehicular traffic on airfield operational areas cannot be avoided, it should be carefully controlled. A basic guiding principle is that the aircraft always has the right-of-way. Some aspects of vehicle control and identification are discussed below. It should be recognized, however, that every airfield presents different vehicle requirements and problems and therefore needs individualized solutions so vehicle traffic does not endanger aircraft operations. Personnel required to drive on the airfield must be knowledgeable of and comply with the procedures outlined in the installation airfield driving program.

B14-6.5.1 Visibility.

Vehicles which routinely operate on airport operations areas should be marked and/or flagged for high daytime visibility and, if appropriate, lighted for nighttime operations. Vehicles which are not marked and lighted may require an escort by one that is equipped with temporary marking and lighting devices. (See Air Force T.O. 36-1-191 and FAA AC 150/5210-5.)

B14-6.5.2 Identification.

It is usually desirable to be able to visually identify specific vehicles from a distance. It is recommended that radio-equipped vehicles which routinely operate on airfields be permanently marked with identifying characters on the sides and roof. Vehicles needing intermittent identification could be marked with tape or magnetically attached markers. Such markers are commercially available. However, select markers that can perhaps be mounted inside the vehicle or tethered to the vehicle so they do not fall off during vehicle operation and present potential foreign object damage (FOD) to aircraft.

B14-6.5.3 Noticeability.

Construction vehicles and equipment should have automatic signaling devices to sound an alarm when moving in reverse.

B14-6.5.4 Movement.

The control of vehicular activity on airfield operations areas is of the highest importance. Airfield management is responsible for developing procedures and providing training regarding vehicle operations to ensure aircraft safety during construction. This requires coordination with airfield users and air traffic control. Consideration should be given to the use of two-way radio, signal lights, traffic signs, flagman, escorts, or other means suitable for the particular airfield. The selection of a frequency for two-way radio communications between construction contractor vehicles and the Air Traffic Control Tower (ATCT) must be coordinated with the ATC tower chief. At non-tower airfields, two-way radio control between contractor vehicles and fixed-base operators or other airport users should avoid frequencies used by aircraft. It should be remembered that even with the most sophisticated procedures and equipment, systematic training of vehicle operators is necessary to achieve safety. Special consideration should be given to training intermittent operators, such as construction workers, even if escort service is being provided.

B14-6.6 Inspection.

Frequent inspections should be made by the airfield manager, civil engineering contract inspectors, and other representatives during critical phases of the work to ensure the contractor is following the prescribed safety procedures and there is an effective litter control program.

B14-6.7 Special Safety Requirements during Construction.

Use the following guidelines to help develop a safety plan for airfield construction.

B14-6.7.1 Runway Ends.

Construction equipment will not penetrate the approach-departure clearance surface.

B14-6.7.2 Runway Edges.

Construction activities normally will not be permitted within 30 meters (100 feet) of the runway edge. However, construction may be permitted within 30 meters (100 feet) of the runway edge on a case-by-case basis with a temporary waiver approved by the installation commander.

B14-6.7.3 Taxiways and Aprons.

Normally, construction activity setback lines will be located at a distance to provide the minimum wingtip clearance required from Table 6-1, items 5 or 6, as appropriate, plus one-half the wingspan of the largest predominant aircraft that will use the taxi route from the centerline of the active taxiway or apron. However, construction activity may be permitted up to the taxiway and aprons in use, provided the activity is approved by the installation commander and NOTAMs are issued; marking and lighting provisions are implemented; and it is determined the height of equipment and materials is safely below any part of the aircraft using the airfield operations areas which might overhang those areas. Alternate taxi routes and procedures for wing-walkers should be included in the safety plan if adequate wingtip clearance cannot be provided.

B14-6.7.4 Excavation and Trenches.

Excavations and open trenches may be permitted along runways up to 30 meters (100 feet) from the edge of an active runway, provided they are adequately signed, lighted and marked. In addition, excavation and open trenches may be permitted within 30 meters (100 feet) of the runway edge on a case-by-case basis; that is, cable trenches, pavement tie-ins, etc., with the approval of the installation commander. Along taxiways and aprons, excavation and open trenches may be permitted up to the edge of structural taxiway and apron pavements, provided the drop-off is adequately signed, lighted and marked.

B14-6.7.5 Stockpiled Materials.

Extensive stockpiled materials should not be permitted within the construction activity areas defined in the preceding four paragraphs.

B14-6.7.6 Maximum Equipment Height.

FAA Form 7460-1 shall be submitted when equipment is expected to penetrate any of the surfaces described in Appendix B, Section 5, FAR Part 77.9.

B14-6.7.7 Proximity of Construction Activity to Navigational Aids.

Construction activity in the vicinity of navigational aids requires special considerations. The effect of the activity and its permissible distance and direction from the aid must be evaluated in each instance. A coordinated evaluation by the airfield manager, civil engineer, safety, and communications personnel is necessary. Particular attention needs to be given to stockpiling materials as well as to the movement and parking of equipment which may interfere with line-of-sight from the tower or interfere with electronic emissions.

B14-6.7.8 Proximity of Construction to Explosives QD Arc.

Wing Explosive safety must obtain a waiver for any construction falling inside an explosives QD Arc.

B14-6.8 Construction Vehicle Traffic.

With respect to vehicular traffic, aircraft safety during construction is likely to be endangered by four principle causes: increased traffic volume; nonstandard traffic patterns; vehicles without radio communication and marking; and operators untrained in airfield procedures. Because each construction situation differs, airfield management must develop and coordinate a construction vehicle traffic plan with airfield users, air traffic control and the appropriate construction engineers and contractors. The plan, when signed by all participants, should become a part of the contract, the work order project requirements checklist, and/or other project guidance documents developed for in-house projects. Airfield management, quality assurance, and safety are responsible for coordinating and enforcing the plan.

B14-6.9 Limitation on Construction.

Open-flame welding or torch cutting operations are prohibited unless adequate fire and safety precautions are provided and have been approved by the fire chief. All vehicles are to be parked and serviced behind the construction restriction line and/or in an area designated by the contract, the work order project requirements checklist, and/or other project guidance documents developed for in-house projects. Open trenches, excavations, and stockpiled material at the construction site should be prominently marked with orange flags and lighted with flashing red or yellow light units during hours of restricted visibility and/or darkness. Under no circumstances are flare pots to be near aircraft operating areas. Stockpiled material should be constrained in a manner to prevent dislocation that may result from aircraft jet blast or wind. Material should not be stored near aircraft operating areas or movement areas.

B14-6.10 Marking and Lighting Closed or Hazardous Areas on Airfields.

To ensure adequate marking and lighting is provided for the duration of the project, the construction specifications, the work order project requirements checklist, and/or other project guidance documents must include a provision requiring the contractor or other construction activity to have a person on-call 24 hours a day for emergency maintenance of airport hazard lighting and barricades. See **\1** AFMAN 32-1040 **/1/**, UFC 3-260-04 and UFC 3-535-01 for marking and lighting requirements for closed pavement areas.

B14-6.11 Temporary Runway Threshold Displacement.

Identification of temporary runway threshold displacements must be provided as indicated in UFC 3-260-04, and UFC 3-535-01. The extent of the marking and lighting should be directly related to the duration of the displacement as well as the type and level of aircraft activity. Temporary visual aids must be placed to provide an unobstructed approach-departure clearance surface with a 3-meter (10-foot) buffer between the surface and the tallest equipment in the construction zone, and a 304.8-meter (1,000-foot) -long overrun safety area beyond the departure end of the runway. Runway threshold displacements must be coordinated with the TERPS office as the displacement will require discontinuation of precision instrument procedures and may affect landing minima for non-precision procedures. Departure procedures will also have to be evaluated to determine the effects of the runway threshold displacements.

APPENDIX B
SECTION 15
ARMY AND AIR FORCE AIRCRAFT TRIM PAD AND THRUST ANCHOR FOR 267 KILONEWTONS (60,000 POUNDS) AND 445 KILONEWTONS (100,000 POUNDS) THRUST

B15-1 PURPOSE.

This Section presents design details for two aircraft trim pad anchoring systems designed to support working loads of 267 kN (60,000 lb) and 445 kN (100,000 lb) of thrust. This Section supersedes Air Force ETL 01-10, *Design and Construction of High-Capacity Trim Pad Anchoring Systems*.

B15-2 BACKGROUND.

A thrust anchor is constructed by embedding a steel anchor block trim pad into a large reinforced concrete block tie to the surrounding anchor concrete slab, and used to constrain fighter aircraft during power checks and routine engine maintenance procedures. Many existing aircraft anchor blocks were designed to withstand loads associated with F-4 operations and 267 kN (60,000 lb) thrust; however, the newer generation of fighter aircraft employs engines with much greater thrusts. At locations supporting those aircraft, the 445 kN (100,000 lb) anchor block must be used. At locations where only aircraft with lower thrust loads, smaller anchor blocks may be designed. **All anchors shall be clearly labeled with the design load rating**.

B15-3 ANALYSIS AND VISUAL INSPECTIONS.

Analyses of anchor block designs have concluded that the likely mode of failure will be rupture of the metal link; however, other modes could occur. Therefore, the critical areas for routine visual inspection should include the surface at the steel-concrete interfaces, the top of the weld between the curved bar and the web plate, and the weld on the metal link. Observable permanent deformation of the steel bar would indicate that appreciable plastic stains have occurred and that the strength of the anchor block system should be reviewed more carefully.

B15-4 CONSTRUCTION.

B15-4.1 Materials and Manufacturing.

The anchor steel shall be high-strength alloy with a yield strength of at least 689.5 MPa (100 kips per square inch). A high strength alloy must be used to keep the thickness of the bar to a diameter than can be bent 180-degrees at an inside radius of 101 mm (4 inches). Also, a thicker bar would make connection design more difficult.

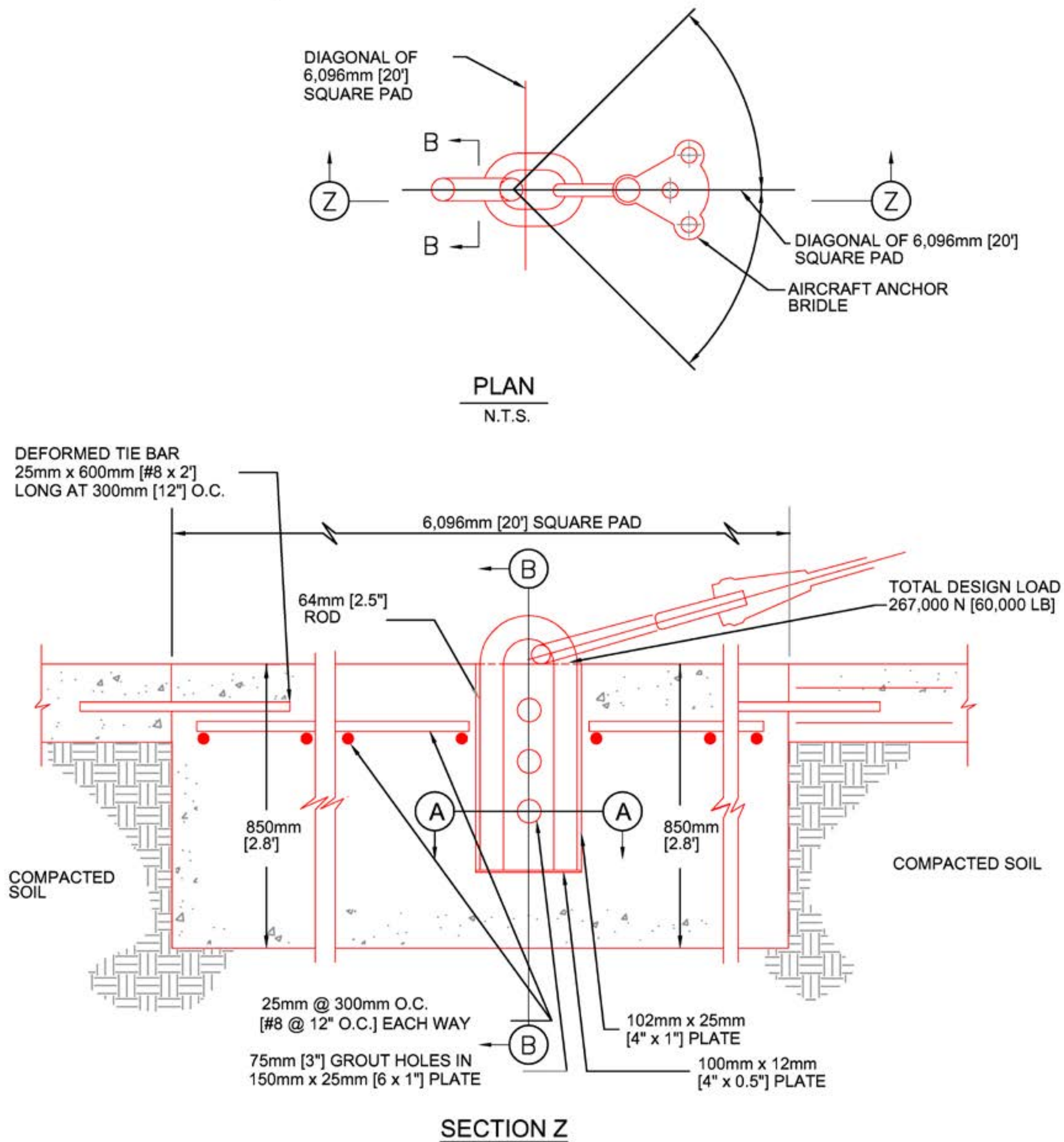
B15-4.2 Placement of Rebar.

For the 445 kN (100,000 lb) anchor block, the rebar is designed so that pulling out the steel anchor would require pulling out the top layer of rebar. The top layer of rebar is set over the 63-millimeter (2.5-inch) steel dowels that go through the web of the steel anchor. A minimum cover of 203 millimeters (8 inches) should be provided and checked before the concrete is poured.

B15-4.3 Pouring and Finishing Concrete.

Approximately 15,300 liters (20 yards) of concrete is needed for the 445 kN (100,000 lb) anchor block. Concrete must be placed evenly on both sides of the anchor so the anchor will not move while pouring. Minimum 34.4-megapascal (5000-psi) compressive strength concrete shall be used in anchor blocks.

Figure B15-1. Example of 267 kN (60,000 LB) Square Aircraft Anchor Block and Cross Section

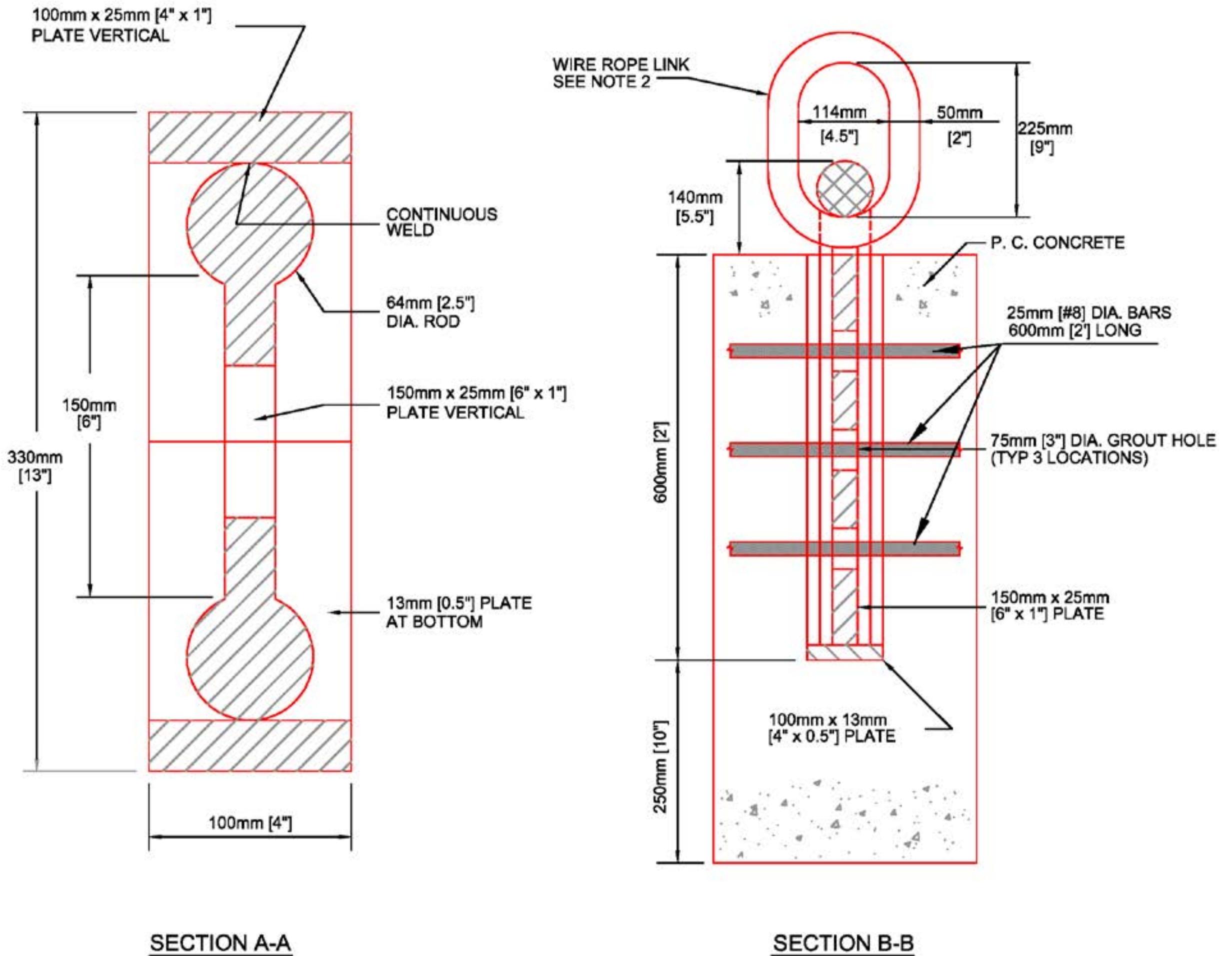


STANDARD 267 kN (60,000 lb) AIRCRAFT ANCHOR BLOCK
N.T.S.

NOTES

1. THIS DESIGN IS FOR UP TO 267,000 N [60,000 LB] THRUST AND WILL ACCOMMODATE FIGHTER AIRCRAFT UP TO AND INCLUDING F-15E. THE DESIGNER MUST VERIFY STRUCTURAL DESIGN FOR THRUST OF DIFFERENT AIRCRAFT AND ENGINE TYPES.
2. DESIGN MAY BE SCALED DOWN TO MEET MISSION AIRCRAFT THRUST LOAD REQUIREMENTS. IF SCALED DOWN, THE ANCHOR MUST BE LABELED WITH THE MAXIMUM THRUST IT IS DESIGNED TO HOLD.
3. SEE FIGURE B15-2 FOR SECTION VIEW.

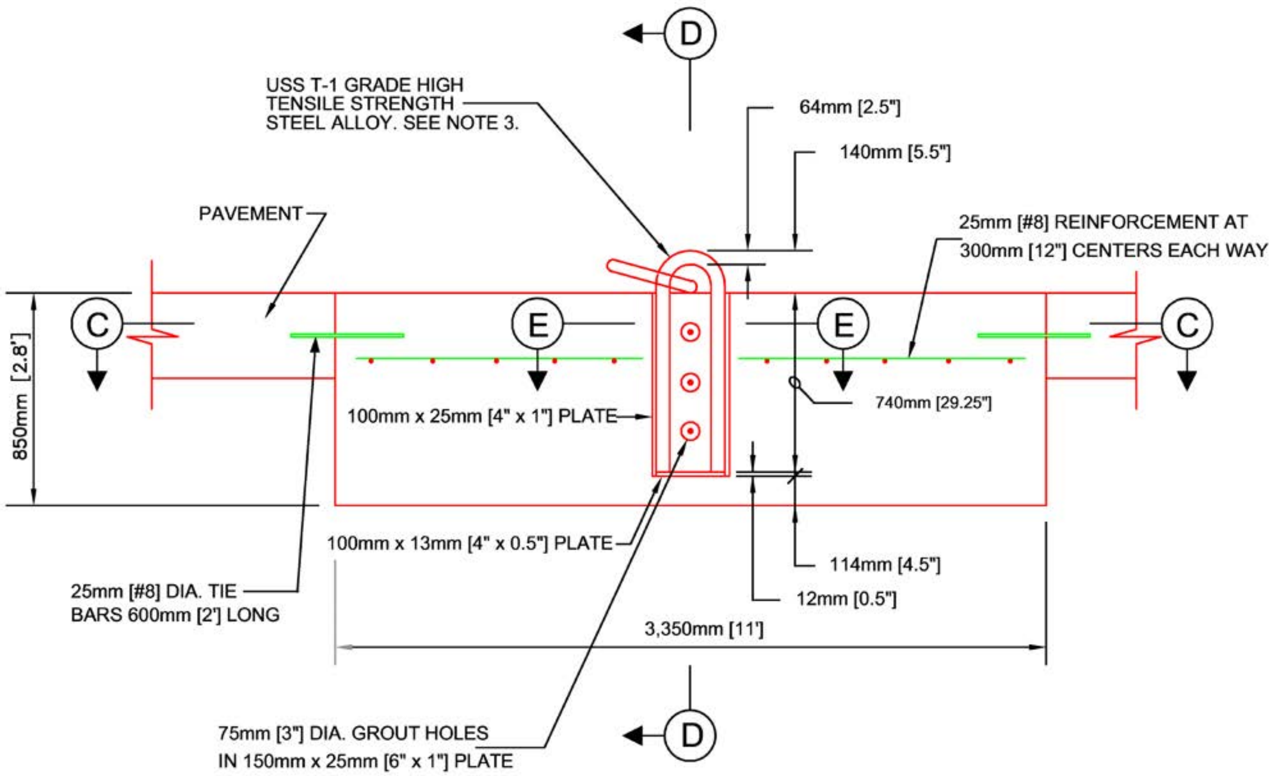
Figure B15-2. Example of 267 kN (60,000 lb) Square Anchor Block, Cross Section A-A and B-B



NOTES

1. THIS DESIGN IS FOR UP TO 267,000 N [60,000 LB] THRUST AND WILL ACCOMMODATE FIGHTER AIRCRAFT UP TO AND INCLUDING F-15E. THE DESIGNER MUST VERIFY STRUCTURAL DESIGN FOR THRUST OF DIFFERENT AIRCRAFT AND ENGINE TYPES.
2. DESIGN MAY BE SCALED DOWN TO MEET MISSION AIRCRAFT THRUST LOAD REQUIREMENTS. IF SCALED DOWN, THE ANCHOR MUST BE LABELED WITH THE MAXIMUM THRUST IT IS DESIGNED TO HOLD.
3. WIRE ROPE LINK TO BE CONSTRUCTED OF HIGH-STRENGTH ALLOY WITH MINIMUM YIELD OF 100 KSI, OR USE A LOAD-CERTIFIED COMMERCIAL SHACKLE. ONE SOURCE FOR LOAD-CERTIFIED SHACKLES IS THE CROSBY GROUP INC.
4. ALL STEEL COMPONENTS USED ARE ASTRALLOY V WITH 1,000 MEGAPASCALS [145,000 PSI] YIELD AND 360 MIN BRINELL HARDNESS EXCEPT FOR SHACKLES AND REINFORCING STEEL.
5. ANCHOR ROD SHOULD HAVE A MINIMUM YIELD OF 100 KSI, BE CORROSION RESISTANT, BENDABLE TO THE SPECIFIED RADIUS WITHOUT LOSS OF STRENGTH, HAVE CONSTANT ENGINEERING PROPERTIES TO 537° C, AND POSSESS GOOD FATIGUE CHARACTERISTICS.

Figure B15-3. Example of 267 kN (60,000 lb) Octagonal Anchor Block



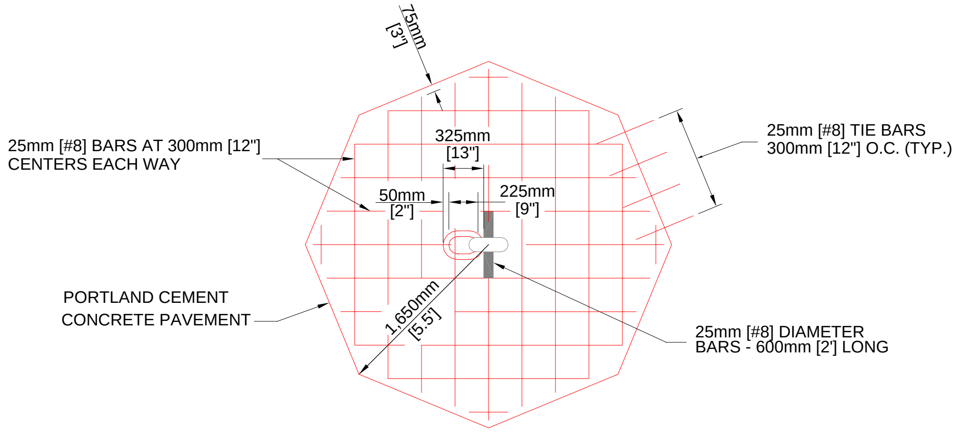
NOTES

1. THIS DESIGN IS FOR UP TO 267,000 N [60,000 LB] THRUST AND WILL ACCOMMODATE FIGHTER AIRCRAFT UP TO AND INCLUDING F-15E. THE DESIGNER MUST VERIFY STRUCTURAL DESIGN FOR THRUST OF DIFFERENT AIRCRAFT AND ENGINE TYPES.

2. SEE FIGURE B15-4 FOR SECTION VIEWS.

3. ANCHOR ROD SHOULD HAVE A MINIMUM YIELD OF 100 KSI, BE CORROSION RESISTANT, BENDABLE TO THE SPECIFIED RADIUS WITHOUT LOSS OF STRENGTH, HAVE CONSTANT ENGINEERING PROPERTIES TO 537° C, AND POSSESS GOOD FATIGUE CHARACTERISTICS.

Figure B15-4. Example of 267 kN (60,000 lb) Octagonal Anchor Block, Cross-Sections C-C, D-D, and E-E

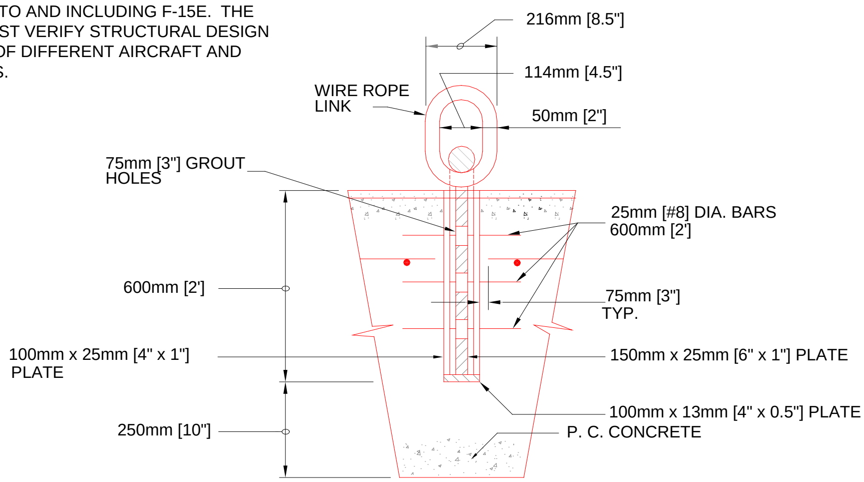


SECTION C-C

N.T.S.

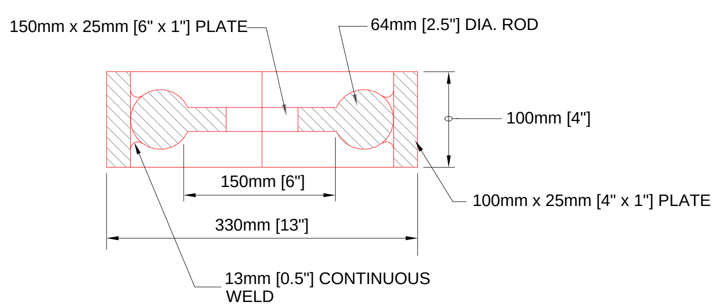
NOTE

THIS DESIGN IS FOR UP TO 267,000 N [60,000 LB] THRUST AND WILL ACCOMMODATE FIGHTER AIRCRAFT UP TO AND INCLUDING F-15E. THE DESIGNER MUST VERIFY STRUCTURAL DESIGN FOR THRUST OF DIFFERENT AIRCRAFT AND ENGINE TYPES.



SECTION D-D

N.T.S.



SECTION E-E

N.T.S.

Figure B15-5. Standard 445 kN (100,000 lb) Thrust Block Steel Anchor

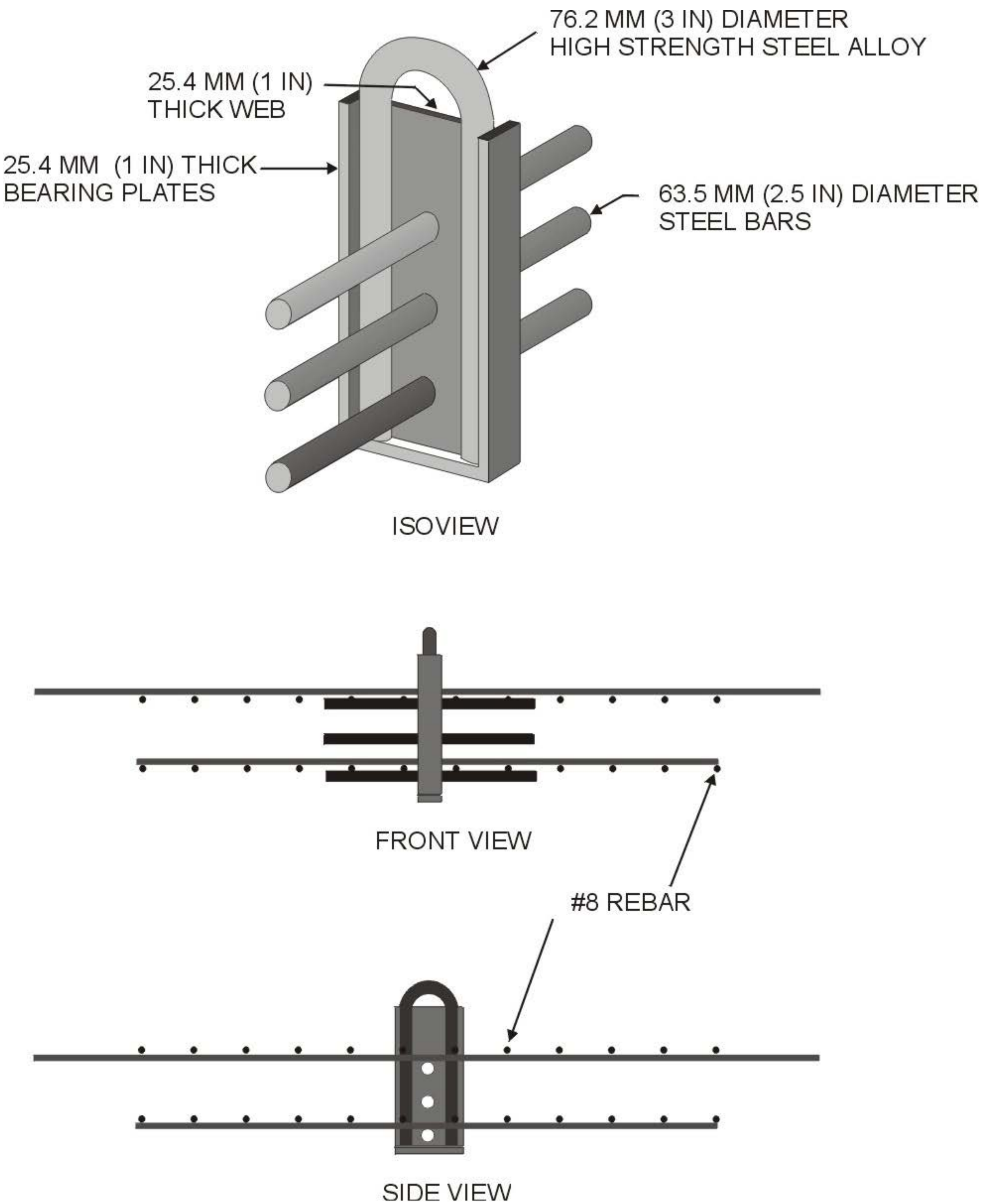


Figure B15-6. Standard 445 kN (100,000 lb) Thrust Block Steel Anchor Dimensions

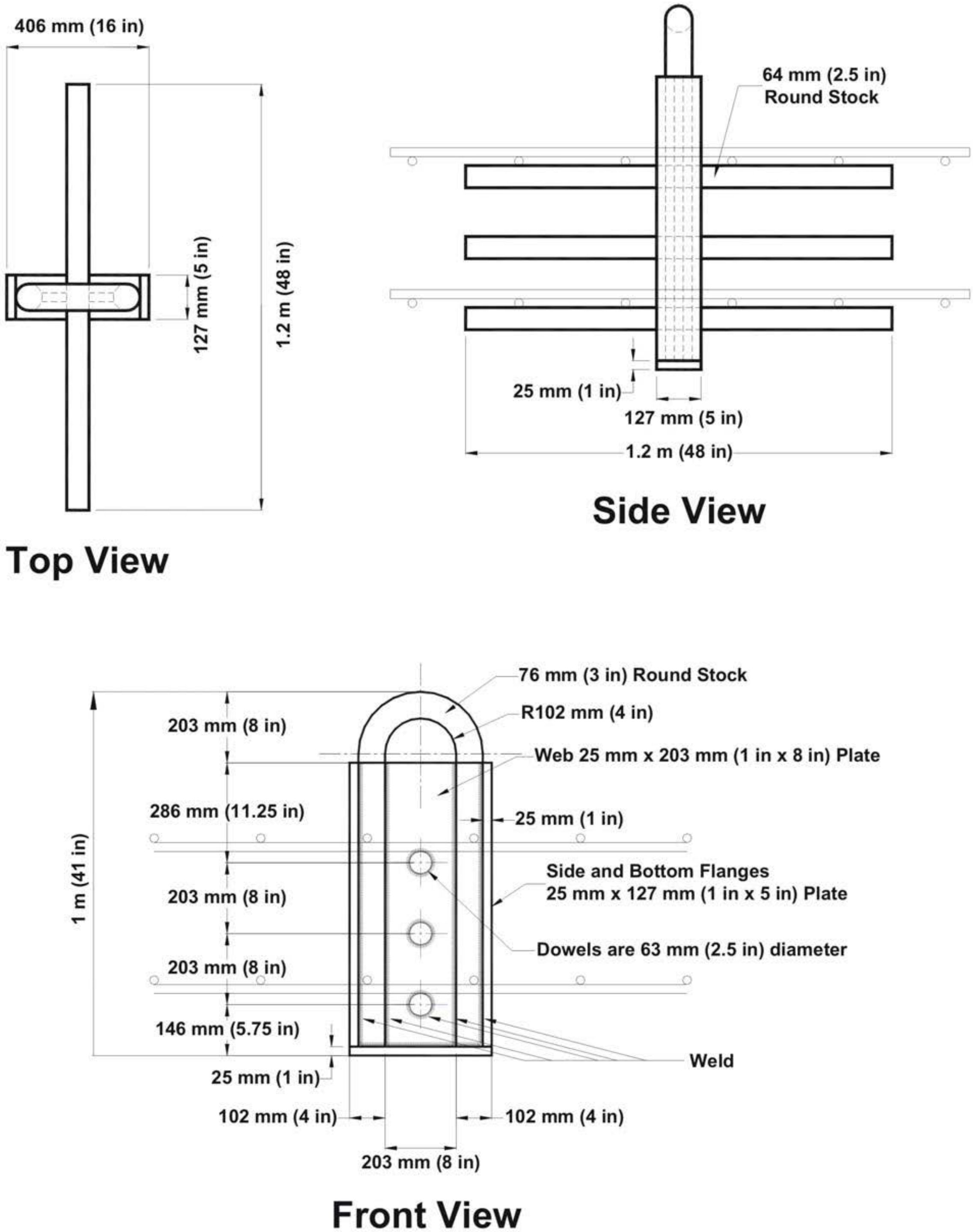


Figure B15-7. Standard 445 kN (100,000 lb) Thrust Concrete Block - Plan View

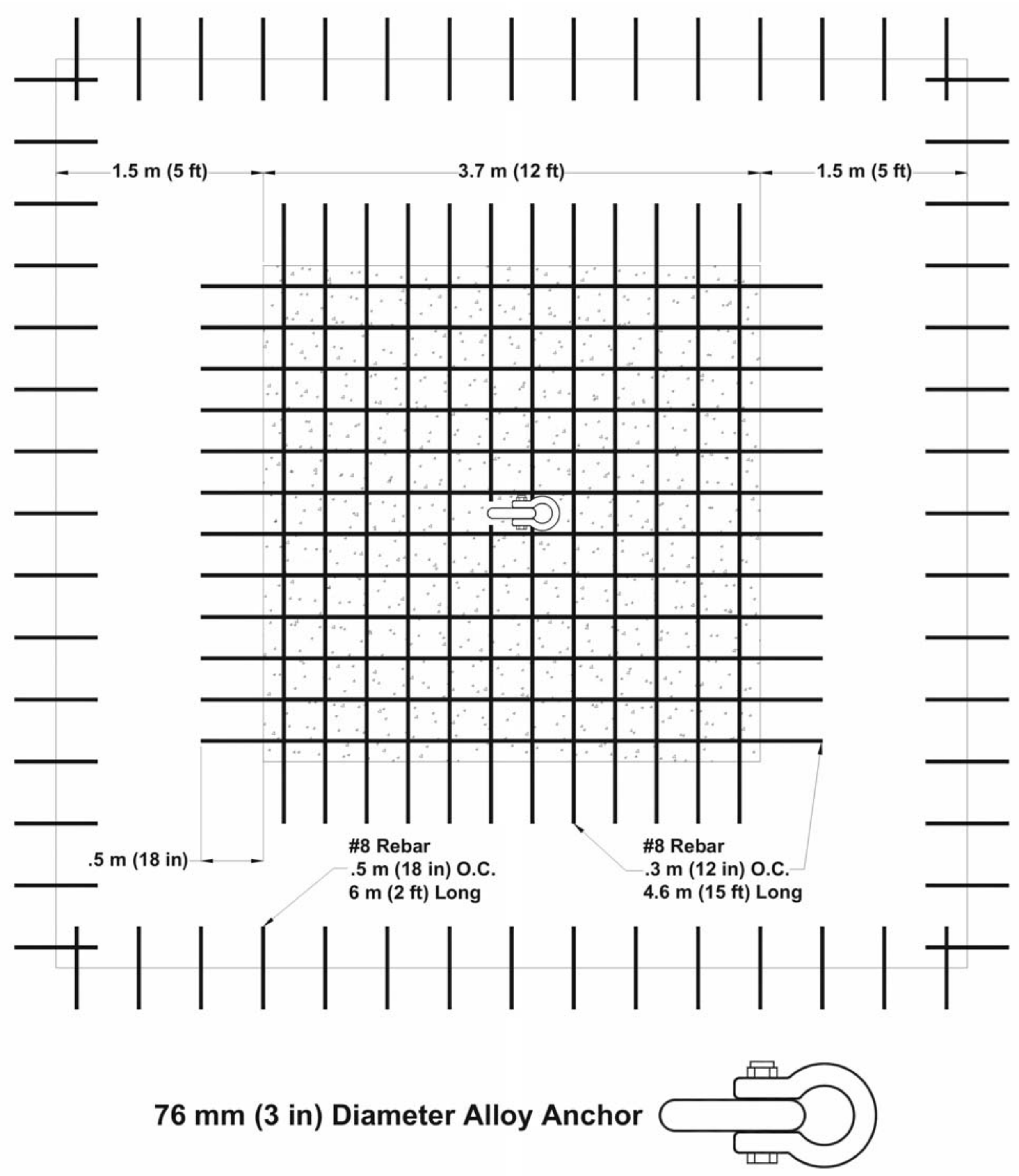
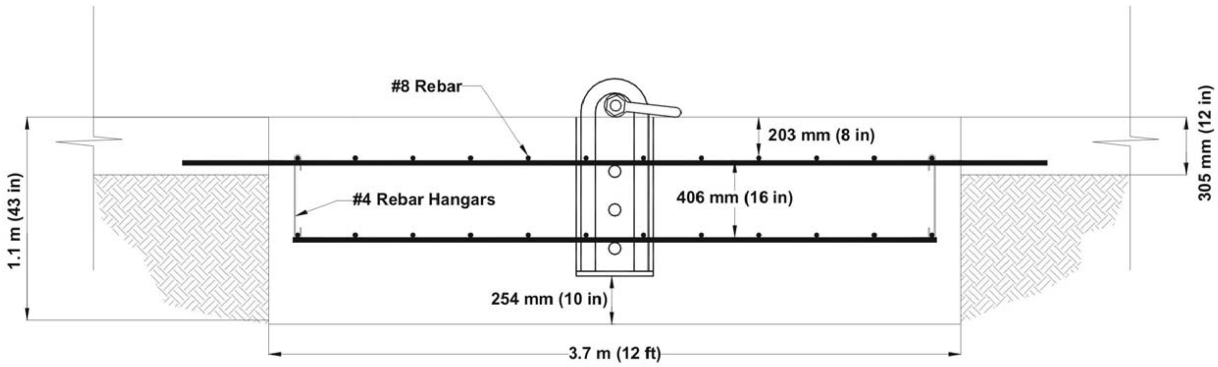


Figure B15-8. Standard 445 kN (100,000 lb) Thrust Concrete Block - Profile View



APPENDIX B
SECTION 16
AIR TRAFFIC CONTROL TOWER SITING CRITERIA

B16-1 GENERAL INFORMATION.

The Air Traffic Control Tower (ATCT) is the focal point for flight operations within the designated airspace of the installation and for controlling aircraft and vehicles on the airport movement area. Locating and siting an ATCT is a complex procedure that involves many operational and technical requirements. The tower cab must be correctly oriented. The area to be controlled must be visible from the cab. The air traffic controller must have proper depth perception of the area under surveillance, and there can be no electronic interference with equipment in the cab or with navigational equipment on the ground. For these considerations and other operational and technical aspects of selecting a site, consult UFC 4-133-01, *Air Traffic Control and Air Operations Facilities* for Service-specific requirements in the early stages of planning. A site survey will be conducted to determine the best siting for the proposed ATCT. For accurate planning and design considerations, the site survey should be conducted within five (5) years of the projected ATCT construction completion date. See UFC 4-133-01 for specific architectural, structural, mechanical, electrical, and other systems design requirements.

B16-2 SITING CRITERIA.

ATCT siting and height determination requires sound engineering principles and close coordination with the host base. Siting project engineers must consider factors that relate to the economics of each candidate site, such as accessibility to utilities, subsoil and ground water conditions, expansion possibilities, as well as selecting a site requiring a tower of the minimum height necessary to meet the specific requirements. The following specific guidelines must be followed:

B16-2.1 Unobstructed View.

The air traffic controllers operating this facility must have a clear, unobstructed, and direct view to all operating positions of the airport traffic area; to the approach end of the primary instrument runway; and all other active runways, taxiways, parking aprons, test pads, and similar areas. The ATCT should be located close to runway midpoints and equidistant from other airfield areas to the greatest extent possible.

B16-2.2 Site Area Requirements.

The site must provide sufficient area to accommodate the initial building and any planned expansions, including vehicle parking, fuel storage tanks, and exterior transformers.

B16-2.3 Quantity Distance Criteria.

See Chapter 1, Paragraph 1-4.1 and Appendix B, Section 9 for additional siting and facility requirements.

B16-2.4 Obstruction Clearance.

As a minimum, the site must conform to ground system and obstruction clearance criteria for Category II Instrument Landing Operations (see FAA Handbook [FAAH] 7110.65 and AFI 11-230).

B16-2.5 Siting Effects on NAVAIDS.

The ATCT must be sited where it will not detract from the performance of existing or planned electronic air navigational facilities (terminal very high frequency omnirange [TVOR], airport surveillance radar [ASR], and tactical air navigation [TACAN]). There are no criteria that establish minimum distances from electronic air navigational facilities. However, the facilities most likely to be affected are the TVOR, TACAN, and ASR. The ATCT should be no closer than 450 meters (1,500 feet) from these three facilities. Other electronic air navigation facilities (e.g., precision approach radar, ILS) are not as likely to be affected because their usage is more directed along the runway's major axis. However, care should be taken in siting the ATCT so it does not conflict with proper operation of these facilities.

B16-2.6 Siting for Proper Depth Perception.

Sufficient depth perception of all surface areas to be controlled must be provided. This is the ability to differentiate the number and type of grouped aircraft and ground vehicles and to observe their movement and position relative to the airfield surface areas. Proper depth perception is provided when the controller's line-of-sight is perpendicular or oblique to the line established by aircraft and ground vehicle movement, and where the line-of-sight intersects the airfield surface at a minimum vertical angle of 35 minutes, with an objective target of 48 minutes vertical angle. Required eye level elevation is determined using the following formula:

$$E_e = E_{as} + D \tan (VA + G s)$$

Where:

E_e = Eye-level elevation (1.5 m [5 ft] above control cab floor).

E_{as} = Average elevation for section of airfield traffic surface in question.

D = Distance from proposed tower site to section of airfield traffic surface in question.

G_s = Angular slope of an imaginary line from the surface of the airfield to the base of the tower, determined by the difference in elevation and the distance between, measured in minutes) (negative value if slope is downward towards the tower, positive value if slope is upward towards the tower).

VA = Line of Sight Vertical Angle. 35 minutes minimum, 48 minutes optimum.

B16-2.7 Compliance with Airfield Standards.

Siting should conform to airfield and airspace criteria in Chapter 3. Deviations should only be considered when they are absolutely necessary. Any siting deviations that would normally require a waiver must be subjected to a TERPS analysis performed by the appropriate service specific office. If the analysis reveals that the ATCT will not adversely affect instrument procedures, the ATCT siting may be considered a permissible deviation with proper service-specific coordination per Chapter 1, Paragraph 1-7.

B16-2.8 Orientation of the Control Cab.

Siting should provide an acceptable orientation of the ATCT Control Cab. The preferred Cab orientation in relation to the runway is obtained when the long axis of the equipment console is parallel to the primary runway. The reason for this orientation is to allow controllers to face the runway and the ATCT instrument panel without frequently turning their heads to observe events on the runway. Preferred direction should be north (or alternatively, east, south, or west, in that order of preference) when sited in the Northern Hemisphere. Locations that place the runway approach in line with the rising or setting sun should be avoided.

B16-2.9 Extraneous Lighting.

Siting should be such that visibility is not impaired by external lights such as floodlights on the ramp, rotating beacons, reflective surfaces, and similar sources.

B16-2.10 Weather Phenomena.

Siting should consider local weather phenomena to keep visibility restriction due to fog or ground haze to a minimum.

B16-2.11 Exhaust Fumes and other Visibility Impairments.

Siting should be in an area relatively free of jet exhaust fumes and other visibility impairments such as industrial smoke, dust, and fire training areas.

B16-2.12 Avoid Sources of Extraneous Noise.

The ATCT should be sited in an area where exterior noise sources are minimized. Special efforts should be made to separate the ATCT from aircraft engine test cells, engine run-up area, aircraft parking areas, and other sources of noise.

B16-2.13 Personnel Access Considerations.

Efforts should be made to site the ATCT so that access can be gained without crossing areas of aircraft operations.

B16-2.14 Compliance with the Comprehensive Plan.

Siting should be coordinated as much as possible with the base comprehensive plan. Particular attention should be given to future construction (including additions or extensions) of buildings, runways, taxiways, and aprons to preclude obstructing controller visibility at a future date.

B16-2.15 Consider the Effects on Meteorological and Communications Facilities.

The ATCT should be sited so it is free of interference from or interference with existing communications-electronics meteorology or non-communications-electronics meteorology facilities. If an acceptable location is not otherwise obtainable, consider relocating these facilities.

Figure B16-1. Runway Profile and New Control Tower

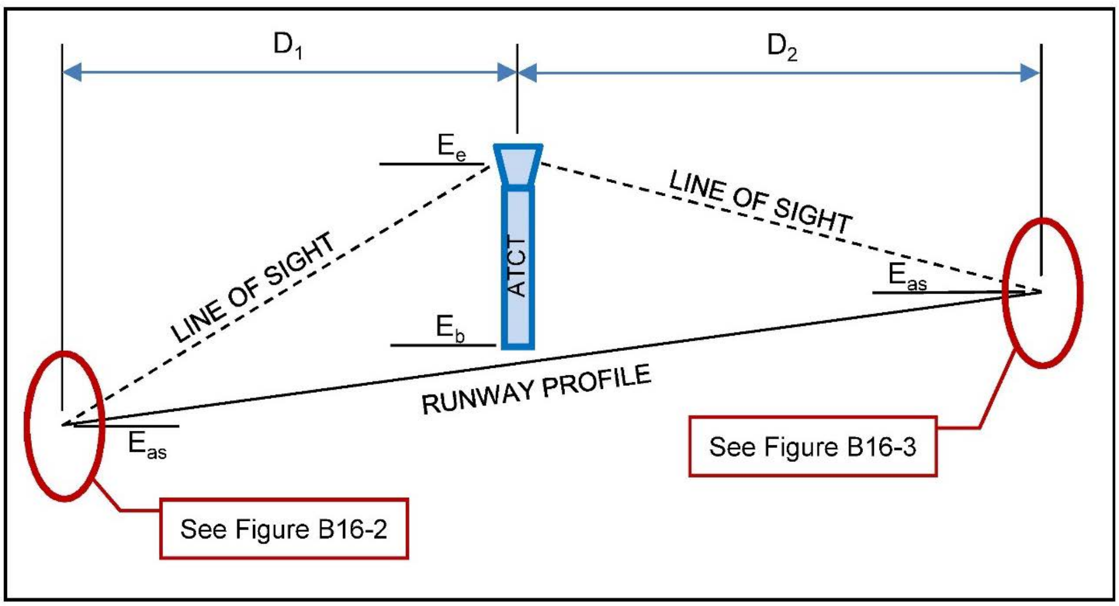
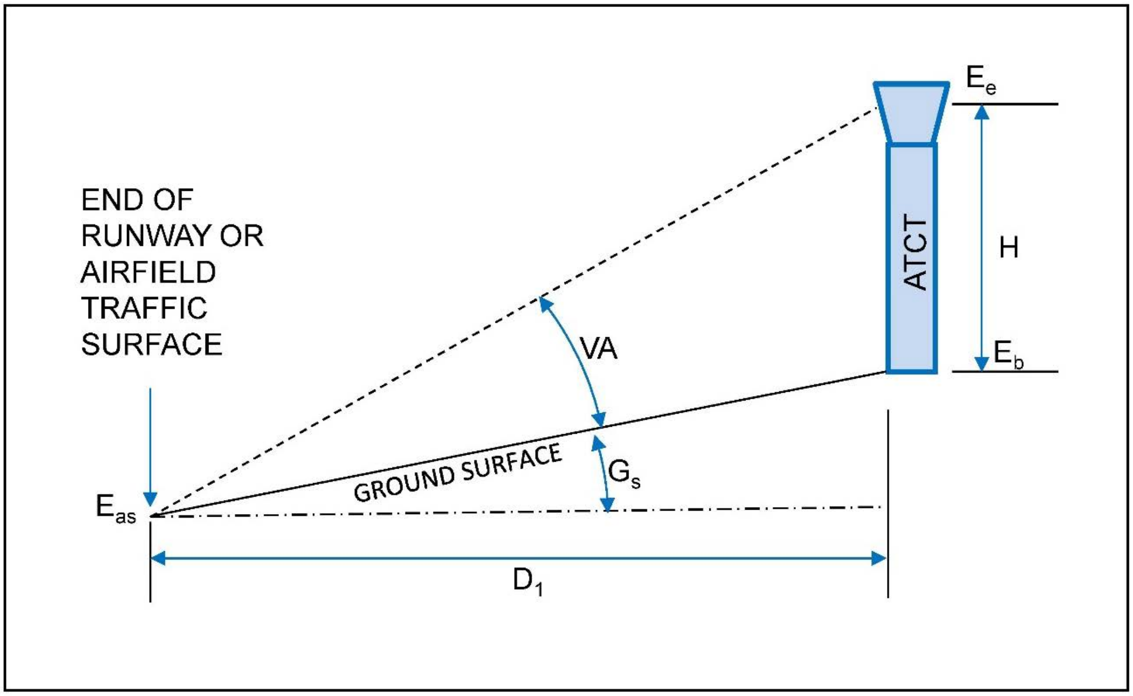


Figure B16-2. Minimum Eye-Level Determination – Tower Higher than Runway End



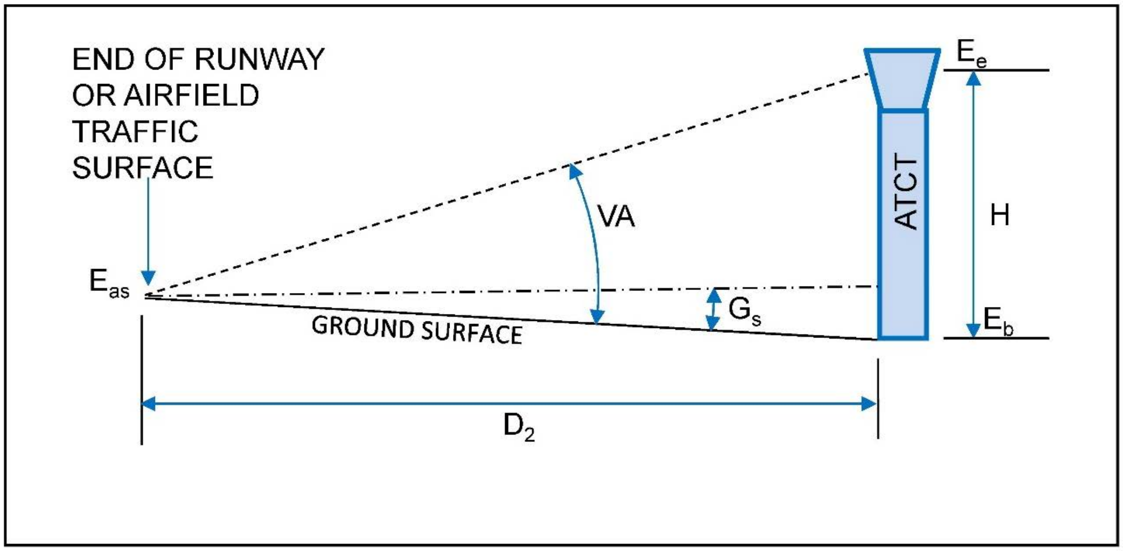
Given: E_{as} = 30.5 m (100') MSL E_b = 32.3 m (106') MSL
D_1 = 1,828.8 m (6,000')
G_s = +2 min
VA = 35 minutes (to reflect minimum requirement)

Find E_e :

E_e = 30.5 m (100') + H
= 30.5 m (100') + (1,828.8 m (6,000') x tan (35 min + 2 min))
= 30.5 m (100') + (1,828.8 m (6,000') x 0.01076)
= 30.5 m (100') + 19.7 m (64.6')
= 50.2 m (164.6') MSL

Minimum Required Eye Level Height = E_e - E_b = 50.2 m (164.6') - 32.3 m (106.0') = 17.9 m (58.6')

Figure B16-3. Minimum Eye-Level Measurement – Tower Lower than Runway End



Given: E_{as} = 33.5 m (110') MSL E_b = 32.3 m (106.0') MSL
D_2 = 1,828.8 m (6,000')
G_s = - 2 min
VA = 35 minutes (to reflect minimum requirement)

Find E_e :

E_e = 33.5 m (110') + H
= 33.5 m (110') + (1,828.8 m (6,000') x tan (35 min - 2 min))
= 33.5 m (110') + (1,828.8 m (6,000') x 0.0096)
= 33.5 m (110') + 17.6 m (57.6')
= 51.1 m (167.6') MSL

Minimum Required Eye Level Height = E_e - E_b = 51.1 m (167.6') - 32.3 m (106.0') = 18.8m (61.6')

CONCLUSIONS:

a. 18.8 m (61.6') height is larger and therefore controls.

b. Eye height to cab ceiling is 2.1 m (7'); therefore, the overall height is 2.1 m (7') + 18.8 m (61.6') = 20.9 m (68.6').

c. In this case, minimum tower height of 20.4 m (67') will not satisfy requirements (see Figure B16-3). Therefore, in order to meet the minimum 35-minute depth perception requirement, an additional floor must be added to increase the overall height of the proposed control tower.

B16-3 MINIMUM REQUIRED FLOOR LEVELS.

See UFC 4-133-01, *Air Traffic Control and Air Operations Facilities* for specific architectural, structural, mechanical, electrical and other systems design requirements.

B16-4 SITING PROCEDURES

The project siting engineer, in determining the site recommendation, should fix the ATCT siting and height to the cab floor with assistance from and concurrence of base communications (plans and programs), base airfield operations flight (control tower and airfield management), and base civil engineering offices. The project engineer for support equipment installation will establish internal ancillary equipment requirements based on an assessment of operational needs. Suggested procedures for selecting an ATCT site are in paragraphs B16-4.1 and B16-4.2.

B16-4.1 Office Study by Siting Engineers.

a. Using elements of the most up-to-date base comprehensive plan, make tentative site selections. Using elements of the base comprehensive plan and the 35-minute depth perception requirements, determine the approximate ATCT height for each tentative site selected.

b. Analyze more than one tentative site if appropriate.

B16-4.2 Field Study by Siting Engineers.

a. Conduct field review of the office-selected tentative sites plus other sites that merit consideration based on discussions with base organizations and the on-location surveys. Consider both siting requirements and siting considerations previously discussed.

b. Consider in the survey of each site the availability and cost of access roads, utility extensions, and communications cable relocations. Also, evaluate each site to determine the adequacy of ground conditions for structural support of the ATCT, drainage characteristics, and availability of utilities.

c. Use profile drawings and shadow maps to determine areas of visibility restrictions due to other structures.

d. If available and practical, obtain panoramic pictures taken at the proposed ATCT Control Cab eye level at each tentative site. Photographs should be in color and oriented to true north to allow precise interpretation of the surfaces and objects viewed and for complete 360-degree horizontal plane around the site. Suggested methods of taking pictures are from a helicopter, cherry picker, or crane boom.

e. Consider the environmental impact of each site. The Environmental Impact Analysis Process (EIAP) is accomplished through the local installation.

B16-4.3 TERPS Analysis.

To determine if a new ATCT will be an obstruction factor, TERPS shall evaluate the proposed ATCT location and final elevation and determine its effect on all existing or planned instrument procedures. Penetrations of the transitional surface may not necessarily affect instrument procedures.

NOTE: ATCTs will not be sited within the primary surface from a runway centerline except at locations required to operate under International Civil Aviation Organization (ICAO) standards. At these locations, the ATCT must be located at least 228.6 meters (750 feet) from the runway centerline.

B16-5 SITE RECOMMENDATIONS.

On completing the field study, siting participants should evaluate each alternative location and should recommend a site. The project siting engineer should then compile all siting data, comparisons, and determinations (including the siting recommendation) in a Statement of Intent (SOI). If practical, the SOI should be signed by all participating personnel, the base communications officer, and the base commander. If practical, the SOI must be completed and signed by appropriate personnel before completing the field study. The SOI should include the following:

- Siting recommendation: location, orientation, and height.
- Data comparisons and determinations made during field study.
- Reasons for deviations, if any, from siting requirements.
- Panoramic pictures, if available.
- Economic evaluations, if applicable.
- Major construction requirements to support communications-electronic (C-E) equipment, if applicable.
- Other special considerations.

B17-6 SOI DISTRIBUTION.

The SOI should be distributed to all signatories. Copies should be retained by the appropriate installation planning, communications, and airfield operations flight offices. Copies should be sent to the appropriate Service program authorities. After agreement to a siting recommendation, the host base submits the siting plan to the appropriate Service program authorities for approval. A sample of an SOI is shown below.

B17-7 SAMPLE SOI.

This is a Statement of Intent (SOI) between (enter name of Service program authority) and (enter name of appropriate installation entity) as it pertains to the (enter date) Site Survey for the proposed new Air Traffic Control Tower at (enter appropriate installation).

The purpose of this SOI is to reserve the area required for this project, to note the major allied support requirements needed for later installation of the project equipment, and to serve as a source document for preparation of the planning documents.

This survey considers (enter appropriate number) possible ATCT locations:

- Site No. 1: (describe location)
- Site No. 2: (describe location)
- Site No. 3: (describe location)

B16-7.1 Site Numbers.

(Insert appropriate numbers) were rejected for the following reasons:

Site No. _________: (Insert reasons for rejection)

Site No. _________: (Insert reasons for rejection)

Based on the results of this survey, it is recommended that Site Number ______ be selected for the new ATCT location. The following rationale supports this recommendation: (Insert rationale.)

The ATCT will be designed using the ________________________ ATCT as a guide. The height of the control ATCT will be (insert height in meters [feet]). See attached sketch. This height is necessary to provide adequate visibility for taxiways/runways and to provide the minimum angle of 35 minutes for depth perception to the farthest aircraft traffic surface on the airdrome.

B16-7.2 Allied Support Requirements

B16-7.3 Utilities.

Electrical power shall be (insert appropriate voltage and frequency), plus or minus 10 percent, three-phase, four wire to the ATCT. Other electrical utility power for mechanical systems shall be (insert appropriate voltage and frequency) to support requirements.

B16-7.3.1 Environmental Requirements.

Environmental control is required in the ATCT Control Cab and the electronic equipment rooms in order to sustain effective and continuous electronic equipment operation. The operational limits and the amount of heat dissipated by the equipment are as follows:

Room Heat Dissipated Temp/Humidity

ATCT Control Cab ______BTU _______/_______

Upper Equipment Room ______BTU _______/_______

Lower Equipment Room ______BTU _______/_______

Other Equipment Room ______BTU _______/_______

B16-7.3.2 Field Lighting Panel.

A field lighting panel, connected to the night lighting vault, will be required for this new structure.

B16-7.3.3 Communications.

All existing communication lines/circuitry for NAVAID monitors and radio transmitters/receivers now terminated in the existing ATCT shall be provided to the new ATCT.

B16-7.3.4 Underground Duct.

The existing base duct system must be extended to the proposed ATCT site for the field lighting cables, primary power cables, control cables, telephone cables, and meteorological cables.

a. After the ATCT project has become a firm MCP item, programming action should be initiated by the base Communications department to relocate the electronic equipment from the existing ATCT to the new ATCT.

b. Points of contact concerning the survey are __________________.

APPENDIX B
SECTION 17
GUIDELINES FOR ESTABLISHING BUILDING RESTRICTION LINE AT AIR FORCE BASES

B17-1 OVERVIEW.

In January 2000, the Chief of Staff directed formation of an Air Force tiger team to address reducing the number of airfield obstructions. To facilitate this effort, the Deputy Chiefs of Staff for Operations, Safety, and Civil Engineering directed that the MAJCOMs provide a listing of airfield obstructions at their bases, along with a cost estimate to remove them. Because many of the obstructions listed were high-cost facilities that were constructed under previous less-stringent standards, and therefore exempt from compliance with current standards, HQ USAF/XOO and ILE issued a policy memorandum directing that all bases must establish building restriction lines (BRL) at the predominant line and height of flight-line facilities. This policy memorandum also authorized further development within the boundaries established by the BRLs without waiver. The guidelines they established for creating the BRLs are provided below to establish a record of the rationale used to accomplish this work and the policy for continued growth within the exempt area. Policy for future modification of BRLs was added to these guidelines for publication within this UFC. See paragraph B17-7.

B17-1.1 General Information.

The BRL is defined as "a line which identifies suitable building area locations on airports." For civilian airports, it is described in FAA AC 150/5300-13. For Air Force installations, the BRL will have the same meaning; however, it will be established at a different location than at civilian airports. Generally, the distance from the runway centerline will be greater. However, in some cases, it may be slightly less than it would be if established in accordance with civil standards.

B17-1.2 Purpose.

The purpose in establishing BRLs on Air Force bases is to identify the area where facilities were constructed under previous standards (exempt facilities) and eliminate waivers for other facilities constructed within this area after the lateral clearance distance standards changed in 1964. (Facilities constructed under previous standards that were consciously omitted from the confines of the BRL must be carried as waivers.) This clarifies existing policy for exempt facilities and creates new policy for new construction and land use to allow continued but controlled development without waiver. This will significantly reduce the administrative burden imposed by the airfield waiver program without increasing risk to flight or ground safety. It will allow continued growth at bases with land constraints and will continue to protect existing airspace. Use the following information to establish the BRL.

B17-2 ESTABLISHING THE BRL AT A BASE.

Establish the BRL laterally from the runway centerline at the predominant line of facilities. The lateral line may have right angles that form indentations or pockets but must exclude all objects and/or facilities that affect existing or planned Terminal Approach and Departure Procedures (TERPS) criteria for your runway, and the 914-meter by 914-meter (3,000-foot by 3,000-foot) clear zone area. See Figure B17-1 for a plan view of a typical BRL. Using the same methodology as described above, establish an elevation control line at the predominant roofline of the facilities within the area formed between the lateral BRL and the lateral clearance distance boundary or the transitional surface, as applicable. The longitudinal slope of the elevation control line should match the slope of the primary surface. This elevation control line will terminate laterally at its intersection with the transitional surface, or at the base boundary, whichever occurs first. See Figure B17-2 for a profile view of a typical BRL.

B17-3 STATUS OF EXISTING AND FUTURE FACILITIES AND OBSTRUCTIONS WITHIN THE AREA.

All facilities beyond and beneath the control lines will be exempt from waiver and obstruction marking and lighting requirements. However, it is imperative that obstruction lighting be maintained along the periphery of the BRL control line. Therefore, maintain obstruction marking and lighting on the facilities used to form the BRL. New facilities constructed at the outer or uppermost limits of the BRL must also be marked and lighted, and appurtenances that extend above the elevation control line must be marked and lighted as obstructions, regardless of their location. Waivers must be maintained for facilities or obstructions that affect instrument procedures (TERPS) and these obstructions must be marked and lighted in accordance with **\1** AFMAN 32-1040 **/1/** and UFC 3-535-01. Obstacles that are behind and beneath the facilities may not need obstruction lights if they are shielded by other obstacles.

B17-4 FUTURE DEVELOPMENT OF AREA WITHIN BRL CONTROL LINES.

B17-4.1 Future Construction.

Future construction within this area is allowed, but only for flightline-related facilities within the following category groups:

- 11, Airfield Pavements
- 12, Petroleum Dispensing and Operating Facilities
- 13, Communications, Navigational Aids, and Airfield Lighting
- 14, Land Operations Facilities
- 21, Maintenance Facilities
- 44 and 45, Storage Facilities Covered, Open and Special Purpose
- 61, Administrative Facilities

- 73, Personnel Support
- 85, Roadway Facilities
- 86, Railroad Trackage
- 87, Ground Improvement Structures.

Utilities and ancillary systems for these types of structures are authorized. See AFH 32-1084 for additional information.

B17-4.2 Existing Facilities.

Existing facilities that are not within the category groups listed above may remain within the exempt zone created by establishing the BRL control lines. However, they must be relocated outside of this area when the facility is replaced.

B17-5 FUTURE MODIFICATION TO BRL.

BRLs may not be modified after they are established except to remove them from the airfield obstruction map if and when all exempt facilities are eventually relocated or to reduce the size of the area encompassed by the BRL as buildings are relocated.

Figure B17-1. BRL – Plan View

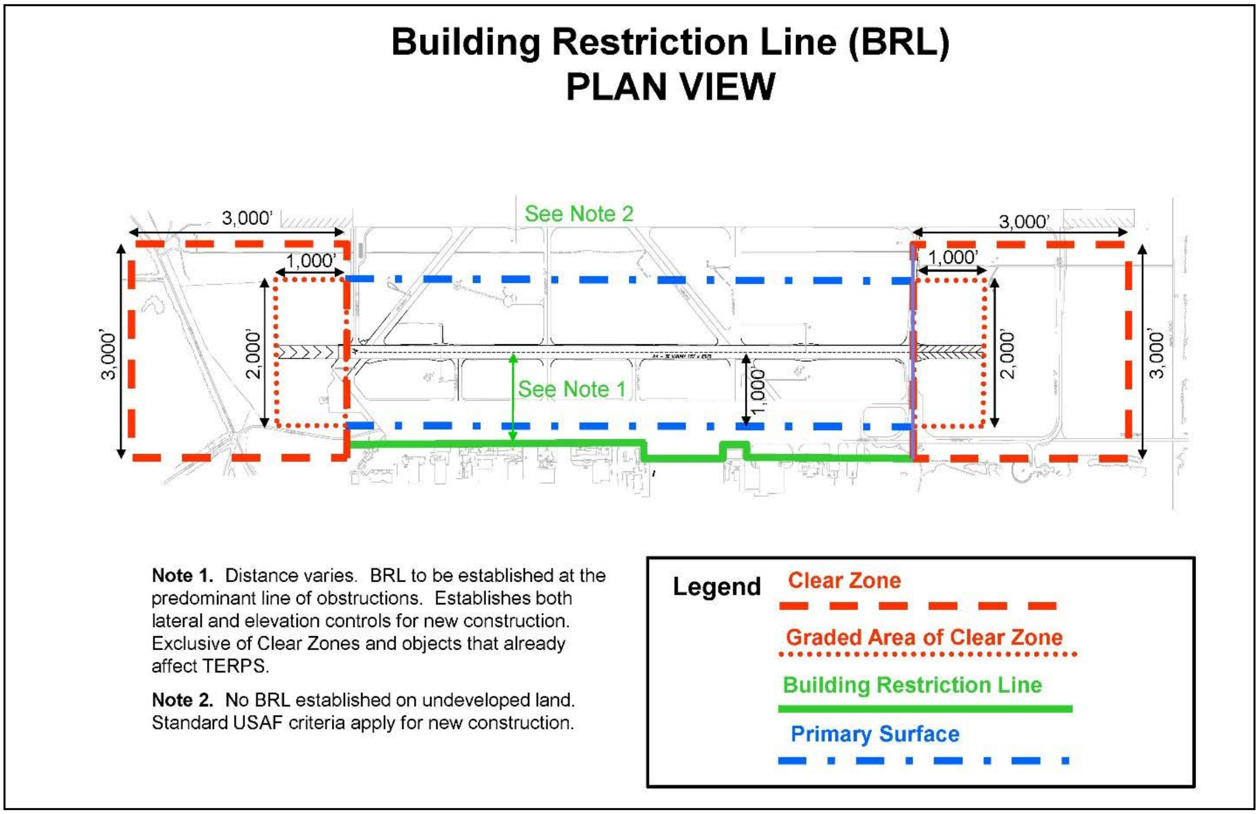
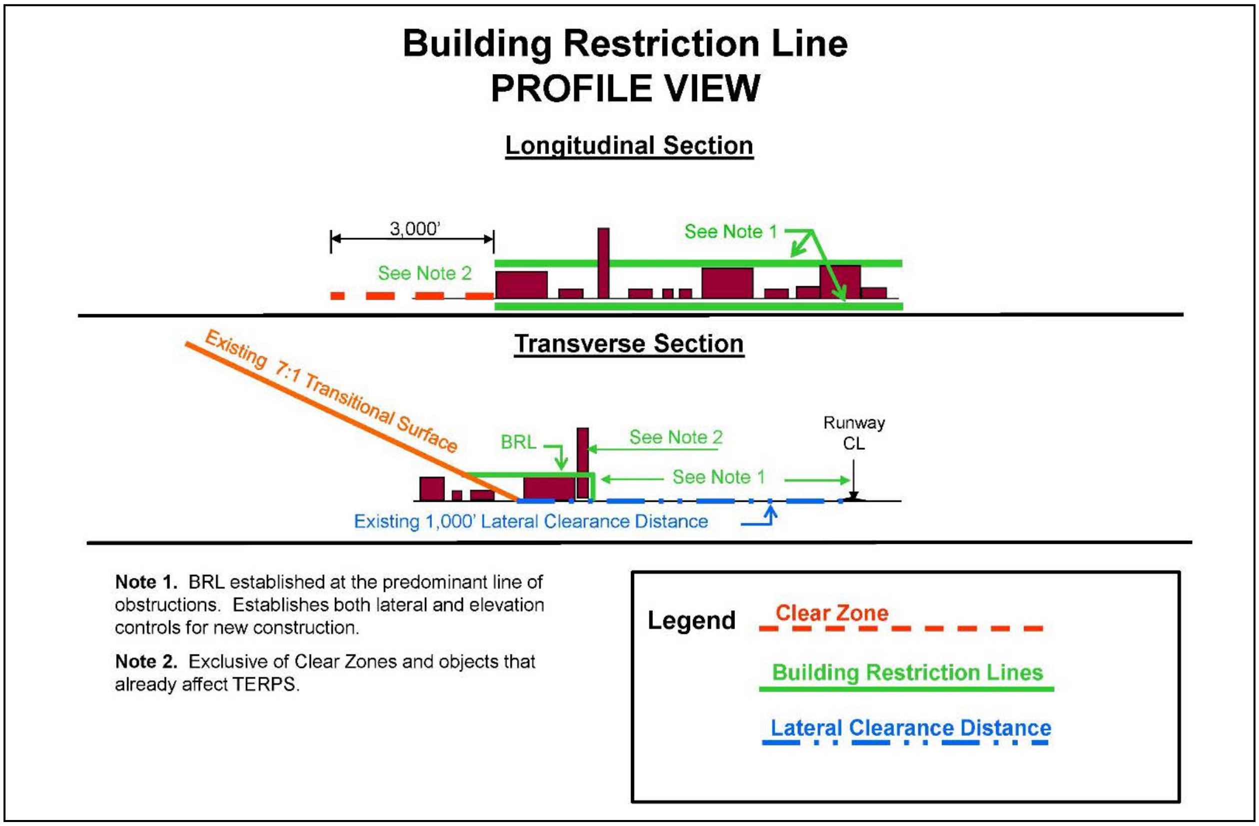


Figure B17-2. BRL – Profile View



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APPENDIX C
GLOSSARY

AASHTO—American Association of State Highway and Transportation Officials

AAF—Army Airfield

AC—Advisory Circular

AC—alternating current

ACN—Aircraft Classification Number

ACOM—Army Command

ADCS—Approach-Departure Clearance Surface

AFCEC—Air Force Civil Engineer Center

AFB – Air Force Base

AFFSA—Air Force Flight Standards Agency

AFH—Air Force handbook

AFI—Air Force instruction

AFIMSC—Air Force Installation Mission Support Center (Air Force)

AFJMAN—Air Force joint manual

AFJPAM—Air Force joint pamphlet

AFM—Air Force manual

AFMAN—Air Force manual

AFPD—Air Force Policy Directive

AFR—Air Force regulation

AFRC—Air Force Reserve Command

AFTTP—Air Force Tactics, Techniques, and Procedures

AGL—above ground level

A/G—arresting gear

AH—attack helicopter

AICUZ—air installations compatible use zones

ALZ—assault landing zone

AM—airfield manager

AMC—Air Mobility Command

AMSL—above mean sea level

AMP—airfield marking pattern

ANG—Air National Guard

AOA—aircraft operating area

AORI—Airfield Obstruction Reduction Initiative

APOE—aerial ports of embarkation

APOE/D—aerial ports of embarkation/debarkation

APOD—aerial ports of debarkation

APZ—accident potential zone

APZ I—accident potential zone I

APZ II—accident potential zone II

APZ-LZ—accident potential zone–landing zone

AR—Army regulation

ARAC—Army Radar Approach Control

ARNG—Army National Guard

ASC/658 AESG – Aeronautical Systems Center, 658 Aeronautical Systems Group

ASCC—Army Service Component Command

ASOS—automatic surface observation station

ASR—airport surveillance radar

ASV—annual service volume

AT&A—air traffic and airspace

ATC—air traffic control

ATCALS—air traffic control and landing systems

ATCT—air traffic control tower

ATIS—automatic terminal information service

ATNAVICS—Air Traffic Navigation, Integration and Coordination System

ATSCOM—Air Traffic Services Command

AVGAS—aviation gasoline

AVIM—Aviation Intermediate Maintenance

AVUM—Aviation Unit Maintenance

AWS—air weather service

BAK—barrier, arresting kit

BASH—bird/animal strike hazard

BCE—base civil engineer

BRL—building restriction lines

CAIMOD2—close-in approach indicator

CARC—chemical agent-resistant coating

CAT I ILS—category I instrument landing system

CAT II ILS—category II instrument landing system

CATEX—categorical exclusion

CBR—chemical, biological, radiological

CCA—carrier controlled approach

CCP—compass calibration pad

C-E—communications-electronic

CFR—Code of Federal Regulations

CH—cargo helicopter

CIP—common installation picture

CNO/CMC—Chief of Naval Operations/Commandant Marine Corps

COE TSC—Corps of Engineers Transportation Systems Center

CONOPS—concept of operations

CONUS—continental United States

CRHTC—continuously reinforced high temperature concrete

CVN—aircraft carrier

CVW—carrier air wing

CZ—clear zone

DA—decision altitude

DA—Department of the Army

DAPAM—Department of the Army pamphlet

DASR—digital airport surveillance radar

dB(a)—decibel

DC—direct current

DFP—defensive fighting position

DH—decision height

DIA—diameter

DM—design manual

DME—distance measuring equipment

DNL—Day-night average sound level

DO—director of operations

DOB—deployed operating base

DoD—Department of Defense

DoDD—DoD Directive

DoDI—DoD Instruction

DPTM—Aviation Division, Directorate of Plans, Training and Mobilization (Army)

DPW—Department of Public Works

DRMO—Defense Reutilization and Marketing Office

DRU—Direct Reporting Unit

Du/Ac—dwelling units per acre

EA—environmental assessment

EAIP – Environmental Impact Analysis Process

EALS—emergency airfield lighting system

EID—electrically initiated devices

EIP—equipment in place

EIS—Environmental Impact Statement

EMC—electromagnetic compatibility

EMR—electromagnetic radiation

ENT—ear, nose, throat

EOR—end of runway

ETL—engineering technical letter

FAA—Federal Aviation Administration

FAA AC—Federal Aviation Administration Advisory Circular

FAAH—Federal Aviation Administration Handbook

FAR—Federal Aviation Regulations

FAR—floor area ratio

FBO—forward base operations

FBPAR—Fixed Base Precision Approach Radar

FBWOS—Fixed Base Weather Observing Systems, formerly known as AWOS

FCLP—field carrier landing practice

FCS—flight control systems

FFM—far field monitor

FHWA—Federal Highway Administration

FIM—facility investment metric

FM—field manual (US Army)

FOB—forward operating base

FONSI—Finding of No Significant Impact

FOD—foreign object damage/foreign object debris

FPS—facility planning system

FPS—foot per second

FSL—flashing strobe light

FSSZ—fuel servicing safety zone

ft—foot

ft-lb/lb—foot-pound per pound

gal—gallon

GCA—ground control approach

GCS—Ground Control Station

GDT—Ground Data Terminal

GM—gallons per minute

GPI—ground point of intercept

GPM—gallons per minute

GPS—Global Positioning System

G/S-3—Operations Section (Army)

GTOW—Gross Takeoff Weight

HH—heavy helicopter

HIRL—high intensity runway edge lights

HMA—hot mix asphalt

HMMWV-ECV—High Mobility Multipurpose Wheeled Vehicles-Expanded Capacity Vehicles

HPI—hover position indicator

HQ AFCEC—Headquarters, Air Force Civil Engineer Center

HQDA—Headquarters, Department of the Army

HQ USAFE—Headquarters United States Air Forces in Europe

HTC—high temperature concrete

HVAC—heating, ventilation and air conditioning

ICAO—International Civil Aviation Organization

ICUZ—Installation Compatible Use Zone

IEEE—Institute of Electrical and Electronic Engineers

IESNA—Illuminating Engineering Society of North America

IFR—instrument flight rules

ILS—instrument landing system

IMC—instrument meteorological conditions

IM—inner marker

in—inch

INST—instruments

IPL—integrated priority list

IR—infrared

LID—low impact development

JSF—joint strike fighter

k—modulus of subgrade reaction

kg—kilogram

kHz—kilohertz

km—kilometer

km/h, kph—kilometers per hour

kN—kilonewton

kPa—kilopascal

kW—kilowatt

L—liter

lb—pound

LDA—localizer type directional aid

LDIN—lead-in lighting system

Ldn—day/night average noise level

LHA—landing, helicopter, assault

LHD—landing, helicopter, deck

LM—liters per minute

LOS—line of sight

L/S—liters per second

LSO—landing signals officer

LSS—landing site supervisor

LTA—lighter-than-air

LZ—landing zone

m—meter

MAAS—mobile aircraft arresting system

MAJCOM—major command (Air Force)

MAJCOM/A7C—major command civil engineer

MAJCOM/CD—major command deputy commander

MALSF—medium-intensity approach lighting system with sequenced flashers

MALS—medium-intensity approach lighting system

MALSR—medium-intensity approach lighting system with runway alignment indicator lights

MATCT—mobile air traffic control tower

max—maximum

MCA—military construction, Army

MDA—minimum descent altitude

METNAV—meteorological NAVAIDS detachment

MFZ—mandatory frangibility zone

MHz—megahertz

MILCON—military construction

MIL-HDBK—military handbook

min—minimum

min—minute

MIRL—medium-intensity runway edge lights

MLG—Main Landing Gear

MLS—microwave landing system

mm—millimeter

MM—middle marker

MMLS—mobile microwave landing system

MOA—military operating area

MOB—main operating base

MOG—maximum on ground

MOTS—Mobile Tower System

mph—miles per hour

MQ—Multi-role unmanned aircraft system

MSL—mean sea level

MTI—moving target indicator

MTMC—Military Traffic Management Command

MUTCD—Manual on Uniform Traffic Control Devices

N/A—not applicable

NAFIG—Navy Flight Information Group

NATO—North Atlantic Treaty Organization

NAVAID or NavAIDS—navigational aids

NAVAIR—Naval Air Systems Command

NAVFAC—Naval Facilities Engineering Command

NAVFACENGCOM—Naval Facilities Engineering Command

NAVFACINST—Naval Facilities Engineering Command instruction

NAVFAC P—Naval Facilities Engineering Command publication

NAVFIG—Naval Flight Information Group

NAVSEA OP—Naval Sea Operations Command operating instruction

NDB—non-directional beacon

NEPA—National Environmental Policy Act

NFPA—National Fire Protection Association

NGB—National Guard Bureau

NLG—Nose Landing Gear

NOTAM—Notice to Airmen

N.T.S.—not to scale

NVG—night vision goggles

O&M—operations and maintenance

OCONUS—outside the continental United States

ODALS—omnidirectional approach lighting system

OH—observation helicopter

OIS—obstacle identification surfaces

OLF—outlying field

OLS—optical landing system

OM—outer marker

OPNAVINST—operations naval instruction

OPR—office of primary responsibility

PACAF/CD—Pacific Air Forces Deputy Commander

PAPI—precision approach path indicator

PAR—precision approach radar

PCASE—Pavement-Transportation Computer Aided Structural Design and Evaluation

PCC—Portland cement concrete

pci—pound per cubic inch

PCN—Pavement Classification Number

PES—potential explosive site

PGCS—portable ground control station

PGDT—portable ground data terminal

PI—point of intersection

PJHTC—plain jointed high temperature concrete

PJPCC—plain jointed Portland cement concrete

PPSL—Predator primary satellite link

POL—petroleum, oil, lubricants

Prime BEEF—Prime Base Engineer Emergency Force

psf—pounds per square foot

psi—pounds per square inch

psia—pounds per square inch absolute

psig—pound per square inch gauge

PUD—planned unit development

Q-D—quantity-distance

°R —degree Rankine

RAIL—runway alignment indicator lights

RAPCON—radar approach control

RCR—runway condition reading

RDO—runway duty officer

RDT&E—research, development, testing, and evaluation

RED HORSE—Rapid Engineers Deployable Heavy Operations Repair Squadron

REIL—runway end identifier light

RF—radio frequency

RIDS—runway ice detection system

RNM—rotorcraft noise model

ROD—record of decision

RPLANS—real property planning and analysis system

RQ—Reconnaissance unmanned aircraft system

RSU—runway supervisory unit

RSZ—refueling safety zone

RVL—rolling vertical landing

RVR—runway visual range

RWOS—representative weather observation station

SALS—short approach lighting system

SI—International System of Units

SLUCM—Standard Land Use Coding Manual

SOI—statement of intent

SPAWARS—Space and Naval Warfare Systems Center

SPAWARSYSCEN—Space and Naval Warfare Systems Center

SPR—single-point receptacle

SSALR—simplified short approach lighting system with runway alignment indicator lights

SSR—Secondary Surveillance Radar

STO—short take-off

STOVL—short take-off, vertical landing

STT—Special Tactics Team

T.O.—technical order

TAAS—tactical area security system

TACAN—tactical air navigation

TALS—Tactical Automated Landing System

TALS-TS—Tactical Automated Landing System – Tracking System

TDA—tables of distribution and allowances

TDZ—touchdown zone

TDP—touchdown point

TERPS—terminal instrument procedures

TM—technical manual

T/O—Take-Off

TO&E—tables of organization and equipment

TSC—Transportation Systems Center

TVOR—terminal very high frequency omnidirectional range

UAS—Unmanned Aircraft System(s)

UPS—uninterruptible power supply

UFC—unified facilities criteria

UH—utility helicopter

UHF—ultra high frequency

US—United States

USA—United States Army

USAASA—US Army Aeronautical Services Agency

USAASDE—United States Army Aeronautical Services Detachment, Europe

USACC—U.S. Army Communication Command

USACE—U.S. Army Corps of Engineers

USACE TSC—U.S. Army Corps of Engineers Transportation Systems Center

USACRC—US Army Combat Readiness/Safety Center

USAF—United States Air Force

USAFEI—United States Air Forces in Europe Instruction

USG—United States Government

USMC—United States Marines Corps

USN—United States Navy

USTRANSCOM—U.S. Transportation Command

VAP—visual aid panel

VASI—visual approach slope indicator

VCSA—Vice Chief of Staff of the Army

VF—fixed-wing fighter

VFR—visual flight rules

VGSI—visual glide slope indicator

VHF—very high frequency

VID—visual identification

VIP—very important person

VL—vertical landing

VLZMP—visual landing zone marker panel

VMC—visual meteorological conditions

VOR—very high frequency omnidirectional range (radio)

VORTAC—very high frequency omnidirectional range (radio) and tactical air navigation

V/STOL—Vertical/Short Take-Off and Landing

VTOL—Vertical Takeoff and Landing

Terms

Aborted Takeoff—An unsuccessful takeoff operation due to power or other mechanical failures.

Accident Potential Zone I (APZ I)—The area beyond the clear zone that possesses a significant potential for accidents.

Accident Potential Zone II (APZ II)—The area beyond APZ I that has a measurable potential for accidents.

AICUZ (Air Installations Compatible Use Zones)—A DoD program designed to promote compatible development around military airfields and to protect the integrity of the installation's flying mission.

Air Traffic—Aircraft in operation anywhere in the airspace and within that area of an airfield or airport normally used for the movement of aircraft.

Aircraft—Fixed-wing (F/W) (airplane) and rotary-wing (R/W) (helicopter).

Aircraft, Class A—Aircraft listed under Class A Runways in Table 3-1 of this manual.

Aircraft, Class B—Aircraft listed under Class B Runways in Table 3-1 of this manual.

Aircraft Arresting Barrier—A device, not dependent on an aircraft hook, used to engage and absorb the forward momentum of an emergency landing or an aborted takeoff.

Aircraft Arresting Cable—That part of an aircraft arresting system which spans the runway surface or flight deck landing area and is engaged by the aircraft arresting gear.

Aircraft Arresting Gear—A device used to engage hook-equipped aircraft to absorb the forward momentum of a routine or emergency landing or aborted takeoff.

Aircraft Arresting System—A series of components used to engage and absorb the forward momentum of a routine or emergency landing or an aborted takeoff.

Aircraft Operating Area—For the purpose of this manual, the aircraft movement area is defined as that area of the airfield encompassed by the primary surface and the clear zones, as well as all apron areas and taxiways, regardless of their location. See paragraph 3-16.1 for the specific use of this term.

Aircraft Wash Area—A specially designed paved area for washing and cleaning aircraft.

Aircraft Wash Rack—Paved areas provided at all facilities to clean aircraft in conjunction with periodic maintenance.

Aircraft Rinse Facility—Paved areas provided at facilities to clean aircraft returning from flight and en route to the parking area.

Airfield—Area prepared for the accommodation (including any buildings, installations, and equipment), of landing and takeoff of aircraft.

Airfield Elevation—Established elevation, in terms of the nearest 300 mm (1 ft) above mean sea level, of the highest point of the usable landing area.

Airfield Reference Point—Designated geographical location of an airfield. It is given in terms of the nearest hundredth of a second of latitude and longitude. The position of the reference point must be as near to the geometric center of the landing area as possible, taking future development of the airfield into account.

Airport—Refers to a civil or municipal airfield.

Airside Facilities—Facilities associated with the movement and parking of aircraft. These include runways, taxiways, apron areas, associated navigational aids and imaginary surfaces.

Airspace—Space above ground or water areas which is or is not controlled, assigned, and/or designated.

Airspace Boundaries—The limits of imaginary surfaces.

Air Traffic Navigation, Integration and Coordination System (ATNAVICS/AN/TPN-31) — Provides air traffic control services for the rapid deployment of troops and equipment to remote locations where no operational airport control and landing system exists. Often deployed on Army airfields for training purposes.

Alert Aircraft Parking—Exclusive paved area for armed aircraft to park and have immediate, unimpeded access to a runway.

Alert Pad—Small paved areas provided for single alert aircraft parking.

Approach Control—Service established to control flights, operating under instrument flight rules (IFR), arriving at, departing from, and operating in the vicinity of airports by direct communication between approach control personnel and aircraft operating under their control.

Approach-Departure Clearance Surface—Inclined plane or combined inclined and horizontal planes arranged symmetrically about the runway centerline extended. The first segment or the beginning of the inclined plane is coincident with the ends and edges of the primary surface, and the elevation of the centerline at the runway end. The surfaces flare outward and upward from these points. See Chapter 3 for fixed-wing ADCS, Chapter 4 for rotary-wing ADCS and Chapter 7 for LZ ADCS dimensions.

Apron—A defined area, on an airfield, intended to accommodate aircraft for the purposes of loading or unloading passengers or cargo, refueling, parking or maintenance.

Apron, Aircraft Access—See Apron, Hangar Access.

Apron, Alert—A designated area for multiple alert aircraft parking.

Apron Edge—See Edge of Apron.

Apron, Hangar Access—Hangar access aprons are paved areas connecting hangars with adjacent aircraft aprons when the hangar is located at the outer boundary of the apron clearance distance. Hangars located beyond the apron clearance distance may be connected to the main apron with a taxiway or a towway.

Apron, Holding (Engine Run up Area)—A paved area adjacent to the taxiway near the runway ends where final preflight warm-up and engine and instrument checks are performed.

Apron, Parking—Parking apron is a designated paved area on an airfield intended to accommodate fixed-and rotary-wing aircraft for parking.

Arming and Disarming—Loading and unloading of missiles, rockets, and ammunition in aircraft.

Arrestment Capable Aircraft—Aircraft whose flight manual specifies arrestment procedures.

Autorotation Lane—A helicopter landing lane or designated area on a runway used for practicing landings under simulated engine failure or certain other emergency conditions. Also known as a slide area when designed specifically for skid-type helicopters.

Aviation Facility—Combination of land, airspace, pavements and buildings which are needed to support an aviation movement or action. An aviation facility can be an airfield, heliport, or helipad. The aviation facility includes “airside” and “landside” facilities.

Aviation Intermediate Maintenance (AVIM)—For Army, units that provide mobile, responsive "one-stop" maintenance and repair of equipment to return to user.

Aviation Movement or Action—An aviation movement or action includes but is not limited to: the landing and takeoff of aircraft; readiness of aircraft; flight training of pilots; loading and unloading of aircraft; and the maintenance and fueling of aircraft.

Aviation Unit Maintenance (AVUM)—For Army, activities staffed and equipped to perform high frequency "on aircraft" maintenance tasks required to retain or return aircraft to a serviceable condition.

Avigation Easement—A legal right obtained from a property owner to operate aircraft over that property and to restrict the height of any construction or growth on that property.

Beam Wind Component—Wind velocities perpendicular to the axis of the runway centerline used to measure the degree by which a runway pattern covers incident wind.

Blast Protective Area—Area at the ends of the runways and taxiways protected by pavement construction against jet blast erosion.

Circling Approach Area—Area in which aircraft circle to land under visual conditions.

Clear Zone—Surface on the ground or water beginning at the runway end and symmetrical about the runway centerline extended.

Compass Calibration Pad—A paved area in an electromagnetically quiet zone where an aircraft's compass is calibrated.

Compass Rose—A graduated circle, usually marked in degrees, indicating directions and printed or inscribed on an appropriate medium.

Conical Surface—An imaginary surface that extends from the periphery of the inner horizontal surface outward and upward at a slope of 20 horizontal to one for a horizontal distance of 2,133.6 m (7,000 ft) to a height, 152.4 m (500 ft) above the established airfield elevation. The conical surface connects the inner horizontal surface with the outer horizontal surface. It applies to fixed-wing installations only.

Construction Waiver—A temporary airfield waiver used to identify, coordinate, and approve construction activity on or near the airfield. The installation commander, or equivalent, is the construction waiver approval authority. Construction waivers apply to airfield systems, facilities, and on-base facilities where construction will require equipment or stockpile areas that may adversely affect flying operations. For more information about construction waivers, see Appendix B, Section 1.

Controlling Obstacle—Highest obstacle relative to a prescribed plane within a specified area. In precision and non-precision approach procedures where obstacles penetrate the approach surface, the controlling obstacle is the one which results in the requirement for the highest decision height (DH) or minimum descent altitude (MDA). For departure procedures, the obstacle that drives the highest climb gradient to the highest climb to altitude.

Correctable Obstruction—An obstruction to aircraft operations or air navigation that can be removed, modified, or relocated to comply with airfield safety criteria with a reasonable level of effort as determined by the MAJCOM or USAASA as applicable.

Crosswind Runway—A secondary runway that is required when the primary runway orientation does not meet crosswind criteria (see Appendix B, Section 4.).

Decision Height (DH) / Decision Altitude (DA)— Specified for a precision approach, at which a missed approach procedure must be initiated if the required visual reference has not been established. Decision altitude (DA) is referenced to mean sea level (MSL) and decision height (DH) is referenced to the threshold elevation.

Displaced Threshold—A runway threshold that is not at the beginning of the full-strength runway pavement. Displacement of a threshold reduces the length of runway available for landings. The portion of the runway behind a displaced threshold may be available for takeoffs and, depending on the reason for the displacement, may be available for takeoffs and landings from the opposite direction.

Edge of Apron—Boundary of an apron, marked by painted stripe in accordance with pavement marking manual.

Exemption (Air Force only)—A facility or other item constructed under a previous standard. Exemptions must be programmed for replacement away from the airfield environment at the end of their useful life cycle. Also, see Chapter 1.

Fixed-Wing Aircraft—A powered aircraft that has wings attached to the fuselage so that they are either rigidly fixed or swing-wing, as distinguished from aircraft with rotating wings, like a helicopter.

Flight Path—Line connecting the successive positions occupied, or to be occupied, by an aircraft, missile, or space vehicle as it moves through air or space.

Fuel Servicing Safety Zone (FSSZ)—The FSSZ is the area required for safety around pressurized fuel carrying servicing components; i.e. servicing hose, fuel nozzle, single point receptacle (SPR), hydrant hose car, ramp hydrant connection point, etc. and around aircraft fuel vent outlets. The fuel servicing safety zone is established and maintained during pressurization and movement of fuel.

Full Stop Landing—Touchdown, rollout, and complete stopping of an aircraft to zero speed on runway pavement.

Grade—Also Gradient—A slope expressed in percent. For example, a 0.5 percent grade means a 0.5-meter (-foot) slope in 100 meters (feet). All grades may be positive or negative unless otherwise specifically noted.

Ground Point of Intercept (GPI)—A point in the vertical plane of the runway centerline or center of a helipad at which it is assumed that the straight line extension of the glide slope (flight path) intercepts the approach surface base line (TM 95-226).

Hardstand—A term used synonymously with Apron. See Apron definition.

Helicopter—Aircraft deriving primarily elements of aerodynamic lift, thrust and control from one or more power driven rotors rotating on a substantially vertical axis.

Helicopter(Light)— Helicopters with a gross weight of 2,722 kg (6,000 lb) or less.

Helicopter(Medium)— Helicopters with a gross weight of 2723 to 5,443 kg (6,001 to 12,000 lb).

Helicopter(Heavy)— Helicopters with a gross weight over 5,443 kg (12,000 lb).

Helicopter Parking Space, Type 1 (Army Only)—In this configuration, rotary-wing aircraft are parked in a single lane, which is perpendicular to the taxilane.

Helicopter Parking Space, Type 2 (Army Only)—In this configuration, rotary-wing aircraft are parked in a double lane, which is parallel to the taxilane.

Helicopter Runway—A prepared surface used for the landing and takeoff of helicopters requiring a ground run.

Helipad—A prepared area designated and used for takeoff and landing of helicopters (includes touchdown and hoverpoint.)

Helipad, IFR—Helipad designed for IFR. IFR design standards are used when an instrument approach capability is essential to the mission and no other instrument landing facilities, either fixed-wing or rotary-wing, are located within an acceptable commuting distance to the site.

Helipad, Limited Use—A VFR rotary-wing facility for use by AH, OH, HH and UH helicopters. These type helipads support only occasional operations at special locations such as hospitals, headquarters facilities, missile sites, and other similar locations. They may also be located on airfields where one or more helipads are required to separate operations of helicopters such as OH, UH, HH and AH) from fixed-wing or other helicopter operations.

Heliport—A facility designed for the exclusive operating, basing, servicing and maintaining of rotary-wing aircraft (helicopters). The facility may contain a rotary-wing runway and/or helipads.

Heliport or Helipad Elevation—Established elevation, in terms of the nearest 300 mm (1 ft) above mean sea level, based on the highest point of the usable landing area.

High-Speed Taxiway Turnoff—A taxiway leading from a runway at an angle which allows landing aircraft to exit a runway at a high speed.

Holding Position—A specified location on the airfield, close to the active runway and identified by visual means, at which the position of a taxiing aircraft is maintained in accordance with air traffic control instructions.

Horizontal Surfaces, Fixed-Wing:

Inner Horizontal Surface—An imaginary plane 45.72 m (150 ft) above the established airfield elevation. The inner boundary intersects with the approach-departure clearance surface and the transitional surface. The outer boundary is formed by scribing arcs with a radius 2,286.0 m (7,500 ft) from the centerline of each runway end, and interconnecting those arcs with tangents.

***Outer Horizontal Surface*—**An imaginary plane 152.4 m (500 ft) above the established airfield elevation extending outward from the outer periphery of the conical surface for a horizontal distance of 9,144.0 m (30,000 ft).

Horizontal Surface, Rotary-Wing—An imaginary plane at 45.72 m (150 ft) above the established heliport or helipad elevation. The inner boundary intersects with the approach-departure clearance surface and the transitional surface. The outer boundary is formed by scribing an arc at the end of each runway, and connecting the arcs with tangents, or by scribing the arc about the center of the helipad. See Chapter 4 for dimensions.

Hover—A term applied to helicopter flight when the aircraft: (1) maintains a constant position over a selected point (1 to 3 m (3 to 10 ft) above ground), and (2) is taxiing (airborne) (1 to 3 m (3 to 10 ft) above ground) from one point to another.

Hoverlane—A designated aerial traffic lane for the directed movement of helicopters between a helipad or hoverpoint and the servicing and parking areas of the heliport or airfield.

Hoverpoint—Prepared and marked surface at a heliport or airfield used as a reference or central point for arriving or departing helicopters.

Imaginary Surfaces. Surfaces in space established around airfields in relation to runway(s), helipad(s), or helicopter runway(s) that are designed to define the obstacle free airspace around the airfield. The imaginary surfaces for DoD airfields are the primary surface, the approach-departure clearance surface, the transitional surface, the graded area of the clear zone, the inner horizontal surface, the conical surface (fixed-wing only), and the outer horizontal surface (fixed-wing only).

Ingress/Egress, Same Direction—One approach-departure route to and from the helipad exists. The direction from which the rotary-wing aircraft approaches the helipad (ingress) is the only direction which the rotary-wing aircraft departs (egress) from the helipad. Typically, the helipad is surrounded by obstacles on three sides which make approaches from other directions impossible. For example, if the rotary-wing aircraft approaches from the southwest, it must also depart to the southwest.

Ingress/Egress, Two Direction—Rotary-wing aircraft can approach and depart the helipad from two directions (one direction and the opposite direction). (See also Ingress/Egress, Same Direction.)

Instrument Runway—Runway equipped with electronic navigation aids for which a precision or non-precision approach procedure is approved.

Instrument Flight Rules (IFR)—Rules that govern the procedure for conducting instrument flight. Also see Instrument Meteorological Conditions.

Instrument Landing System—System of ground equipment designed to provide an approach path for exact alignment and descent of an aircraft on final approach to a runway. The ground equipment consists of two highly directional transmitting systems and, along the approach, three (or fewer) marker beacons. The directional transmitters are known as the localizer and glideslope transmitters.

Instrument Meteorological Conditions—Meteorological conditions expressed in terms of visibility, distance from cloud, and ceiling; less than minimums specified for visual meteorological conditions.

Intermediate Area—Area between runways and between runways and taxiways that is graded or cleared for operational safety.

Joint/Shared Use Airfield—Airports that are shared by a civilian DoD agency covered under the *Airports and Airway Improvement Act of 1982* (Public Law 97-248, Sep 3, 1982, 49 USC, APP 2201). Only those facilities (i.e., runways/taxiways) that are used by both civilian and DoD agencies are considered shared/joint use. All other facilities (parking ramps, hangars, terminals, and so forth) are the sole property of the using agency. An installation where agreements exist among the DoD, civil, and host nation authorities for joint use of all or a portion of airfield facilities.

Landing Area—See Takeoff and Landing Area.

Landing Field—Any area of land consisting of one or more landing strips, including the intermediate area, that is designed for the safe takeoff and landing of aircraft.

Landing Lane—A defined lane on the airfield used for simultaneous takeoff and landings of multiple (up to four at one time) helicopters. Landing lanes are used at airfields or heliports when a high density of helicopters are parked on an apron or in the process of takeoff and landings.

Landing Rollout—Distances covered in stopping the aircraft, when loaded to maximum landing weight, following touchdown using standard operation and braking procedures on a hard, dry-surfaced, level runway with no wind.

Landing Strip—Portion of an airfield that includes the landing area, the end zones, and the shoulder areas; also known as a flight strip.

Landing Zone (LZ)—A prepared or semi-prepared (unpaved) airfield used to conduct operations in an airfield environment similar to forward operating locations. LZ runways are typically shorter and narrower than standard runways.

Landside Facilities—Landside facilities are facilities not associated with the movement and parking of aircraft but are required for the facilities' mission. These include aircraft maintenance areas, aviation support areas, fuel storage and dispensing, explosives and munitions areas and vehicular needs.

Large Transport Aircraft—Transport aircraft with a wing span of 33.5 m (110 ft) or greater.

Light Bar—Set of lights arranged in a row perpendicular to the light system centerline.

Line Vehicle—Vehicle used on the landing strip, such as a crash fire truck or tow tractor.

Localizer—Directional radio beacon which provides to an aircraft an indication of its lateral position relative to a predetermined final approach course.

Localizer Type Directional Aid (LDA)—A NAVAID used for non-precision instrument approaches with utility and accuracy comparable to a localizer but which is not part of a complete ILS. The LDA is not aligned with the runway. The alignment is greater than 3 degrees (3°) and less than 30 degrees (30°) from the runway centerline.

Magnetic North—Direction indicated by the north-seeking pole of a freely suspended magnetic needle, influenced only by the earth's magnetic field.

Magnetic Variation—At a given place and time, the horizontal angle between the true north and magnetic north measured east or west according to whether magnetic north lies east or west of true north.

Magnetically Quiet Zone—A location where magnetic equipment, such as a compass, is only affected by the earth's magnetic forces.

Non-Precision Approach—Approach flown by reference to electronic navigation aids in which glideslope information is not available.

Non-Instrument Runway—Runway intended for operating aircraft under VFR.

Obstacle—An existing object, natural growth, or terrain, at a fixed geographical location, or which may be expected at a fixed location within a prescribed area, with reference to which vertical clearance is or must be provided during flight operations. *Fixed Obstacles* include man-made or natural features such as buildings, trees, rocks and terrain irregularities. *Mobile Obstacles* include parked aircraft, parked and moving vehicles, railroad cars and similar equipment. Taxiing aircraft are exempt from this restriction. Vehicles in performance of official duties, such as emergency vehicles, maintenance vehicles and inspection vehicles, are exempt from this restriction only when authorized by Airfield Management and operating the vehicle in accordance with local driving rules and regulations.

Obstacle Clearance—Vertical distance between the lowest authorized flight altitude and a prescribed surface within a specified area.

Obstruction—Natural or man-made object that violates airfield or heliport clearances or projects into imaginary airspace surfaces. Navy and Marine Corps see UFC 2-000-05N.

Overrun Area—Area the width of the runway plus paved shoulders extending from the end of the runway to the outer limit of the end zone. This portion is a prolongation of the runway which is the stabilized area.

Parking, Aircraft Undergoing Maintenance—Apron parking space is provided for parking aircraft which must undergo maintenance.

Parking, Alert Aircraft—Parking for aircraft that must be in flight upon short notice.

Parking, Operational Aircraft—Parking for operational aircraft assigned to a particular installation.

Parking, Transient Aircraft—Parking for transient aircraft (non-operational) at the installation, but not assigned there.

Parking, Transport Aircraft—Parking for transport aircraft carrying cargo and personnel which must be loaded and unloaded.

Pass—The movement of an aircraft over a specific spot or location on a pavement feature.

Pavement (Paved Surface)—A durable weather and abrasion resistant surface made from a prepared or manufactured material placed on an established base. General categories of pavements are flexible and rigid.

Permanent Waiver—See **Waiver, Permanent**.

Permissible Deviation (Air Force and Army only)—Airfield support facilities that are not required to meet airfield clearance criteria; however, they must meet siting criteria specified in Appendix B, Section 13, of this UFC.

Power Check—Full power test of an aircraft engine while the aircraft is held stationary.

Power Check Pad—Aircraft power check pad is a paved area, with an anchor block in the center, used to perform full-power engine diagnostic testing of aircraft engines while the aircraft is held stationary.

Precision Approach—Approach in which azimuth and glideslope information are provided to the pilot.

Primary Surface (Fixed-Wing Runways)—An imaginary surface symmetrically centered on the runway, extending 60.96 m (200 ft) beyond each runway end. The width varies depending upon the class of runway and coincides with the lateral clearance distance. The elevation of any point on the primary surface is the same as the elevation of the nearest point on the runway centerline.

Primary Surface (Rotary-Wing Runways and Landing Lanes)—Imaginary surface symmetrically centered on the runway, extending beyond the runway ends. The width and length depends upon whether the runway/landing lane is to accommodate VFR or IFR operations. The lateral clearance distance coincides with the width of the primary surface. The elevation of any point on the primary surface is the same as the elevation of the nearest point on the runway centerline.

Relocated Threshold-- A threshold that is located at a point on the runway other than the beginning of the full-strength pavement and the paved area between the former threshold and the relocated threshold is no longer used for landing or takeoff of aircraft, but may be used for taxiing aircraft.

Runway—A defined rectangular area of an airfield or heliport, with no curves or tangents, prepared for the landing and takeoff run of aircraft along its length.

Runway (Class A)—Class A runways are primarily intended for small light aircraft. Ordinarily, these runways have less than 10 percent of their operations involving aircraft in the Class B category. These runways are normally less than 2,440 m (8,000 ft).

Runway (Class B)—Class B runways are all fixed-wing runways that accommodate normal operations of Class B Aircraft.

Runway End—As used in this manual, the runway end is where the normal threshold is located. When the runway has a displaced threshold, the responsible airfield authority will evaluate each individual situation and, based on this evaluation, will determine the point of beginning for runway and airspace imaginary surfaces.

Runway Exit—Taxiway pavement provided for turnoffs from the runway to a taxiway either at normal or high speed.

Runway, Parallel—Two or more runways at the same airport whose centerlines are parallel. In addition to runway number, parallel runways are designated as L (left) and R (right) or, if three parallel runways exist, L (left), C (center), and R (right).

Runway, Rotary-wing— Runway for rolling landings and takeoff of rotary-wing aircraft. The rotary-wing runway allows for a helicopter to quickly land and roll to a stop compared to the hovering stop used during a vertical helipad approach.

Runway Threshold—A line perpendicular to the runway centerline designating the beginning of that portion of a runway usable for landing.

Runway Visual Range—The maximum distance in the direction of takeoff or landing from which the runway, or the specified lights or markers delineating it, can be seen from a position above a specified point on its centerline at a height corresponding to the average eye-level of pilots at touchdown.

Service Point—Receptacle, embedded in certain airfield pavements, containing outlets for utilities required to service aircraft.

Short Takeoff And Vertical Landing (STOVL)— a fixed-wing aircraft capable of clearing a 15 m (50 ft) obstacle within 450 m (1,500 ft) of commencing take-off run, and capable of landing vertically. This term only applies to F-35B aircraft.

Shoulder—Prepared (paved or unpaved) area adjacent to the edge of an operational pavement.

Slide Area, Helicopter—Specially prepared but usually unpaved area used for practicing helicopter landings under simulated engine failure or certain other emergency conditions. VFR Helicopter runway criteria apply to these type facilities. (Also known as a Skid Pad.)

Slope Ratio—Slope expressed in meters (feet) as a ratio of the horizontal to the vertical distance. For example, 50:1 means 50 m horizontal to 1 m vertical (50 ft horizontal to 1 ft vertical).

Standard VFR Helipad—Helipad designed to VFR. VFR design standards are used when no requirement exists or will exist in the future for an IFR helipad.

Standby Parking Pad—At individual helipad sites where it is necessary to have one or more helicopters on standby, an area adjacent to the helipad, but clear of the landing approach and transitional surfaces.

Sunshade—A cover, usually semi-circular in shape, to protect aircraft from the sun's ultraviolet rays. For Air Force, see AFI 21-136 *Aircraft Sunshade Management*.

Suppressed Power Check Pad—Enclosed power check pad, referred to as a "hush house," where full power checks of jet engines are performed.

Takeoff and Landing Area—Specially prepared or selected surface of land, water, or deck designated or used for takeoff and landing of aircraft.

Takeoff Safety Zone—Clear graded area within the approach-departure zone of all VFR rotary-wing facilities. The land use of this area is comparable to the clear zone area applied to fixed-wing facilities.

Taxilane—Designated path marked through parking, maintenance or hangar aprons, or on the perimeter of such aprons to permit the safe ground movement of aircraft operating under their own power.

Taxilane, Interior (secondary taxi routes)—Taxilane which provides a secondary taxi route to individual parking positions or a hangar and is not intended or used as a primary taxi route for through traffic.

Taxilane, Peripheral—Taxilane located along the periphery of an apron that may be considered a primary or a secondary taxi route. Provide wing tip clearance commensurate with the intended use. See Taxilane, Interior; Taxilane, Through; and Table 6-1, Items 5 and 6.

Taxilane, Through (primary taxi routes)—A taxilane providing a route through or across an apron which is intended as a primary taxi route for access to other taxilanes, aprons, taxiways or the runway.

Taxitrak—A specially prepared or designated path, on an airfield other than mass parking areas, on which aircraft move under their own power to and from taxiways to dispersed platforms.

Taxiway—A specially prepared or designated path, on an airfield or heliport other than apron areas, on which aircraft move under their own power to and from landing, service and parking areas.

Taxiway, Apron Entrance—Taxiway which connects a parallel taxiway and an apron.

Taxiway, End Turnoff (Entrance Taxiway) (Connecting Taxiway) (Crossover Taxiway)—A taxiway located at the end of the runway that serves as both an access and departure location for aircraft at the runway thresholds.

Taxiway, High-Speed Turnoff (High-Speed Exit) (Acute-angled Exit Taxiway)—A taxiway located intermediate of the ends of the runway and "acute" to the runway centerline to enhance airport capacity by allowing aircraft to exit the runways at a faster speed than normal turnoff taxiways allow. Aircraft turning off runways at high speeds (maximum 100 km/h (55 knots)) require sufficient length for a high-speed turnoff taxiway to decelerate to a full stop before reaching the parallel taxiway.

Taxiway, Normal Turnoff (Ladder Taxiway) (Intermediate Taxiway) (Exit Taxiway)—A taxiway located intermediate of the end of the runway, typically perpendicular to the runway centerline that allows landing aircraft to exit and clear runways as soon as possible.

Taxiway, Parallel—Taxiway which parallels the runway. The curved connections to the end of the runway permit aircraft ground movement to and from the runway and are considered part of the parallel taxiway when there are no other taxiway exits on the runway.

Taxiway Turnoff—A taxiway leading from a runway to allow landing aircraft to exit and clear the runway after completing their initial landing roll.

Temporary Waiver—See **Waiver, Temporary**.

Threshold Crossing Height—Height of the straight-line extension of the guide slope above the runway at the threshold.

Tie-down Anchor—A device, installed in certain airfield pavements, to which lines tying down an aircraft are secured. Electrical grounding may be provided. This is not to be confused with the aircraft trim pad and thrust anchor shown in Appendix B, Section 15.

Touchdown Point—Designated location on a landing lane, taxiway, or runway for permitting more rapid launch or recovery of helicopters in a high-density area.

Towway—Paved surface over which an aircraft is towed.

Transitional Surface— An imaginary surface that extends outward and upward at right angles to the runway centerline and the runway centerline extended at a slope ratio of 7H:1V. The transitional surface connects the primary and the approach-departure clearance surfaces to the inner horizontal, the conical, and the outer horizontal surfaces.

Transitional Surfaces (Rotary-Wing)—The imaginary plane which connect the primary surface and the approach-departure clearance surface to the horizontal surface, or extends to a prescribed horizontal distance beyond the limits of the horizontal surface. Each surface extends outward and upward at a specified slope measured perpendicular to the runway centerline or helipad longitudinal centerline (or centerlines) extended.

True North—Direction from an observer's position to the geographic North Pole. The north direction of any geographic meridian.

Unsuppressed Power Check Pad—A power check pad without an enclosure or other type of noise suppressor. It is generally used as a backup or interim facility to a suppressed power check pad. The unsuppressed power check pad, in its simplest form, is a paved area on which full power engine diagnostic testing can be performed without noise or jet blast limitations.

Visual Flight Rules (VFR)—Rules that govern the procedures for conducting flight under visual conditions. Also see Visual Meteorological Conditions.

Visual Meteorological Conditions (VMC)—Weather conditions in which visual flight rules apply; expressed in terms of visibility, ceiling height, and aircraft clearance from clouds along the path of flight. When these criteria do not exist, instrument meteorological conditions prevail and IFR must be complied with. Also see Visual Flight Rules.

Vertical Sight Distance—The longitudinal distance visible from one location to another. Usually, a height above the pavement surface is also defined.

Vertical/Short Takeoff and Landing (V/STOL)—A tilt-rotor vertical takeoff and landing aircraft that has the ability to operate as either a fixed- or rotary-wing aircraft. This applies to V-22 and AV-8 aircraft.

Waiver, Construction—A temporary airfield waiver used to identify, coordinate and approve construction activity on or near the airfield. The installation commander is the approval authority for construction waivers. See Appendix B, Section 1, for additional information.

Waiver, Permanent (Army)—An airfield waiver established for violations that cannot be reasonably corrected and pose little or no risk to flying operations. Such violations are typically caused by natural topographic features. See Appendix B, Section 1 for approval authority.

Waiver, Permanent (Air Force)— Permanent waivers are established for criteria violations that cannot be reasonably met. See Paragraph B1-2.1.2 for details.

Waiver, Temporary (Army)—An airfield waiver established to address safety mitigation for correctable obstructions or violations of other airfield criteria such as grades. See Appendix B, Section 1 for approval authority.

Waiver, Temporary (Air Force)— Temporary waivers are established for criteria violations that can be corrected within eight years. See Section B1-2.1.3 for details.

Wind Rose—A diagram showing the relative frequency and strength of the wind in correlation with a runway configuration and in reference to true north. It provides a graphic analysis to obtain the total wind coverage for any runway direction.

Wind Direction—Direction from which the wind is blowing in reference to true north.

UFC 3-260-02
30 June 2001

UNIFIED FACILITIES CRITERIA (UFC)

PAVEMENT DESIGN FOR AIRFIELDS

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

UNIFIED FACILITIES CRITERIA (UFC)

PAVEMENT DESIGN FOR AIRFIELDS

U.S. ARMY CORPS OF ENGINEERS (Preparing Activity)

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

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

Change No.	Date	Location

This UFC supersedes TM 5-818-2/AFM 88-6, Chap 4, dated January 1985; TM 5-822-2/AFM 88-7, Chap 5, dated July 1987; TM 5-822-13/AFJMAN 32-1018, dated October 1994; TM 5-822-5/AFM 88-7, Chap 1, dated June 1992; TM 5-5-824-1/AFM 88-6, Chap 1, dated June 1987; TM 5-825-2/AFM 88-6, Chap 2/DM 21.3, dated August 1978; TM 5-825-2-1/AFM 88-6, Chap 2, Sec A, dated November 1989; TM 5-825-3/AFM 88-6, Chap 3, dated August 1988; and TM 5-825-3-1/AFM 8-6, Chap 3, Sec A, dated September 1988.

FOREWORD

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

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Support Agency (AFCESA) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale should be sent to the respective service proponent office by the following electronic form: Criteria Change Request (CCR). The form is also accessible from the Internet sites listed below.

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

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Unified Facility Criteria
3-260-02

PAVEMENT DESIGN FOR AIRFIELDS

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CHAPTER 1

INTRODUCTION

1. PURPOSE. This document establishes general concepts and criteria for the design of airfield pavements for the U.S. Army, Navy, Air Force, and Marine Corps.

2. SCOPE. This document prescribes procedures for determining the thickness, material, and density requirements for airfield pavements in nonfrost and frost areas. It includes criteria for the California Bearing Ratio (CBR) procedure and elastic layered analysis for flexible pavements and the Westergaard Analysis and elastic layered analysis for rigid pavements. The elastic layered analysis for rigid pavements covers only plain concrete, reinforced concrete, and concrete overlay pavements.

3. REFERENCES. Appendix A contains a list of references used in these instructions.

4. UNITS OF MEASUREMENT. The unit of measurement system in this document is the International System of Units (SI). In some cases inch-pound (IP) measurements may be the governing critical values because of applicable codes, accepted standards, industry practices, or other considerations. Where the IP measurements govern, the IP values may be shown in parenthesis following a comparative SI value or the IP values may be shown without a corresponding SI value.

5. PAVEMENT. A pavement as used in this document is a surfaced area designed to carry aircraft traffic and includes the entire pavement system structure above the subgrade. All slabs on grade required to support aircraft loadings, whether interior (hangar floors) or exterior, are to be considered airfield pavements.

a. Flexible Pavement. Flexible pavements are so designated due to their flexibility under load and their ability to withstand small degrees of deformation. The design of a flexible pavement structure is based on the requirement to limit the deflections under load and to reduce the stresses transmitted to the natural subsoil. The principal components of the pavement include a bituminous concrete surface, graded crushed aggregate base course, stabilized material, drainage layer, separation layer, and subbase courses. A bituminous concrete surface course is hot mixed bituminous concrete designed as a structural member with weather and abrasion resisting properties. It may consist of wearing and binder or intermediate course. Figure 1-1 illustrates the components and the terminology used in flexible pavements. Examples of all bituminous concrete pavements (ABC) and flexible pavements utilizing stabilized layers are shown in Figures 1-2 and 1-3. Not all layers shown in the figures are required in every pavement.

b. Rigid Pavement. A rigid pavement is considered to be any pavement system that contains portland cement concrete as one element. Rigid pavements transfer the load to the subgrade by bending or slab action through tensile forces as opposed to shear forces. The principal components of a rigid pavement are the concrete slab, base course, drainage layer, and separation layer. However, a stabilized layer may be required based on site conditions. Figure 1-4 illustrates the components of a rigid pavement. The drainage and separation layer will normally serve as the base course. The following pavements are considered to be rigid pavements:

(1) Plain concrete pavement is a nonreinforced jointed rigid pavement.

(2) Reinforced concrete pavement is a jointed rigid pavement that has been strengthened with deformed bars or welded wire fabric.

(3) Continuously reinforced concrete pavement is a rigid pavement that is constructed without joints and uses reinforcing steel to maintain structural integrity across contraction cracks that form in the pavement.

(4) Fibrous concrete pavement is a rigid pavement that has been strengthened by the introduction of randomly mixed, short, small-diameter steel fibers. Nonsteel fibers have been used in portland cement concrete (PCC) to control shrinkage cracking, but their use is not covered in this TI.

(5) Prestressed concrete pavement is a rigid pavement that has been strengthened by the application of a significant horizontally applied compressive stress during construction.

(6) Rigid overlay pavement is a rigid pavement used to strengthen an existing flexible or rigid pavement.

(7) Nonrigid overlay pavement is either all-bituminous or bituminous with base course used to strengthen an existing rigid pavement.

6. USE OF FLEXIBLE PAVEMENTS. The use of flexible pavements on airfields must be limited to those pavement areas not subjected to detrimental effects of fuel spillage, severe jet blast, or parked aircraft. Jet blast damages bituminous pavements when the intense heat is allowed to impinge in one area long enough to burn or soften the bitumen so that the blast erodes the pavement. Hot-mix asphaltic concretes generally will resist erosion at temperatures up to 150 degrees Celsius (300 degrees Fahrenheit). Temperatures of this magnitude are produced only when aircraft are standing and are operated for an extended time or with afterburners operating. Fuel spillage leaches out the asphalt cement in asphaltic pavements. In an area subject to casual minor spillage, the leaching is not serious, but where spillage is repeated in the same spot at frequent intervals, the leaching will expose loose aggregate. Flexible pavements are generally satisfactory for runway interiors, secondary taxiways, shoulders, paved portions of overruns, or other areas not specifically required to have a rigid pavement surfacing.

7. USE OF RIGID PAVEMENTS. The following pavements will be rigid pavement: all paved areas on which aircraft or helicopters are regularly parked, maintained, serviced, or preflight checked, on hangar floors and access aprons; on runway ends (305 meters (1,000 feet)) of a Class B runway; areas that may be used from the runway end to 90 meters (300 feet) past the barrier to control hook skip; primary taxiways for Class B runways; hazardous cargo, power check, compass calibration, warmup, alert, arm/disarm, holding, and washrack pads; and any other area where it can be documented that flexible pavement will be damaged by jet blast or by spillage of fuel or hydraulic fluid. Navy aircraft arresting gear pavement protection shall be designed in accordance with NAVFAC design definitive #1404521 and 1404522 shown in NAVFAC P-272. The 2 meters (6.56 feet) of pavement on both the approach and departure sides of the arresting gear pendent shall be PCC for Navy and Marine Corps. Rigid pavements shall also be used at pavement intersections where aircraft/vehicles have a history of distorting flexible pavements and where sustained operations of aircraft/vehicles with tire pressures in excess of 2.06 MPa (300 psi) occur. Continuously reinforced concrete pavement will be used in liquid oxygen (LOX) storage and handling areas to eliminate the use of any organic materials (joint sealers, asphalt pavement, etc.) In those areas. The type of pavement to be used on all other paved areas will be selected on the basis of life cycle costs.

8. SOIL STABILIZATION. Soils used in pavements may be stabilized or modified through the addition of chemicals or bitumens. A stabilized soil is one which has improved load-carrying and durability characteristics through the addition of admixtures. The principal benefits of stabilization include a reduction in pavement thickness, provision of a construction platform, decreased swell potential, and reduction of the susceptibility to pumping as well as the susceptibility to strength loss due to moisture. Lime, cement, and fly ash, or any combination of these, and bitumen are the commonly used additives for soil stabilization. A modified soil is one which has improved construction characteristics through the use of additives. However, the additives do not improve the strength and durability of the soil sufficiently to qualify as a stabilized soil with a subsequent reduction in thickness. Criteria for the design of stabilized soils is contained in TM 5-822-14/AFMAN 32-1019. Additional discussion of soil stabilization is found in TM 5-818-1/AFM 88-3, Chapter 7.

9. DESIGN ANALYSIS. The outlines in Appendixes B and C will be used to prepare design analyses for all projects under design. All pertinent items and computational details will be included showing how design results were obtained.

10. WAIVERS TO CRITERIA. Each DoD Service component is responsible for setting administrative procedures necessary to process and grant formal waivers. Waivers to the criteria contained in this manual will be processed in accordance with Appendix D.

11. COMPUTER PROGRAMS. Computer programs have been developed for the design of pavements. The computer programs may be obtained electronically from the following:

a. Word Wide Web (WWW) address: http://pcase.com.

b. FTP Anonymous Site: pavement.wes.army.mil.

Disks may also be obtained from the U.S. Army Corps of Engineers, Transportation Systems Center, 215 North 17th Street, Omeha, NE 68102-4978.

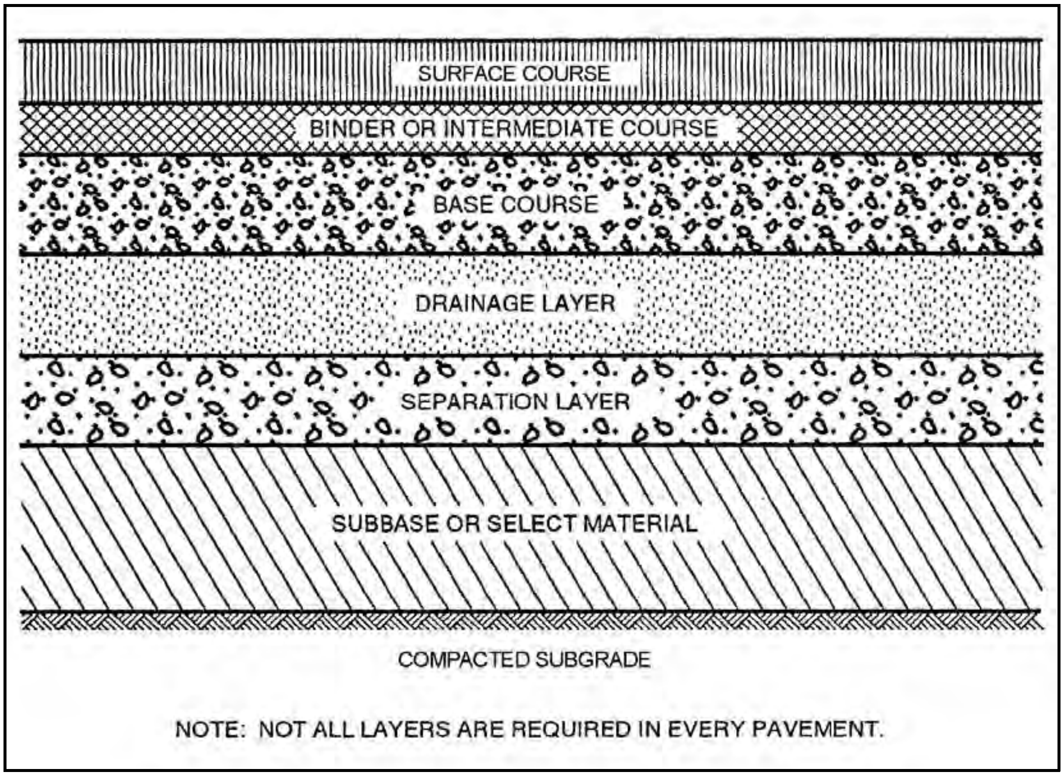


Figure 1-1. Typical flexible pavement structure

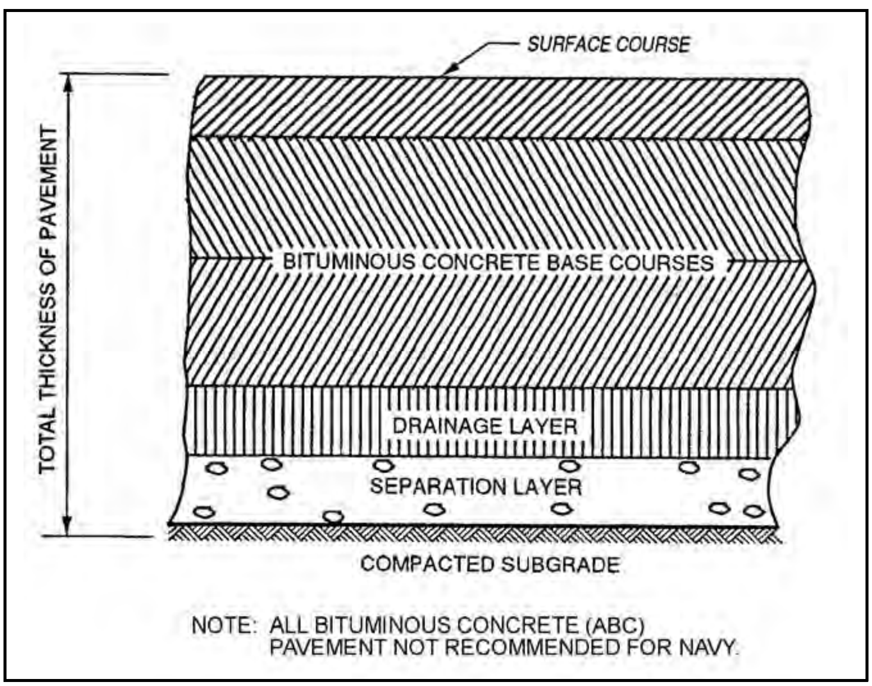


Figure 1-2. Typical all-bituminous concrete pavement

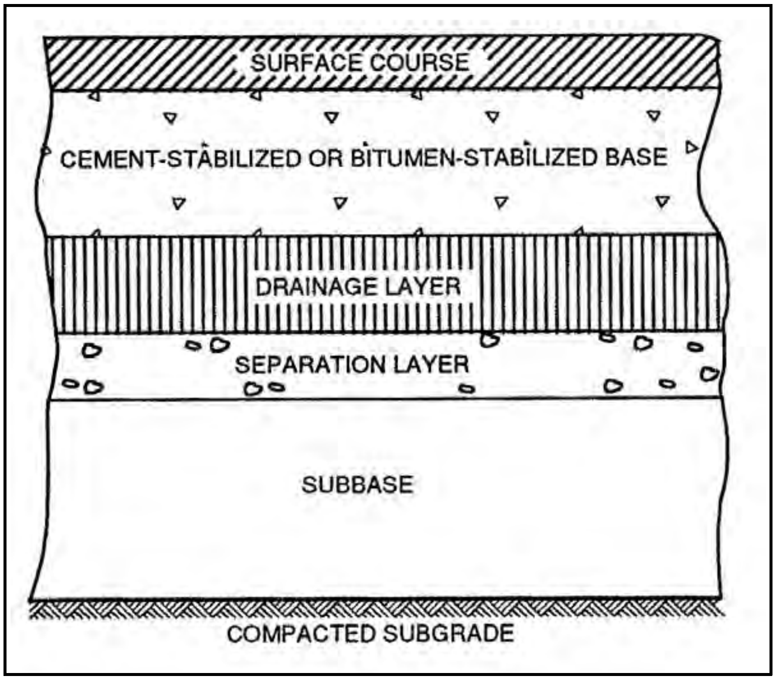


Figure 1-3. Typical flexible pavement with stabilized base

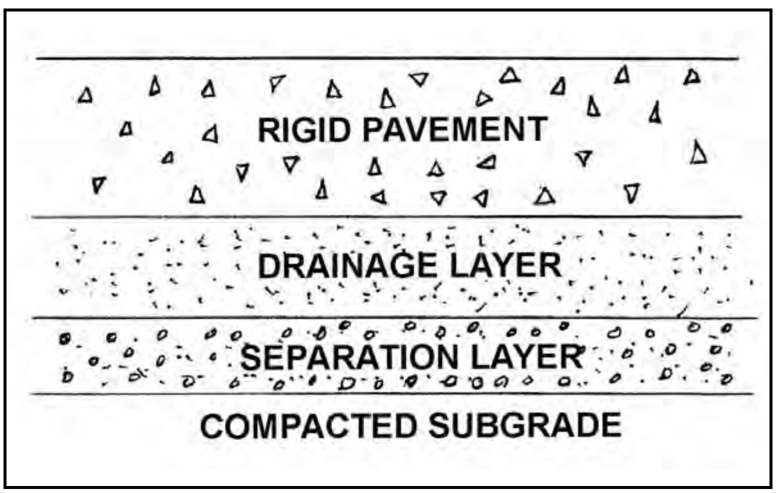


Figure 1-4. Typical rigid pavement structure

CHAPTER 2

ARMY AIRFIELD/HELIPORT REQUIREMENTS

1. ARMY AIRFIELD/HELIPORT CLASSES. Army airfields are divided into six classes referred to as Class I (heliports-helipads with aircraft 11,340 kilograms (25,000 pounds) or less), Class II (heliports-helipads with aircraft over 11,340 kilograms (25,000 pounds)), Class III (airfields with Class A runways), Class IV (airfields with Class B runways), Class V contingency (theater of operations) heliports or helipads supporting Army assault training missions, and Class VI assault landing zones for contingency (theater of operations) airfields supporting Army training missions.

2. ARMY AIRFIELD AND HELIPORT LAYOUT. The layout for all Class I, II, III, and IV Army airfields, heliports, and helipads will be designed in accordance with the tri-service manual UFC 3-260-01. All Class V and VI Army contingency (theater of operations) airfield, heliport, and helipad layouts shall be designed in accordance with FM 5-430-00-2/AFJPAM 32-8013, Vol. II. Class VI airfields used for Army contingency training missions shall be designed in accordance with AF ETL 98-5. Any deviations from these criteria must be submitted through the installation MACOM to the U.S. Army Aeronautical Services Agency (USAASA) for waiver approval.

3. TRAFFIC AREAS FOR ARMY AIRFIELD PAVEMENTS. Construction of primary taxiways, runways, and apron taxi lanes with keel sections (alternating variable thickness) as indicated by traffic will not be authorized for Army aircraft operational surfaces. Uniform pavement section thicknesses will be used.

a. Class I and II Heliports. These heliport classes have only one traffic area, Type B.

b. Class III Airfields. These airfields contain three traffic areas, Types A, B, and C. Type A traffic areas consist of the primary taxiways and the first 152 meters (500 feet) of runway ends. Type B traffic areas consist of parking aprons, warm-up pads, arm/disarm pads, compass calibration pads, power check pads, dangerous/ hazardous cargo pads, and taxiways connecting the primary taxiway to aprons and pads. Type C traffic areas consist of runway interiors between the 152-meter (500-foot) end sections, secondary (ladder) taxiways, hangar floors, washracks, and hangar access aprons. Type C traffic areas are designed using 75 percent of the aircraft gross weight and the same aircraft passes as Type A traffic areas. A typical layout of Army airfield traffic areas for Class III airfields is shown in Figure 2-1.

c. Class IV Airfields. These airfields contain three traffic areas, Types A, B, and C. Type A traffic areas consist of the primary taxiways and the first 305 meters (1,000 feet) of runway ends. Type B traffic areas consist of the parking aprons, warm-up pads, arm/disarm pads, power check pads, compass calibration pads, dangerous/hazardous cargo pads, and taxiways from the primary taxiway to aprons and pads. Type C traffic areas consist of runway interiors between the 305-meter (1,000-foot) end sections, secondary (ladder) taxiways (between runway and primary taxiway), hangar floors, hangar access aprons, and washracks. A typical layout of Army airfield traffic areas for Class IV airfields is shown in Figure 2-1.

d. Class V Heliports. This heliport has only one traffic area, Type B.

e. Class VI Airfields. This airfield has only one traffic area, Type A.

f. Exceptions. At facilities other than assault landing zones where a parallel taxiway is not provided, the runway shall be designed as Type A Traffic Area with double the required traffic.

4. ARMY AIRCRAFT DESIGN LOADS AND PASS LEVELS. Army airfield pavements will be designed according to mission requirements of each airfield, heliport, and helipad for a 20-year design life to include the military and civilian peacetime aircraft traffic plus all anticipated special operations and/or mobilization requirements defined by the Army installation and its MACOM. The total 20-year design aircraft traffic is based on specific aircraft types, their mission operational weights, and their projected pass levels. The airfield mission traffic used for design requires the approval of the MACOM and USAASA. Aircraft hangar floors or apron pavements shall not be designed for jacking loads as long as the foot print of the jack is equal to or greater than the contact area of the combined tires on the aircraft gear being elevated. Army aircraft operational pavements may consist of one or a combination of the following Army airfield-heliport classes:

a. Class I. Heliports and helipads with aircraft maximum operational weights equal to or less than 11,340 kilograms (25,000 pounds). The design of heliports and helipads will be based on the number of equivalent passes of the UH-60 aircraft at a 7,395-kilogram (16,300-pound) operational weight. The projected equivalent passes will be generated for the airfield mission traffic but shall not be less than 50,000 passes for a heliport nor less than 20,000 passes for a helipad.

b. Class II. Heliports that support aircraft with maximum operational weights over 11,340 kilograms (25,000 pounds). The design will be based on the number of equivalent passes of the CH-47 aircraft at a 22,680-kilogram (50,000-pound) operational weight. The projected equivalent passes will be generated for the airfield mission traffic but shall not be less than:

(1) 50,000 passes for visual flight rules (VFR) heliports.

(2) 20,000 passes for VFR helipads.

(3) 100,000 passes for instrument flight rules (IFR) heliports.

(4) 30,000 passes for IFR helipads.

c. Class III. Airfields that primarily support fixed wing aircraft requiring a Class A runway as defined in UFC 3-260-01. The design will be based on the projected number of aircraft operations but not less than 50,000 passes of a C-23 aircraft at an 11,200-kilogram (24,600-pound) operational weight plus 10,000 passes of a CH-47 aircraft at an operational weight of 22,680-kilograms (50,000-pounds).

d. Class IV. Airfields supporting aircraft requiring a Class B runway as defined in EI 02C013/ AFMAN 32-1013/NAVFAC P-971.

(1) The design for an airfield with its longest runway extending less than or equal to 1,525 meters (5,000 feet) will be based on the number of projected equivalent passes of the C-130 aircraft at a 70,310-kilogram (155,000-pound) or the C-17 aircraft at 263,100-kilograms (580,000-pound) operational weight. The projected equivalent passes will be generated for the airfield mission traffic but shall not be less than 75,000 passes for the C-130 or 50,000 passes for the C-17.

(2) The design for an airfield with its longest runway extending over 1,525 meters (5,000 feet) but less than or equal to 2,745 meters (9,000 feet) will be based on the number of projected equivalent

passes of the C-17 aircraft at a 263,100-kilogram (580,000-pound) operational weight. The projected equivalent passes will be generated for the airfield mission traffic but shall not be less than 75,000 passes.

(3) The design for an airfield with its longest runway extending over 2,745 meters (9,000 feet) will be based on the number of projected equivalent passes of the C-17 aircraft at a 263,100-kilogram (580,000-pound) operational weight. The projected equivalent passes will be generated for the airfield mission traffic but shall not be less than 100,000 passes.

e. Class V. Contingency (theater of operations) heliports or helipads supporting Army assault training missions. The design for the heliport or helipad will be based on the number of projected equivalent passes of the CH-47 aircraft at a 22,680-kilogram (50,000-pound) operational weight. The projected equivalent passes will be generated for the airfield mission traffic but shall not be less than 5,000 passes. Army assault heliport or helipad structural sections shall be designed in accordance with the criteria in this document with a bituminous surface or a military landing mat as described in FM5-430-00-2/AFJPAM 32-8013, Vol II.

f. Class VI. Assault landing zones for contingency (theater of operations) airfields or airstrips supporting Army training missions that have semi-prepared or paved surfaces. The design for airfields supporting Army training missions will be based on the number of equivalent passes of the C-130 aircraft at a 70,310-kilogram (155,000-pound) operational weight or the C-17 aircraft at a 263,100-kilogram (580,000-pound) operational weight. The equivalent passes will be not less than 10,000 passes for paved airfields. Army assault airfield or airstrip structural sections shall be designed in accordance with this manual. Army assault airfields with semi-prepared (unsurfaced) surfaces shall be designed in accordance with TM 5-822-12, TM 5-822-14, or Air Force ETL 98-2.

5. ROLLER-COMPACTED CONCRETE PAVEMENT. Roller-compacted concrete pavement (RCCP) is a rigid pavement and can be used as pavement except for runway and high-speed taxiway pavements for fixed-wing aircraft. RCCP can be used for all helipad and heliport pavements. RCCP shall be designed in accordance with ETL 1110-3-475.

6. RESIN MODIFIED PAVEMENT. Resin Modified Pavement (RMP) can be used as an Army pavement except for fixed-wing runways and high-speed taxiways. RMP can be used for helipads and heliport pavements and for both rotary-wing and fixed-wing parking aprons.

7. PAVED SHOULDERS.

a. Location. Paved shoulders should be provided for airfield and heliport construction as designated in UFC 3-260-01.

b. Structural Requirements. As a minimum, paved shoulders shall be designed to support 5,000 coverages of a load of 4,535 kilograms (10,000 pounds) imposed by a single wheel with a tire pressure of 0.69 MPa (100 psi). When shoulder pavements are to be used by support vehicles (snow removal equipment, fire trucks, fuel trucks, etc.), the shoulder should be designed accordingly for whichever governs.

8. SURFACE DRAINAGE. Design of surface drainage shall be in accordance with TM 5-820-1/ AFM 88-5, Chapter 1.

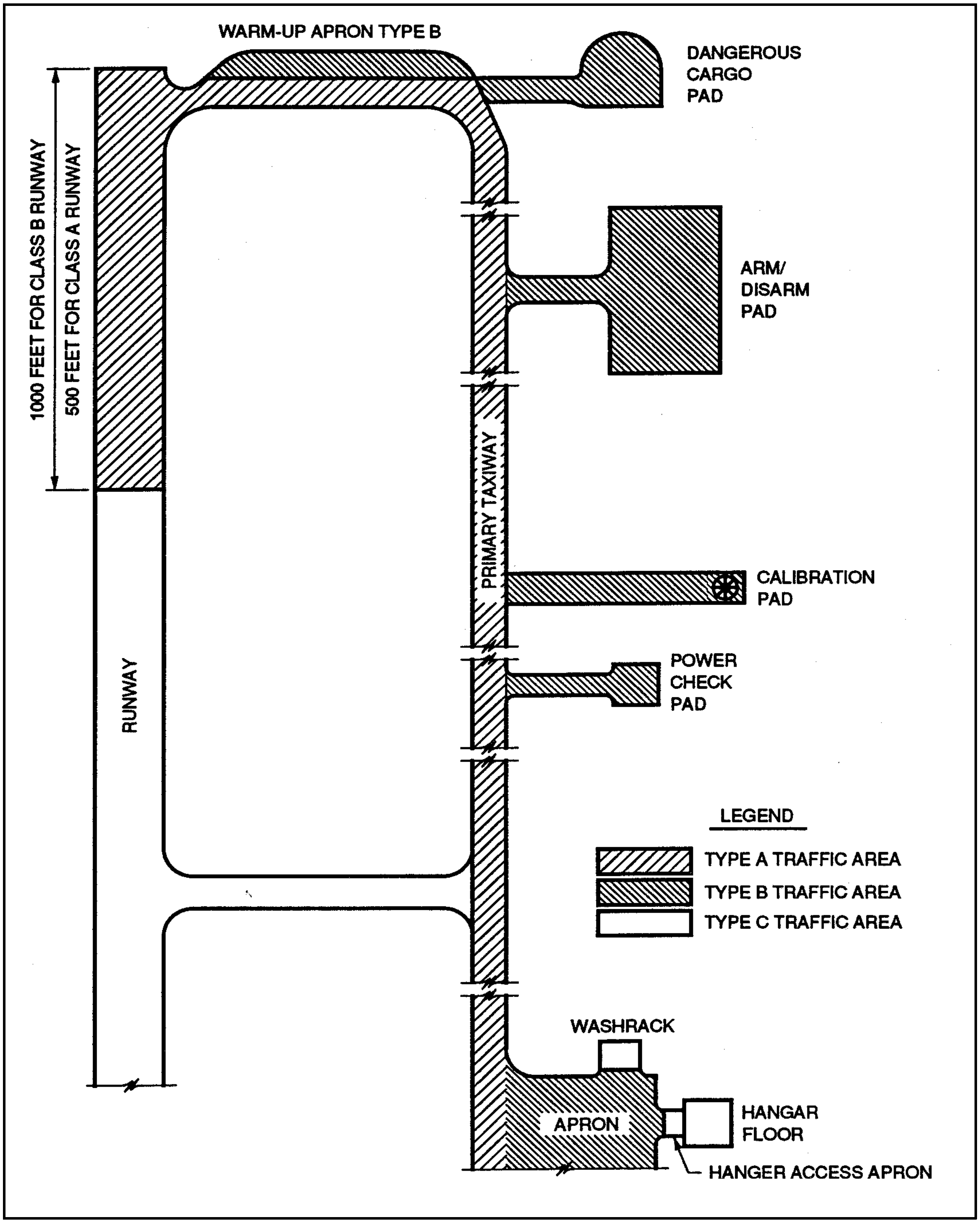


Figure 2-1. Typical layout of traffic areas for Army Class III and IV airfields

CHAPTER 3

AIR FORCE AIRFIELD AND AGGREGATE SURFACED HELICOPTER SLIDE AREAS AND HELIPORT REQUIREMENTS

1. AIR FORCE AIRFIELD TYPES. Airfield mission and operational procedures have resulted in the development of six types of Air Force airfields: light, medium, heavy, modified heavy, auxiliary, and assault landing zone. The decision on which airfield type to design for will be made by the appropriate Major Command (MAJCOM). Designs should generally be based upon medium load criteria with the following exceptions.

a. Air Training Command bases should be designed as light load. Auxiliary airfields at Air Training Command bases will be designed for the load and pass level selected by the Major Command.

b. For bases where B-52's are the critical missions, use heavy load criteria.

c. For bases where the B-1 and/or KC-10's are the critical mission, use modified heavy load criteria.

d. Assault landing zone criteria should be used to design runways for C-130 or C-17 training.

e. MAJCOMs should plan for future missions. For example, if the current mission uses KC-135 tankers but will use KC-10 aircraft in the future, the KC-10 should be the design aircraft.

f. In lieu of the above criteria, MAJCOMs have the option to design for specific aircraft and projected pass levels.

2. TRAFFIC AREAS FOR AIR FORCE AIRFIELDS. On normal operational airfields, the pavements can be grouped into four traffic areas designated as Types A, B, C, and D which are defined below and shown in Figures 3-1, 3-2, or 3-3 for each type airfield. A layout of the assault landing zone is not shown since all areas are Type A traffic areas. Modified heavy-load airfields will have the same traffic areas as medium-load airfields. Auxiliary airfields will have the same traffic areas as light-load airfields.

a. Type A Traffic Areas. Type A traffic areas are those pavement facilities that receive the channelized traffic and full design weight of aircraft. Aircraft with steerable gear, including fighter-type aircraft, operate within a relatively narrow taxilane producing sufficient coverages or stress repetition within the narrow lane to require special design treatment. Type A traffic areas for pavements are dictated by the operational patterns of aircraft. These traffic areas require a greater pavement thickness than those areas where the traffic is more evenly distributed. Pavement features considered to be Type A traffic areas on each airfield type are as follows:

(1) Heavy-load airfield.

(a) Portions of long straight sections of primary taxiways will be Type A traffic areas. Traffic channelization is limited to the center of the taxiway for aircraft with a bicycle-gear configuration. Therefore, the center 7.6-meter (25-foot) (minimum) of long straight sections will be designed as a Type A traffic area. The outside lanes will be designed as Type B traffic areas. An alternative design is to provide uniform thickness for the full width of the taxiway.

(b) Taxiways connecting runway ends and primary taxiways, short lengths of primary taxiway turns, and intersections of primary taxiways will be Type A traffic areas. The effects of traffic channelization on these areas cannot be well defined; therefore, these pavements will be designated as Type A traffic areas requiring a uniform pavement thickness for the full width of the taxiway.

(c) Through taxilanes or portions of through taxiways on aprons (7.6-meter (25-foot) minimum) will be designed as Type A traffic areas.

(d) Portions of the first 305 meters (1,000 feet) of runway ends will be Type A traffic areas. On these pavements, the effects of channelized traffic are generally confined to the center 23-meter (75-foot) width and the approach area from the connecting taxiway. These portions will be designed as Type A traffic areas and will require a uniform thickness. The dimensions of the approach area will correspond to the width of the connecting taxiway plus the taxiway fillets. An alternate design for the first 305 meters (1,000 feet) of runway ends is to provide a uniform thickness for the full width of the pavement. Design of the pavement for channelized traffic must include the lanes where the traffic of the design landing-gear type (bicycle or tricycle) is applied. For the present heavy-load pavement (bicycle-landing gear), the selection of a thickened center section or a uniform thickness for the full width of the facility will be determined on the basis of life cycle costs and projected future mission. In seasonal frost areas, it is often desirable to use a constant transverse section to preclude differential frost heave.

(2) Medium-load and modified heavy-load airfield.

(a) Primary taxiways will be designed as Type A traffic areas. The effects of channelized traffic are well defined on long straight sections. However, the channelization is not as confined as for a heavy-load pavement, and it is not practical to construct primary taxiways of alternating variable thicknesses as indicated by traffic requirements. Therefore, the primary taxiways for medium-load and modified heavy-load airfields will normally be constructed to provide a uniform thickness for the full width of pavement facility. The entire primary taxiway, including straight sections, turns, and intersections, will be designated as Type A traffic areas.

(b) Through taxilanes and portions of through taxiways on aprons (11-meter (35-foot) minimum) will be designed as Type A traffic areas.

(c) Portions of the first 305 meters (1,000 feet) of runway ends will be designed as Type A traffic areas. On these pavements, the effects of channelized traffic are generally confined to the center 23-meter (75-foot) width and the approach area from the connecting taxiway. These portions will be designed as Type A traffic areas and will require a uniform thickness. The dimensions of the approach area will correspond to the width of the connecting taxiway plus the taxiway fillets. An alternate design for the first 305 meters (1,000 feet) of runway ends would be to provide a uniform thickness for the full width of the pavement facility. The selection of a thickened center section or a uniform thickness for full width of the facility will be determined on the basis of life cycle costs unless mission requirements dictate a uniform thickness (an example is formation takeoffs). In frost areas, it is often desirable to use a uniform thickness to preclude differential frost heave.

(3) Light-load and auxiliary airfields. Primary taxiways and the first 305 meters (1,000 feet) of runway ends will be designed as Type A traffic areas. The effects of channelized traffic are reasonably well defined on long straight sections. However, it is not considered practical to construct primary taxiways and runway ends of alternating variable thicknesses for light-load and auxiliary airfields as indicated by traffic requirements. Therefore, the primary taxiways and the first 305 meters (1,000 feet) of runway ends for light-load and auxiliary airfields will normally be constructed to provide a uniform

thickness for the full width of pavement facility. The entire primary taxiway, including straight sections, turns, and intersections, will be designated as Type A traffic areas.

(4) Assault landing zone airfield. The type of aircraft operations conducted on these pavements will require the entire runway, the 91-meter (300-foot) overruns, and the short access taxiways to be designed as Type A traffic areas.

b. Type B Traffic Areas. Type B traffic areas are those in which the traffic is more evenly distributed over the full width of the pavement facility but which receive the full design weight of the aircraft during traffic operations. Inasmuch as there is a better distribution of the traffic on these pavements, the repetition of stress within any specific area is less than on Type A traffic areas; therefore, a reduction in required pavement thickness can be allowed. Pavement facilities considered to be Type B traffic areas on each airfield type are as follows:

(1) Heavy-load airfield. All aprons (except hangar access aprons), pads, and hardstands, and traffic lanes adjacent to the center lane on long straight sections of primary taxiways are designed as Type B traffic areas.

(2) Medium-load and modified heavy-load airfields. All aprons (except hangar access aprons), pads, and hardstands are Type B traffic areas.

(3) Light-load and auxiliary airfields. All aprons (except hangar access aprons), hardstands, and power check pads are Type B traffic areas.

(4) Assault landing zone. No Type B traffic area.

c. Type C Traffic Areas. Type C traffic areas are those in which the volume of traffic is low or the applied weight of the operating aircraft is generally less than the design weight. In the interior portion of runways, there is enough lift on the wings of the aircraft at the speed at which the aircraft passes over the pavements to reduce considerably the stresses applied to the pavements. Thus, the pavement thickness can be reduced in these portions of the runways. Therefore, all runway interiors, except shortfield, will be designated as Type C traffic areas regardless of type of design loadings. For the heavy, modified heavy, and medium-load airfields, the edges of the runway seldom receive a fully loaded aircraft; therefore, for these airfields, the Type C traffic areas are limited to the center 23-meter (75-foot) width of runway interior. However, in seasonal frost areas, it may be necessary to use a uniform thickness for the entire width of the runway to preclude frost heave. Pavement facilities at all airfields considered to be Type C traffic areas are as follows:

(1) Heavy-load airfields.

(a) Secondary (ladder) taxiways.

(b) The center 23-meter (75-foot) width of runway interior between the 305-meter (1,000-foot) runway ends and at runway edge adjacent to intersections with ladder taxiways.

(c) Main gear path area of hangar access aprons and floors and washrack pavements. (The pavement outside the main gear path area of hangar access aprons and floors and washracks are designed as a light-load Type C traffic area.)

(2) Medium-load and modified heavy-load airfields.

(a) Secondary (ladder) taxiways.

(b) The center 23-meter (75-foot) width of runway interior between 305-meter (1,000-foot) runway ends and at runway edges adjacent to intersections with ladder taxiways.

(c) Hangar access aprons and floors and washrack pavements. At Air Mobility Command Installations, hangar access aprons shall be designed as Medium Load Type C Traffic Area for the main gear plus 3 meters (10 feet) on each side. The remainder of the access apron shall be Light Load Type C Traffic Area.

(3) Light-load and auxiliary airfields.

(a) Full width of runway interior between the 305-meter (1,000-foot) runway ends and secondary (ladder) taxiways.

(b) Hangar access aprons and floors.

(c) Washrack pavements.

(4) Assault landing zone. No Type C traffic areas.

d. Type D Traffic Areas. Type D traffic areas are those in which the traffic volume is extremely low and/or the applied weight of operating aircraft is considerably lower than the design weight. The pavement facilities considered to be Type D traffic areas are the edges of runways that are designed for heavy-load, medium-load, and modified heavy-load airfields. Aircraft on heavy-, modified heavy-, or medium-load runways seldom, if ever, operate outside of the center 23-meter (75-foot) width of the runway interior, and the only traffic that will occur on the edges of the runway will be occasional heavy, medium, or modified heavy aircraft loads or frequent light aircraft loads. Therefore, a substantial reduction in required pavement thickness can be made. Pavement facilities considered to be Type D traffic areas are as follows:

(1) Heavy-load airfields. The outside edges of the entire length of runway, except for the approach and exit areas at taxiway intersections, are Type D traffic areas.

(2) Medium-load and modified heavy-load airfields. The outside edges of the entire length of runway except for the approach and exit areas at taxiway intersections are Type D traffic areas.

(3) Light-load and auxiliary airfields. There are no Type D traffic areas on light-load or auxiliary pavements.

(4) Assault landing zone. No Type D traffic areas.

3. AIRCRAFT DESIGN LOADS FOR AIR FORCE PAVEMENTS. The design loads for light, medium, heavy, modified heavy, auxiliary, and assault landing zone airfield pavements have been established by the Air Force and are shown in Table 3-1. The concept is to design each airfield type for a mixture of aircraft traffic at the loads shown. These loads represent the design gross weights for each type traffic area and overruns on the airfield. Aircraft hangar floors or apron pavements shall not be designed for jacking loads as long as the foot print of the jack is equal to or greater than the contact area of the combined tires on the aircraft gear being elevated.

4. DESIGN PASS LEVELS FOR AIR FORCE PAVEMENTS. Aircraft traffic data reports indicating type and frequency of aircraft traffic at selected Air Force bases have been analyzed to establish criteria to be used in the design of airfield pavements. These design pass levels are shown in Table 3-1 for the different traffic areas and aircraft types. Airfield pavements may be designed for alternate pass levels if dictated by the intended use of the facility and subject to the approval of the appropriate Air Force Major Command.

5. RESIN MODIFIED PAVEMENT. Resin Modified Pavement (RMP) can be used as an Air Force pavement except for runways and high-speed taxiways. RMP can be used for helipads and heliport pavements and for both rotary-wing and fixed-wing aprons.

6. PAVED SHOULDERS.

a. Location. Paved shoulders should be provided for airfield and heliport construction as designated in UFC 3-260-01.

b. Structural Requirements. As a minimum, paved shoulders shall be designed to support a load of 4,535 kilograms (10,000 pounds) imposed by a single wheel with a tire pressure of 0.69 MPa (100 psi). When shoulder pavements are to be used by support vehicles (snow removal equipment, fire trucks, fuel trucks, etc.), the shoulders should be signed accordingly for whichever governs.

7. AGGREGATE SURFACED HELICOPTER SLIDE AREAS AND HELIPORTS. Geometric and structural criteria for the design of aggregate surfaced helicopter slide areas and heliports are listed below. These criteria are applicable to all Air Force organizations with pavement design and construction responsibilities.

a. Geometric Criteria. Geometric criteria can be found in UFC 3-260-01.

b. Structural Criteria. Airfield structural design criteria are presented below.

(1) Thickness (Non-Frost Areas). Factors which determine thickness are the California Bearing Ratio (CBR) of the subgrade, helicopter weight, and passes. The minimum required thickness is 150 millimeters (6 inches). Use Figure 3-6 for design of aggregate surface thickness for helicopters. Enter Figure 3-4 with the subgrade CBR (see Chapter 6 for selection of subgrade CBR) to determine the thickness required for a given load and pass level. The thickness determined from the figure may be constructed of surface course material for the total depth over the natural subgrade; or in a layered system consisting of select material, subbase, and surface course over compacted subgrade for the same total depth. Check the layered section to ensure sufficient material protects the underlying layer, based upon the CBR of the underlying layer. The top 150 millimeters (6 inches) must meet the gradation requirements of Table 3-2.

(2) Select Materials and Subbases. Select design CBR values materials and subbases in accordance with Chapter 7, except as modified in Table 3-3.

(3) Thickness (Frost Areas). In areas where frost effects impact pavement design, there are additional considerations concerning thicknesses and required layers in the pavement structure. For frost design, soils are divided into eight groups as shown in Table 3-4. Only the non-frost-susceptible (NFS) group is suitable for base course. NFS, S1, or S2 soils may be used for subbase course, and any

Table 3-1
Design Gross Weights and Pass Levels for Airfield Pavements

Airfield Type	Design Aircraft	A Traffic Area Weight Pounds	A Traffic Area Passes	B Traffic Area Weight Pounds	B Traffic Area Passes	C Traffic Area[1] Weight Pounds	C Traffic Area[1] Passes	D Traffic Area[1] Weight Pounds	D Traffic Area[1] Passes	Overruns[1] Weight Pounds	Overruns[1] Passes	Shoulder
Light	F-15 C/D	68,000	400,000	68,000	400,000	51,000	400,000	NA	NA	51,000	4,000	Shoulders are designed to support 5,000 coverages of a 10,000 pound single-wheel load having a tire pressure of 100 psi.
	C-17	580,000	400	580,000	400	435,000	400			435,000	1	
Medium	F-15 E	81,000	100,000	81,000	100,000	60,750	100,000	60,750	1,000	60,750	1,000	
	C-17	580,000	400,000	580,000	400,000	435,000	400,000	435,000	4,000	435,000	4,000	
	B-52[2]	400,000	400	400,000	400	300,000	400	300,000	4	300,000	4	
Heavy	F-15 E	81,000	100,000	81,000	100,000	60,750	100,000	60,750	1,000	60,750	1,000	
	C-17	580,000	200,000	580,000	200,000	435,000	200,000	435,000	2,000	435,000	2,000	
	B-52	480,000	120,000	480,000	120,000	360,000	120,000	360,000	1,200	360,000	1,200	
Modified Heavy	F-15 E	81,000	100,000	81,000	100,000	60,750	100,000	60,750	1,000	60,750	1,000	
	C-17	580,000	200,000	580,000	200,000	435,000	200,000	435,000	2,000	435,000	2,000	
	B-1	480,000	120,000	480,000	120,000	360,000	120,000	360,000	1,200	360,000	1,200	
Assault Landing Zone	C-130	175,000	50,000 per squadron	NA	NA	NA	NA	NA	NA	175,000	50,000 per squadron	
	C-17	502,000	100,000	NA	NA	NA	NA	NA	NA	502,000	100,000	
Auxiliary	F-15	Design loads and passes are determined by the major command.										

[1] The design gross weights for Types C and D traffic areas and overruns are 75 percent of the design gross weights for Types A and B traffic areas. Pass levels for Type D traffic areas and overruns are one percent of the pass levels forType A traffic area. Assault landing zone overruns are designed the same as rest of pavement.

[2] B-52 aircraft will not be included in the mixed traffic design of medium load airfields with less than 200-foot-wide runways.

Conversion Factors
Kilograms = 0.453 × pounds
Megapascals = 0.006894 × psi
Meters = 0.3048 × feet

Table 3-2
Gradation for Aggregate Surface Courses (Percent Passing)

Sieve Designation	No. 1	No. 2	No. 3	No.4
25.0 mm (1”)	100	100	100	100
9.5 mm (3/8”)	50-85	60-100		
No. 4	35-65	50-85	55-100	70-100
No. 10	25.50	40.70	40-100	55-100
No. 40	15.30	24-45	20-50	30-70
No. 200	8-15	8-15	8-15	8-15

Note: The percent by weight finer than 0.02 millimeter (0.04 inch) shall not exceed 3 percent.

Table 3-3
Maximum Permissible Values for CBR and Gradation Requirements

Material	Maximum CBR	Maximum Size	Maximum % Passing		Maximum Liquid Limit*	Maximum Plasticity Index*
			#10	#200		
Subbase	50	50 mm (2”)	50	15	25	5
Subbase	40	50 mm (2”)	80	15	25	5
Subbase	30	50 mm (2”)	100	15	25	5
Select Material	20	75 mm (3”)	--	--	35	12

* ASTM D 4318.

Table 3-4
Frost Design Soil Classification

Frost Group	Type Soil	Percentage Finer Than 0.02 mm (0.04”) by Weight	Unified Soil Classification Soil Types***
NGS*	(a) Gravels Crushed Stone Crushed rock	0-1.5	GW, GP
	(b) Sands	0-3	SW, SP

(Continued)

Table 3-4 (Concluded)

Frost Group	Type Soil	Percentage Finer Than 0.02 mm (0.04”) by Weight	Unified Soil Classification Soil Types***
PFS*	(a) Gravels Crushed Stone Crushed rock	1.5-3	GW, GP
	(b) Sands	3-10	SW, SP
S1	Gravelly soils	3-6	GW, GP, GW-GM, GP-GM
S2	Sandy soils	3-6	SW, SP, SW-SM, SP-SM
F1	Gravelly soils	6-10	GM, GW-GM, GP-GM
F2	(a) Gravelly soils	10-20	GM, GW-GM, GP-GM
	(b) Sands	6-15	SM, SW-SM, SP-SM
F3	(a) Gravelly soils	over 20	GM, GC
	(b) Sands, except very fine silty sands	over 15	SM, SC
	(c) Clays, PI 12	--	CL, CH
F4	(a) Gravelly soils	--	ML, MH
	(b) Sands, except very fine silty sands	over 15	SM
	(c) Clays, PI 12	--	CL, CL-ML
	(d) Verved clays and other fine grained banded sediments	--	CL, ML, SM and CH

* Nonfrost-susceptible.
** Possible frost-susceptible, but requires laboratory test to determine frost design soil classification.
*** Defined in AFM 89-3, *Materials Testing*.

of the eight groups may be found as subgrade soils. Soils are listed in approximate order of decreasing bearing capability during periods of thaw.

(a) Required Thickness. Where there are frost-susceptible subgrades, determine section thickness according to the reduced subgrade strength method. The reduced 3-5 subgrade strength method uses the frost area soil support indexes (FASSI) in Table 3-5. Use FASSI like CBR values. The term CBR is not applied, because FASSI are weighted average values for an annual cycle and their values cannot be determined by CBR tests. Enter Figure 3-4 with the soil support indexes (vice CBR values) to determine the required section thickness.

Table 3-5
Frost Area Soil Support Indices (FASSI) of Subgrade Soils

Frost Group	FASSI
F1 and S1	9.0
F2 and S2	6.5
F3 and F4	3.5

(b) Pavement Section Layers. When frost is a consideration, recommend the pavement section consist of layers that will ensure the stability of the system, particularly during thaw periods. The layered system may consist of a 150-millimeter- (6-inch-) thick minimum wearing surface of fine crushed stone, a coarse-graded base course, and/or a well-graded subbase of sand or gravely sand. To ensure the stability of the wearing surface, the width of the base course and subbase should exceed the final desired surface width by a minimum of 0.35 meter (1 foot) on each side.

(c) Wearing Surface. The wearing surface contains fines (material passing the #200 sieve) to provide stability in the aggregate surface. The presence of fines improves the layer's compaction characteristics and helps to provide a relatively smooth surface.

(d) Base Course. The coarse-graded base course is important in providing drainage of the granular fill. Base course should be non-frost-susceptible to retain strength during spring thaw periods.

(e) Subbase. A well-graded subbase provides additional bearing capacity over the frost-susceptible subgrade. It also provides a filter layer between the coarsegraded base course and the subgrade to prevent migration of the subgrade into the voids in the coarser material during periods of reduced subgrade strength. Therefore, the material must meet standard filter criteria. The subbase must be either non-frost susceptible or of low frost susceptibility (SI or S2), The filter layer may or may not be necessary depending upon the type of subgrade material. If the subgrade consists principally of gravel or sand, the filter layer may not be necessary, and may be replaced by additional base course if the gradation of the base course meets filter criteria. For finer grained soils, the filter layer will be necessary. If using a geotextile, the sand subbase/filter layer may be omitted, as the fabric will be placed directly on the subgrade and acts as a filter.

(f) Compaction. The subgrade should be compacted to provide uniformity of conditions and a working platform for placement and compaction of subbase. Compaction will not change a subgrade's frost-area soil support index. However, because frost weakens the subgrade, compacted subgrade in frost areas will not be considered part of the layered system of the airfield, which should be comprised of only the wearing, base, and subbase courses.

(g) Base Course and Filter Layer. Relative thicknesses of the base course and filter layer vary, and should be based on the required cover and economic considerations.

(h) Alternate Design. The reduced subgrade strength design provides a soil thickness above a frost-susceptible subgrade which minimizes frost heave. For a more economical design, a frost-susceptible select material or subbase may be used as a part of the total thickness above the frost-susceptible subgrade. However, thickness above the select material or subbase must be determined by using the FASSI of the select or subbase material. Frost-susceptible soils used as select materials or subbases must meet current specifications; the restriction on the allowable percent finer than 0.02 mm is waived.

(4) Surface Course. Materials requirements for construction of aggregate surfaced airfields depend upon whether frost is a factor in the design.

(a) Nonfrost Areas. Material used for airfields should be sufficiently cohesive to resist abrasive action. It should have a liquid limit no greater than 35 and a plasticity index between 4 and 9. It also should be graded for maximum density and minimum volume of voids to enhance optimum moisture retention while resisting excessive water intrusion. Gradation should consist of an optimal combination of coarse and fine aggregates to ensure minimum void ratios and maximum density. This material will exhibit cohesive strength as well as intergranular shear strength. Recommended gradations are shown in Table 3-6. If the fines fraction of the material does not meet plasticity characteristics, the material may be modified by adding chemicals. Chloride products can, in some cases, enhance moisture retention, and lime can be used to reduce excessive plasticity.

(b) Frost Areas. Where frost is a consideration, a layered system should be used. The percentage of fines should be restricted in all the layers to facilitate drainage and reduce the loss of stability and strength during thaw periods. Use gradation numbers 3 and 4 shown in Table 3-6 with caution, since they may be unstable in a freeze-thaw environment.

Table 3-6
Gradation for Aggregate Surface Courses (Percent Passing)

Sieve Designation	No. 1	No. 2	No. 3	No.4
25.0 mm (1”)	100	100	100	100
9.5 mm (3/8”)	50-85	60-100	--	--
No. 4	35-65	50-85	55-100	70-100
No. 10	25.50	40.70	40-100	55-100
No. 40	15.30	24-45	20-50	30-70
No. 200	8-15	8-15	8-15	8-15

Note: The percent by weight finer than 0.02 mm (0.04 in.) shall not exceed 3 percent.

(5) Compaction. Compaction requirements for the subgrade and granular layers are expressed as a percent of maximum CE 55 density as determined by using CRD-C653, *Standard Test Method for Determination of Moisture-Density Relations of Soils*. For granular layers, compact the material to 1 00 percent of maximum CE 55 density. Select materials and sub-qrades in fills must have densities equal to or greater than the values shown in Table 3-7, except that fills will be placed at no less than 95 percent compaction for cohesionless soils (PI - 5; LL 25) or 90 percent compaction for cohesive soils (PI > 5; LL > 25). Subgrades in cuts must have densities equal to or greater than the values shown in Table 3-7. Subgrades occurring in cut sections will be either compacted from the surface to meet the densities shown in Table 3-7 removed and replaced before applying the requirements for fills, or covered with sufficient material so that the uncompacted subgrade will be at a depth where the in-place densities are satisfactory. Depths in Table 3-7 are measured from the surface of the aggregate, and not the surface of the subgrade.

Table 3-7
Compaction Requirements for Helicopter Pads and Slide Areas

	Cohesive Soils					Cohesionless Soils			
Percent	100	95	90	85	80	100	95	90	85
Depth Below Pavement Surface, millimeters	100	150	200	250	300	150	250	325	400
(inches)	(4)	(6)	(8)	(10)	(12)	(6)	(10)	(13)	(16)

c. Drainage. Drainage is a critical factor in aggregate surface airfield design, construction, and maintenance. It should be considered prior to construction; and, when necessary, serve as a basis for site selection.

(1) Provide adequate surface drainage to minimize moisture damage. Quick removal of surface water reduces absorption and ensures more consistent strength and reduced maintenance. Drainage must not result in damage to the aggregate surfaced airfield through erosion of fines or erosion of the entire surface layer. Ensure changes to the drainage regime can be accommodated by the surrounding topography without damage to the environment, or the newly constructed slide area or pad.

(2) The surface geometry of an airfield should be designed so that drainage is provided at all points. Depending upon the surrounding terrain, surface drainage can be achieved by a continual cross slope, or by a series of two or more interconnecting cross slopes.

(3) Provide adequate drainage outside the airfield area to accommodate maximum flow. Use culverts sparingly, and only in areas where adequate cover of granular fill is provided over the culvert. Evaluate drainage for adjacent areas to determine if rerouting is needed to prevent water from other areas flowing across the airfield.

d. Maintenance. The two primary causes of deterioration of aggregate surfaced areas requiring frequent maintenance are the environment and traffic. Rain or water flow will wash fines from the aggregate surface; traffic action causes erosion of surface materials. Maintenance should be performed at least every six months, and more frequently if required. Frequency of maintenance will be high for the first few years of use, but will decrease over time to a constant value. Most of the maintenance will consist of grading to remove ruts and potholes and replacing fines. Occasionally, the surface layer may have to be scarified, additional aggregate added to restore original thickness. and the wearing surface recompacted to the specified density.

e. Dust Control. A dust palliative prevents soil particles from becoming airborne as a result of wind or traffic. Dust palliatives used on traffic areas must withstand abrasion. An important factor limiting use of dust palliatives in traffic areas is the extent of surface rutting or abrasion that will occur under traffic. Some palliatives will tolerate deformations better than others, but ruts in excess of 13 millimeters (1/2 inch) will usually destroy any thin layer or shallow-depth penetration dust palliative treatment. A wide selection of materials for dust control is available, Several materials have been recommended for use and are discussed in AFJMAN 32-1019.

8. SURFACE DRAINAGE. Design of surface drainage shall be in accordance with TM 5-820-1/ AFM 88-5, Chapter 1.

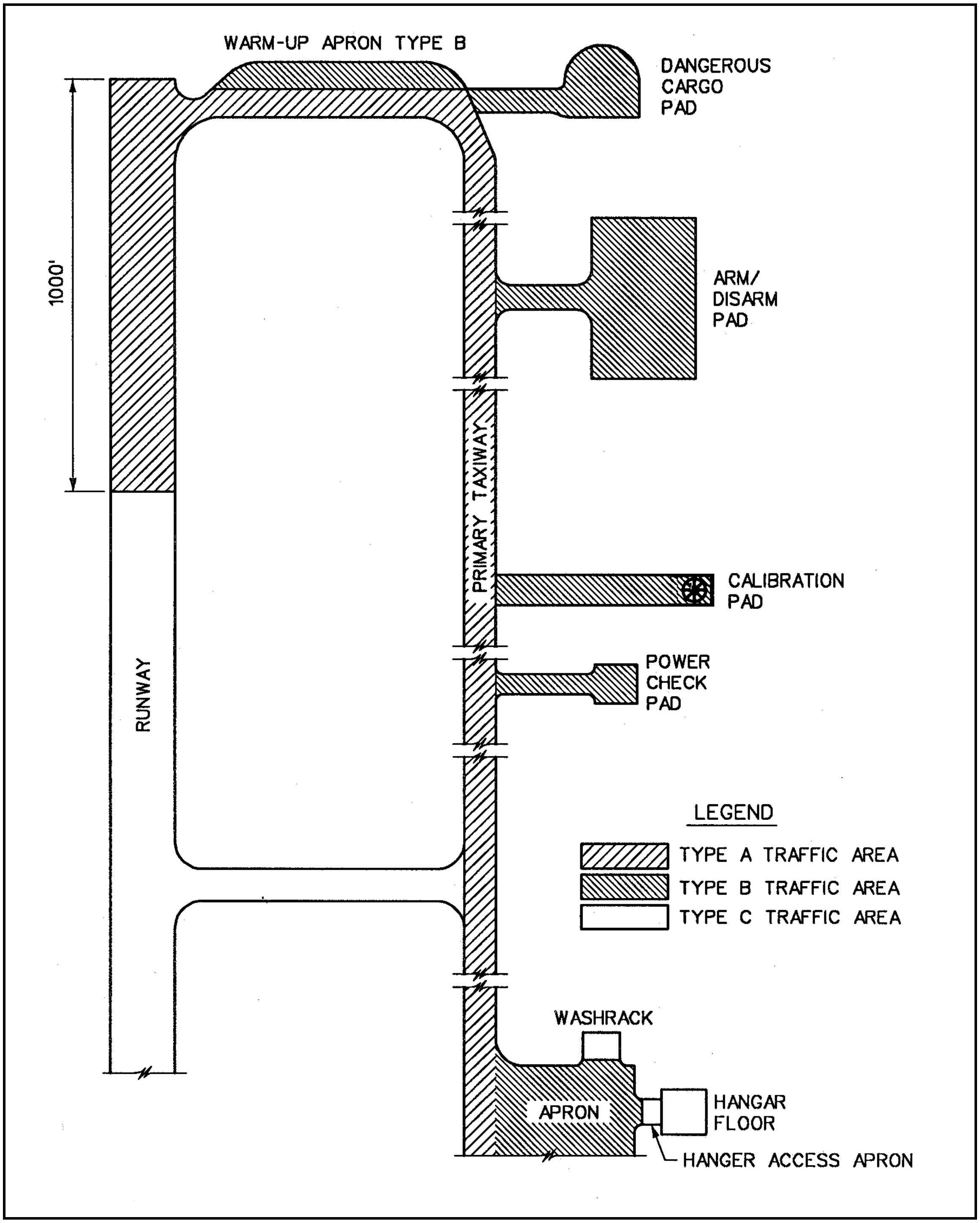


Figure 3-1. Typical layout of traffic areas for Air Force light-load and auxiliary airfield pavements

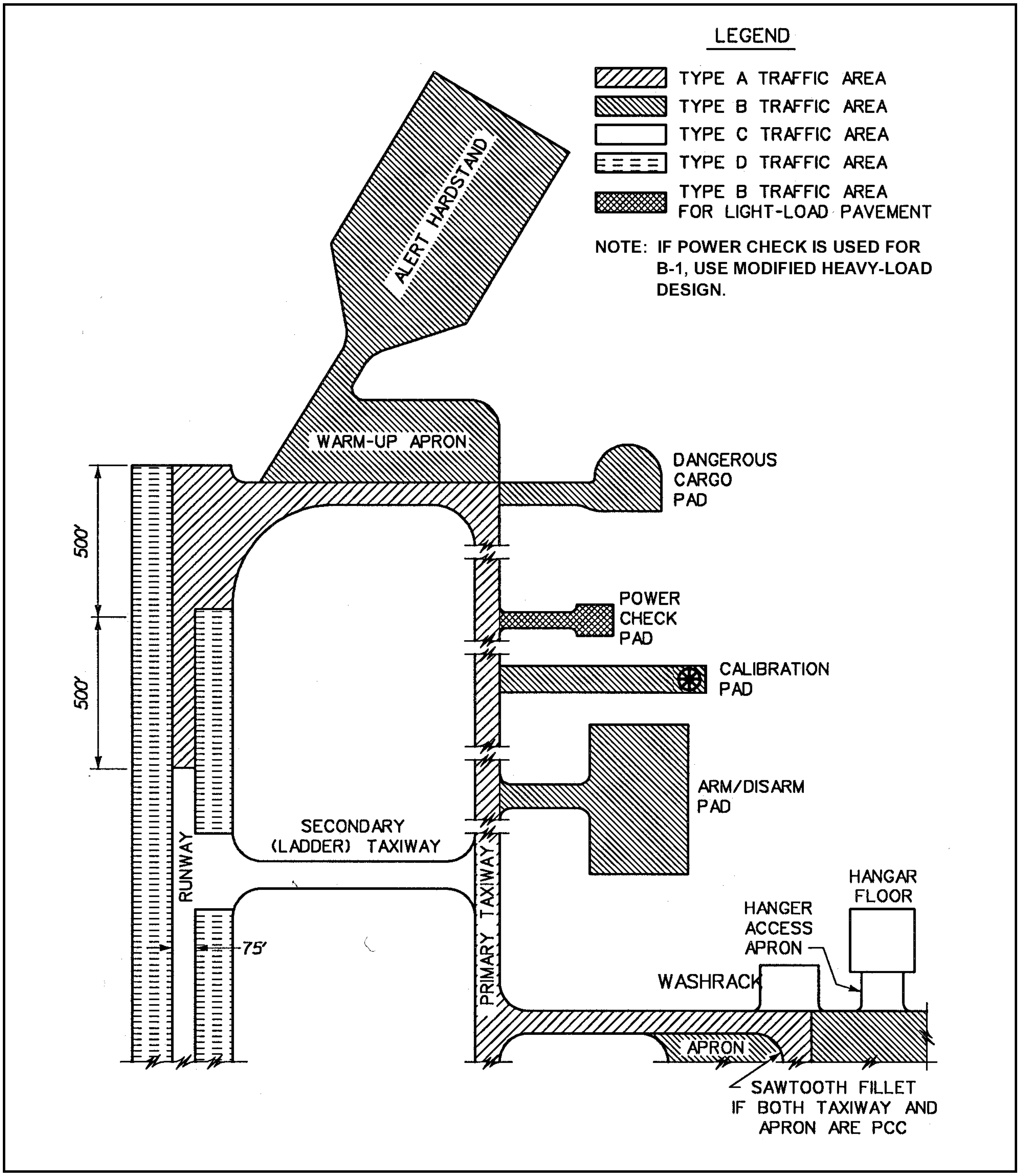


Figure 3-2. Typical layout of traffic areas for Air Force medium- and modified-heavy-load airfield pavements

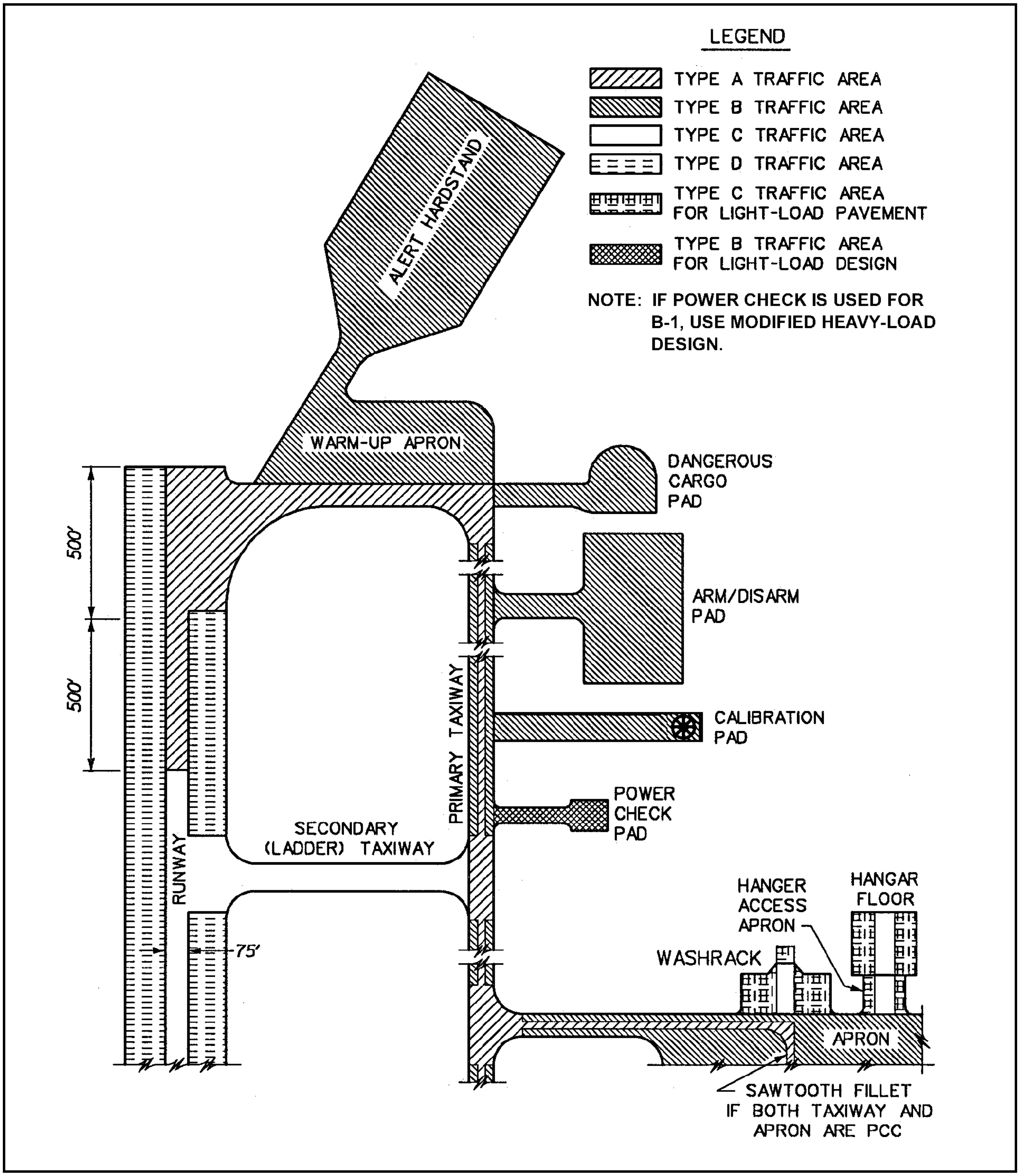
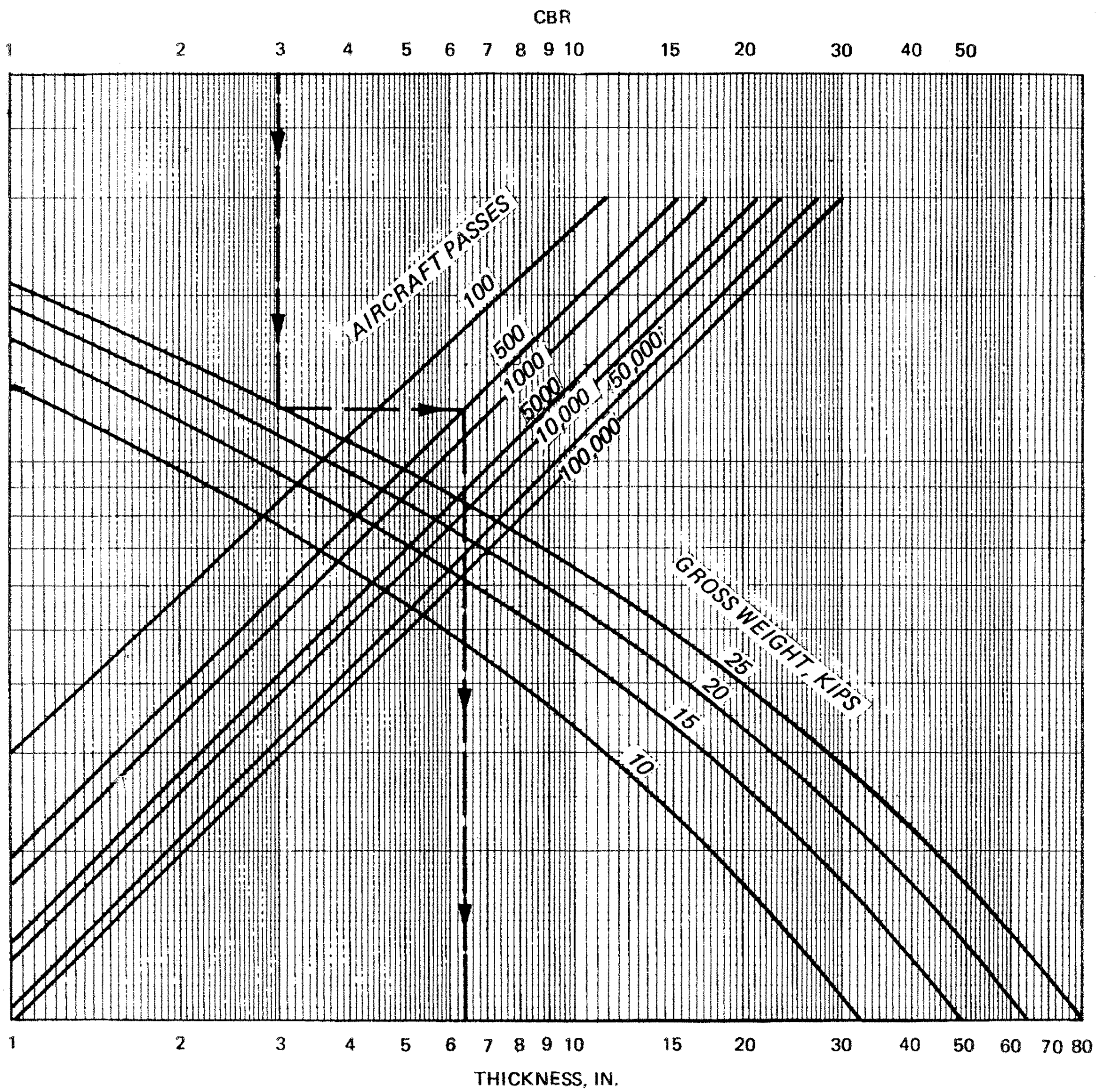


Figure 3-3. Typical layout of traffic areas for Air Force heavy-load airfield pavements



CONVERSION FACTORS
MILLIMETERS = 25.4 X INCHES
KILOGRAMS = 0.4535 X POUNDS

Figure 3-4. Aggregate surfaced design curves for helicopters

CHAPTER 4

NAVY AND MARINE CORPS AIRFIELD REQUIREMENTS

1. TRAFFIC. Traffic is an important input for pavement thickness design. An airfield pavement shall be designed to support a forecast number of loadings by one or more types of aircraft expected to use the facility over the design period. This requires information related to:

a. Aircraft types (gear configurations).

b. Maximum gross weight of each aircraft type.

c. Lateral wander associated with each aircraft type.

d. Predicted number of operations of each aircraft type over the design life of the pavement.

2.T RAFFIC AREAS. Airfield pavements are categorized by traffic area as a function of either lateral traffic distribution or aircraft weight or both. The three principal traffic areas recognized on Navy and Marine Corps air stations are primary, secondary, and supporting. For purposes of standardization and for preparation of the Tri-Service design criteria, a primary area corresponds to an Air Force B traffic area and a secondary traffic area corresponds to an Air Force C traffic area. These designated traffic areas for a typical airfield layout plan are shown in Figure 4-1.

a. Primary Traffic Areas. Primary traffic areas require high pavement strength due to the combination of high operating weights and channelized traffic. Primary traffic areas include:

(1) First 305 meters (1,000 feet) of runways.

(2) Primary taxiways.

(3) Holding areas.

(4) Aprons.

b. Secondary Traffic Areas. Secondary traffic areas are normally subjected to unchannelized traffic and aircraft operating at lower weights than primary traffic areas. Secondary traffic areas include:

(1) Runway interiors.

(2) Intermediate taxiway turnoffs.

c. Supporting Areas. Supporting areas are not intended for normal aircraft operations. They are designed to withstand occasional passes of aircraft on an emergency basis. Supporting traffic areas include:

(1) Inner 3 meters (10 feet) of runway shoulders.

(2) Stabilized portions of runway overruns.

(3) Blast protective pavement.

3.AIRCRAFT LOADINGS. Factors which must be considered in pavement thickness design are the landing gear configuration, weight distribution, gear loads, number of wheels, wheel spacing, tire width, and tire inflation pressure. These characteristics are different for each aircraft and will result in a different pavement response. All aircraft expected to use the facility over the design period shall be considered in the pavement thickness design.

a. Aircraft Types. A landing gear assembly shall consist of a single wheel for smaller aircraft, or dual and dual tandem wheels for larger aircraft. Figure 4-2 illustrates the various multiwheel landing gear assemblies and lists typical aircraft for each.

b. Design Weight. The maximum static gear loads are used for pavement thickness design. Table 4-1 presents the design gear loads and other characteristics for Navy and Marine Corps aircraft. To use the design curves herein, the design gear load must be converted to the design gross aircraft weight (typically, the maximum gross take-off weight) by assuming that 95 percent of the gross aircraft weight is carried by the main gears. The design gear loads given in Table 4-1 represent the maximum static gear loads expected to be applied to a pavement.

c. Use of Other Gear Loads in Design. Gear loads other than those listed in Table 4-1 may be used for design when required. Since certain areas of an airfield (e.g., runway shoulders, runway overruns) do not normally carry fully loaded aircraft, they do not need to be designed for the maximum gross weight.

d. Hangar Floors. Aircraft in hangars are not normally loaded with cargo, fuel, or armaments. Hangar floors shall be designed for the empty weight of the aircraft. When exact data are not available, 60 percent of the maximum gross weight of the aircraft shall be used. Aircraft hangar floors or apron pavements shall not be designed for jacking loads as long as the foot print of the jack is equal to or greater than the contact area of the combined tires on the aircraft gear being elevated.

e. Standard Design Aircraft. One aircraft in each gear assembly group has been designated the representative aircraft for that group. The tabulation below identifies these five standard aircraft types which are to be used as default values in the design of rigid and flexible pavements only when site-specific aircraft loadings are not available.

Standard Design Aircraft Types

Landing Gear Assembly	Representative Aircraft	Tire Pressure Mpa (psi)	Design Gear Load, kg (lb)
Single	F-14	1.65 (240)	13,608 (30,000)
Dual	P-3	1.31 (190)	30,845 (68,000)
Single Tandem	C-130	0.65 (95)	38,100 (84,000)
Dual Tandem	C-141	1.24 (180)	70,310 (155,000)
Twin Delta Tandem	C-5A	0.79 (115)	86,190 (190,000)

Table 4-1
Aircraft Characteristics and Design Loadings

Type	DOD Designation	Type of Loading Gear	Design Gear Load (lb)	Design Tire Pressure (psi)	Pass/Coverage[3] Chan.	Pass/Coverage[3] Unchan.	Empty Weight (lb)	Maximum Take-off Weight (lb)	Wing Span (ft)	Length (ft)	Wheel Base (in.)	Tread (in.)	Main Gear Tire Spacing A (in.)[4]	Main Gear Tire Spacing B (in.)[5]
Attack	A-3B	S	37,000	245	3.48	14.96		78,000	72.5	76.4			--	--
	A-4M	S	12,500	200	11.63	23.26	10,500	24,500	27.5	41.25	160.5	93.5	--	--
	A-5	S	29,500	300	9.27	18.54	38,000	80,000	53.3	76.5	264.0	150.5	--	--
	RA-5C	S	38,000	350	8.82	17.64	38,800	81,700	53.3	76.5	264.0	150.5	--	--
	A-6E	S	28,700	200	7.67	15.35	36,600	60,400	53.0	55.75	206.0	132.0	--	--
	A-7K	S	21,000	200	8.97	13.91	21,800	42,000	38.7	46.1	188.1	113.9	--	--
	AV-8B	Special	15,000	125	3.89	7.47	12,000	24,000	30.3	45.7	135.0			
Fighter	F-4E	S	22,500	300	13.70	27.39	31,800	58,000	38.4	58.3	279.0	215.0	--	--
	F-8E	S	18,000	265	13.69	27.39	19,700	34,300	85.7	54.5			--	--
	F-14	S	30,000	240	8.58	17.00	36,700	72,600	64.1	61.98	276.5	192.0	--	--
	F/A-18	S	21,000	200	8.22	16.44	30,000	51,900	40.4	56.0	213.7		--	--
Trainer	T-1	S	9,000	200	13.69	27.39							--	--
	T-2C	S	7,000	165	14.10	28.20	8,000	14,000	37.9	38.8	155.0	221.0	–	–
	TC-4C	T		123				36,000	78.3	67.9		290.0	–	–
	TA-4F/J	S		350				24,500	27.5	46.2			--	--
	T-39A	S	9,000	165	12.45	24.89	10,000	18,700	44.4	43.8	174.0	86.0	--	--
	T-28D	S	4,300	60	10.85	21.02	6,700	9,000	41.0	33.0	144.0	162.0	--	--
	T-34C	S	1,500	60			2,200	3,000	33.3	28.8			--	--
	T-44A	S	4,500	90	12.99	24.75	6,300	9,600	50.3	35.5	147.5	153.0	–	–
	T-45A	S		125	11.68	22.31		14,500	30.8	39.3	170.0	154.0	--	--
Patrol	P-3C	TT	68,000	190	3.45	6.49	66,200	143,000	99.7	116.8	357.0	374.0	26.0	--
	S-3A	S	19,000	245	10.43	20.87	26,864	46,000	68.7	53.3	225.0	165.0	--	--
Transport and Tanker	C-1A	S		142			20,640	26,800	69.7	42.3	106.9	222.0	–	–
	C-2A	S		235	7.91	15.69		60,000	80.6	56.8	278.4	234.0	–	–
	C-5A	TDT	190,000	115	0.83	1.05	318,000	837,000	222.7	247.8	765.1	449.5		
	C-17	TRT	260,000		1.37	1.9	279,000	580,000	2088.0	2038.0			--	--
	C-121	T	81,000	170	3.45	6.18			123.0	113.6	599.0	336.0	28.0	--
	C-130	ST	84,000	95	4.36	8.56	72,000	175,000	132.6	97.8	388.0	171.0	--	60.0
	KC-10	SBTT	212,000	181	3.77	5.59	271,000	599,000	165.3	182.3	869.0	416.0	--	--
	KC-135	TT	142,000	155	3.37	5.97	104,300	301,600	130.8	136.3	708.0	265.0	35.8	59.8
	C-141B	TT	155,000	180	3.49	6.25	140,000	344,900	160.0	145.0	678.7	251.0	32.5	48.0
	C-9B	T	51,300	152	3.85	7.18	62,000	108,000	93.3	119.3	638.5	196.0	25.0	--
	C-117	S	15,300	56	5.56	11.11		36,800	85.0	64.4	440.0	222.0	--	--
	C-118A	T	54,300	124	3.48	6.39	59,000	112,000	117.5	106.8	432.0	296.5	29.0	--
Bomber	B-52	TTB	250,000	240	1.58	2.15	230,000	480,000	185.0	162.0	597.0	136.0	62.0	--

(Continued)

S = Single Tricycle, T = Dual Tricycle, TDT = Twin Delta Tandem, ST = Single Tandem Tricycle, TT = Dual Tandem Tricycle

NOTES:
1. Blank spaces indicate data not readily available.
2. This data represents the best available figures at the time of publication. The user should update this information for later models of the design aircraft.
3. Values given are for rigid and flexible pavements. Pass to Coverage Ratios for flexible pavements for aircraft with Dual Tandem Tricycle Gear are equal to one-half the value shown. All Tandem Wheel Aircraft produce only one maximum stress for each pass of the gear for rigid pavements.
4. A represents the transverse tire spacing on one main gear.
5. B represents the longitudinal tire spacing on one main gear.

Table 4-1 (Concluded)

Type	DOD Designation	Type of Loading Gear	Design Gear Load (lb)	Design Tire Pressure (psi)	Pass/Coverage[3] Chan.	Pass/Coverage[3] Unchan.	Empty Weight (lb)	Maximum Take-off Weight (lb)	Wing Span (ft)	Length (ft)	Wheel Base (in.)	Tread (in.)	Main Gear Tire Spacing A (in.)[4]	Main Gear Tire Spacing B (in.)[5]
Commercial	B-707	TT	157,000	180	3.30	5.87	146,400	333,600	145.8	152.9	708.0	265.0	34.5	56.0
	B-727	T	98,000	150	3.30	5.88	101,500	209,500	108.0	153.6	760.0	225.0	34.0	--
	B-737	T	54,000	150	3.20	5.80	60,500	125,000	93.0	100.0	447.0	206.0	30.5	--
	B-747	DDT	190,000	195	3.84	5.43	363,000	778,000	195.7	231.3	1,008.0	434.0	43.25	54.0
	B-757-200	TT	105,000	170	3.30	5.88	129,900	220,000	124.5	155.3				
	B-767-200	TT	143,000	183	3.71	6.05	180,540	300,000	156.3	159.1				
	DC-8	TT	172,000	196	3.19	5.82		350,000	148.5	187.4	930.0	250.0	30.0	55.0
	DC-9 Series 10	T	57,000	170	3.61	6.73	50,840	90,500	89.4	104.4	524.4	196.8	24.0	--
	DC-10 Series 30	TT	210,500	165	3.77	5.61	267,197	572,000	165.3	181.6	868.6	429.0	54.0	64.0
	(Center Dual)		91,100	140	2.63	3.96	248,485	466,000						
	L-1011-200	TT	219,000	165	3.66	5.57	249,100	450,000	155.3	177.8	840.0	432.0	52.0	70.0
Early Warning	E-1B	S		151				27,400	72.3	45.2			–	–
	E-2C	S	24,500	260	8.58	17.00	38,100	51,900	80.6	57.6	278.0	233.8	--	--
	E-3A	TT	155,000	180	3.30	5.87	88,000	325,000	145.8	152.9	708.0	265.0	34.5	56.0
	EA-6B	S		230				61,500	53.0	59.8			--	--
	EP-3E	T						142,000	99.7	105.9			--	--
	ES-3A	S		245			34,000	52,500	68.7	53.3	225.0	165.0	--	--
Reconnaissance	UC-12M	S		64				13,500	54.5	43.8	179.4	206.0	--	--
Rotary Wing	AH-1W						10,200	14,750	48.0	58.0	146.4	84.0	--	--
	CH-46E	T			8.01	15.22	16,000	24,300	51.0	84.3	297.6	176.4	20.0	–
	CH-53E	T	26,558	165			33,226	69,750	79.0	90.0	327.0	156.0		
	HH-3A	T						19,100	62.0	72.9	282.5	156.0	--	--
	HH-60H	S			11.94	19.49		21,880	53.7	64.8		104.0	--	--
	MH-53E	T			5.23	9.53	36,745	69,750	79.0	99.0		156.0	15.0	--
	RH-53D	T			5.23	9.53		42,000	72.2	88.6		156.0	15.0	--
	SH-3H	T						21,000	62.0	72.9	282.5	156.0	--	--
	SH-60F	S			11.94	19.49		21,880	53.7	64.9		104.0	–	--
	TH-57B/C							3,350	33.3	39.2	56.5	75.5	–	–
	UH-1N							10,500	48.0	57.3		109.0	–	–
	UH-3H							21,000	62.0	72.9	282.5		–	–
	UH-46E	T	9,800	150			12,550	22,800	51.0	84.4	298.0	176.4		
	VH-3A							19,100	62.0	72.9		156.0	--	--
VTOL	MV-22	T		117	4.72	8.66		57,000	1014.6	747.2	3000.0	156.0	--	--

4.T RAFFIC VOLUME. The traffic type, volume, and pavement design life are essential inputs to the pavement design procedure. Determine the total number of passes of each aircraft type that the pavement will be expected to support over its design life. The minimum design life for Navy and Marine Corps facilities is 20 years. Only aircraft departures are normally included as passes in pavement thickness design. The exception to this is in touchdown areas on runways where the impact due to aircraft performing touch-and-go operations will cause pavement damage. On pavements that are to be used for touch-and-go operations, add the expected number of touch-and-go operations over the design life to the number of departures to arrive at the design traffic. Obtain data for the specific Navy and Marine Corps airfield facility under design to forecast aircraft traffic operations over the design life of the pavement. When site-specific traffic projections are not available, the traffic pass levels listed below are the minimum pass levels to be used in design.

Aircraft	**Total Passes Over 20 Year Design Life**[1]
F-14	300,000
P-3	100,000
C-130	50,000
C-141	25,000
C-5A	25,000

[1] Departures at Maximum Gross Weight.

5.RO LLER-COMPACTED CONCRETE PAVEMENT. Roller-compacted concrete pavement (RCCP) is a rigid pavement and can be used as pavement except for runway and high-speed taxiway pavements for fixed-wing aircraft. RCCP can be used for all helipad and heliport pavements.

6.RESIN MODIFIED PAVEMENT. Resin Modified Pavement (RMP) can be used as an Navy pavement except for fixed-wing runways and high-speed taxiways. RMP can be used for helipads and heliport pavements and for both rotary-wing and fixed-wing parking aprons.

7.PAVED SHOULDERS.

a. Location. Paved shoulders should be provided for airfield and heliport construction as designated in EI 02C013/AFJMAN 32-1013/NAVFAC P-971.

b. Structural Requirements. As a minimum, paved shoulders shall be designed to support a load of 4,535 kilograms (10,000 pounds) imposed by a single wheel with a tire pressure of 0.69 MPa (100 psi).

8.PAVEMENT DESIGN POLICY. The Navy recognizes PCASE rigid and flexible pavement design programs and consensus industry standard programs in addition to the traditional Navy rigid pavement design program. Designers are encouraged to consider life cycle costs when designing new pavements. When the life of the pavement can be extended by more than 10 times, it is acceptable to increase the pavement thickness by 1 inch or less as determined by the Navy's traditional rigid pavement center panel loading procedure. Use of the Army/Air Force edge loading condition is another way to provide for improved pavement life cycle costs. Designers shall complete a sensitivity analysis of the above mentioned programs and review with the senior airfield designer in their geographic area of responsibility.

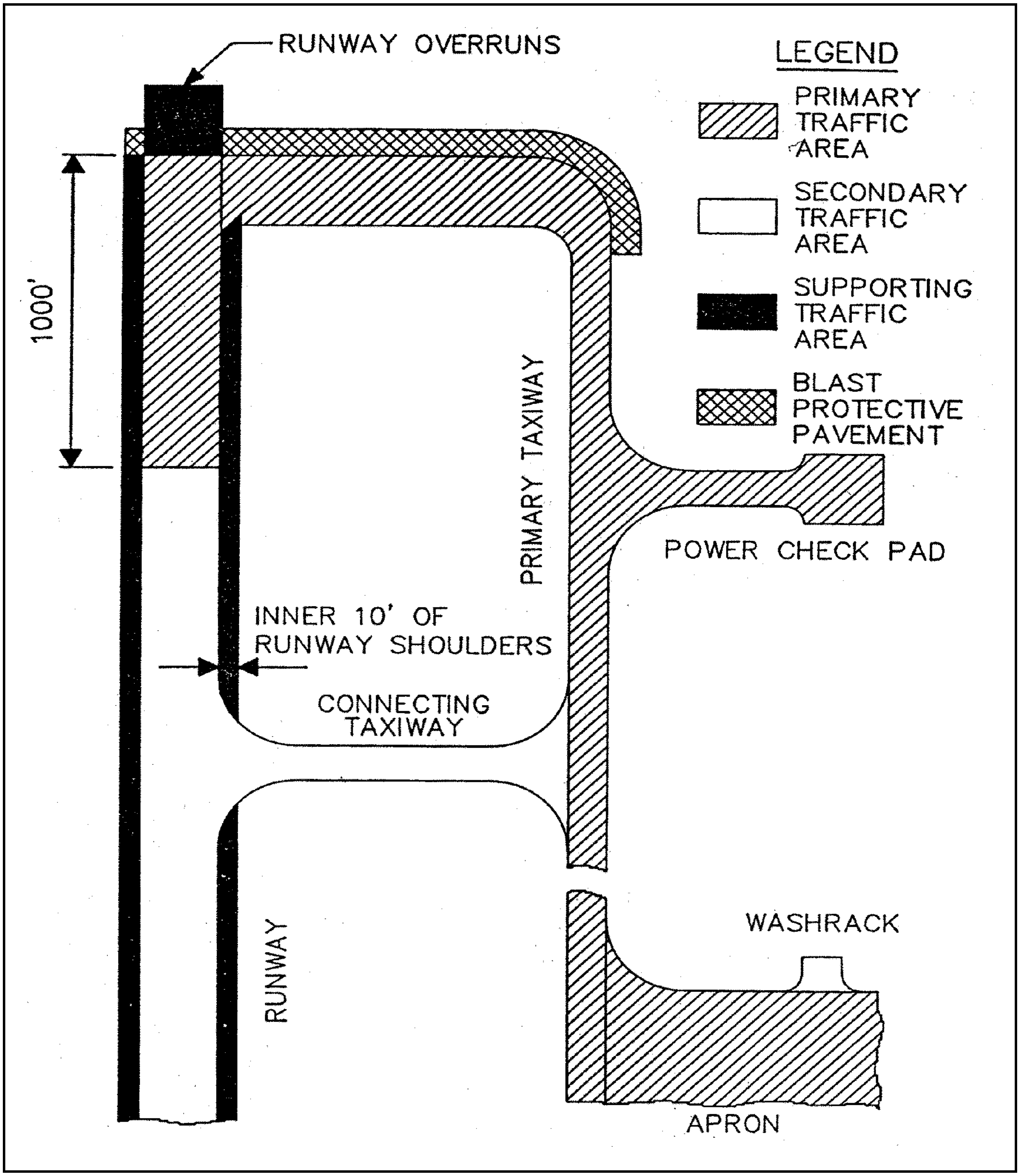


Figure 4-1. Primary, secondary, and supporting traffic areas for Navy and Marine Corps airfield pavements

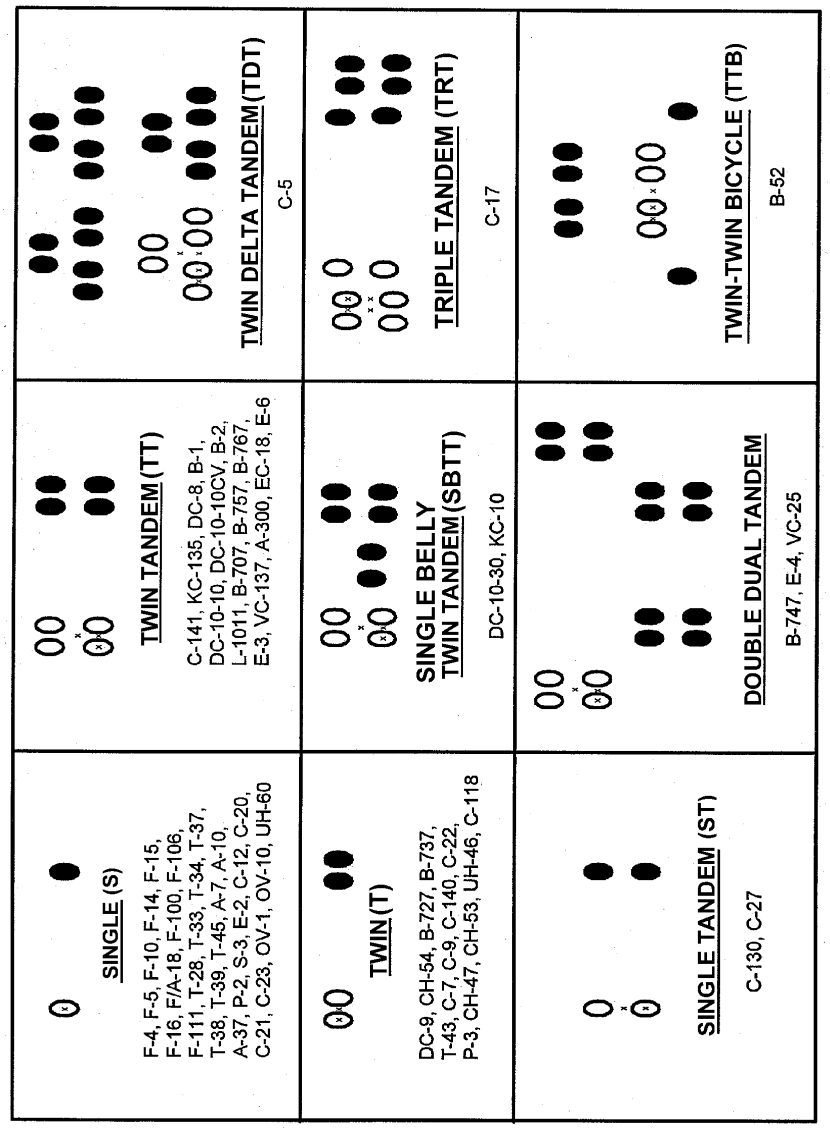


Figure 4-2. Landing gear assemblies

CHAPTER 5

SITE INVESTIGATIONS

1. GENERAL. The design of pavements must be based on a complete and thorough investigation of climatic conditions, topographic conditions, subgrade conditions, borrow areas, and sources of base course, subbase course paving, and other materials. These preliminary investigations will necessitate use of standard tests and all other available information such as aerial photographs, pavement evaluations, condition surveys, construction records, soil maps, geologic maps, topographic maps, and meteorological data. Table 5-1 lists sampling and testing standards used in soil investigations. Although previous investigations should be used to establish preliminary soil characteristics, additional investigations must be performed for final design.

2. SUBGRADE INVESTIGATIONS.

a. Field Reconnaissance. Conduct field reconnaissance with the available topographical, geographical, and soil maps; aerial photographs; meteorological data; previous investigations; and condition surveys and pavement evaluation reports. This step should precede an exploratory boring program.

b. Spacing of Preliminary Borings. The subgrade conditions in the area to be used for airfield pavement construction should be determined by exploratory borings. The recommended maximum spacing of borings should be as shown in the following tabulation, and should be supplemented with additional borings whenever variations in soil conditions or unusual features are encountered.

Item	**Spacing of Borings**
Runway and taxiways ≤ 61 meters (200 ft) wide	One boring every 61 to 152 meters (200 to 500 feet) longitudinally on alternating side of pavement centerline
Runways >61 meters (200 feet) wide	Two borings every 61 to 152 meters (200 to 500 feet longitudinally (one boring on each side of centerline)
Parking aprons and pads	One boring per 2,325-square-meter (25,000-square-foot) area

c. Depth of Borings. In cut sections, borings should extend to a minimum depth of 3 meters (10 feet) below the finished grade or to rock. In shallow fill sections, borings should extend to a minimum depth of 3 meters (10 feet) below the surface of the natural subgrade or to rock. Shallow fills are those where the effect of the weight of the fill on the natural subgrade is small compared to the weight of the design aircraft (generally 1.8 meters (6 feet) or less). In high-fill sections, borings should extend to a minimum depth of 15.2 meters (50 feet) below the surface of the natural subgrade or to rock. Results of borings will be used to develop boring logs as illustrated in Figure 5-1.

d. Samples. Soil samples should be obtained from the borings for classification purposes. After these samples are classified, soil profiles should be developed and representative soils selected for testing. A typical soil profile is shown in Figure 5-2. Test pits or large-diameter borings may be required to obtain the samples needed for CBR testing, or to permit in-place tests of the various soil layers. The types and number of samples required will depend on the characteristics of the subgrade soils. Subsoil

Table 5-1
Soil Sampling and Testing Standards

Category	Description	ASTM	CRD
Exploratory boringsAuger	samples	D 1452	
	Split barrel sampling	D 1586	
	Thin walled sampling	D 1587	
Identification and classification tests	Liquid limit	D 4318	
	Plastic limit	D 4318	
	Sieve analysis	D 422	
	Finer than No. 200 Sieve	D 1140	
	Classification (Unified Soil Classification)	D 2487	
Laboratory tests	Moisture-density relations	D 1557	
	Remolded CBR	C-654	
	Moisture content	D 2216	
	Unconfined compression	D 2166	
	Permeability test	D 2434	
	Consolidation test	D 2435	
In-place tests	Density and moisture content:		
	Sand cone	D 1556	
	Drive cylinder	D 2937	
	Rubber balloon	D 2167	
	Nuclear method (density)	D 2922	
	Nuclear method (moisture content)	D 3017	
	In-place CBR	C-654	
	Dynamic Cone Penetrometer (DCP)	See Note (2)	
	CBR by small aperture		
	Modulus of soil reaction		C-655

Note: (1) Testing for Air Force and Army Pavements will be by ASTM or CRD.
(2) Description and application of the DCP is provided in FM 5-430-00-2/AFJPAM 32-8013, Vol II, Appendix J.

investigations in the areas of proposed pavement should include measurements of in-place water content, density, and strength to ascertain the presence of weak areas and soft layers in the subsoil.

e. Borrow Areas. Where material is to be borrowed, borings should be made in these areas to a depth of 0.6 to 1.2 meters (2 to 4 feet) below the anticipated depth of borrow. One boring should be made for each 930 square meters (10,000 square feet) with a minimum of three borings per borrow area. Samples from the borings should be classified and tested for water content, density, and strength.

f. Environmental Hazards. When conducting subsurface investigations, hazardous or toxic waste material may be located, and appropriate environmental actions will have to be taken. This may be true around fueling areas particularly if replacing an existing fueling apron where fuel has leaked through the pavement and contaminated the soil. There may also be buried materials that have to be dealt with in some areas.

3. SELECT MATERIAL AND SUBBASE FOR FLEXIBLE PAVEMENTS. Areas within the airfield site or within a reasonable haul distance from the site should be explored for possible sources of select material and subbase. Exploration procedures similar to those described for subgrades should be used. Test pits or large auger borings are required to obtain representative samples of gravelly materials.

4. BASE COURSES, DRAINAGE LAYERS, SEPARATION LAYERS, CONCRETE AND BITUMINOUS CONCRETE. Since these pavement layers are generally constructed using crushed and processed materials, a survey should be made of existing sources plus other possible sources in the general area. Significant savings may be made by developing possible quarry sites near the airfield location. This is particularly important in remote areas where no commercial producers are operating and in areas where commercial production is limited in quantity.

5. OTHER CONSTRUCTION MATERIALS. The availability and quality of bituminous materials and portland cement should be determined. The availability and type of lime and fly ash will also aid in the evaluation and applicability of stabilized layers. This information will be helpful in developing designs and alerting designers to local conditions and shortages.

6. SOIL CLASSIFICATION. All soils will be classified in accordance with the unified soil classification system (USCS) as given in American Society for Testing and Materials (ASTM) D 2487. Sufficient investigations will be performed at a particular site so that all soils to be used or removed during construction can be described in accordance with the USCS plus any additional description considered necessary. When classifying soils, be alert to the presence of problem soils such as:

a. Clays that Lose Strength When Remolded. The types of clays that show a decrease in strength when remolded are generally in the CH and OH groups. They are clays that have been consolidated to a very high degree, either under an overburden load or by alternate cycles of wetting and drying, or that have by other means developed a definite structure. They have a high strength in the undisturbed state. Scarifying, reworking, and rolling these soils in cut areas may produce a lower bearing value than that of the undisturbed soils.

b. Soils that Become “Quick” When Molded. Some soils deposits such as silts and very fine sands, (predominantly in classifications ML, SM, and SC) when compacted in the presence of a high water table, will pump water to the surface and become “quick” or “spongy” with a loss of practically all bearing value. The condition can also develop in most silts and poorly drained very fine sands if these materials are compacted at a moisture content higher than optimum. This is because compaction reduces the air voids so that the available water fills practically all the void space.

c. Soils With Expansive Characteristics. Expansive soils are generally those with a liquid limit more than 40 and a plasticity index more than 15. Soils with expansive characteristics give the most trouble when significant changes occur in moisture content of the subgrade during different seasons of the year. TM 5-818-7 may be helpful in identifying expansive soils.

7. SOIL COMPACTION TESTS. Soil compaction tests will be used to determine the compaction characteristics of soils. The degree of compaction required is expressed as a percentage of the maximum density obtained by the test procedure used. Table 5-1 shows test methods to be used for determining density. The laboratory compaction control tests should not be used on soil that contains particles easily broken under the blow of the hammer. Also, the unit weight of certain types of sands and gravels obtained by this method is sometimes lower than the unit weight that can be obtained by field methods. Density tests in these cases should be made under some variations of the test methods, such as vibration or tamping (alone or in combination) to obtain higher laboratory density. In some cases, it may be necessary to construct field test sections to establish compaction characteristics.

8. SOIL STRENGTH. Soil strength is measured by the CBR for use in designing flexible pavements and by the modulus of soil reaction (k) for the design of rigid pavements. Strength tests must be made on material that represents the field condition that will be most critical from a design standpoint. Details of the CBR test procedure are given in CRD-C 654 and details of the modulus of soil reaction test are given in CRD-C 655. Figure 5-3 shows approximate relationships between soil classifications and soil strength values. The relationships will not be used for design of pavements. They are given for checking and estimating, not as a substitute for testing. Guidance in determining soil strength values are presented in Chapters 6 through 8.

9. IN-PLACE SOIL STRENGTH TESTS. Test pits for in-place soil strength tests and associated moisture-density tests should be located at approximately 305-meter (1,000-foot) intervals for runways and taxiways. For parking aprons and pads, one test pit should be located for each 16,720 square meters (20,000 square yards). The number and spacing of test pits may be modified whenever variations in soil conditions or unusual features are encountered.

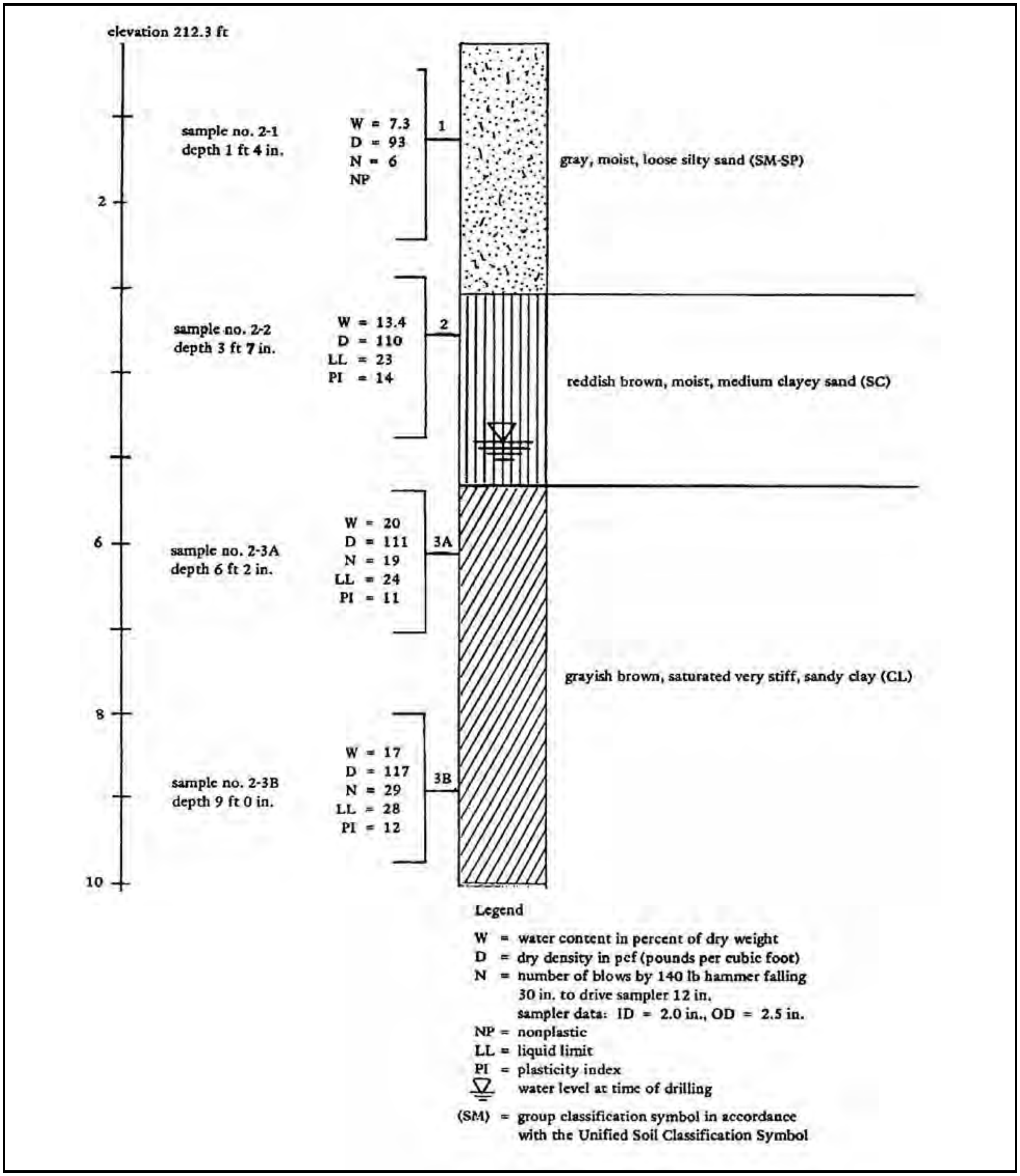


Figure 5-1. Typical boring log

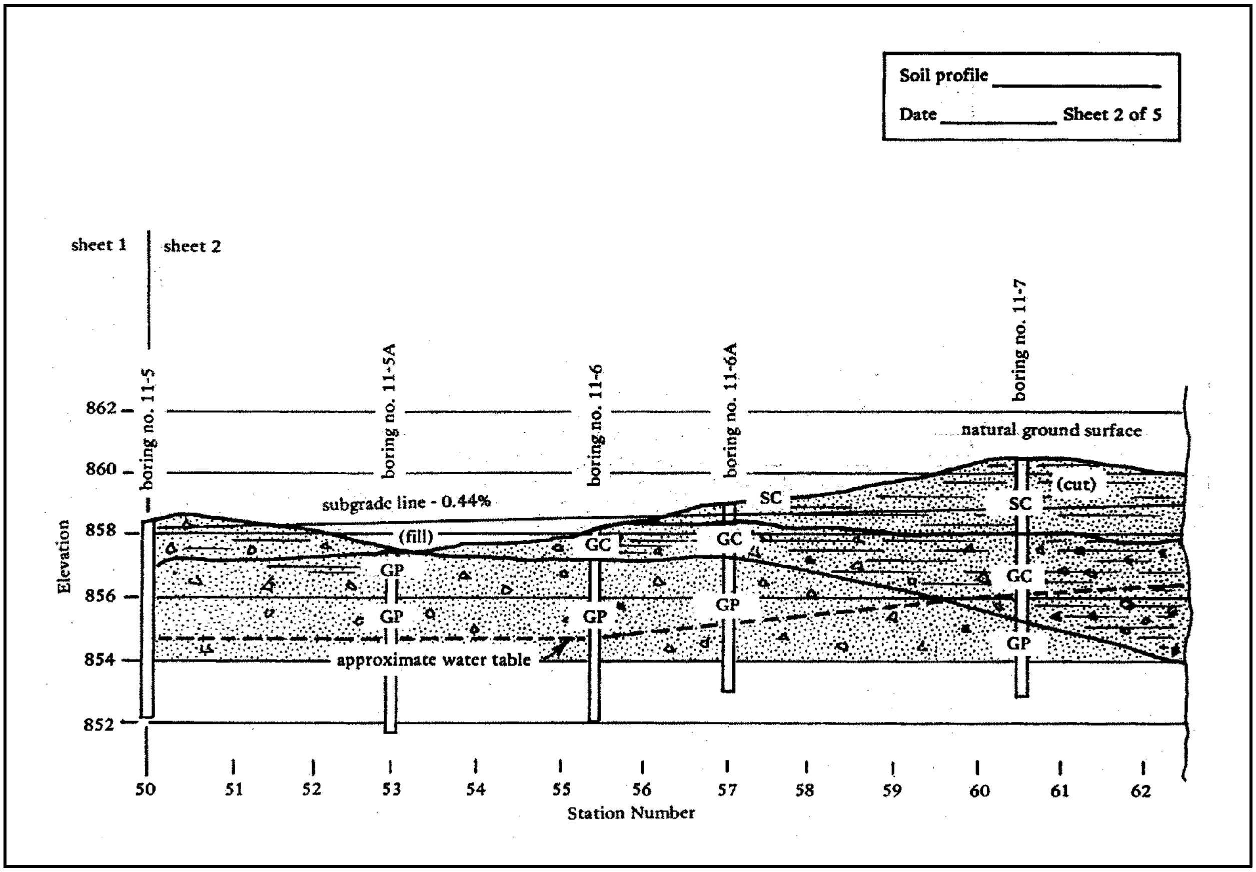
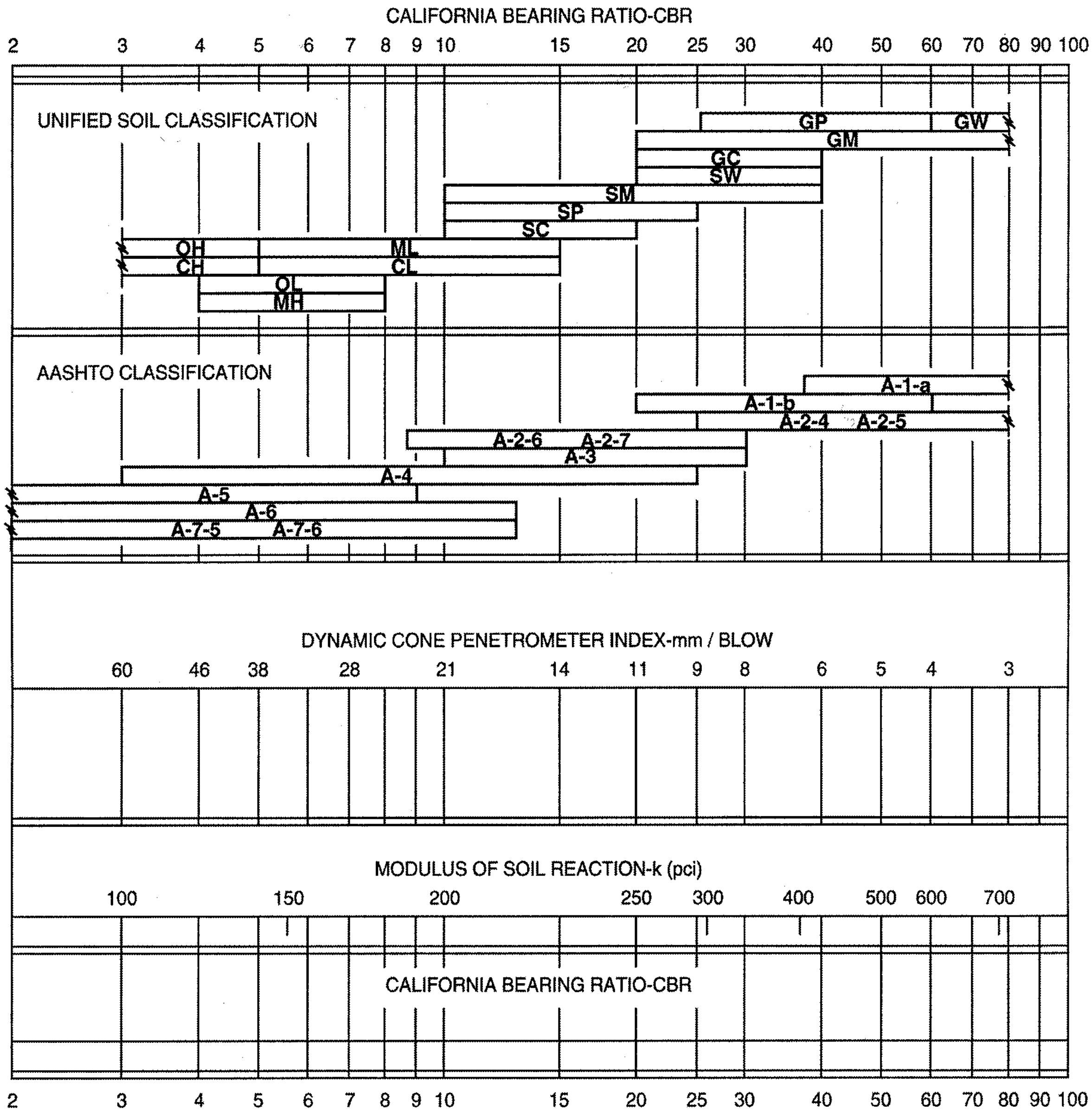


Figure 5-2. Typical soil profile



NOTE: CORRELATIONS NOT TO BE USED FOR DESIGN. AFTER PORTLAND CEMENT ASSOCIATION "THICKNESS DESIGN FOR CONCRETE HIGHWAY AND STREET PAVEMENTS" PACKARD, ROBERT G., 1984.
DESIGN LIMIT FOR k IS 500.

Figure 5-3. Approximate relationships of soil classification and soil strength

CHAPTER 6

SUBGRADE

1. SUITABILITY OF SUBGRADE. The information obtained from the explorations and tests previously described should be adequate to enable full consideration of all factors affecting the suitability of the subgrade and subsoil. The primary factors are as follows:

a. The general characteristics of the subgrade soils.

b. Depth to bedrock.

c. Depth to water table (including perched water table).

d. The compaction that can be attained in the subgrade and the adequacy of the existing density in the layers below the zone of compaction requirements.

e. The strength that the compacted subgrade, uncompacted subgrade, and subsoil will have under local environmental conditions.

f. The presence of weak or soft layers in the subsoil.

g. Susceptibility to detrimental frost action.

h. Settlement potential.

I. Expansion potential.

j. Drainage characteristics.

2. GRADE LINE. The soil type together with information on the drainage requirements, balancing cut and fill, flooding potential, depth to water table, depth to bedrock, and the compaction and strength characteristics should be considered in locating the grade line of the top of the subgrade. Generally, this grade line should be established to obtain the best possible subgrade material consistent with the proper utilization of available materials; however, economics of plans for construction must be given prime consideration.

3. SUBGRADE CBR. The strength of the subgrade may be expressed in terms of the CBR for flexible pavement design. The CBR test is described in CRD-C 654. It includes procedures for making tests on samples compacted to the design density in test molds and is soaked 4 days for making in-place CBR tests and for making tests on undisturbed samples. These tests are used to estimate the CBR that will develop in the pavement structure. However, a subgrade design CBR value above 20 is not permitted unless the subgrade meets the requirements for subbases. The CBR selected for the subgrade will be based on the predominant moisture conditions occurring during the life of the pavement. This moisture situation can be obtained from pavement evaluation reports and from soil tests under existing pavements. Where long duration soil moisture conditions cannot be determined with confidence, the soaked laboratory CBR will be selected for the subgrade soil.

a. Laboratory Tests. Tests results should include a full family of curves (Figure 6-1) as described in CRD-C 654. These curves show the three-way relationship of water content at the time of compaction, compacted density, and CBR after soaking. These curves should be studied in view of the actual water contents and densities that can be expected considering the natural scatter when specific control values are specified. The scatter that can be expected with normal control procedures will vary with the soil type. A spread of plus or minus 2 percent can be anticipated for soils with low optimum moisture contents (in the range of 10 percent), whereas a spread of plus or minus 4 percent can be anticipated for soils with high optimum moisture contents (in the range of 25 percent). Poor construction control may result in even greater scatter. A comparable scatter in the density can also be expected. After the range of moisture contents and densities that can be expected during actual construction is estimated, the range of CBR values that will result from these variations in moisture and density should be determined. The design CBR value for the specific soil tested should be selected near the lower part of the range. The following steps along with Figure 6-1 illustrate the selection of a design CBR value.

(1) Step A. Determine moisture/density relationship (CRD-C 653) at 12, 26, and 55 blows/layer. Plot density to which soil can be compacted in the field. For the clay of this example, use 95 percent of maximum density. Plot the desired moisture content range. For the clay of this example, use ±1-1/2 percent of optimum moisture content for approximately 13 and 16 percent. Shaded area represents compactive effort greater than 95 percent and within ±1-1/2 percent of optimum moisture content.

(2) Step B. Plot laboratory CBR (CRD-C 654) for 12, 26, and 55 blows/layer.

(3) Step C. Plot CBR versus dry density at constant moisture content. Plot attainable compaction limits of 1,770 and 1,840 kg/m^3 (110.6 and 115 lb/ft^3) for this example. The hatched area represents attainable CBR limits for desired compaction 1,770 and 1,840 kg/m^3 (110.6 to 115 lb/ft^3) and moisture content (13 to 16 percent). CBR varies from 11 (95 percent compaction and 13 percent moisture content) to 26 (15 percent moisture content and maximum compaction). For design purposes, a CBR at the low end of range is used. In the example, a CBR of 12 with a moisture content specified between 13 and 16 percent is selected.

b. In-place Tests and Tests on Undisturbed Samples. Where an existing pavement at the site has a subgrade constructed to the same standards as the job being designed, in-place tests or tests on undisturbed samples may be used in selecting the design CBR value. Also, where no compaction is anticipated, as in the layers below the zone of compaction, tests should be conducted on the natural material. The in-place CBR may be used where little increase in moisture is anticipated, such as coarse grained cohesionless soils, soils which are at least 80 percent saturated in the natural state, and soils under existing similar pavements which have reached the maximum water content expected, and thus no soaking is required. When in-place tests or tests on undisturbed soils are used, a statistical approach is recommended for selecting the design CBR. An illustration of selecting the design CBR is as follows: Given 20 CBR test values from a runway site.

(1) CBR = 4, 4, 4, 4, 5, 5, 5, 5, 5, 6, 6, 6, 6, 6, 7, 7, 8, 8, 10, and 11. This is a total of 20 separate tests.

(2) Percent of CBR values equal to or greater than each different value:

CBR	Number Equal to or Greater than Each Different Value	Percent Equal to or Greater than Each Different Value
4		
4		
4		
4	20	(20/20)100 = 100
5		
5		
5		
5		
5	16	(16/20)100 = 80
6		
6		
6		
6		
6	11	(11/20)100 = 55
7		
7	6	(6/20)100 = 30
8		
8	4	(4/20)100 = 20
10	2	(2/20)100 = 10
11	1	(1/20)100 = 5

(3) Plot CBR versus percent equal to or greater as shown in Figure 6-2.

(4) Enter Figure 6-2 at 85 percent. Continue to plotted curve then down to design CBR value of 4.7. If a sample from a test location has a value so low (indicating a weak area) that it is not representative of the other tests in the area, obtain additional samples to determine the extent of the area and whether special consideration is required. Where soil conditions vary substantially, a separate set of CBR determinations will be required for each distinct soil type.

4. SUBGRADE MODULUS OF SOIL REACTION. The strength of the subgrade is expressed in terms of the modulus of soil reaction (k) for rigid pavement design. The k value will be determined by the field plate bearing test as described in CRD-C 655.

a. Strength Test. The field plate bearing test will be performed on representative areas of the subgrade, taking into consideration such things as changes in material classification, fill or cut areas, and varying moisture (drainage) conditions which would affect the support value of the subgrade. While it is not practical to perform a sufficient number of field plate bearing tests to make a statistical analysis of the k value, a sufficient number must be performed to give confidence that the selected value will be representative of the in-place conditions. This means that at least two tests for each significantly different subgrade condition should be conducted. Considering the limited number of measured k values that can be obtained, maximum use of other pertinent soil data must be made to aid in the selection of the design k value. The pavement thickness is not affected appreciably by small changes in k values.

Therefore, the assignment of k values in increments of 2.71 MN/m^3 (10 pci) for values up to and including 68 MN/m^3 (250 pci) and in increments of 6.8 MN/m^3 (25 pci) for values exceeding 68 MN/m^3 (250 pci) should be sufficient. A maximum k value of 135 MN/m^3 (500 pci) will be used. Typical values of k for different soil types and moisture contents are shown in Table 6-1.

Table 6-1
Typical Values of Modulus of Soil Reaction

Soils	Typical Range (lb/in.^{2}/in.)	Suggested Default Pavement Design Values if No Test Data is Available (lb/in.^{2}/in.)
Organic Soils (OL, OH, Pt)	25 - 100	25
Silts and Clays of High Plasticity (CH, MH)	50 - 150	50
Silts and Clays of Low Plasticity (CL, ML)	50 - 200	100
Silty and Clayey Sands (SM, SC)	50 - 250	150
Well- and Poorly-Graded Sands (SW, SP)	150 - 400	200
Silty and Clayey Gravels (GC, GM)	200 - 500	250
Well- and Poorly-Graded Gravels (GW, GP)	300 - 500	350

Pavement design should be based on test data or at least historical data of past designs and evaluations at the same facility if at all possible. These default values are suggested for use for preliminary calculations or for small projects or projects where better data simply cannot be obtained. Inadequate testing or evaluation budgets are not an excuse to use these values for final design.

b. Special Conditions. Test Method CRD-C 655 requires a correction of the field plate bearing test results to account for saturation of the soil after the pavement has been constructed. Most fine-grained soils exhibit a marked reduction in the modulus of soil reaction with an increase in moisture content, and a saturation correction is applicable. However, in arid regions or regions where the water table is 3.0 meters (10 feet) or more below ground level throughout the year, the degree of saturation that may result after the pavement has been constructed may be less than that on which the saturation correction is based. If examination of existing pavements (highway or airfield) in the near vicinity indicates that the degree of saturation of the subgrade is less than 95 percent and if there is no indication of excessive loss of subgrade support at joints due to erosion or pumping, the correction for saturation may be deleted.

5. SUBGRADE COMPACTION FOR FLEXIBLE PAVEMENTS - NORMAL CASES. In general, compaction increases the strength of subgrade soils and the normal procedure is to specify compaction in accordance with the following requirements.

a. Subgrades with CBR values above 20.

(1) Army and Air Force. One hundred percent density from ASTM D 1557 except where it is known that a higher density can be obtained practically. Then, the higher density will be required.

(2) Navy and Marine Corps. Compact to 95 percent of ASTM D 1557 maximum density.

b. Subgrades with CBR values of 20 or less.

(1) Fills. Subgrades in fills shall have densities equal to or greater than the values determined from Tables 6-2 through 6-7. Cohesionless fill will not be placed at less than 95 percent nor cohesive fill at less than 90 percent of maximum density from ASTM D 1557. The top 6 inches of subgrade will be compacted to 95 percent of maximum density from ASTM D 1557.

(2) Cuts. Subgrades in cuts shall have natural densities equal to or greater than the values determined from Tables 6-1 through 6-6. When they do not, the subgrade shall be (a) compacted from the surface to meet the densities required, (b) removed and replaced (then the requirements given above for fills apply), or (c) covered with sufficient select material, subbase, and base so that the uncompacted subgrade will be at a depth where the in-place densities are satisfactory. The top 152 millimeters (6 inches) of subgrade will be compacted to 95 percent of maximum density from ASTM D 1557.

c. Natural Densities. The natural densities occurring in the subgrade should be compared with the compaction requirements to determine if densification at the deeper depths under design traffic is a problem. If such densification is likely to occur, means must be provided for compacting these layers, or the flexible pavement structure must be established so that these layers are deep enough that they will not be affected by aircraft traffic.

d. Compaction Levels and Moisture Content. Compaction of soils and aggregates accomplishes two specific purposes: (1) it achieves sufficient density in each layer of material such that future traffic will not cause additional densification and consequent rutting and (2) it achieves the designer's desired engineering properties, normally strength used for the pavement design. The requirements for density in Tables 6-2 through 6.6 coupled with proof rolling (paragraph 9 of Chapter 8) accomplish the first objective. The interaction between specified compaction levels and moisture contents and design strength is described in paragraph 3 of this chapter and Figure 6-1. Controlling field compaction of soils and aggregates using a specified percent of a laboratory compaction value and a specific range of allowable compaction moisture contents based on the laboratory optimum has proven simple and effective in practice for over a half century. Compaction curves of actual rollers in the field conform to the general shape and characteristics of the laboratory compaction curves but will deviate slightly from the actual laboratory curve. This deviation is not generally significant. Failure to control compaction moisture is probably one of the most common causes of failure to achieve specified density in the field. The contractor must thoroughly mix and disperse the moisture in the soils and aggregates and must allow for evaporation which can be significant on clear or windy days in many soils. Some soils such as silts have very steep compaction curves requiring fairly close control of the moisture to achieve compaction. Truly cohesionless soils compact best saturated but a relatively small increase in fines in such materials can make them spongy and uncompactable at saturation. Experience and field evaluation of each soil's behavior under compaction is usually needed to meet the stringent compaction standards used in military airfield construction. It is important to meet both the minimum specified density and to accomplish the compaction within the specified ranges of moisture content.

Table 6-2
Compaction Requirements for Cohesive Subgrades and Select Materials Under Flexible Pavements - Air Force Pavements (LL > 25; PI > 5)

	Depth of Compaction Below the Pavement Surface, inches															
	85 percent				90 percent				95 percent				100 percent			
Airfield Type	A	B	C	D or Overruns	A	B	C	D or Overruns	A	B	C	D or Overruns	A	B	C	D or Overruns
Light	34	32	28	16	27	25	22	12.5	20	19	16	9.5	13	12	10	4
Medium	62	60	50	33	46	45	36	24	31	30	24	16	17	16	13	9
Heavy	69	68	57	36	53	52	41	27	34	34	28	19	21	20	17	11
Modified heavy	68	66	55	35	51	49	40	26	35	33	26	17	21	19	15	10
Shortfield	42	--	--	21	31	--	--	16	22	--	--	12	12	--	--	6
Auxiliary	14	13	11	8	11	10	9	6	8	7	6	4	4	4	3	3

Conversion Factor: Millimeters = 25.4 × inches.

Table 6-3
Compaction Requirements for Cohesionless Subgrades and Select Materials Under Flexible Pavements - Air Force Pavements (LL < 25; PI < 5)

	Depth of Compaction Below the Pavement Surface, inches															
	85 percent				90 percent				95 percent				100 percent			
Airfield Type	A	B	C	D or Overruns	A	B	C	D or Overruns	A	B	C	D or Overruns	A	B	C	D or Overruns
Light	64	60	52	27	50	44	37	21	33	31	26	15	20	19	16	10
Medium	109	106	91	65	85	82	70	48	58	56	47	31	31	30	24	16
Heavy	149	145	105	73	95	94	79	55	65	64	55	34	35	34	28	19
Modified heavy	123	119	102	70	96	93	78	52	65	62	51	33	35	33	26	17
Shortfield	79	--	--	39	59	--	--	29	39	--	--	--	22	--	--	11
Auxiliary	24	23	20	11	19	18	15	9	14	13	11	6	8	7	6	3

Conversion Factor: Millimeters = 25.4 × inches.

Table 6-4
Compaction Requirements for Cohesive Subgrades and Select Materials Under Flexible Pavements - Army Pavements (LL ≤ 25; PI ≤ 5)

Airfield Type	Depth of Compaction Below the Pavement Surface, inches											
	85 percent			90 percent			95 percent			100 percent		
	A	B	C	A	B	C	A	B	C	A	B	C
Class I												
Heliport	--	14	--	--	11	--	--	8	--	--	5	--
Helipad	--	13	--	--	10	--	--	7	--	--	5	--
Class II												
VFR Heliport	--	24	--	--	19	--	--	13	--	--	7	--
VFR Heliport	--	22	--	--	17	--	--	12	--	--	7	--
IFR Heliport	--	25	--	--	20	--	--	14	--	--	8	--
IFR Heliport	--	23	--	--	18	--	--	12	--	--	7	--
Class III												
Runway ≤ 4,000 feet	17	16	13	13	12	10	10	9	7	6	5	4
Runway > 4,000 feet	13	12	11	10	10	8	6	6	5	3	3	2
Class IV												
Runway ≤ 5,000 feet	40	38	32	30	28	24	21	20	16	11	11	8
Runway > 5,000 feet and Runway ≤ 9,000 feet	57	55	46	43	41	33	29	27	22	16	16	12
Runway > 9,000 feet	59	57	47	44	42	34	29	28	23	17	16	13
Class V												
Heliport or Helipad	--	20	--	--	16	--	--	11	--	--	6	--

Conversion Factor: Millimeters = 25.4 × inches.
Meters = 0.3048 × feet.

Table 6-5
Compaction Requirements for Cohesionless Subgrades and Select Materials Under Flexible Pavements - Army Pavements (LL > 25; PI > 5)

Airfield Type	Depth of Compaction Below the Pavement Surface, inches											
	85 percent			90 percent			95 percent			100 percent		
	A	B	C	A	B	C	A	B	C	A	B	C
Class I												
Heliport	--	25	--	--	19	--	--	14	--	--	9	--
Helipad	--	22	--	--	17	--	--	13	--	--	8	--
Class II												
VFR Heliport	--	41	--	--	32	--	--	23	--	--	13	--
VFR Heliport	--	38	--	--	29	--	--	21	--	--	12	--
IFR Heliport	--	44	--	--	35	--	--	25	--	--	14	--
IFR Heliport	--	40	--	--	31	--	--	22	--	--	12	--
Class III												
Runway ≤ 4,000 feet	27	26	23	21	20	18	15	15	13	9	9	7
Runway > 4,000 feet	24	23	19	18	17	14	12	12	10	6	6	5
Class IV												
Runway ≤ 5,000 feet	76	72	61	57	54	45	38	36	30	21	20	16
Runway > 5,000 feet and Runway ≤ 9,000 feet	104	100	85	79	77	65	54	52	43	29	28	22
Runway > 9,000 feet	106	103	87	81	79	66	56	54	44	30	28	23
Class V												
Heliport or Helipad	--	30	--	--	27	--	--	19	--	--	11	--

Conversion Factor: Millimeters = 25.4 × inches.
Meters = 0.3048 × feet.

Table 6-6
Compaction Requirements for Navy and Marine Corps Flexible Pavements

Aircraft	Depth of Compaction Below the Pavement Surface, inches											
	85 percent			90 percent			95 percent			100 percent		
	Primary	Secondary	Supporting	Primary	Secondary	Supporting	Primary	Secondary	Supporting	Primary	Secondary	Supporting
	Cohesive Soils											
Single wheel	39	37	14	31	29	11	23	22	8	15	14	5
P-3	45	43	18	35	34	14	25	24	10	15	14	6
C-130	41	39	18	31	30	14	22	21	10	12	11	5
C-141	57	54	26	42	40	19	28	27	13	16	15	10
C-5A	57	56	32	39	38	23	25	24	15	14	13	9
	Cohesionless Soils											
Single wheel	65	62	23	51	49	18	37	35	13	23	22	8
P-3	78	75	34	61	58	25	43	41	17	25	24	10
C-130	79	75	34	59	56	26	39	37	18	22	21	10
C-141	102	98	69	79	76	38	54	52	24	28	27	17
C-5A	125	124	74	88	87	51	53	52	30	25	24	15

Conversion Factor: Millimeters = 25.4 × inches.

6. SUBGRADE COMPACTION FOR RIGID PAVEMENTS - NORMAL CASES. Compaction improves soil strength and ensures that densification with resulting voids under the concrete slab does not occur. Subgrade soils that gain strength when remolded and compacted will be prepared in accordance with the following criteria.

Table 6-7
Compaction Requirements for Shoulders

Percent Compaction	[1]Depth of Compaction in inches for Cohesive Subgrades and Select Materials (LL $\leq$ 25; PI $\leq$ 5)	[1]Depth of Compaction in inches for Cohesionless Subgrades and Select Materials (LL > 25; PI > 25)
85	17	29
90	14	23
95	10	16
100	6	10

[1] Depth is measured from pavement surface.
Conversion Factor: Millimeters = 25.4 × inches.

a. Compacting Fill Sections. Fills composed of soil having a plasticity index (PI) greater than 5 or a liquid limit (LL) greater than 25 will be compacted to not less than 90 percent of ASTM D 1557 maximum density. Fills composed of soil having a PI equal to or less than 5 and an LL equal to or less than 25 will be compacted as follows: the top 152 millimeters (6 inches) will be 100 percent of ASTM D 1557 maximum density; the remaining depth of fill will be 95 percent of ASTM D 1557 maximum density. Large fills on natural soil should be analyzed for bearing capacity and settlement using conventional soil mechanics.

b. Compacting Cut Sections. The top 152 millimeters (6 inches) of subgrades composed of soil having a PI greater than 5 or an LL greater than 25 will be compacted to not less than 90 percent of ASTM D 1557 maximum density. If the natural subgrade exhibits densities equal to or greater than 90 percent of other ASTM D 1557 maximum density, no compaction is necessary other than that required to provide a smooth surface. Soils having a PI equal to or less than 5 and an LL equal to or less than 25 will be compacted as follows: the top 152 millimeters (6 inches) will be 100 percent of ASTM D 1557 maximum density; the 455 millimeters (18 inches) below the top 152 millimeters (6 inches) will be 95 percent of ASTM D 1557 maximum density. Again, if the natural subgrade exhibits densities equal to or in excess of the specified densities, no compaction will be necessary other than that required to provide a smooth surface; in most cases, these densities can be obtained by surface rolling only.

c. Permissible Variations in Field Density. The above criteria should be considered as minimal values. Also, it is emphasized that it is often difficult to correlate field densities with those obtained by practical compaction procedures in the field. Higher densities should result in higher foundation strengths and thus thinner pavements which may offset the added cost of compaction. Experience has shown that the highest densities for all but the special cases (that is, soils that lose strength when remolded, become “quick” when remolded, or have expansive characteristics) result in lower permanent deformations, less susceptibility to pumping, and improved overall performance.

7. TREATMENT OF PROBLEM SOILS. Although compaction increases the strength of most soils, some soils decrease in stability when scarified, worked, and rolled. There are also some soils that shrink excessively during dry periods and expand excessively when allowed to absorb moisture. When these soils are encountered, special treatment is required. General descriptions of the soils in which these conditions may occur and suggested methods of treatment are outlined as follows:

a. Clays that Lose Strength When Remolded. These types of clays have a high strength in the undisturbed state. Scarifying, reworking, and rolling these soils in cut areas may produce a lower bearing value than that of the undisturbed soils. When such clay soils are encountered, bearing values should be obtained for both the undisturbed soil and the soil remolded and compacted to the design density at the design moisture content and adjusted to the future moisture content conditions. If the undisturbed value is the higher, no compaction should be attempted, and construction operations should be conducted to produce the least possible disturbance of the soil. Since compaction cannot be effected in these cases, the total thickness design above the subgrade may be governed by the required depth of compaction rather than the CBR requirements.

b. Soils that Become “Quick” When Molded. It is difficult to obtain the desired densities in these silts and very fine sands at moisture contents greater than optimum. Also, during compaction of the base, the water from a wet, spongy silt subgrade will often enter the subbase and base with detrimental effects. The bearing value of these silts and very fine sand is reasonably good if they can be compacted at the proper moisture content. Drying is not difficult if the source of water can be removed, since the soils are usually friable and can be scarified readily. If the soils can be dried, normal compaction requirements should be applied. However, removing the source of water is often very difficult and in some cases impossible in the allotted construction period. In cases of high water table, drying is usually not satisfactory until the water table is lowered, as recompacting operations will again cause water to be pumped to the surface. Local areas of this nature are usually treated satisfactorily by replacing the soil with subbase and base materials or with a dry soil that is not critical to water. There are cases where drainage is not feasible and a high water table cannot be lowered, or cases where such soils become saturated from sources other than high water table and cannot be dried out (as in necessary construction during wet seasons). In such cases, the subgrade should not be disturbed, and additional thickness of base and pavement should be used to ensure that the subgrade will not be overstressed or compacted during subsequent traffic by aircraft.

c. Soils with Expansive Characteristics. Soils with expansive characteristics, if highly compacted, will swell and produce uplift pressures of considerable intensity if the moisture content of the soil increases after compaction. This action may result in intolerable differential heaving of flexible pavements. Where the amount of swell is less than about 3 percent (as determined from soaked CBR test), special consideration will not normally be needed. However, where an airfield subgrade includes interspersed patches of soil with different swell characteristics, even amounts of swell less than 3 percent may require special consideration.

(1) Proper moisture content and density. A common method of treating a subgrade with expansive characteristics is to compact it at a moisture content and to a unit weight that will minimize expansion. The proper moisture content and unit weight for compaction control of a soil with marked expansion characteristics are seldom the optimum moisture content and unit weight determined by the compaction test. These factors may be determined from a study of the relations between moisture content, unit weight, percentage of swell, and CBR for a given soil. A combination of moisture, density,

CBR, and swell that will give the greatest CBR and density consistent with a tolerable amount of swell must be selected. The CBR and density values so selected are those that must be considered in the design of overlying layer thickness. Field control of the moisture content must be carefully exercised because if the soil is too dry when compacted, the expansion will increase; and if it is too wet, low unit weight will be obtained and the soil will shrink during a dry period and then expand during a wet period. This method requires detailed testing and extensive field control of compaction.

(2) Overburden load. In order to limit swell of expansive soils, it may be desirable to provide overburden if expansion cannot be limited by other procedures to acceptable amounts. Special swell tests normally will be needed to determine the amount of weight (overburden) necessary to restrict the swell to tolerable magnitudes. These tests can be variations of the standard soaked CBR test described in CRD-C 656, or they can be specially designed tests using a consolidometer apparatus.

(3) Special solutions. Special solutions to the problem of swelling soils are sometimes possible and should not be overlooked where pertinent. For instance, where climate is suitable, it may be possible to place a permeable layer (aquifer) over a swelling soil to maintain the swelling soil in a saturated condition. Moisture buildup in this layer maintains the soil in a stable, swelled condition. Designs must, of course, be based on the swelled CBR and density values of such a material when so treated. Other possible solutions are treatment with lime (TM 5-822-14/AFJMAN 32-1019), replacement of the swelling soil, or working the soil to make it more uniform.

d. Design Considerations for Special Cases. Whenever subgrades are given special treatments that cause their resulting strength or their resulting density to be less than when normally treated, these lesser values must be considered in design of the overlying layers. When a low CBR results, sufficient thickness of overlying structure must be provided to protect a subgrade of such low strength. When a low density results, the thickness of overlying material must be such that the density versus depth requirements of the specifications are met.

8. STABILIZED SUBGRADES. Subgrades can be stabilized by the addition of lime, cement, or a combination of these materials with flyash. Design of pavements using stabilized soils is discussed in Chapter 9 of this document and in TM 5-822-14/AFJMAN 32-1019. Lime should not be used with soils containing sulfates.

9. SUBGRADES IN FROST AREAS. In areas where frost susceptible subgrade soils will be subjected to cycles of freeze-thaw, pavements must be designed in accordance with the requirements of Chapter 20.

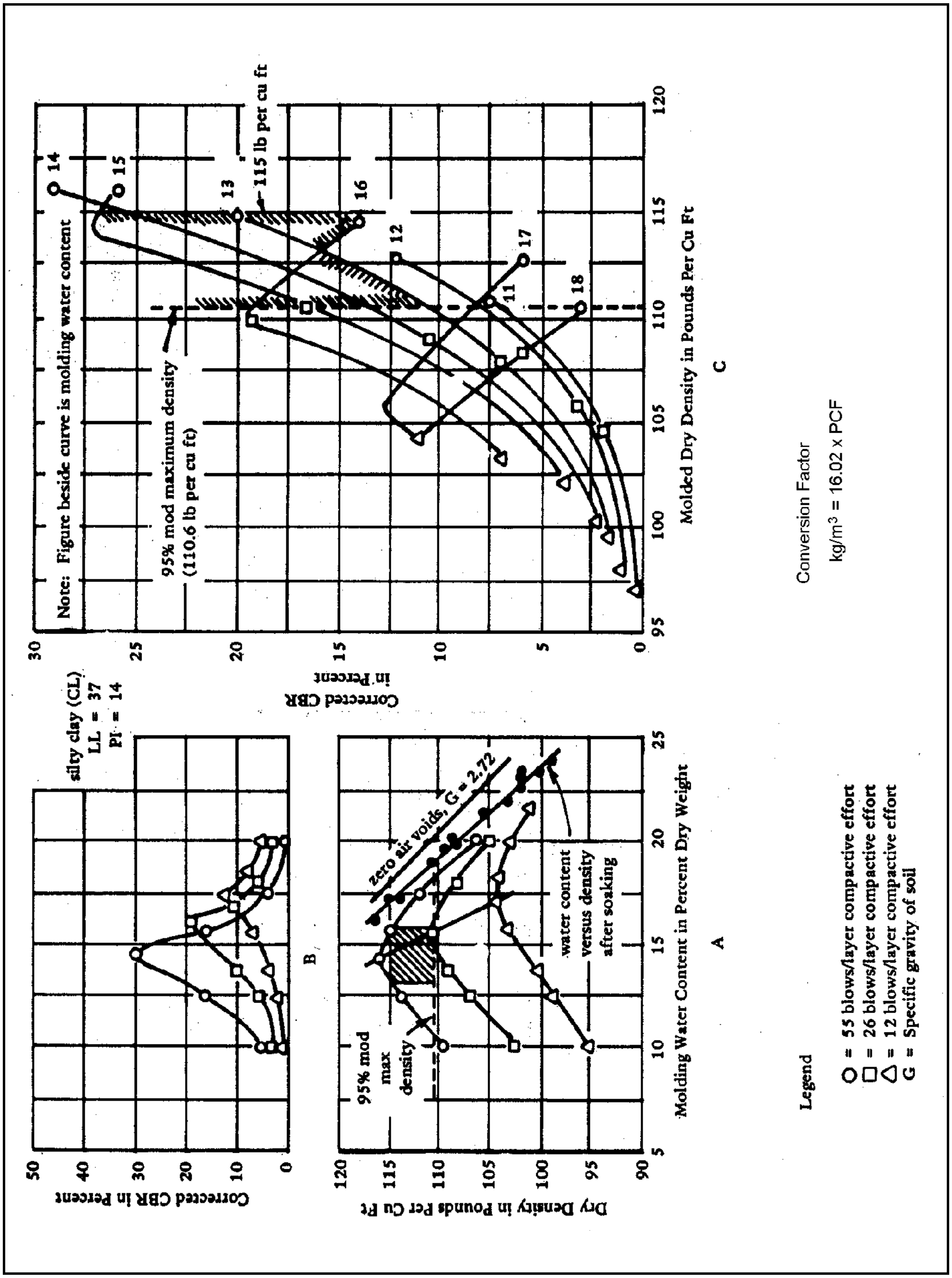


Figure 6-1. Procedure for determining laboratory CBR of subgrade soils

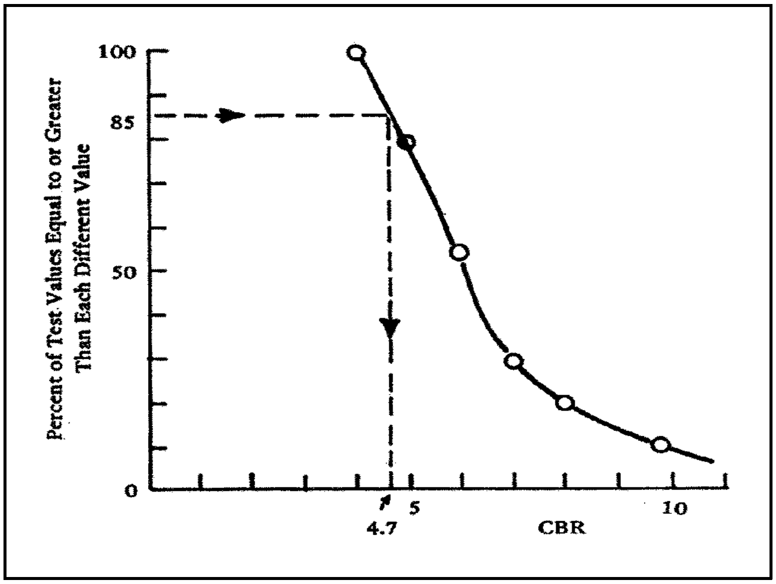


Figure 6-2. Selection of design subgrade CBR using in-place tests

CHAPTER 7

SELECT MATERIALS AND SUBBASE COURSES FOR FLEXIBLE PAVEMENTS

1.GEN ERAL. It is common practice in flexible pavement design to use locally available or other readily available materials between the subgrade and base course for economy. The Navy and Marine Corps designate these layers as subbases and require a minimum CBR of 30. The Army and Air Force refer to these layers as subbases when the design CBR is above 20 and as select materials subbase when the CBR is 20 or less. Minimum thicknesses of pavement and base have been established to eliminate the need for subbases with design CBR values above 50. Guide specifications have been prepared for select materials and subbases. Where the design CBR value of the subgrade without processing is in the range of 20 to 50, select materials and subbases may not be needed. However, the subgrade cannot be assigned design CBR values above 20 unless it meets the gradation and plasticity requirements for subbases. In some cases, where subgrade materials meet plasticity requirements but are deficient in grading requirements, it may be possible to treat an existing subgrade by blending in stone, limerock, sand, etc., to produce an acceptable subbase. However, “blending in” cohesionless materials to lower the plasticity index will not be allowed.

2.MAT ERIALS. The investigations described in Chapter 5 will be used to determine the location and characteristics of suitable soils for select material and subbase construction. Limerock, coral, shell, blast furnace slags (steel slag is not suitable), cinders, caliche, recycled concrete and asphalt, and other such materials in addition to gravels and rock should be considered when they are economical and when they meet the requirements of paragraph 4 entitled SELECTION OF DESIGN CBR. Do not use material which has a swell of 3 percent or greater, as determined from the CBR mold, for subbase. These materials will meet the LA Abrasion requirements of not more than 50 percent..

a. Select Materials. Select materials will normally be locally available coarse-grained soils. Recommended gradation and plasticity requirements for select materials are listed in paragraph 4 entitled SELECTION OF DESIGN CBR.

b. Subbase Materials. Subbase materials may consist of naturally occurring coarse-grained soils or blended and processed soils. Gradation and plasticity requirements for subbases are listed in paragraph 4 entitled SELECTION OF DESIGN CBR. The existing subgrade may meet the requirements for a subbase course or it may be possible to treat the existing subgrade to produce a subbase. Also, admixing native or processed materials will be done only when the unmixed subgrade meets the liquid limit and plasticity index requirements for subbases because it has been found that “cutting” plasticity in this way is not satisfactory. However, it may be permissible to decrease the plasticity of some materials by using lime or portland cement in sufficient amounts to meet the plasticity requirements of subbases. In order to be considered stabilized for thickness design purposes, the soil must meet the minimum strength requirements as shown in Table 7-1.

3.CO MPACTION REQUIREMENTS. Subbases will be compacted to 100 percent of maximum density as determined by ASTM D 1557. Select materials will be compacted to the densities shown in Tables 6-2 to 6-7, except that cohesionless select materials will be placed at no less than 95 percent and cohesive select materials at no less than 90 percent of ASTM D 1557 maximum density.

4.SELECT ION OF DESIGN CBR. The select material or subbase will generally be uniform, and the problem of selecting a limiting condition, as described for the subgrade, does not ordinarily exist. Tests

Table 7-1
Minimum Unconfined Compressive Strength for Cement, Lime, Lime-Cement, and Lime-Cement-Fly Ash Stabilized Soils

	Minimum Unconfined Compressive Strength, psi[1]	
Stabilized Soil Layer	Flexible Pavement	Rigid Pavement
Base course	750	500
Subbase course, select material or subgrade	250	200

[1] Unconfined compressive strength determined at 7 days for cement stabilization and 28 days for lime, lime fly ash, or lime-cement-fly ash stabilization.

are usually made on soaked remolded samples; however, where existing similar construction is available, CBR tests should be made in-place on material when it has attained its maximum expected water content or on undisturbed soaked samples. The procedures for selecting test values described for subgrades apply to select materials and subbases. Experience has shown that CBR tests on gravelly materials in the laboratory have tended to give CBR values higher than those obtained in tests in the field. The difference is attributed to the processing necessary to test the sample in the 152-millimeter (6-inch) mold, and to the confining effect of the mold. Therefore, the CBR test is supplemented by gradation and Atterberg limits requirements for subbases, as shown in Table 7-2. Suggested limits for select materials are also indicated. In addition to these requirements, the laboratory CBR must be equal to or higher than the CBR assigned to the material for design purposes.

Table 7-2
Gradation and Atterberg Limit Requirements for Subbases and Select Materials

			Maximum Permissible Value[1]			
	Maximum[1]		Gradation Requirements Percent Passing			
Material	Design CBR	Size, mm (in.)	2.0 mm (No. 10)	.075 mm (No. 200)	LL	PI
Subbase	50	75 (3)	50	15	25	5
Subbase	40	75 (3)	80	15	25	5
Subbase	30	75 (3)	100	15	25	5
Select material	20	75 (3)[2]	--	25[2]	35[2]	12[2]

Note: LL signifies liquid limit; PI signifies plasticity index.
[1] EI 02C202/AFJMAN 32-1016 contains maximum values for open graded and rapid draining materials.
[2] Suggested limits.

a. Navy Minimum Subbase CBR. On Navy airfield pavements, material with a minimum CBR of 30 should be used in the upper 152 millimeters (6 inches) of the subbase.

b. Exceptions to Gradation Requirements. Cases may occur in which certain natural materials that do not meet the gradation requirements may develop satisfactory CBR values in the field. Exceptions to the gradation requirements are permissible when supported by adequate in-place CBR tests on construction that has been in service for several years.

c. Example. As an example of the selection of a design CBR for subbases or select materials, consider the following material.

Soaked laboratory CBR = 40
Maximum size, millimeters (inches) = 50 (2.0)
Percent passing 2.0 millimeters (No. 10) = 85
Percent passing 0.075 millimeters (No. 200) = 14
Liquid limit = 12
Plasticity index = 3

The design CBR for this material would be 30 rather than the measured value of 40 because 80 percent passing the 2.0 millimeters (No. 10) sieve is the maximum permitted for higher CBR values and this material has 85 percent passing.

5. SEPARATION LAYERS. The gradation requirements shown in paragraph 4 are the maximum allowable limits. The designers can and should include additional gradation requirements to ensure that this material will meet the requirements for a separation layer as described in EI02C202/AFJMAN 32-1016. These additional gradations are dependent on the base course or drainage layer gradations and the gradations of the existing subgrade material; therefore, the designer should tailor these changes for each project.

6. STABILIZED SELECT MATERIALS AND SUBBASES. The design of pavements using stabilized soils is discussed in Chapter 9 of this document and in TM 5-822-14/AFJMAN 32-1019.

7. DESIGN FOR SEASONAL FROST CONDITIONS. In areas where the pavement will be subject to cycles of freezing and thawing, Army and Air Force pavements will be designed in accordance with the requirements in Chapter 9.

8. DRAINAGE LAYERS. The requirements for drainage layers used for subbase are presented in EI 02C202/AFJMAN 32-1016 and NAVFAC DM 21.06. For pavements in nonfrost areas and having a subgrade with a permeability greater than 20 feet/day, one can assume that the vertical drainage will be sufficient such that no drainage layer is required. Also, flexible pavements in nonfrost areas with a total thickness of 8 inches or less are not required to have a drainage layer. For pavements requiring drainage layers, the design of the drainage layer shall be based on the premise that the capacity of the drainage layer should be greater than the volume of water entering the pavement and that the drainage layer, if saturated, should reach a degree of drainage of 0.85 within 1 day after the inflow of water stops. The degree of drainage for the drainage layer is defined as the volume of water that has drained from the layer over a specified time period divided by the total volume of water in the layer that can be drained by gravity.

CHAPTER 8

AGGREGATE BASE COURSES

1. USE OF AGGREGATE BASE COURSES. Aggregate base courses may be required for one or more of the following reasons: distribution of load, provide drainage, protect from frost, provide uniform bearing surface for the pavement surfacing, replace unsuitable soils, provide working platform, increase strength of pavement system or prevent pumping.

2. MATERIALS FOR AGGREGATE BASE COURSES IN FLEXIBLE PAVEMENTS. Aggregate base-course materials for flexible pavement must be of high quality and conform to agency guide specifications. Since natural cementation of the materials listed in subparagraphs c, d, e, f, and g occurs progressively in place, there is a potential that the strength of these materials will increase with time, resulting in higher CBR values than laboratory tests indicate. Special requirements for aggregate base courses in frost areas are discussed in Chapter 20. Aggregate base courses used as drainage layers must meet the requirements of EI 02C202/AFJMAN 32-1016. Those materials generally used as aggregate base-course materials are listed below:

a. Graded Crushed Aggregate Base Course--100 CBR. Stone is quarried from formations of granite, traprock, and limestone. Gravel is quarried from deposits of river or glacial origin. The stone and gravel are crushed and screened to produce a dense-graded crushed aggregate material meeting requirements of guide specifications. The percentage of loss shall not exceed 40 when tested in accordance with ASTM C-131. The material shall also meet the requirements listed in CEGS 02722 for flat and elongated particles, liquid limit and plasticity index, and magnesium sulfate soundness when tested in accordance with ASTM C 88. Gradation requirements for graded crushed aggregates are as follows:

Table 8-1
Gradation Requirements for Graded Crushed Aggregates, Base Courses, and Aggregate Base Courses

	Percentage by Weight Passing Square-Mesh Sieve		
Sieve Designation	No. 1	No. 2	No. 3
50-mm (2-in.)	100	--	--
37.5-mm (1-1/2-in.)	70-100	100	--
25-mm (1-in.)	45-80	60-100	100
12.5-mm (1/2-in.)	30-60	30-65	40-70
4.75-mm (No. 4)	20-50	20-50	20-50
2.0-mm (No. 10)	15-40	15-40	15-40
0.425-mm (No. 40)	5-25	5-25	5-25
0.075-mm (No. 200)	0-8	0-8	0-8

b. Aggregate Base Course--80 CBR. This material is a blend of crushed and natural materials processed to provide a dense graded mix (often referred to as mechanically stabilized base course).

The percentage of loss shall not exceed 50 when tested in accordance with ASTM C-131. The material shall also meet the requirements listed in CEGS 02722 for flat and elongated particles, liquid limit and plasticity index, and magnesium sulfate soundness when tested in accordance with ASTM C 88. The gradation requirements are the same as for the 100 CBR material, but fractured faces relaxed to 50 percent.

c. Blast Furnace Slag. Slag is a by-product of steel manufacturing. It is air cooled, crushed, and graded to produce a dense mix. Fines from other sources may be used for blending. Requirements for a graded crushed aggregate apply. Only blast furnace slag will be used. Minimum required unit weight of slag is 1,200 kg/m^3 (75 lb/ft^3).

d. Shell Sand. Shell sand consists of oyster and clam shells that have been crushed, screened, and blended with sand filler. Ratio of the blend shall be not less than 67 percent shell to 33 percent sand. Refer to local specifications where available.

e. Coral. Coral consists of hard cemented deposits of skeletal origin. Coralline limestone quarried from inland deposits and designated quarry coral is the most structurally sound of the various coral materials available. Other types useful for base materials are reef coral and bank run coral. Quarry coral is crushed and graded to a dense mix. The following gradation is recommended:

Sieve Designation	**Percent Passing**
50-mm (2-in.)	100
37.5-mm (1-1/2-in.)	70-100
19-mm (3/4-in.)	40-90
4.75-mm (No. 4)	25-60
0.425-mm (No. 40)	5-20
0.075-mm (No. 200)	0-10

The percentage of wear (ASTM C-131) is not to exceed 50.

f. Limerock. Limerock is a fossiliferous limestone of the oolitic type generally located in Florida.

g. Shell Rock. Shell rock or marine limestone are deposits of hard cemented shells located in North Carolina and South Carolina. Refer to local guide specifications where available. Percentage of loss should not exceed 50 when tested in accordance with ASTM C-131..

h. Stabilized Materials. Stabilized materials consist of granular materials that have been improved by the addition of cement, lime, bitumen, or a combination of those additives with flyash. See Chapter 9 for a discussion of stabilization.

i. Crushed Recycled Concrete. Crushed recycled concrete shall consist of previously hardened portland cement concrete or other concrete containing pozzolanic binder material. The recycled material shall be free of all reinforcing steel, bituminous concrete surfacing, and any other foreign material and shall be crushed and processed to meet the required gradations for coarse aggregate. Crushed recycled concrete shall meet all other applicable requirements specified below. Recycled concrete to be exposed to sulfates in the ground or water must be checked for sulfate resistance. Contact MAJCOM for guidance.

3. AGGREGATE BASE COURSES FOR ARMY AND AIR FORCE RIGID PAVEMENT.

a. General. Drainage layers generally serve as aggregate base courses under rigid pavements and must meet the requirements of EI 02C202/AFJMAN 32-1016. A minimum aggregate base-course thickness of 102 millimeters (4 inches) will be required over subgrades that are classified as CH, CL, MH, ML, and OL (ASTM D 2487) for protection against pumping except in arid climates where experience has shown that there is no need for the aggregate base course to prevent pumping. In certain cases of adverse moisture conditions (high water table or poor drainage), SM and SC soils may also require aggregate base courses to prevent pumping. Engineering judgment must be exercised in the design of aggregate base-course drainage to ensure that water is not trapped directly beneath the pavement, which invites the pumping condition that the base course is intended to prevent. In addition, aggregate base courses in inlay sections should be constructed to drain toward the outside edge. Daylighting of the aggregate base course may also be required. Care must also be exercised when selecting aggregate base-course materials to be used with slipform construction of the pavement. Generally, slipform pavers will operate satisfactorily on materials meeting aggregate base-course requirements. However, cohesionless sands, rounded aggregates, etc., may not provide sufficient stability for slipform operation and should be avoided if slipform paving is to be a construction option. The designer should consider extending the aggregate base course 1.5 to 3.0 meters (5 to 10 feet) outside the edge of the pavement to provide a working platform for construction equipment.

b. Material Requirements. A complete investigation will be made to determine the source, quantity, and characteristics of available materials. The aggregate base course may consist of natural materials or processed materials, as discussed for flexible pavements. In general, the unbound aggregate base material will be a well-graded, high-stability material. All aggregate base courses to be placed beneath airfield rigid pavements will conform to the following requirements in addition to those requirements in base course guide specifications (sieve designations are in accordance with American Society for Testing and Materials (ASTM E 11):

- Well-graded, coarse to fine.
- Not more than 85 percent passing the 2.0-millimeter (No. 10) sieve.
- Not more than 15 percent passing the 0.075-millimeter (No. 200) sieve.
- PI not more than 8 percent.

However, when it is necessary for the base course to provide drainage, the requirements set forth in EI 02C202/AFJMAN 32-1016 will be followed.

4. AGGREGATE BASE COURSES FOR NAVY AND MARINE CORPS RIGID PAVEMENTS.

a. General. The main structural support element in a rigid pavement is the portland cement concrete slab. The most important function of the aggregate base-course material in a rigid pavement is to provide uniform long-term support to the slab with adequate drainage to prevent pumping and loss of support. The aggregate base course must be constructed of quality material and properly designed to ensure a good foundation. If pumping and loss of support occur, the performance of the concrete slab will be reduced.

b. Material Requirements. Suitable materials for aggregate base courses include natural, processed, manufactured, and stabilized materials which meet ASTM D 2940. These are the most common types of base course materials. Select local materials if possible, and consider local experience and practices when selecting a base material.

c. Gradation. To provide adequate drainage, the base course must contain little or no fines (material that passes the 0.075-millimeter (No. 200) sieve). Gradation requirements assure adequate stability and drainage by the base course under repeated loads. Crushed aggregates have greater stability than round-grained materials.

d. Wear Resistance. Aggregates suitable for base-course material must have the ability to withstand abrasion and/or crushing. Do not use soft aggregates for base course material because they may break down into fines which will inhibit drainage. Use the Los Angeles abrasion test (ASTM C 131) for determining aggregate abrasion resistance. Aggregates suitable for base course shall have a percentage loss in the Los Angeles abrasion test less than or equal to 40 percent.

e. Lean Concrete Bases. Lean concrete mixtures may be used as base material to provide increased support and reduce pumping. They may also be more economical than stabilized bases. Lean concrete refers to a mixture composed of low-cost, locally available aggregates that may not meet specifications for normal concrete mixtures and an amount of portland cement that is usually less than for normal concrete mixtures. Local aggregates, substandard aggregates, and recycled materials may all be used in lean concrete mixtures for base materials. When properly designed, these materials can provide a strong and erosion-resistant base.

(1) Material specifications and gradation requirements for aggregates used in lean concrete mixtures are not as restrictive as those for aggregates used in normal concrete. Aggregate gradations should conform to one of the gradations given in Table 8-2. The aggregate materials should be free from any elongated or soft pieces and dirt. Mix design for lean concrete bases is discussed in Chapter 11.

Table 8-2
Gradations for Lean Concrete Base Materials

Sieve Size (square opening) mm (in.)	Percentage by Weight Passing Sieve		
	A	B	C
50 (2)	100	--	--
37.5 (1.5)	--	100	--
25 (1.0)	55-85	70-95	100
19 (0.75)	50-80	55-85	70-100
4.75 (No. 4)	30-60	30-60	35-65
0.425 (No. 40)	10-30	10-30	15-30
0.075 (No. 200)	0-15	0-15	0-15

(2) Any bond between the lean concrete base and the concrete slab to be placed on top must be prevented to retard reflective cracking. A bond breaking material such as a wax-based curing compound should be placed on top of all lean concrete base courses.

f. Recycled Concrete Bases. Recycled portland cement concrete can serve as an aggregate for use in a granular base course or in recycled concrete base. The concrete must be properly crushed and sized to meet gradation requirements.

g. Geotextile Fabrics. Geotextile fabrics may be considered for reinforcement of the subgrade to provide a working platform for base course construction and to separate the subgrade and base course to maintain the original base course gradation. See NAVFAC DM 7.01 and NAVFAC DM 21.06 for design criteria on geotextile fabrics. The use of geotextile fabric is encouraged to prevent loss of fines from the surrounding soil through subsurface utility lines.

5. STRENGTH OF AGGREGATE BASE COURSES FOR RIGID PAVEMENTS. The modulus of soil reaction k of the unbound base courses will be determined by field plate bearing tests performed on the surface of the compacted base course or by tests on the subgrade and from Figure 8-1. If both methods are used, the lower value obtained by the two methods will be used for the pavement design. A sufficient number of field plate bearing tests must be performed on the top of a finished base course to determine a realistic design K value. Consideration should be given to the variations in base-course thickness, types of materials, and the variation in subgrade strengths. Figure 8-1 yields an effective k value at the surface of the base course as a function of the subgrade k value and base-course thickness. These relationships have been generated by field testing. If the design k value is selected from Figure 8-1, it should be verified in the field. The maximum value for the modulus of soil reaction to be used in design is 135 KPa/mm (500 pci).

6. STRENGTH OF AGGREGATE BASE COURSES FOR FLEXIBLE PAVEMENTS. Because of the effects of processing samples for the laboratory CBR tests and because of the effects of the test mold, the laboratory CBR test will not be used in determining CBR values of base courses. Instead, selected CBR ratings will be assigned as shown in the following tabulation. These ratings have been based on service behavior records and, where pertinent, on in-place tests made on materials that have been subjected to traffic. It is imperative that the materials conform to the quality requirements given in the guide specifications so that they will develop the needed strengths.

Aggregate Base Course	**Design CBR**
Graded Crushed Aggregate	100[1]
Aggregate[2]	80
Limerock	80
Shell Sand	80
Coral	80
Shell Rock	80

Note: See Chapter 6 for open-graded and rapid-draining material requirements
[1] Limited to 80 CBR for Navy and Marine Corps.
[2] Formerly mechanically stabilized aggregate.

7. MINIMUM THICKNESS REQUIREMENTS FOR FLEXIBLE PAVEMENTS. The minimum allowable thicknesses for aggregate base courses in flexible pavements are listed in Table 8-3 for Army airfields, Table 8-4 for Navy and Marine Corps airfields, and Table 8-5 for Air Force airfields. These thicknesses have been established so that the required subbase CBR will always be 50 or less.

Table 8-3
Minimum Surface and Aggregate Base-Course Thickness Requirements for Army Flexible Pavement Airfields, Inches

		100 CBR Base			80 CBR Base[1]		
Airfield Heliport Class	Traffic Area	Surface	Base	Total	Surface	Base	Total
I	B	2	6	8	2	6	8
II	B	2	6	8	3	6	9
III	A	2	6	8	2	6	8
	B	2	6	8	2	6	8
	C	2	6	8	2	6	8
IV	A	4	6	10	5	6	11
(Runway ≤ 5,000 feet)	B	4	6	10	5	6	11
	C	3	6	9	4	6	10
IV	A	4	6	10	5	6	11
(Runway > 5,000 feet)	B	4	6	10	5	6	11
	C	3	6	9	4	6	10
IV	A	4	6	10	5	6	11
(Runway ≥ 9,000 feet)	B	4	6	10	5	6	11
	C	3	6	9	4	6	10
V	B	2	6	8	3	6	9

[1] Florida limerock and graded crushed aggregate (80 CBR) permitted.
Conversion Factor: Millimeters = 25.4 × inches

Table 8-4
Minimum Flexible Pavement Surface and Aggregate Base-Course Thickness Requirements for Navy and Marine Corps Flexible Pavement Airfields

Aircraft Gross Weight kg (kips)	Tire Pressure MPa (psi)	Minimum Thicknesses, mm (in.) Surface	Base[1]	Total
< 5,440 (<12)	All pressures	50 (2)	152 (6)	203 (8)
5,440 to 13,600 (12 to 30)	<1.38 (200)	76 (3)	152 (6)	228 (9)
5,440 to 13,600 (12 to 30)	1.38 (200) or greater	102 (4)	203 (8)	305 (12)
>13,600 (>30)	All pressures	102 (4)	203 (8)	305 (12)

[1] Unbound or stabilized.

Table 8-5
Minimum Surface and Aggregate Base-Course Thickness Requirements for Air Force Flexible Pavement Airfields, Inches

		100 CBR Base			80 CBR Base[1,2,3]		
Airfield Type	Traffic Area	Surface	Base	Total	Surface	Base	Total
Light load	A	4	6	10	5	6	11
	B	4	6	10	5	6	11
	C	3	6	9	4	6	10
	Shoulders	2	6	8	2	6	8
Medium load	A	4	6	10	5	6	11
	B	4	6	10	5	6	11
	C	3	6	9	4	6	10
	D	3	6	9	3	6	9
	Shoulders	2	6	8	2	6	8
Heavy load	A	5	10	15	6	9	15
	B	5	9	14	6	8	14
	C	4	9	13	5	8	13
	D	3	6	9	3	6	9
	Shoulders	2	6	8	2	6	8
Modified heavy load	A	5	8	13	6	8	14
	B	5	8	13	6	8	14
	C	4	8	12	5	8	13
	D	3	6	9	3	6	9
	Shoulders	2	6	8	2	6	8
Shortfield	A	4	6	10	5	6	11
Auxiliary	A	3	6	9	3	6	9
	B	3	6	9	3	6	9
	C	3	6	9	3	6	9
	Shoulders	2	6	8	2	6	8

Note: When the underlying subbase has a design CBR of 80, the minimum base-course thickness will be 6 inches.
[1] Restricted to Florida limerock for heavy load pavements and modified heavy load pavements except that graded crushed aggregate (80 CBR) or cement modified or bituminous modified aggregate will be permitted in type D traffic areas.
[2] Florida limerock or graded crushed aggregate (80 CBR) cement modified or bituminous modified aggregates permitted in type B, C, and D traffic areas for medium load pavements.
[3] Florida limerock or graded crushed aggregate (80 CBR), cement modified or bituminous modified permitted for light load, shortfield, and auxiliary pavements.
Conversion Factor: Millimeters = 25.4 × inches.

8. MINIMUM THICKNESS REQUIREMENTS FOR RIGID PAVEMENTS.

a. Army and Air Force. The minimum thickness of aggregate base course under rigid pavements will be 100 millimeters (4.0 inches) over CH, CL, MH, ML, and OH subgrades or that required to meet minimum thicknesses for drainage layers as shown in EI 02C202/AFJMAN 32-1016.

b. Navy and Marine Corps. The minimum thickness requirements for aggregate base courses are listed in Table 8-6. The minimum thickness for granular materials is set for construction purposes. The additional base thickness required over clays and silts is to aid in preventing pumping. Consider experience with local aggregates and materials when selecting the base course thickness.

Table 8-6
Aggregate Base-Course Minimum Thickness Requirements for Navy and Marine Corps Rigid Pavements

Base Material	Minimum Thickness
Granular Material	152 mm (6 in.)
Cement Stabilized	152 mm (6 in.)
Asphalt Stabilized	152 mm (6 in.)
Asphalt Concrete	102 mm (4 in.)
Lean Concrete Mixture	102 mm (4 in.)

Note: For subgrades classified as CH, CL, MH, ML, or OL, the minimum granular base-course thickness shall be 203 mm (8 in.).

9. COMPACTION AND PROOF ROLLING REQUIREMENTS FOR FLEXIBLE PAVEMENTS. The aggregate base course will be compacted to 100 percent of ASTM D 1557 maximum density. In addition to compacting the base course to the required density, proof rolling shall be performed on the surface of completed aggregate base courses as designated below. Open-graded and rapid-draining layers will not be proof rolled. The layer immediately under lying the open-graded or rapid-draining layer shall be proof rolled instead. The proof roller will consist of a heavy rubber-tired roller having four tires, each loaded to 13,608 kilograms (30,000 pounds) and inflated to 720 kPa (125 psi). Repetitions of the proof roller are expressed as coverages where a coverage is the application of one tire print over each point on the surface of the designated area. TM 5-820-2/AFJMAN 32-1016 presents special proof rolling and compaction requirements for drainage layers.

a. Air Force Bases. Proof roll top of subbase and each layer of base course of type A traffic areas and the center 23 meters (75 feet) of heavy, modified heavy, and medium load runways with 30 coverages.

b. Navy and Marine Corps Airfields. Proof roll top of completed aggregate base course on center 12 meters (40 feet) of taxiways and on center 30.5 meters (100 feet) of runways with eight coverages. To all other paved areas exclusive of runway overrun and blast protection areas, apply four coverages.

c. Army Airfields. On Class IV airfields with runways greater than 1,525 meters (5,000 feet), proof roll top of subbase and each layer of crushed aggregate base course in type A traffic areas and center 23 meters (75 feet) of runways with 30 coverages.

10. COMPACTION REQUIREMENTS FOR ARMY AND AIR FORCE RIGID PAVEMENT AGGREGATE BASE COURSES. High densities are essential to keep future consolidation to a minimum, but thin aggregate base courses placed on yielding subgrades are difficult to compact to high densities. Therefore, the design density in the aggregate base-course materials should be the maximum that can be obtained by practical compaction procedures in the field but not less than:

a. 95 percent of ASTM D 1557 maximum density for aggregate base courses less than 254 millimeters (10 inches) thick.

b. 100 percent of ASTM D 1557 maximum density in the top 152 millimeters (6 inches) and 95 percent of ASTM D 1557 maximum density for the remaining thickness for aggregate base courses 254 millimeters (10 inches) or more in thickness.

11. COMPACTION REQUIREMENTS FOR NAVY AND MARINE CORPS RIGID PAVEMENT AGGREGATE BASE COURSES. Compact granular and cement-treated base courses to 100 percent of maximum density according to ASTM D 1557 and D 558, respectively. Compact asphaltic concrete base courses to 97 percent of the maximum density as determined from the Marshall mix design method.

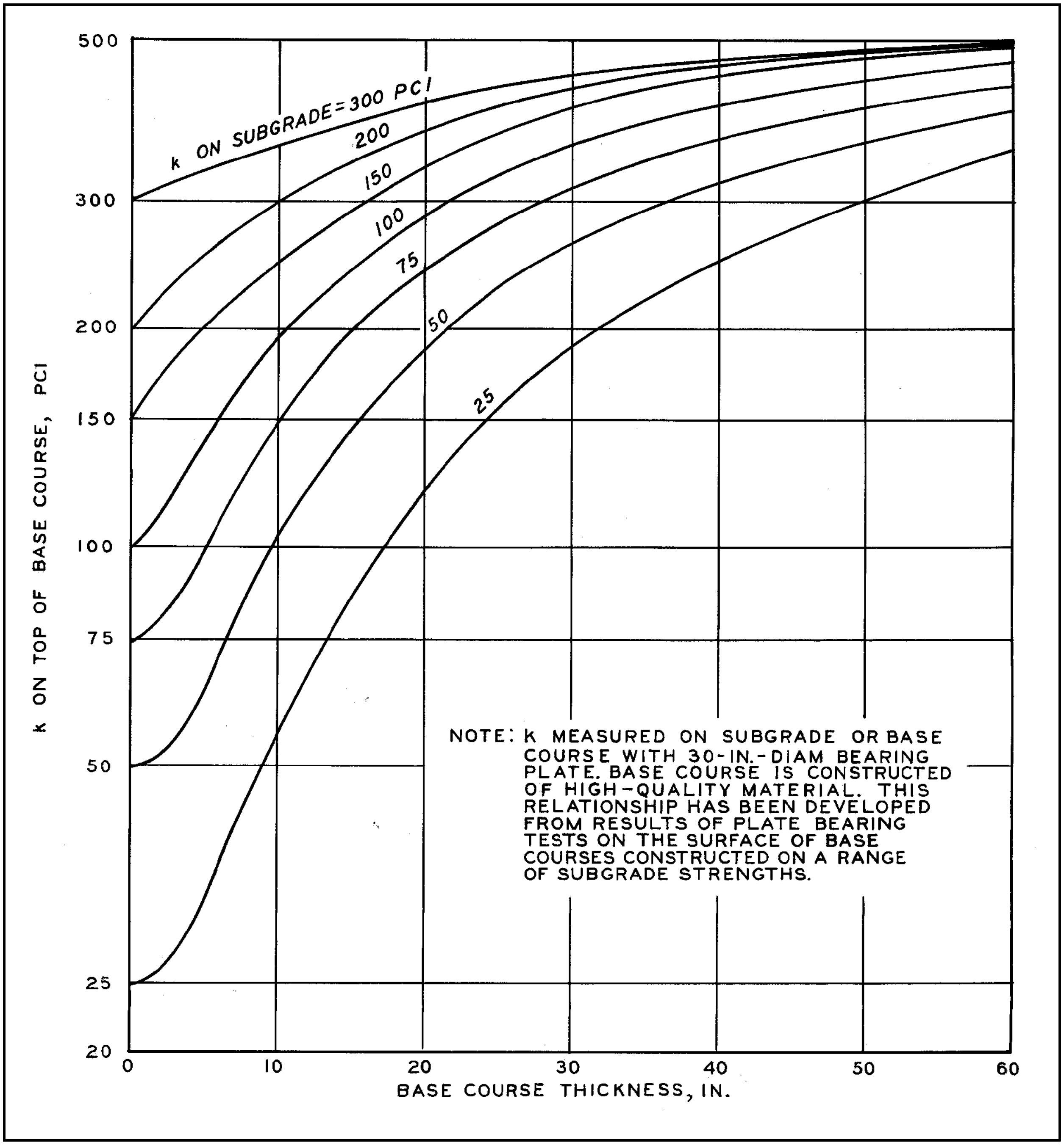


Figure 8-1. Effect of base-course thickness on modulus of soil reaction for nonfrost conditions

CHAPTER 9

PAVEMENT MATERIALS

1. GENERAL. This chapter provides the designer an overview of pavement materials that might be used in military airfield pavements. This overview will include soil and aggregate stabilization, asphaltic concrete, portland cement concrete, and recycled materials. More comprehensive and detailed descriptions, policy, and guidance on uses and limitations, testing requirements, suitable materials, mixture proportioning, and construction can be found in TM 5-822-14/AFJMAN 32-1019 for stabilization, TI 822-08/AFMAN 32-1131 V8(1)/DM 21.11 for asphalt concrete, and TM 5-822-7/AFM 88-6, Chapter 8, for portland cement concrete. In addition, each service also maintains recommended guide specifications for these materials that the engineer can edit for specific jobs. Materials technology evolves constantly, and new guidance on pavements materials is available from HQUSACE (CEMP-ET), appropriate Air Force MAJCOM pavements engineer, or Naval Facilities Engineering Service Center as changes develop. This chapter is a short overview to aid the designer during the design process, and the more comprehensive guidance documents noted above should be consulted concerning each service's specific limitations and requirements for these materials and for preparing individual project specifications.

2. STABILIZATION. . Existing soils or aggregates may not be suitable for use in airfield construction (e.g., poor grading, low strength, or excessive plasticity) or may have other undesirable characteristics (e.g., tendency to shrink or swell with moisture content changes). By stabilizing such materials with appropriate additives, their engineering and construction properties can be improved. Lime, portland cement, and asphalt are the most common stabilizers, but pozzolans (notably fly ash), ground granulated blast furnace slag, and a wide variety of proprietary materials are also available. TM 5-822-14/AFJMAN 32-1019 provides official guidance on use of lime, portland cement, lime-fly ash, and bituminous materials for stabilization. HQUSACE (CEMP-ET), appropriate Air Force MAJCOM pavements engineer, or Naval Facilities Engineering Service Center should be consulted for assistance on use of other stabilizers and conditions not covered in the existing guidance.

a. Purpose. Stabilization is most commonly associated with achieving strength to reduce pavement thickness requirements. However, other equally important and perhaps even more important uses of stabilization include improvement in soil workability, prevention of pumping in rigid pavements, mitigation of adverse volume changes in expansive soils, providing a construction platform to ease and speed construction operations, reduction of effects of adverse weather during construction, and allowing use of an economical local material that fails conventional specifications in lieu of importing more expensive materials from elsewhere.

b. Requirements. Subsequent chapters in this manual provide detailed guidance on how to incorporate stabilized materials in each of the different thickness design methods for flexible and rigid pavements. To qualify for a reduced thickness in these design methods, the stabilized material must achieve a compressive strength of not less than 5.17 MPa (750 psi) for base courses in flexible pavements, 3.45 MPa (500) psi for base courses in rigid pavements, and 1.72 MPa (250) psi for flexible pavement subbases for the Army and Air Force or 1.03 MPa (150 psi) for subbases for the Navy. These strengths are determined after 7 days of curing at 22.8 °C (73 °F) for portland cement and after 28 days of curing at 22.8 °C (73 °F) for lime, slag, and combinations with pozzolanic materials (e.g., lime-fly ash mixtures). In addition to strength, there are specific requirements for durability and material properties that must also be met. Even if a material fails to qualify for the reduced pavement thickness requirements, stabilization may prove desirable for some of the other reasons noted above. If stabilization results in granular layers sandwiched between relatively impervious layers (e.g., granular base course between an asphalt concrete surface and a stabilized subbase), then this pervious intermediate layer should be positively drained. Because of the potential for poor performance of such geometries, such designs must be approved before use by HQUSACE (CEMP-ET), appropriate Air Force MAJCOM pavements engineer, or Naval Facilities Engineering Service Center.

c. Terminology. The term "*stabilization*" as used in this chapter will encompass the addition of any materials to a soil or aggregate to improve its strength or physical characteristics for use as pavement subgrade, fill, subbase, or base course. As employed here, the term will include combinations with common additives such as lime and portland cement or lime-portland cement-fly ash as well as those materials often referred to as *soil-cement, lean concrete base*, *econocrete*, etc. TM 5-822-14/AFJMAN 32-1019 differentiates between soil stabilization and soil modification where the later only results in an improvement in some property but does not by design cause a significant increase in strength. This level of differentiation is not needed for the generalized discussion of the topic in this chapter, so *stabilization* is used here as an all-inclusive term.

d. Seasonal Frost Areas. Use of stabilized materials in areas subject to seasonal frost must address two extra concerns. First, the stabilized material must be durable for its intended purpose under the freezing and thawing exposure to which it will be exposed. Secondly, many stabilizers (e.g., portland cement or lime) must cure to gain strength, and the necessary chemical reactions to gain strength are greatly retarded and may cease altogether at low temperatures. Consequently, some stabilized materials placed late in the fall may not be able to gain adequate strength prior to the onset of freezing weather. Consequently, local climatic conditions will determine a cutoff date well in advance of anticipated freezing conditions after which date it is not prudent to place stabilized materials. Additional assistance on problems with stabilized materials under seasonal frost exposure is available from the Army Cold Regions Research and Engineering Laboratory, 72 Lyme Road, Hanover, NH 03755.

e. Combinations of Stabilizers. Under some circumstances, it may be desirable to use combinations of stabilizers to take advantage of each stabilizer's characteristics (e.g., use of a combination of lime and then portland cement relying on the lime to improve a plastic clay's workability and the portland cement for more rapid strength gain than available from the slower pozzolanic reactions of lime alone).

f. Mixing. The stabilizer and soil or aggregate to be stabilized may be mixed in situ or mixed at a central plant and then transported to the construction site and placed according to the project specifications. Proper mixing is crucial to stabilizers achieving their desired purpose. Central plants provide the best and most consistent product. In situ mixing may vary from repeated working with a grader to highly sophisticated mixers specifically designed for the task. It is harder to achieve good distribution and mixing of the stabilizer with in situ mixing techniques than with plant mixing. Consequently, stabilizer contents are sometimes increased ½ to 1 percent over the laboratory determined design stabilizer content to account for uncertainties of in situ mixing.

g. Compaction. Stabilized materials must be adequately compacted to achieve their desired purpose. Stabilization is not a substitute for compaction, and poorly compacted stabilized layers are prone to premature failure. Essentially, the compaction equipment and procedures and the quality-control techniques used with conventional earthwork are adequate for stabilized materials. Compaction equipment of sufficient size is needed, and lift thicknesses should be restricted to a maximum of 150 millimeters (6 inches) unless the contractor can demonstrate in the field that project specified density levels are achieved throughout the lift for thicker placements. To check the latter, the density must be measured in the bottom of the lift and not just at the surface or as an average through the entire lift. Generally, stabilized layers used in subbase and base courses of military airfields should be compacted to 100 percent of the laboratory modified compaction-energy density. TM 5-822-14/AFJMAN 32-1019 provides more comprehensive guidance on requirements for laboratory compaction and testing procedures to be used with different stabilized materials. Addition of the stabilizer changes the laboratory compaction characteristics of the soil or aggregates, and the trends are not always predictable. For example, increasing the percent of portland cement used to stabilize a soil may either shift the laboratory compaction curve up and to the left (i.e., increase maximum density and decrease optimum moisture content) or down and to the right (i.e., decrease maximum density and increase optimum moisture content). On the other hand, increasing lime contents decrease the laboratory maximum density and increase the optimum moisture content for compaction. If field stabilizer contents are increased for in situ mixing as noted in the previous paragraph, this may affect the laboratory maximum density value that the contractor is required to meet in the field, and assessment of the contractor’s field compaction must take this into account. For instance, if the lime content is increased in the field over that used in the laboratory, the contractor may encounter problems achieving the specified density because the actual laboratory target density was decreased by the additional lime. When these complex soil-stabilizer interactions are combined with field variation from distribution and mixing of the stabilizer, fairly assessing the contractor’s compaction efforts may become difficult. In circumstances where stabilizer contents are being increased in the field, supplemental one-point compaction tests of the in situ stabilized materials may prove helpful for assessing compaction compliance. HQUSACE (CEMP-ET), appropriate Air Force MAJCOM pavements engineer, or the Naval Facilities Engineering Service Center may be consulted for assistance with difficult cases.

h. Curing. In the subsequent sections, curing requirements are identified for many stabilizers. It is crucial that this curing take place adequately for the stabilizer to achieve the desired results. Generally, this means that temperatures must be high enough for the desired chemical reactions to occur, and moisture must be maintained within the material and evaporation stopped or at least severely retarded. Inadequate curing can negate the benefits of stabilization.

i. Testing. Tight financial restraints on military construction today often discourage adequate testing. However, when working with stabilized materials, it is important to verify in the laboratory that the proposed stabilization scheme will achieve the desired results. For instance, it is not sufficient to simply select a suggested lime content for stabilizing a clay because the soils/clay mineralogy or the presence of organic or some iron compounds in the soil may totally change or inhibit the chemical reactions that occur. It is always prudent to perform sufficient laboratory work to verify that the percentages of stabilizer, stabilizer type, and actual soil or aggregate will achieve the desired results when they are mixed, compacted, and cured.

j. Lime Stabilization. Hydrated lime ($Ca(OH)_2$), quick lime (CaO), or the dolomitic variants of these limes are suitable for lime stabilization of soils. Requirements for the limes for soil stabilization are contained in ASTM C 977. Calcium carbonate ($CaCO_3$) is often sold under names such as agricultural lime and is not suitable for soil stabilization.

(1) Mechanisms. Several things happen when lime is added to a soil. As the lime hydrates, it dries the soil. Anhydrous quicklime is particularly effective for this. Some fine clay-sized soil particles agglomerate when lime is added to the soil which results in a decrease in the measured number of clay-sized soil particles. Essentially, a clayey soil fabric becomes siltier, and the soil is easier to work, dry, etc. Also, cation exchange occurs, and the calcium from the lime replaces sodium and potassium in clay minerals. This results in a reduction in plasticity of the soil. The above reactions (drying, particle agglomeration, and cation exchange) occur rapidly after the lime is added to the soil. With time, some, but not all, clays may undergo a further pozzolanic reaction with the lime and develop additional strength

from the resulting calcium silicate and calcium aluminate hydrate compounds. Soil compressive strength gain, after 28-day cures at 22.8 °C (73 °F) from the pozzolanic reaction between lime and some clay minerals may range from negligible to 10.34 MPa (1,500 psi). Typically, a well-compacted, reactive lime-stabilized soil will achieve compressive strengths in the range of 100 to 500 psi.

(2) Uses. Lime added to soil can rapidly dry the soil; it coarsens the particle texture which often makes the soil easier to work; and it reduces the soil's plasticity, making it more workable, generally reducing the soil's strength loss when it is wetted, and often reducing adverse shrinking and swelling behavior. The pozzolanic strength gain, which is typically assessed after 28 days of curing at 22.8 °C (73 °F), can significantly improve soil strength of subgrades and can often meet the strength requirements for a stabilized subbase for flexible pavements. The requirements for stabilized bases are harder to meet with lime alone, and the addition of cement with the lime may be needed to gain the required strength. Many characteristics of lime stabilization make it very useful as a construction expedient and soil improvement additive for difficult plastic clay soils (e.g., drying, coarser texture, reduced plasticity and water susceptibility, construction platform, reduced shrink-swell behavior) rather than for structural strength alone.

(3) Durability. Lime stabilization should provide sufficient durability to accomplish the required objectives under the anticipated exposure conditions.

(a) Moisture. Lime-stabilized soils generally retain over two-thirds of their strength when exposed to water and have performed well in structures exposed to water (e.g., levees, canals, and dams and as expedient (lime-stabilized clay surface) military airfields in Latin America). However, a few clays have shown poor strength retention when soaked in the laboratory. Consequently, some soaked strength tests or the optional wet-dry test (ASTM D 560) limits in TM 5-822-14/AFJMAN 32-1019 may be checked if strength when exposed to soaking or wetting and drying is a critical design parameter.

(b) Seasonal frost exposure. Lime-stabilized materials generally expand and lose strength when exposed to freezing and thawing. As cycles of freezing and thawing increase there is a progressive decrease in the strength of the lime-stabilized material. Generally, the first winter is the critical exposure as extended curing in subsequent seasons will provide additional strength, and there are data to suggest these materials may heal autogenously under favorable curing temperatures. TM 5-822-14/AFJMAN 32-1019 has specific testing criteria and limits based on ASTM D 560 that must be met if the lime-stabilized material is to be exposed to freezing and thawing. Because of the relatively slow rate of pozzolanic strength gain in lime stabilization, adequate time for curing must be allowed prior to the stabilized layer's being exposed to freezing. Consequently, the lime-stabilized material must be in place well in advance (e.g., perhaps 30 days) prior to the onset of freezing weather which shortens the construction season for some areas. Alternatively, it must be protected from freezing (e.g., by placement of overlying pavement layers), and the temperature maintained high enough to allow pozzolanic reactions to occur. Additional assistance on problems with lime-stabilized materials under seasonal frost exposure is available from the Army Cold Regions Research and Engineering Laboratory, 72 Lyme Road, Hanover, NH 03755.

(c) Leaching. There is some limited evidence that soils stabilized with low levels of lime may have the benefits of lime stabilization reduced by leaching over time. The problem appears to be relatively rare and generally associated with low levels of lime stabilization (e.g., 3 percent and less). In general, this should not be an issue for lime stabilization levels for airfield pavements as their strength and durability requirements would normally require lime contents above those where leaching has been a reported problem.

(d) Carbonation. Atmospheric carbon dioxide can react with lime to form calcium carbonate which can adversely affect lime-stabilization reactions. Proper and prompt mixing, storage, compaction, and curing procedures that minimize the exposure of the lime-stabilized soil to atmospheric carbon dioxide avoids the problem. Reported problems have been with highly weathered materials in Africa that were poorly compacted and cured.

(e) Sulfate attack. Lime-stabilized materials are susceptible to sulfate attack if sulfates are present in the soil or water in contact with the stabilized material or if they are present in materials that are being stabilized. The sulfate attack reactions are expansive and highly disruptive. Technical guidance on this problem is incomplete. If lime stabilization is contemplated where sulfates are present, the HQUSACE (CEMP-ET), appropriate Air Force MAJCOM pavements engineer, or Naval Facilities Engineering Service Center should be consulted for up-to-date guidance on this difficult issue.

(4) Suitable Soils. Clayey soils with a plasticity index of 12 or more are generally best suited for lime stabilization. Organic soils and clays containing some iron compounds do not respond well to lime stabilization, and some highly weathered soils may require a larger than expected dosage of lime stabilizer to be effective.

k. Portland-Cement Stabilization. Type I portland cement and, more rarely, Types II, I/II, and III meeting the requirements of ASTM C 150 may be mixed with soils or aggregates to provide a cohesive cemented material often referred to *as soil-cement, econocrete, lean concrete base*, etc.

(1) Mechanisms. When mixed with water, portland cement develops cementing compounds that bind the soil and aggregate particles together. Unlike lime, there is no necessary chemical reaction with the soil particles themselves. Portland cement contains free lime as one of its constituents so the same cation exchange and pozzolanic reactions with clayey soils will occur with portland cement, but these are minor effects compared with the dominant formation of the conventional portland-cement hydration compounds that serve to bind the particles together.

(2) Uses. Portland-cement stabilization can provide a material with compressive strengths from a few MPa (few hundred) to well over ten MPa (several thousand psi), depending on amount of stabilizer and soil properties. These higher-strength stabilized materials are often referred to as *econocrete, lean concrete*, etc. with cement contents in the range of 134 to 223 kg/m^3 (225 to 375 lb/yd^3). Such high cement content and high-quality stabilized mixes are usually proportioned and placed with the same techniques as conventional concrete. In general, cement stabilization of fine-grained soils provides a lower strength than cement stabilization of coarse-grained soils. The reactions of portland cement are faster than pozzolanic stabilizers such as lime. A major drawback for cement stabilization is the formation of shrinkage cracks which can reflect up through surfacing layers. This is usually a severe problem with cement-stabilized bases under asphaltic concrete surfaces, but it has also occurred with concrete surfaces placed directly on high-strength cement-stabilized layers. To minimize problems with reflective cracking, the Air Force limits the allowable content of portland cement in stabilized bases in flexible pavements to a 4-percent maximum. A double application of curing compound is often sprayed on cement-stabilized bases to reduce the chance of reflective cracking in overlying portland-cement concrete surfaces in rigid pavements. Portland-cement stabilization is most often used for a relatively high-strength layer that may provide a construction platform, an all-weather construction surface, or a significant structural layer within the pavement. It is also probably the most expensive of the common soil stabilizers. Materials stabilized with portland cement should be placed and compacted within 2 hours of the mix water coming into contact with the cement.

(3) Durability.

(a) Seasonal frost exposure. Cycles of freezing and thawing can damage cement-stabilized materials so TM 5-822-14/AFJMAN 32-1019 has specific testing criteria and limits based on ASTM D 560 that must be met if the cement-stabilized material is to be exposed to freezing and thawing. Adequate curing time in the field must also be available prior to the onset of freezing. Additional assistance on problems with cement-stabilized materials under seasonal frost exposure is available from the Army Cold Regions Research and Engineering Laboratory, 72 Lyme Road, Hanover, NH 03755.

(b) Carbonation. As with lime, atmospheric carbon dioxide can react with portland cement to form calcium carbonate which can adversely affect portland cement-stabilization reaction products. Proper and prompt mixing, compaction, and curing procedures that minimize the exposure of the stabilized soil to atmospheric carbon dioxide avoid the problem. Reported problems have been with highly weathered materials in Africa that were poorly compacted and cured.

(c) Sulfate attack. Cement-stabilized materials are susceptible to sulfate attack if sulfates are present in the soil or water in contact with the stabilized material or if sulfates are present in materials that are being stabilized. The sulfate attack reactions are expansive and highly disruptive. If the soils or aggregates being stabilized contain clay minerals, sulfate resistant cements (Type II and V) will not prevent sulfate attack. If cement-stabilization is contemplated where sulfates are present, the HQUSACE (CEMP-ET), appropriate Air Force MAJCOM pavements engineer, or Naval Facilities Engineering Service Center should be consulted for up-to-date guidance on this issue.

(4) Suitable Soils. The most economical materials for cement stabilization will generally be well-graded sandy gravels or gravelly sands with a spectrum of particle sizes. Fine materials, coarse materials, or poorly-graded materials will often require uneconomically high cement contents to achieve adequate stabilization. Sticky materials such as CH clays may be difficult or impossible to mix adequately with the cement stabilizer. Organic soils and some acidic sands respond poorly to cement stabilization.

l. Pozzolan and Slag Stabilization. ASTM C 618 classifies pozzolans as Type N (natural pozzolans), Type C (high-lime-content fly ash, a byproduct of burning lignite or subbituminous coal), or Type F (low-lime-content fly ash, a by product of burning bituminous or anthracite coal). These materials are not normally cementitious by themselves, but when combined with calcium hydroxide (lime), they will form cementitious, pozzolanic bonds. Granulated blast furnace slag is a by-product of iron production which can be ground to produce a slag cement. ASTM C 989 provides requirements and grade classifications for this material. Neither material has been used extensively as a stabilizer by the military, but their use is expanding in the construction industry. TM 5-822-14/AFJMAN 32-1019 provides guidance on fly ash (the most commonly available pozzolan) stabilization. Slag is not addressed in the manual, and HQUSACE (CEMP-ET), appropriate Air Force MAJCOM pavements engineer, or Naval Facilities Engineering Service Center should be consulted for current guidance on use of this material in military construction.

(1) Mechanisms. Pozzolans and ground granulated blast furnace (GGBF) slag react with hydroxides to form cementitious bonds. Lime or occasionally portland cement are mixed with these materials to provide the hydroxide activator. Some Class C fly ashes contain sufficient free lime (calcium hydroxide) to be self-cementing, but the military has no experience at present using these materials as a stabilizer without the addition of lime or portland cement. Properly cured lime-fly ash mixes often have compressive strengths of 3.45 to 6.89 MPa (500 to 1,000 psi) with appreciably higher long-term

strengths. If more rapid strength gain is needed, addition of 0.5 to 1.5 percent portland cement can be used as an activator for the fly ash and as contributor to early-age strength.

(2) Uses. Pozzolans and slags gain strength more slowly than portland cement, but are more economical, have less shrinkage and shrinkage cracking, and longer working times than portland cement. Typical fly ash-stabilized mixes will use 2-1/2 to 4 percent lime with 10 to 30 percent fly ash. Coarser soils and aggregates require less stabilizer than fine-grained soils. Some slag mixes used overseas have 8 to 20 percent GGBF slag mixed with 1 percent lime.

(3) Durability. Because of the slower strength gain of these materials, it is crucial that sufficient time be allowed between their placement and the onset of freezing weather. These chemical reactions almost cease below 4.4 °C (40 °F) so this curing period must include moderate temperatures to assure adequate curing of these materials. They can be vulnerable to freezing and thawing damage, so TM 5-822-14/AFJMAN 32-1019 requires laboratory freeze-thaw testing after 28 days curing. Additional assistance on problems with lime-pozzolan or slag-stabilized materials under seasonal frost exposure is available from the Army Cold Regions Research and Engineering Laboratory, 72 Lyme Road, Hanover, NH 03755.

(4) Suitable Soils. Granular materials are effectively stabilized with these materials. Because of their relative economy compared to portland cement, they are particularly effective with poorly graded materials where they can effectively function as a filler more efficiently than the more expensive portland cement. Many clays are naturally pozzolanic so there is little value in adding another pozzolanic material like fly ash. These are usually best handled with lime alone. However, for clays that do not develop pozzolanic reactions with lime or for silty materials that do not contain sufficient clay minerals to react with lime, pozzolanic and slag stabilizers offer an economical and effective alternative to portland cement.

m. Bituminous Stabilization. Asphalt cement (AASHTO PP6, ASTM D 3381, or ASTM D 946), emulsified asphalt (asphalt emulsified with water, ASTM D 977 and D2397), or cutback asphalt (asphalt dissolved in a solvent, D 2026, 2027, and 2028) may be mixed with a soil or aggregate to provide a water resistant, cohesive stabilized material. The mix design for bituminous stabilized materials in a military airfield subbase or base course will be done using a conventional Marshall mix design. Binder contents for subgrade stabilization are often estimated on the basis of empirical equations and then adjusted during construction in the field to achieve the desired results. TM 5-822-14/AFJMAN 32-1019 provides detailed guidance on bituminous stabilization requirements and procedures.

(1) Mechanisms. Asphalt coats the soil and aggregate particles being stabilized and binds it into a water-resistant, cohesive material. Both strength and waterproofing are provided. No chemical reactions are involved. Asphalt-cement stabilization requires no curing other than cooling. Liquid asphalts require different amounts of curing depending on the emulsifying agent or solvent used and the atmospheric conditions. The emulsion must break and the water must either evaporate or drain off for the emulsified asphalt to be effective. Similarly, the solvent in cutback asphalts must evaporate. Premature compaction of liquid-asphalt stabilized materials before adequate water or solvent evaporation may cause very slow curing and leave the stabilized material too soft. The asphalt droplets in an emulsified asphalt may have either a negative electric charge (anionic emulsion) or a positive electric charge (cationic emulsion) that can be matched to the aggregate charge (e.g., an anionic emulsion (negatively charged droplets) used with limestone aggregate (positive charge)).

(2) Uses. Asphalt stabilization provides cohesion to bind individual particles into a mass and can provide significant waterproofing. Asphalt cements are generally mixed with a higher quality

aggregate at an asphalt plant to produce a structural quality subbase or base course stabilized material. The liquid asphalts (emulsified and cutback asphalts) may be plant mixed but are often in situ mixed for less severe loading such as in the subgrade or the subbase or for lighter load applications. As a general rule, the local paving grade asphalt cement will be appropriate for the binder for asphalt-cement stabilization. For liquid asphalts, the highest possible viscosity liquid asphalt that can be handled in the field and mixed with the soil or aggregate being stabilized should be used.

(3) Durability. Water may displace asphalt particles on a soil or aggregate particle in a process known as stripping. Some aggregates have a strong affinity for water and tend to be particularly difficult to coat with asphalt. They are prone to stripping and may prove impossible to coat with liquid asphalt. Additions of lime or liquid antistrip agents or changing the charge of an emulsified asphalt may help combat these problems. Potential moisture problems and effective countermeasures should be a fundamental part of a bituminous stabilization laboratory evaluation and mix design.

(4) Suitable Soils. Bituminous stabilization is most effective with granular materials as excess fines or plastic fines may make it impossible to properly mix the materials and require high binder contents. As the plasticity index increases past 6 and the fines (percent passing the No. 200 sieve) increases above 12 percent, problems with bituminous stabilization increase. In general, the plasticity index should be below 10 and the fines should be less than 30 percent. As the plasticity and percent fines increase, liquid asphalt become better stabilizing agents than asphalt cement. The plasticity of a material to be stabilized can be reduced by adding lime.

n. Nontraditional Stabilizers. A wide variety of special, and often proprietary, stabilizers are actively marketed. These materials have seen very little use or testing by the military, and no guidance is currently available. Many, but not all, proprietary stabilizers that have been evaluated by the military have not lived up to the manufacturer's claims, and no proprietary stabilizer should be used on a military airfield without first evaluating it in the laboratory and in independent field trials. HQUSACE (CEMP-ET), appropriate Air Force MAJCOM pavements engineer, or Naval Facilities Engineering Service Center should be consulted prior to using any of these nontraditional stabilizers.

(1) Types: Nontraditional stabilizers include a wide variety of acids, salts, electrolytes (often a sulfonated oil), polymers, enzymes, natural resins, cation exchange agents, lignins, and polymers among others. Claimed benefits include strength gain, reduced water susceptibility, improved compaction, reduced dusting, reduced plasticity, and better soil texture.

(2) Evaluation. The claimed benefit of any stabilizer should be evaluated quantitatively so that the cost-effectiveness of including the material on a specific project can be determined. It is important to identify what soil property is being changed by the stabilizer and develop a quantitative scheme for evaluating this property. For example, electrolytes reduce a clay mineral's ability to hold water so they have a potential role in dealing with expansive soils. A swelling test with and without the stabilizer is appropriate to evaluate this stabilizer's effectiveness, whereas a strength test would provide no information on the electrolyte's effectiveness. Experience with some of these materials has found that often the amount of the stabilizer needed is higher than the manufacturer's suggested dosage.

3. PORTLAND-CEMENT CONCRETE. Portland-cement concrete is the surfacing for rigid pavement. It carries load through bending and is the major structural component for supporting load. Unreinforced concrete is generally the most serviceable and cost-effective surfacing for military airfields and will be used in most circumstances.

a. Reinforcing. Reinforcement may be added to concrete pavement to accomplish specific purposes, but reinforcing is the exception rather than the rule for military airfield pavements. Reinforcing concrete pavements usually adds cost and complicates construction so it is used only where its added value balances these negative factors. Conventional reinforcing steel is added to keep cracks tightly closed and to slow deterioration of the cracks. Therefore, it is useful wherever cracking cannot be avoided (e.g., odd-shaped slabs, extra-large slabs, etc.). Because reinforcing slows the deterioration of cracks, a relatively small empirical reduction in pavement design thickness is allowed by the material for reinforcing up to 0.5 percent. Continuously reinforced concrete pavements use much more steel (0.6 percent and more) which added to resist deterioration in cracks developed from environmental stresses. The steel is continuous, and the pavement has no joints. It provides a joint-free, smooth pavement, but repairs to these pavements are often difficult. Fiber reinforcing products are actively marketed. Steel fibers can significantly reduce the required pavement thickness, but there are concerns that the fibers pose a foreign object damage (FOD) on military airfields with current finishing techniques. Plastic fibers are of no particular value for military airfields. Their primary advantage for conventional concrete appears at present to be resistance to plastic shrinkage cracking, but proper construction and curing should handle this concern without adding plastic fibers at additional expense to the military. As noted later, these fibers have been found useful in concrete exposed to exhaust from vertical and short take off aircraft like the Harrier. Prestressed pavements are very efficient and produce the most structural capacity for any given cross section of concrete pavement. The design and construction of prestressed pavement is more sophisticated than conventional pavements, but prestressing construction technology has been evolving and is more cost-effective today than in past years. More details on these various reinforced pavements and their design is provided in subsequent chapters.

b. Constituents. Portland-cement concrete is composed of portland cement, aggregates, water, and various additives. Portland cement must meet the requirements of ASTM C 150, and the various types of portland cement are described in Table 9.1. Type I cement will be the most common cement, although Type II, Type I/II, and more seldom Type V may be used in areas with sulfate exposures. Type III cement might be encountered where its rapid strength gain is necessary or in cold weather concreting where its higher heat of hydration is useful. Cements may be specified to be low alkali when problems with alkali-aggregate reactions are anticipated, but such cements may not always be readily available and may be expensive. Addition of fly ash is very common in modern concretes, and the addition of ground granulated blast furnace slags is beginning to be used more often. Both may be used as economical partial replacements for portland cement in the concrete mixture and can be used to provide other desirable characteristics such as enhanced workability, lower permeability, sulfate resistance, protection against alkali-aggregate reaction, etc. Aggregate quality requirements in TM 5-822-7/AFM 88-6, Chapter 8, for military airfield pavements are appreciably tighter than those used in ASTM C 33 which is the most commonly specified concrete aggregate requirement for the concrete industry. The tighter requirements reflect the military's concern over potential FOD hazards to aircraft on airfield pavements. These tighter restriction were adopted by the military in the 1950's after severe problems with popouts developed on new airfield pavements at Selfridge AFB. Air entrainment is crucial for protecting the concrete matrix against damage from freezing and thawing and will be used in all military airfield pavements unless clearance not to do so is first obtained from the HQUSACE (CEMP-ET), appropriate Air Force MAJCOM pavements engineer, or Naval Facilities Engineering Service Center. Air entrainment causes some loss in strength, but it also enhances workability. Therefore, proper mixture proportioning can use this enhanced workability to reduce the water-cement ratio and thereby negate the strength loss from air entrainment. The proper dosage of air-entraining admixture to achieve the targeted air content is affected by factors such as the amount of carbon (measured as loss on ignition) in fly ash or the temperature. Therefore, all air entrainment for military airfield concrete will be provided by liquid admixtures added at the plant. This allows the dosage to be adjusted to reflect specific mixture characteristics and environmental fluctuations at the project site. Air entraining admixtures that are interground with the cement and designated as Type IA, Type IIA, etc. are not suitable for this use as they do not provide the flexibility of adjusting admixture dosage to reflect changing mixture and site conditions. A number of other admixtures besides those for air-entrainment are available to accomplish specific tasks (primarily retarders, accelerators, and those for enhanced workability at a given water-cement ratio). Use of these is generally at the discretion of the engineer doing the mixture proportioning for a specific project or of the contractor who must deal with a specific site problem. The engineer responsible for the mixture proportioning is responsible for selection of admixtures and concrete materials that are compatible and cause no adverse interactions. If the contractor elects to use an admixture (e.g., a retarder because of lengthy haul times), then he or she is responsible for selecting an admixture compatible with the concrete mixture and which has no adverse effect on the fresh or hardened concrete mixture.

c. Special Air Force Requirement. During the 1980s and 1990s, newly placed concrete airfield pavement on Air Force bases had widespread problems with excessive spalling derived primarily from construction related problems, part of which sprung from the common use of concrete mixtures with poor workability. To partially address these problems, the Air Force now requires a well-graded concrete aggregate be used for all their airfield pavements with specific limitations depending on anticipated placement methods (i.e., slipform, with form-riding equipment, or by hand). Specific requirements and details are contained in the Air Force Concrete Mix Design Handbook and will be conformed to for all Air Force pavements unless a waiver is obtained from the Air Force MAJCOM pavements engineer.

d. Durability. Properly proportioned and placed, portland-cement concrete is a highly durable material. Protection against freezing and thawing is achieved by ensuring adequate strength gain before the concrete is first allowed to freeze (crucial issue in cold-weather concreting), using aggregates that are resistant to freezing effects (avoiding aggregates that are prone to produce popouts and D-cracking), and providing adequate air entrainment to protect the concrete matrix. Special precautions are needed when concrete will be exposed to sulfates or if the concrete mixture contains certain aggregates susceptible to reactions between the portland cement alkalis and some aggregate minerals (most commonly certain specific forms of silica and more rarely certain dolomitic materials). Details on these durability issues and guidelines on selecting appropriate levels of air entrainment are provided in TM 5-822-7/AFM 88-6, Chapter 8. The water-cement ratio in military airfield paving mixtures is limited to a maximum of 0.45. This requirement enhances durability by keeping the concrete permeability low as well as improves strength when compared to using higher water to cement ratios in the concrete mixture.

e. Design Strength.

(1) Test Method. Military airfield pavements are designed on the basis of the third point, flexural beam test (ASTM C 78). Thickness design is based on fatigue relationships from full-scale field tests that characterized the test pavement with the flexural test determined in this manner. Other test methods (e.g., center-point flexural beam or splitting tensile test) give numerically different values from this test and are therefore not suitable substitutes. Pavement thickness design is based on classical fatigue analysis, and the results are very sensitive to the specific value of flexural strength used in the design. Consequently, it is important that military airfield pavement design define the concrete strength consistently with the fatigue relationship used in the design procedure. Consequently, all military airfield design will be based on the ASTM C 78 flexural strength.

(2) Correlations. There are no unique relationships between different concrete strength tests (third-point flexural beam, center-point flexural beam, compressive, splitting tensile, etc.), and all such tests are indices of strength rather than an inherent material property. There are many published relationships that allow estimation of one strength test result as a function of another test (e.g., estimate

third-point flexural strength from the concrete compressive strength). However, the variation of the data upon which such relations are based is quite large and the results too inaccurate to allow the use of such relations reliably for military airfield pavement design. The different tests respond differently to changes in the concrete mixture. For example, flexural tests are much more sensitive to inclusion of crushed aggregates in the mixture than are compressive strength tests. It is possible to develop very good correlations between the different tests if the correlation is based on tests on the specific concrete mixture and the same materials are used in the laboratory as will be used in the field mixture. However, simply changing an aggregate source can change the correlation. Correlations are allowed for quality control testing of military concrete pavements during construction, but the correlations must be developed for the specific concrete mixture being used on the project, and the mixture constituents used during construction must be the same as used to develop the correlation in the laboratory.

(3) Selection of Design Strength. The designer should base the pavement thickness design on a strength that is readily achievable with local materials. Design strengths on past projects at the base or discussions with local producers should allow selection of a design strength that is readily achievable with local materials. If no such information is available, some trial laboratory mixtures should be prepared to evaluate local aggregate sources. Traditionally, pavement thickness design for military airfields is based on the 90-day strength of laboratory-cured specimens. This lengthy cure time takes maximum advantage of the long-term gradual strength gain characteristic of conventional portland-cement concrete. On many rehabilitation projects today, pavements are returned to the user after much shorter periods. Consequently, design strengths are often specified based on these shorter periods when the pavement is returned to the user. Fly ash and GGBF slag gain strength more slowly than portland cement, so the designer must be aware that strength tests at early ages for concrete mixtures containing these materials may not reflect the ultimate long-term strength well at all. Specifying very high strengths, particularly at early ages, usually requires very rich mixtures with liberal use of admixtures. This may introduce workability and construction problems, excessive shrinkage, or other undesirable characteristics that negate the economies of higher strength. In general, design ASTM C 78 flexural strengths of 414 to 448 MPa (600 to 650 psi) are readily achievable with most local materials, and the designer should use higher design strengths only with caution.

f. Special Airfield Exposure Conditions. Properly proportioned, placed, and cured portland-cement concrete requires no surface sealers, coatings, or treatments to withstand normal military aircraft operations such as startup, warmup, taxiing, takeoff, and landing.

(1) Heat Effects on Portland-Cement Concrete. Rapid heating of moist concrete can vaporize water in the concrete capillaries and cause explosive spalling. As the concrete temperature begins to rise above about 149 °C (300 °F), the progressive cement paste dehydration, thermal incompatibilities between paste and aggregate, and aggregate deterioration lead to irreversible damage and progressive loss of strength that is more pronounced as the temperature rises. Aggregates have a major impact on the thermal behavior of concrete and in decreasing order of desirability for thermal resistance they are lightweight aggregates (e.g., expanded slags, clays, and shales or natural pumice or scoria), fine-grained igneous rocks such as basalt or diabase, calcareous aggregates, and siliceous aggregates. Including slag cements in the concrete mixture also seems to enhance thermal resistance. Heat resistant conventional concrete can be achieved by proper mixture proportioning, use of appropriate aggregates, inclusion of slag cement, and high-quality concrete placement, finishing, and curing. However, if the concrete temperature will reach 204 °C (400 °F), conventional concrete probably will not be sufficient, and thermal cycling at lower temperatures can cause damage. HQUSACE (CEMP-ET), appropriate Air Force MAJCOM pavements engineer, or Naval Facilities Engineering Service Center should be consulted for guidance for concrete that will be exposed to high temperatures or that will be exposed to repeated cycles of high thermal exposure. Concrete is a moderately good insulator so there

is a significant lag between exposure to an elevated temperature and heating of the concrete to that temperature. Normal military aircraft operations do not heat concrete pavements to temperatures that cause damage.

(2) Power Check Pads and Similar Facilities. If the jet engine exhaust plume is allowed to impinge directly on the concrete surface, severe erosion can occur. This is a potential problem for facilities such as power check pads where engines have to be operated for extended periods and where the configuration of some aircraft will project the engine exhaust plume into contact the pavement surface. For this reason, these facilities are often specifically designed to have larger slopes than normal to keep the exhaust plume from directly impinging on the pavement surface. Pavement damage can arise when parking ramps, old taxiways, etc. are converted to use as power check pads, and the conventional slopes on these facilities allow the exhaust to come into direct contact with the pavement surface.

(3) Pavements Exposed to Vertical/Short Take-Off and Landing Aircraft Exhaust. The introduction of the Harrier aircraft exposed pavements to new higher levels of heat and blast than conventional aircraft. This trend is likely to continue with development of new aircraft like the joint strike fighter currently scheduled for deployment in about 2008. The Naval Facilities Engineering Services Center has conducted extensive research in support of deployment of the Harrier in the Marine Corps. They found that reinforced conventional concrete made with diabase aggregate has provided good performance in the field for up to 15 years. Recent studies have also found that improved performance could be achieved with portland-cement concrete with lightweight aggregate and nylon fibers, a proprietary blended cement with lightweight aggregate, and nylon fibers, and a proprietary magnesium phosphate cement with lightweight aggregate. The Naval Facilities Engineering Service Center, 1100 23rd Avenue, Port Hueneme, CA 93043-4370, should be contacted for current guidance and research results in this area.

(4) Pavements Exposed to Auxiliary Power Unit (APU) Exhaust. The APU on the B-1, FA-18, and certain models of aircraft currently under development are mounted so that the exhaust is directed downward and into contact with the pavement surface. With extended operation of these units, the surface of the concrete may be heated to temperatures approaching 177°C (350°F). This leads to scaling and spalling in the limited area around the exhaust impingement area. Studies by the Naval Engineering Service Center, Air Force Wright Laboratories, and the U.S. Army Engineer Research and Development Center have identified two mechanisms contributing to this damage. Repeated heating and cooling lead to thermal fatigue and surface failure. At these elevated temperatures, fluids high in esters such as fuel, lubricants, and hydraulic fluids can chemically react with portland-cement concrete and lead to scaling of the pavement. In parking areas for these aircraft, the APU exhaust impinges on the concrete where there is significant collection of these fluids that have leaked from the aircraft in normal maintenance and operation. At present there is no technical solution to this problem. Ad-hoc solutions and trials in the field have included bolting steel plates to the pavement in the area where the exhaust contacts the pavement, various coatings, refractory concretes, and specialty concretes with generally mixed or unsatisfactory results. HQUSACE (CEMP-ET), appropriate Air Force MAJCOM pavements engineer, or Naval Facilities Engineering Service Center should be contacted for guidance when designing parking areas for these aircraft.

g. Specification and Construction. It is crucial that proper material and construction specifications be developed to accompany the thickness design and geometric design and detailing. There have been numerous problems with military concrete airfield pavements in recent decades as the result of improper construction techniques, poor finishing, inadequate curing, late saw-cutting of joints, use of aggregates susceptible to alkali-aggregate reactions without proper countermeasures, inclusion of deleterious materials, and inadequate durability when exposed to freezing and thawing or sulfates. The result has been unsatisfactory performance, increased maintenance, and dissatisfied users in some cases. The designer should be certain to consult current versions of each service's guide specification and TM 5-822-7/AFM 88-6, Chapter 8, for assistance in preparing project specifications.

4. ASPHALTIC CONCRETE. Asphaltic Concrete is the normal surfacing for flexible pavements. Unlike portland cement concrete, it normally functions as a relatively thin wearing surface and is not the major structural element of the pavement. Asphaltic concrete on airfields is exposed to much more severe loads than on highways and is quite different from highway asphaltic concrete mixes. Substitution of asphaltic concrete highway mixes for asphaltic concrete airfield mixes is not acceptable and is a major engineering blunder. The requirements of TM 822-08/AFMAN 32-1131 V8(1)/DM 21.11 will provide an asphaltic concrete that will stand up to the loads of modern military aircraft in all environmental conditions.

a. Constituents. Asphaltic concrete is composed of well-graded aggregates (approximately 95 percent by weight) and an asphalt cement binder (approximately 5 percent by weight).

(1) Binder. Asphalt cement from the distillation of petroleum is the most common binder in asphaltic concrete. Liquid asphalts from emulsifying asphalt cement with water or dissolving the asphalt cement in a solvent have many applications in pavements but are not normally used as a binder for high-quality airfield pavements. Tars from the distillation of coal are seldom used as binder in airfield pavements today. There are also natural asphalts that occasionally are used as binder material for asphaltic concrete.

(a) Characteristics. Asphalt is a complex hydrocarbon product whose composition and properties vary depending on the petroleum source and distillation process. Asphalt is probably the most viscoelastic material used by civil engineers in routine construction. Its stiffness increases as its temperature drops or as the speed of loading increases, and in reverse the stiffness drops as temperature increases or as the speed of loading is slowed. Asphalt cement functions as a cohesive binder for the aggregate and helps provide a nominally waterproof surface.

(b) Specification. The asphalt binder should be specified in accordance with the new Strategic Highway Research Program (SHRP) pavement grading (PG) system (AASHTO PP6). This new system matches specific characteristics of the asphalt cement with environmental exposure conditions. This improved matching of binder properties and project environmental conditions should extend the effective life of asphaltic concrete pavements. TM 822-08/AFMAN 32-1131 V8(1)/DM 21.11 provides guidance on selecting PG grades of asphalt cement for different project locations. SHRP PG grading is not used universally worldwide, therefore alternate specification methods based on viscosity (ASTM D 3381) and penetration (ASTM D 946) can be substituted depending on the local market practice. Polymer additives are increasingly being used with asphalt binders and have been particularly effective for enhancing cold-weather properties. This is an evolving area so TM 822-08/AFMAN 32-1131 V8(1)/DM 21.11 and HQUSACE (CEMP-ET), appropriate Air Force MAJCOM pavements engineer, or Naval Facilities Engineering Service Center should be consulted for up-to-date guidance.

(2) Aggregates. The deformation resistance of asphalt concrete exposed to military aircraft traffic is primarily a function of the aggregate, and the binder's contribution is secondary in comparison. The aggregate gradation, particle shape, and control of these parameters during production are crucial in providing an asphalt concrete that will resist the high tire pressure of modern military aircraft. Limiting the natural sand that has rounded particles to no more than 15 percent of the total aggregate by weight is an important requirement in the military requirements for asphalt concrete for military airfields. At

higher natural sand contents, there have been repeated problems with rutting under military aircraft. TM 822-08/AFMAN 32-1131 V8(1)/DM 21.11 provides detailed guidance on aggregate requirements.

b. Mix Design. Mix design of asphalt concrete requires balancing durability, load resistance, and economics. Relatively lean mixes tend to have high load resistance but suffer environmental aging more quickly than richer mixes. Rich mixes tend to be unstable but are more resistant to environmental aging.

(1) Military Requirements. Asphalt concrete for military airfields will be designed based on the 75-blow Marshall mix design method. Details are provided in TM 822-08/AFMAN 32-1131 V8(1)/DM 21.11 and the Asphalt Institute MS-2 procedures.

(2) SHRP Mix Design. The SHRP produced an asphalt concrete mix design procedure and recommended aggregate gradations that are being widely used by state Departments of Transportation. These gradations and mix design procedures were developed for highway use and have not been evaluated for airfield use. These SHRP mix design procedures and aggregate gradations are not approved for military airfields until testing and trials demonstrate their adequacy for airfield loads and conditions. Approval from HQUSACE (CEMP-ET), appropriate Air Force MAJCOM pavements engineer, or Naval Facilities Engineering Service Center is needed before these new guidelines are used on military airfields.

c. Special Asphalt Mixes. Porous friction courses are relatively thin (~ 25 to 38 mm (~1 to 1-1/2 in.)) surface layers of a special open-graded asphalt concrete with clearly visible voids. This mix provides high skid resistance and combats aircraft hydroplaning, but its open texture allows more rapid environmental aging of the asphalt binder and makes it very vulnerable to fuel spills. These mixes were widely used by the Air Force in the 1970s and 1980s, but their use has declined as improved grooving of conventional asphalt concrete mixes provides similar skid resistance without the disadvantages of the porous friction courses. Stone mastic asphalt (SMA), sometimes also called stone matrix asphalt, has a coarse aggregate gradation that provides stone-to-stone contact with the voids between aggregate particles filled with a relatively rich mastic of asphalt cement, sand, and fibers. The stone-to-stone contact of the coarse aggregate provides a stiff rut-resistant mineral skeleton, while the rich mastic provides improved environmental resistance. Two trial applications of SMA by the Air Force for airfield pavements in the United Kingdom and Italy have performed well to date. Thin applications of fuel resistant sealers to asphalt concrete pavements provide limited resistance to fuel spills. The fuel-resistant sealers economically available in the United States are usually coal tar based and are prone to environmental induced cracking that limits their effectiveness. This cracking often occurs at early ages. Polymer modification of some of these products has helped but not solved the cracking problem. Slurry seals are thin applications of emulsified asphalt and sand to oxidized asphalt concrete surfaces to try to extend the pavement life. They have problems with low skid resistance and are prone to localized failures that generate FOD. Slurry seals are not allowed on military airfield pavements. Highly polymerized proprietary systems known as *microtexturing* that use thin surface applications of a binder and aggregate to oxidized asphalt concrete surfaces have shown promise but are still in the evaluation stage. Rejuvenators are composed of lighter-end hydrocarbons that, when sprayed on an oxidized asphaltic concrete surface, soften the binder and counter some of the aging effect. These materials have given mixed results in practice and invariably lower the skid resistance of the pavement. Consequently, they are not allowed to be used on military airfields. The military has used an open-graded asphalt concrete mix with its voids filled with a proprietary modified hydraulic cement grout to provide a surface more abrasion and fuel resistant than conventional asphalt concrete. This system is referred to as resin-modified pavement, and several successful pavements have been built with this material. HQUSACE (CEMP-ET), appropriate Air Force MAJCOM pavements engineer, or Naval

Facilities Engineering Service Center should be consulted for up-to-date guidance on these and other specialty asphalt mixes.

d. Durability.

(1) Aging and Oxidation. Asphalt oxidizes and stiffens over time which leads to a loss of cohesion and flexibility. This eventually leads to cracking and raveling. Asphalt cements from different sources oxidize and age differently. Research suggests that additives to the asphalt cement may slow oxidation, but firm conclusions and guidance are not available yet.

(2) Cold Weather Cracking. As the temperature drops, asphalt cement becomes stiffer and more brittle. With repeated exposure to cold temperatures and in conjunction with other stiffening and aging mechanisms, the asphalt concrete will develop cracking. The SHRP PG grading system of rating asphalt binders that has been adopted by the military specifically tries to select binder characteristics to resist this cracking based on the exposure at the project location.

(3) Fuel Spillage. Fuels, oils, hydraulic fluids, and similar liquids are solvents for the asphalt binder. Hence asphalt concrete should not be used where it will be exposed to such materials. Resin-modified pavement may be used as a surfacing over conventional asphalt concrete to obtain fuel resistance. Coal-tar based fuel resistant sealers have only a temporary life expectancy before cracking reduces their effectiveness.

(4) Stripping. Several mechanisms contribute to moisture damage to asphalt concrete and are generally referred to as stripping. These mechanisms include displacement of the asphalt film coating the aggregate by water, emulsion of the asphalt cement, and pore pressure development. Stripping seems to require water, stripping susceptible aggregates (e.g., siliceous aggregates), and repeated loads. Lime and proprietary liquid antistrip agents can combat the problem. Also, proper aggregate selection, and drainage to reduce the asphalt concrete's exposure to water can help mitigate the dangers of stripping. Fortunately, stripping seems to be relatively uncommon in military airfield pavements. Stripping potential and the need for countermeasures should be addressed in the mix design process.

e. Construction. Production and placement of high-quality asphaltic concrete suitable for military airfields is a demanding and skillful operation. Proper mixing and delivery of the asphaltic concrete, proper placement procedures that prevent segregation, skillful construction of the longitudinal joints, and compaction with equipment of adequate size and at appropriate temperatures are all required to achieve a suitable final product.

5. RECYCLED MATERIALS. Today, portland-cement concrete and asphaltic concrete are routinely recycled as aggregate for subbase and base course material, drainage layers, fill, and as aggregate in new asphaltic and portland-cement concrete. In all recycling operations, maintaining consistency in the recycled product is a challenge. If the recycled product all comes from a single project with consistent properties and constituents, the recycled product will probably have consistent properties and can be incorporated into construction without difficulty. If recycled materials from different projects are intermingled, the recycled product properties are likely to be highly variable, and meeting stringent airfield pavement material requirements with such mixed-source materials is highly problematic. Including debris from building demolition in the recycled product to be used in the airfield pavement structure is not allowed as contamination with undesirable material such as brick or gypsum board is likely and the recycled material from such sources tends to be highly variable. Recently, major problems developed on a project that used recycled portland-cement concrete as fill and as base course in an

environment with abundant sulfates in the soils and water. The recycled concrete suffered from sulfate attack causing heaving of the overlying surfaces. This occurred even though the recycled concrete came from nearby airfield pavements that were built to be sulfate resistant and had existed in the same environment for 30 years without problem. Reliable guidance on use of recycled concrete to be exposed to sulfate exposure is not available, and HQUSACE (CEMP-ET), appropriate Air Force MAJCOM pavements engineer, or Naval Facilities Engineering Service Center should be consulted for guidance if recycled concrete is to be exposed to sulfates. As a general policy, the military encourages use of recycled materials in airfield pavements, but this should not be done at the expense of quality or performance of the final pavement. More extensive guidance and specific limitations used by each service can be found in TM 5-822-14/AFJMAN 32-1019, TI 822-08/AFMAN 32-1131 V8(1)/DM 21.11, and TM 5-822-7/AFM 88-6, Chapter 8, and each service's guide specifications.

Table 9-1
Types of Portland Cement

Type of Cement	Characteristics
I	Ordinary
II	Moderate sulfate resistant
I/II	Meets ASTM C 150 for both Type I and II cements
III	High, early strength
IV	Low heat of hydration
V	Sulfate resistant for more severe sulfate exposure conditions

CHAPTER 10

FLEXIBLE PAVEMENT DESIGN - CBR METHOD

1.REQ UIREMENTS. Flexible pavement designs must provide sufficient compaction of the subgrade and each layer during construction to prevent objectionable settlement under traffic; provide adequate thickness above the subgrade and above each layer together with adequate quality of base and subbase materials to prevent detrimental shear deformation under traffic; provide adequate subsurface drainage control or reduce to acceptable limits the effects of frost heave or permafrost degradation where frost conditions are a factor; and provide a stable, weather-resistant, wear-resistant, waterproof pavement. Attention must also be given to providing adequate friction characteristics.

2.BASI S FOR DESIGN. The thickness design procedures included herein for conventional flexible pavement construction are based on CBR design methods. Design procedures for pavements that include stabilized layers are based on modifications of the conventional procedures utilizing thickness equivalencies developed from research and field experience. Design of flexible pavements using the elastic layer method is covered in Chapter 11.

3.T HICKNESS DESIGN CURVES. Figures 10-1 through 10-32 are design curves for use in determining the required pavement thickness for Army, Navy, Marine Corps, and Air Force airfield pavements. The individual curves indicate the total thickness of pavement required above a soil layer of given strength for a given gross aircraft weight and aircraft passes.

4.THICKNESS DESIGN. The thickness design procedure consists of determining the CBR of the material to be used in a given layer and applying this CBR to design curves (Figures 10-1 through 10-32) to determine the thickness required above the layer to prevent detrimental shear deformation in that layer during traffic. The specific steps to follow are:

a.Det ermine design CBR of subgrade.

b.Det ermine total thickness above subgrade.

(1) For Army and Navy design and Air Force design for a specific aircraft, enter appropriate design curve with subgrade design CBR and follow it downward to the intersection with design gross weight curve, then horizontally to design aircraft passes curve then downward to the required total thickness above the subgrade.

(2) For Air Force standard designs, enter the appropriate design curve with the design subgrade and read the thickness required above the subgrade for a given traffic area.

c.Det ermine design CBR of subbase.

d.Det ermine thickness of material required above the subbase by entering the appropriate design curve with the design subbase CBR and using above procedures to read the required thickness.

e.Det ermine the minimum thickness of surface and base course from Tables 8-3, 8-4, or 8-5. When the minimum thickness of surface and base is less than the thickness of surface and base required above the subbase, the minimum thicknesses would be increased to the actual thickness required.

f. Subtract thickness of the surface and base from total thickness required above subgrade to obtain the required thickness of subbase. If thickness of subbase is less than 150 millimeters (6 inches), consider increasing thickness of base course.

5. ADDITIONAL CONSIDERATIONS FOR THICKNESS DESIGN.

a. CBR Values less than 3. Normally, sites which include large areas of the natural subgrade with CBR values of less than 3 are not considered adequate for airfield construction. However, CBR values of less than 3 are included on the flexible pavement design curves so that thickness requirements for occasional isolated weak areas can be determined.

b. Frost Areas. Pavement sections in frost areas must be designed and constructed with nonfrost-susceptible materials of such depth to prevent destructive frost penetration into underlying susceptible materials. Design for frost areas in accordance with Chapter 20.

c. The thickness of the rapid-draining or open-graded material is determined from AFJMAN 32-1016 and is substituted for an equivalent thickness of base or subbase according to design requirements.

d. Expansive Subgrade. Ensure that moisture condition of expansive subgrade is controlled and that adequate overburden is provided.

e. Limited Subgrade Compaction. Where subgrade compaction must be limited for special conditions, pavement thickness must be increased in conformance with reduced density and CBR of the prepared subgrade.

f. Rainfall and Water Table. In regions where the annual precipitation is less than 380 millimeters (15 inches) and the water table (including perched water table) will be at least 4.6 meters (15 feet) below the finished pavement surface, the potential for subgrade saturation is reduced. Where in-place tests on similar construction in these regions indicate that the water content of the subgrade will not increase above the optimum, the total pavement thickness, as determined by CBR tests on soaked samples, may be reduced by as much as 20 percent. The reduction will be effected in the subbase course having the lowest CBR value. When only limited rainfall records are available, or the annual precipitation is close to the 380-millimeter (15-inch) criterion, careful consideration will be given to the sensitivity of the subgrade to small increases in moisture content before any reduction in thickness is made. For assistance in interpolating limited rainfall data, the USAF Environmental Technical Applications Center, USAFETAC/ECE Scott AFB, IL 62225-5000, may be contacted.

6. DESIGN EXAMPLES.

a. Example 1.

(1) Design an Air Force heavy-load pavement type B traffic area. Design CBR of the lean clay subgrade is 13; the natural in-place density of the clay is 87 percent extending to 3 meters (10 feet). The analysis that follows assumes that subgrade does not require special treatment and frost penetration is not a problem.

(2) Enter Figure 10-19 at a CBR equal to 13, move down to type B traffic area curve, then move horizontally to the required total thickness of pavement above the subgrade, 735 millimeters (29 inches).

(3) The design CBR of the subbase material has been determined to be 30. Enter Figure 10-19 at a CBR equal to 30 and find that the required thickness of base and surface is 405 millimeters (16 inches) for the design aircraft. From Table 8-5, the required minimum thickness of the surface course is 127 millimeters (5 inches) and of the 100 CBR base, 228 millimeters (9 inches). Use a 127-millimeter (5-inch) asphalt concrete (AC) surface and 280 millimeters (11 inches) of 100 CBR base to provide the 405 millimeters (16 inches) required above the 30 CBR subbase.

(4) The required thickness of subbase is 330 millimeters (13 inches), 735 minus 405 millimeters (29 less 16 inches).

(5) From Table 6-2, it is determined that for cohesive subgrade soils, 95 percent compaction is required for 864 millimeters (34 inches) below pavement surface and 90 percent compaction for a 1,320-millimeter (52-inch) depth.

(6) The design section for type B traffic area is illustrated below:

127-mm (5-in.) AC surface
280-mm (11-in.) 100 CBR Base[1]
330-mm (13-in.) 30 CBR Subbase[1]
Top of Subgrade
203-mm (8-in.) 95 percent compaction
457-mm (18-in.) 90 percent compaction

[1] Base and subbase compacted to 100 percent.

(7) Design for drainage layers is illustrated in TM 5-820-2/AFJMAN 32-1016.

b. Example 2.

(1) Design an Army Class III airfield apron (type B traffic area) for a single-wheel tricycle gear aircraft with a gross weight of 11,200 kilograms (24.6 kips) for 50,000 passes plus 10,000 passes of a CH-47 with a gross weight of 22,680 kilograms (50,000 pounds). The runway length is less than 1,220 meters (4,000 feet). Subgrade is a poorly graded sand with a design CBR of 16; in-place density of the subgrade is 90 percent to a depth of 3 meters (10 feet).

(2) From Figure 10-3, the total pavement section required is 240 millimeters (9.5 inches).

(3) From Table 8-3, the minimum required surface and base thicknesses are 50 and 152 millimeters (2 and 6 inches), respectively, for a total of 203 millimeters (8 inches).

(4) Use a 240-millimeter (9.5-inch) pavement section consisting of 50 millimeters (2 inches) of AC surface and 190 millimeters (7.5 inches) of 100 CBR base on subgrade to provide the 241 millimeters (9.5 inches) required above the subgrade.

(5) Determine the compaction requirements from Table 6-5.

(6) The design section is as follows:

50-mm (2-in.) AC surface

190-mm (7.5-in.) Base[1]

Top of Subgrade

152-mm (6.0-in.) 95 percent compaction

[1] Base is compacted to 100 percent.

Since the existing subgrade has an in-place density of 90 percent, the compaction of the 152-millimeter (6.0-inch) upper layer of the subgrade may be achieved by moistening and compacting in place.

c. Example 3.

(1) Design a secondary traffic area pavement for a Navy single-wheel aircraft with a gross weight of 31,750 kilograms (70 kips) and 2.75-MPa (400-psi) tire pressure for 300,000 passes. The subgrade consists of a silty sand (SM) with a design CBR of 6 and an in-place density of 86 percent. Subbase is a sand-shell mixture with a CBR rating of 30. Base is also a sand-shell mixture with a CBR of 80.

(2) From Figure 10-8 (2.75-MPa (400-psi) tire pressure) for a design subgrade CBR of 6 and a gross weight of 31,750 kilograms (70 kips) and 300,000 passes, the pavement section required is 635 millimeters (25 inches). The thickness of base and surface required above the 30 CBR subbase is 228 millimeters (9 inches).

(3) From Table 8-4, the minimum thickness requirements are 102 millimeters (4 inches) of bituminous surface and 203 millimeters (8 inches) of base. Use 330-millimeter (13-inch) subbase.

(4) Determine the compaction requirements from Table 6-6. This table would require the top 102 millimeters (4 inches) of the subgrade to be compacted to 90 percent of maximum density. However, there is an overriding requirement that the top 152 millimeters (6 inches) of the subgrade be compacted to 95 percent of maximum density.

(5) The design section is as follows:

102-mm (4-in.) AC surface

203-mm (8-in.) Base[1]

330-mm (13-in.) Subbase[1]

Top of Subgrade

152-mm (6-in.) 95 percent compaction

In situ density of 86 percent is satisfactory

[1] Base and subbase compacted to 100 percent maximum density.

d.Example 4.

(1) The design curves may be used to design an airfield pavement for a mix of aircraft traffic. This example will demonstrate the procedure for an Air Force airfield using the aircraft, gross weights, and pass levels shown in Table 10-1. The subgrade has a CBR of 6 and the traffic area is type B.

(2) The procedure is demonstrated as follows using Table 10-1 as an example.

(a) Column 1. List aircraft to be considered in design.

(b) Column 2. List pavement design curve figure no. for respective aircraft.

(c) Column 3. List gross weight of aircraft at which they will operate on pavement.

(d) Column 4. List number of passes anticipated at indicated gross weight.

(e) Column 5. Select the thickness required for each aircraft at the pass level and gross weight shown from the appropriate design curve (Figures 10-1 to 10-32).

(f) Column 6. Determine the pass level permissible for each aircraft for the greatest thickness in column 4. The C-141 and the F-15 both require 635 millimeters (25 inches) of total thickness. In this case, the larger aircraft would normally be selected for comparisons, although it may be necessary to check design in terms of both aircraft. The C-141 is therefore selected for comparisons. The design curves are entered with the subgrade CBR of 6, then move downward to intersection with the aircraft gross weight curve, then horizontally to intersection with the 635-millimeter (25-inch) thickness line. The pass level occurring at this intersection should be recorded in column 6.

(g) Column 7. Divide the passes in column 6 by the passes permissible at 635 millimeters (25 inches) for the C-141 (1,000) and enter in column 7. Column 7 gives the equivalent passes on a 635-millimeter (25-inch) pavement by each aircraft in terms of one pass of the C-141. That is, one pass of the C-141 is equivalent to 1.2 passes of the B-52 or is equivalent to 7.5 passes of the P-3.

(h) Column 8. Divide the number of passes in column 4 by the equivalencies in column 6 to determine the design passes in terms of the C-141 and record in column 8. The total equivalent passes of all aircraft in terms of the C-141 is 2,910. Figure 12-31 is entered with the subgrade CBR of 6, the C-141 gross weight of 145,150 kilograms (320 kips,) and the equivalent pass level of 2,910 to select the required thickness of pavement of 711 millimeters (28 inches). The thickness of the individual layers will then be determined in the conventional manner using the minimum thicknesses of pavement and base for the C-141.

7.ST ABILIZED PAVEMENT SECTIONS. Stabilized layers may be incorporated in the pavement sections to make use of locally available materials which cannot otherwise meet the criteria for base course or subbase course. The major factor in deciding whether or not to use a stabilized layer is usually economic. Additional factors include moderate reduction of the overall pavement section and increased design options. The strength and durability of the stabilized courses must be in accordance with requirements of Chapter 9. For Air Force and Army, see requirements in TM 5-822-14/ AFJMAN 32-1019. For Air Force design, stabilized subbase may not be used without a stabilized base unless the base course has adequate drainage. (Approval from Air Force major command is required when use of stabilized components is contemplated.)

Table 10-1
Example Design Using Mixed Traffic

(1) Aircraft	(2) Figure No.	(3) Gross Weight kg (kips)	(4) Aircraft Passes	(5) Preliminary Thickness in.	(6) Allowable Passes at 25 in.	(7) Column 6 Divided by 1,000	(8) Column 4 Divided by Column 7
B-52	10-32	136,080 (300)	300	21.5	1,200	1.20	250
C-141	10-28	145,150 (320)	1,000	25.0	1,000	1.0	1,000
P-3	10-9	64,410 (142)	5,000	24.0	7,500	7.5	660
F-15	10-26	31,750 (70)	200,000	25.0	200,000	200	1,000
OV-1	10-3	6,800 (15)	1,000,000	12.5	Unlimited	--	—
					Total passes on basis of C-141 aircraft = 2,910		

Conversion Factor: Millimeters = 25.4 × inches; kilograms = 453.6 × kips

a. Navy and Marine Corps Design.

(1) Thickness reduction factors. Stabilized base course and subbase course materials meeting the requirements for strength and durability in Chapter 8 may be substituted for unstabilized materials. Procedures for pavement design with stabilized layers are as follows:

(a) Design a conventional pavement section as previously described.

(b) Convert the base or subbase courses into equivalent thicknesses of stabilized materials by use of the equivalency factors shown in Chapter 9.

(c) Adjust the thicknesses of stabilized base and subbase courses so that the minimum base course thickness requirements are met.

(2) Design examples. Design a primary traffic area pavement section for a C-5A aircraft with a gross weight of 385,560 kilograms (850 kips) at 100,000 passes. Design CBR of subgrade is 5; CBR of unstabilized subbase is 20; CBR of unstabilized base is 100.

(a) Alternative design 1, Conventional Section. From Figure 10-18 the required conventional pavement section is 1,093 millimeters (43 inches) for a subgrade CBR of 5, and the required cover over the subbase is 355 millimeters (14 inches). The required minimum thickness of base and surface from Table 8-3 is 203 millimeters (8 inches) of aggregate base course and 102 millimeters (4 inches) of AC surface. The conventional section is as follows:

Conventional Flexible Pavement Section, mm (in.)	Layer Description
102 (4)	Bituminous surface
254 (10)	Aggregate base course
737 (29)	Aggregate subbase course
1,093 (43) Total thickness	

(b) Alternative design 2. A 102-millimeter (4-inch) surface over cement stabilized base with unbound aggregate subbase is required.

Conventional Thickness, mm (in.)		Stabilized Section Thickness, mm (in.)	
Surface	102 (4)	Surface	102 (4)
Base	254 (10)	CT base 254/1.5 (10/1.5) =	169 (6.7)
Subbase	737 (29)	Subbase	737 (29)
Total	1,093 (43)	Total	1,008 (39.7)

CT = Cement treated

(c) Alternative design 3. A 102-millimeter (4-inch) surface over unbound aggregate base with lime stabilized subbase is required.

Conventional Thickness, mm (in.)		Tentative Stabilized Section Thickness, mm (in.)	
Surface	102 (4)	Surface	102 (4)
Base	254 (10)	Base	254 (10)
Subbase	737 (29)	Lime stabilized subbase 737/1.2 (29/1.2) =	614 (24)
Total	1,093 (43)	Total	990 (38)

(d) Alternative design 4. Bituminous base and lime-stabilized subbase are required.

Conventional Thickness, mm (in.)		Tentative Stabilized Section Thickness, mm (in.)	
Surface	102 (4)	Surface	102 (4)
Base	254 (10)	Bituminous base 254/1.5 (10/1.5) =	169 (6.7)
Subbase	737 (29)	Lime stabilized subbase 737/1.2 (29/1.2) =	614 (24)
Total	1,093 (43)	Total	882 (34.7)

b. Army and Air Force Design.

(1) Equivalency factors. The use of stabilized soil layers within a flexible pavement provides the opportunity to reduce the overall thickness of pavement structure required to support a given load. An equivalency factor represents the number of millimeters (inches) of conventional base or subbase that can be replaced by 25 millimeters (1 inch) of stabilized material. Equivalency factors will be determined for Army and Air Force designs from Table 10-2 and for Navy and Marine Corps designs from Table 10-3.

(2) Design. The design of a pavement having stabilized soil layers is accomplished through the application of the equivalency factors to the individual unbound soil of a pavement. A conventional flexible pavement is first designed, and then the base and subbase are converted to an equivalent thickness of stabilized soil. This conversion is made by dividing the thickness of unbound material by the equivalency factor for Army and Air Force airfields. For example, assume that a conventional pavement has been designed consisting of 102 millimeters (4 inches) of AC, 254 millimeters (10 inches) of base, and 381 millimeters (15 inches) of subbase for a total thickness above the subgrade of 737 millimeters (29 inches). It is desired to replace the base and subbase with cement-stabilized GW material having an unconfined compressive strength of 6.27 MPa (910 psi). The equivalency factor from Table 9-1 for the base-course layer is 1.15; therefore, the thickness of stabilized GW to replace 254 millimeters (10 inches) of base course is 254/1.15 (10/1.15) or 220 millimeters (8.7 inches). The equivalency factor for the subbase layer is 2.3, and the thickness of stabilized GW to replace the 381-millimeter (15-inch) subbase is 381/2.3 (15/2.3) or 165 millimeters (6.5 inches). The thickness of stabilized GW needed to replace the base and subbase would be 406 millimeters (16 inches).

c. All-Bituminous Pavement Section. Alternate procedures have been developed for design of Army and Air Force airfield pavements composed entirely of AC. These procedures are based on layered elastic theory and incorporate the concept of limiting tensile strain in the AC and vertical compressive strain in the subgrade. The procedures are applicable for trial optional designs with the approval of TSMCX, for Army airfields and the appropriate Major Command for Air Force airfields. These design procedures are contained in Chapter 11.

8. SPECIAL AREAS. Areas such as overrun areas, airfield and heliport shoulders, blast areas, and reduced load areas require special treatment as described in the following text for the various services.

a. Air Force Bases.

(1) Overrun areas. Overrun areas will be paved for the full width of the runway exclusive of shoulders, and for a length of 305 meters (1,000 feet) on each end of heavy, modified heavy, medium, light, and auxiliary runways and for 90 meters (300 feet) on each end of an assault landing zone runway. Surface the overrun areas with double-bituminous surface treatment except for the first 45 meters (150 feet) abutting the runway pavement end which will have a wearing surface of 51 millimeters (2 inches) of dense graded AC. That portion of the overrun used to certify barriers or that must support snow removal equipment may also be surfaced with dense graded AC. Design the pavement thickness in accordance with Figures 10-17 to 10-32 herein, except that the minimum base-course thickness will be 152 millimeters (6 inches). The strength of the assault overrun shall be equal to the strength of the runway. Minimum base-course CBR values are as follows:

Table 10-2
Equivalency Factors for Army and Air Force Pavements

Material	Equivalency Factors: Base	Equivalency Factors: Subbase
Asphalt-Stabilized		
All-Bituminous Concrete	1.15	2.30
GW, GP, GM, GC	1.00	2.00
SW, SP, SM, SC	--[1]	1.50
Cement-Stabilized		
GW, GP, SW, SP	1.15[2]	2.30
GC, GM	1.00[2]	2.00
ML, MH, CL, CH	--[1]	1.70
SC, SM	--[1]	1.50
Lime-Stabilized		
ML, MH, CL, CH	--[1]	1.00
SC, SM, GC, GM	--[1]	1.10
Lime, Cement, Fly Ash Stabilized		
ML, MH, CL, CH	--[1]	1.30
SC, SM, GC, GM	--[1]	1.40
Unbound Crushed Stone	1.00	2.00
Unbound Aggregate	–[1]	1.00

[1] Not used as base course.
[2] For Air Force Bases, cement is limited to 4 percent by weight or less.

Table 10-3
Equivalency Factors for Navy and Marine Corps Pavements

Stabilized Material	Equivalency Factors
1 mm (in.) of lime-stabilized subbase	1.2 mm (in.) of unstabilized subbase course
1 mm (in.) of cement-stabilized subbase	1.2 mm (in.) of unstabilized subbase course
1 mm (in.) of cement-stabilized base	1.5 mm (in.) of unstabilized base course
1 mm (in.) of bituminous base	1.5 mm (in.) of unstabilized base course

Design Loading	Minimum Base-Course CBR for Overruns
Heavy-load pavement	80
Modified heavy-load pavement	80
Medium-load pavement	80
Light-load pavement	50
Assault landing zone pavement	50
Auxiliary pavement	50

(2) Paved shoulders. Paved shoulders will be provided adjacent to runways, taxiways, aprons, and pads where authorized by AFM 86-2. The remaining shoulder width will be constructed of existing soils, select soils, or stabilized soils with a turf cover. Design the paved shoulders in accordance with Table 3-1, Table 8-4, and Figure 10-27.

b.Army Airfields.

(1) Paved shoulders. Paved shoulders should be provided for airfields and heliport/helipad facilities as designated in EI 02C013/AFJMAN 32-1013/NAVFAC P-971. Design paved shoulders in accordance with Chapters 2 and Figure 10-27. Use a 50-millimeter (2-inch) dense graded AC wearing surface on a minimum 150-millimeter (6-inch) base consisting of 50 CBR material or better. The remaining shoulder width will be constructed of existing compacted soils, select soils, or stabilized soils with a vegetative cover or liquid palliative to provide dust and erosion control against jet blast and rotor wash.

(2) Paved overruns. Paved overruns should be provided for runways and landing lanes in accordance with EI 02C013/AFMAN 32-1013/NAVFAC P-971. Design the pave portion of overruns for 75 percent of the gross weight of the design aircraft and 1 percent of the design pass levels. The paved overrun should also be checked for adequacy of supporting crash rescue vehicles. Use a 50-millimeter (2-inch) dense graded AC wearing surface on a minimum 150-millimeter (6-inch) base consisting of 50 CBR material or better. The remaining overrun area will be constructed of double-bituminous surface treatment on a 100-millimeter (4-inch) base course of 40 CBR material or better.

c.Navy and Marine Corps Airfields.

(1) Overrun areas. Pave the overrun areas for a width of 61 meters (200 feet) or the width of the runway if less than 61 meters (200 feet), centered on the runway centerline and for a length of 305 meters (1,000 feet), where feasible. Surface the overrun areas with an AC surface course. Design the pavement thickness for 75 percent of the gross weight of the design aircraft at 200 passes, except that a minimum 152-millimeter (6-inch) base course of 80 CBR or better will be provided.

(2) Blast protection areas. Design the pavement thickness of the blast protection areas for 200 passes at 75 percent of the gross weight of the design aircraft. Normally, these areas are constructed of portland cement concrete for Navy and Marine Corps airfields; where operational experience has shown asphalt surfacing to be satisfactory, use a minimum 76-millimeter (3-inch)

AC surface over 152 millimeters (6 inches) of 80 CBR base. Blast protection pavement design should be checked for adequacy for crash rescue vehicles.

(3) Shoulders.

(a) Fixed-wing aircraft. Pave the first 3 meters (10 feet) of runway shoulders. Design the pavement thickness for 75 percent of the gross weight of the design aircraft at 200 passes. Surface with 50 millimeters (2 inches) of AC on a minimum 152-millimeter (6-inch) base of 80 CBR. Provide the outer 43 meters (140 feet) of runway shoulders and all taxiway shoulders with dust and erosion control using vegetative cover, liquid palliative, such as asphalt, or a combination of methods.

(b) Rotary-wing aircraft. Pave the first 7.5 meters (25 feet) of shoulder adjacent to helicopter pads, runways, and taxiways with 50 millimeters (2 inches) of AC on a minimum 152-millimeter (6-inch) base course of 60 CBR. Provide the outer 15 meters (50 feet) of shoulder with a liquid palliative or vegetative cover, or a combination of methods.

9. JUNCTURE BETWEEN RIGID AND FLEXIBLE PAVEMENTS. (See paragraph 12.j of Chapter 12.)

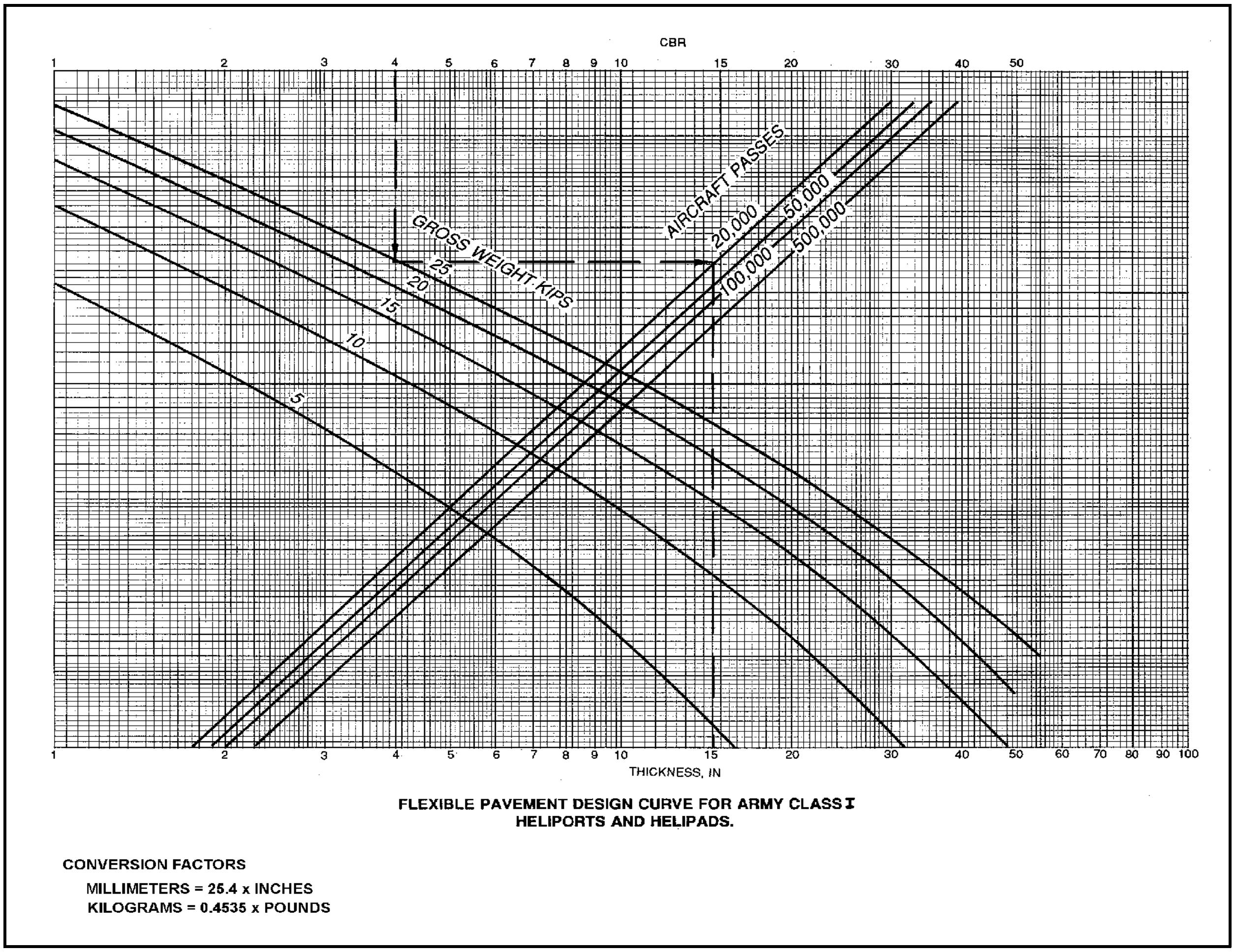
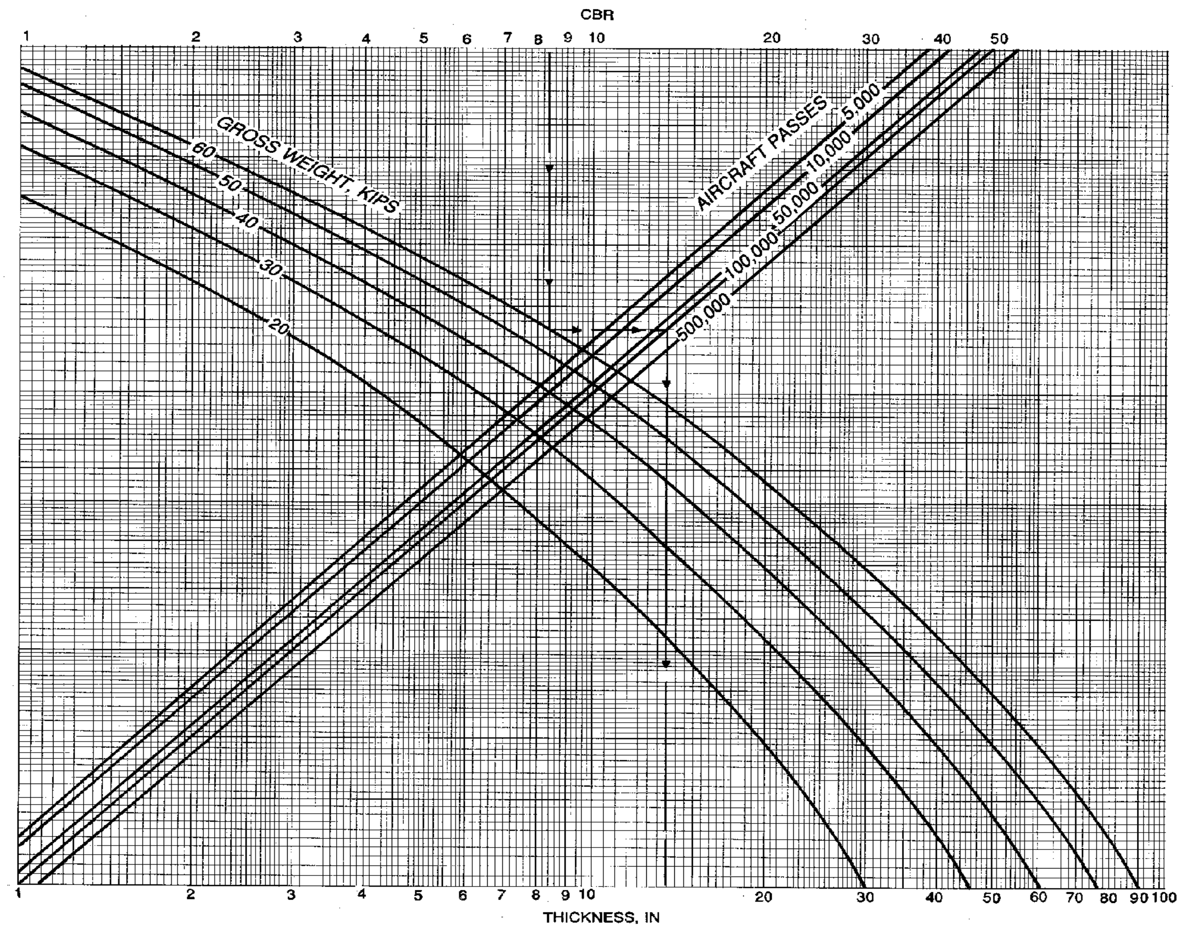


Figure 10-1. Flexible pavement design curves for Army Class I heliports and helipads



FLEXIBLE PAVEMENT DESIGN CURVE FOR ARMY CLASS II AND V HELIPORTS AND HELIPADS.

CONVERSION FACTORS

MILLIMETERS = 25.4 x INCHES
KILOGRAMS = 0.4535 x POUNDS

Figure 10-2. Flexible pavement design curves for Army Class II and V heliports and helipads

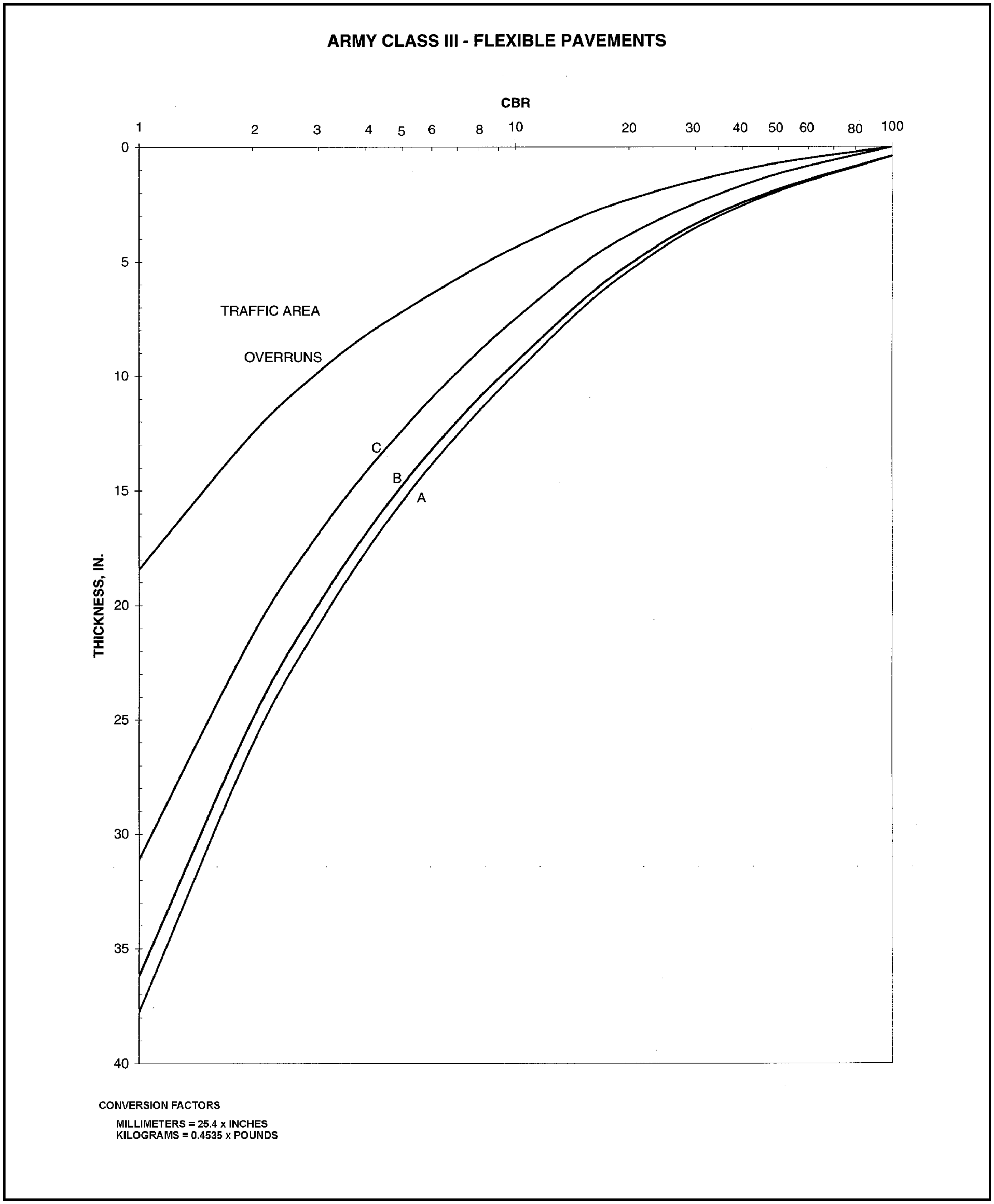


Figure 10-3. Flexible pavement design curves for Army Class III airfields as defined in paragraph 4.c of Chapter 2

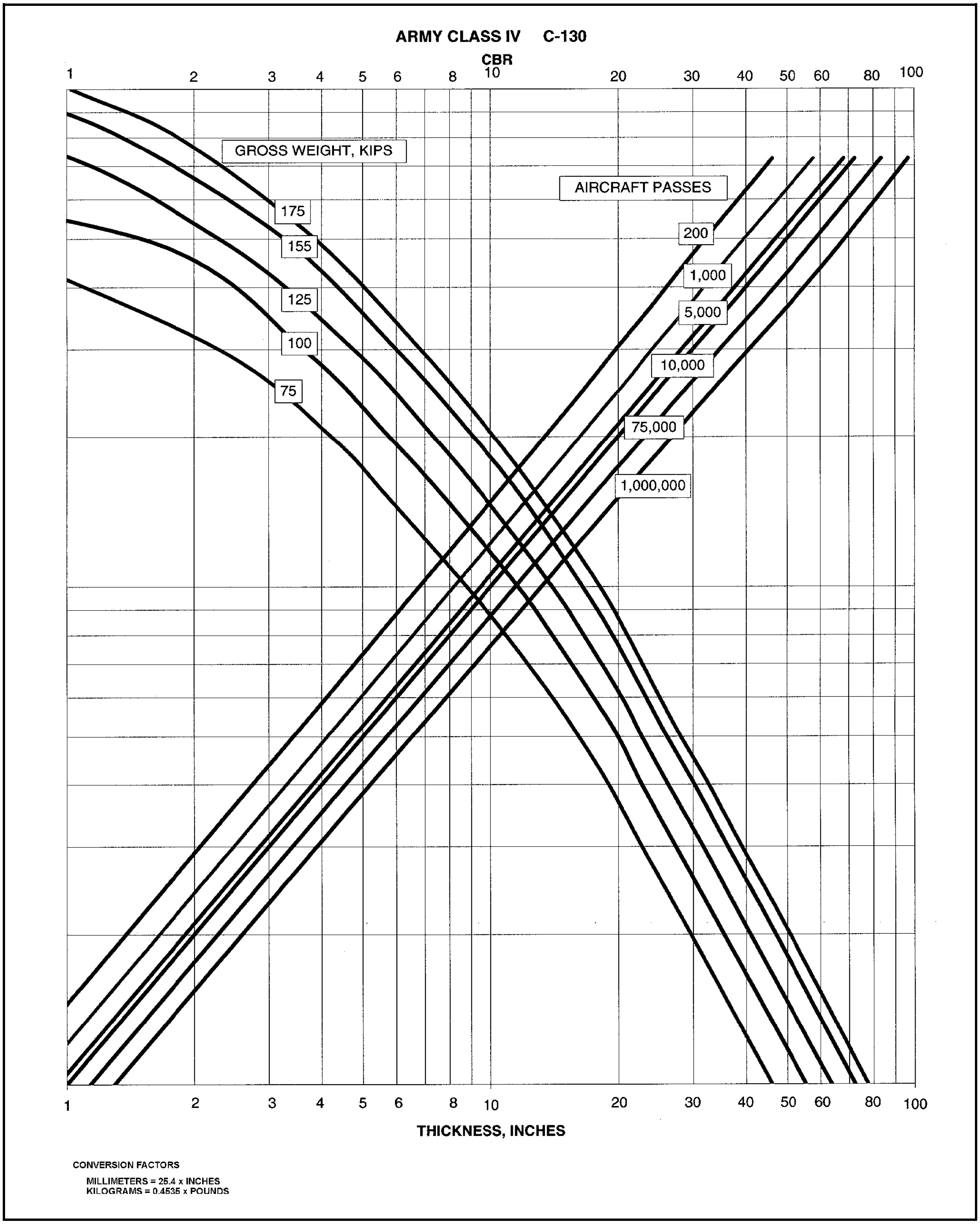


Figure 10-4. Flexible pavement design curves for Army Class IV airfields (C-130 aircraft) with runway ≤ 1,525 meters (≤ 5,000 feet), type A traffic areas

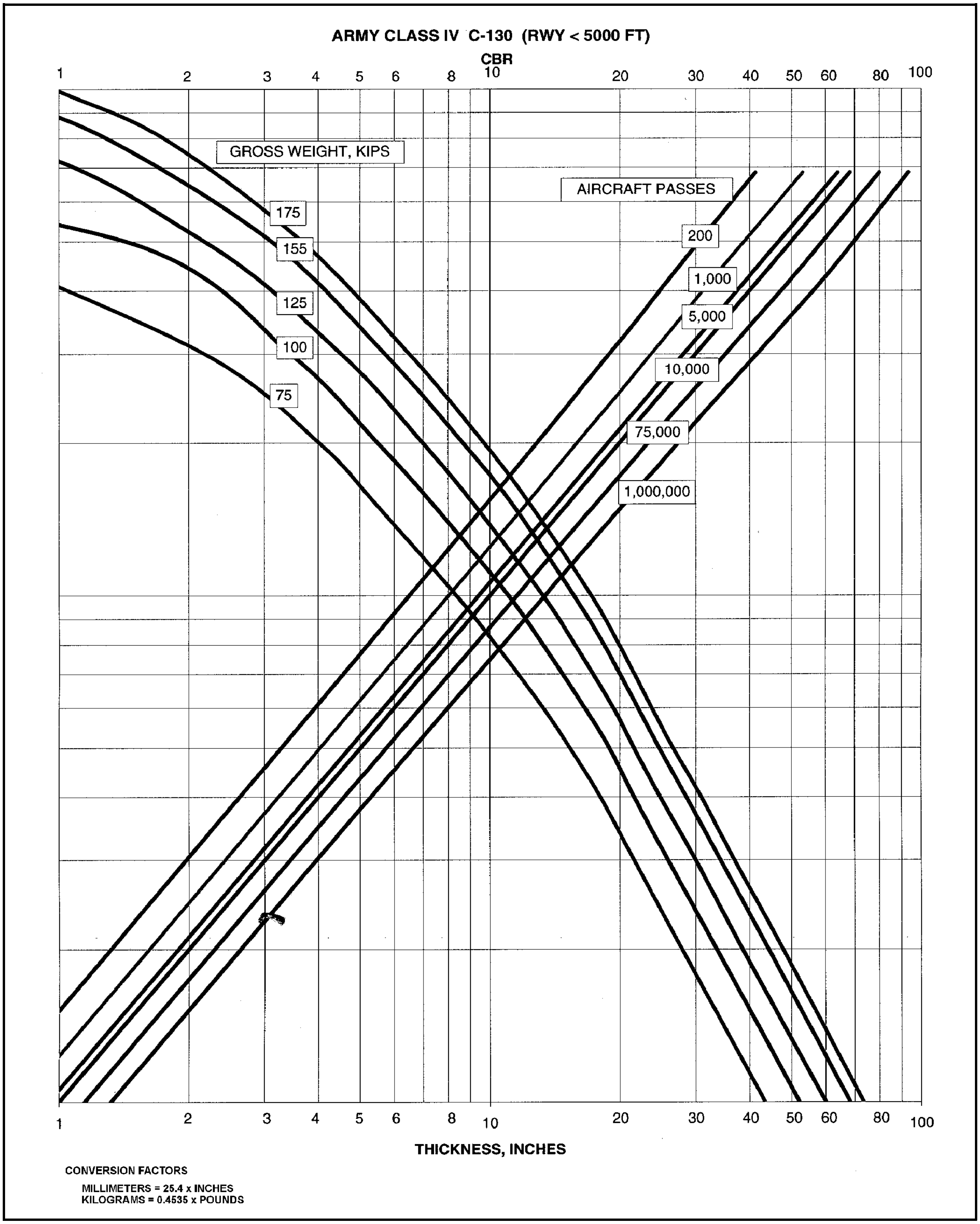


Figure 10-5.F lexible pavement design curves for Army Class IV airfields (C-130 aircraft) with runway ≤ 1,525 meters (≤ 5,000 feet), types B and C traffic areas

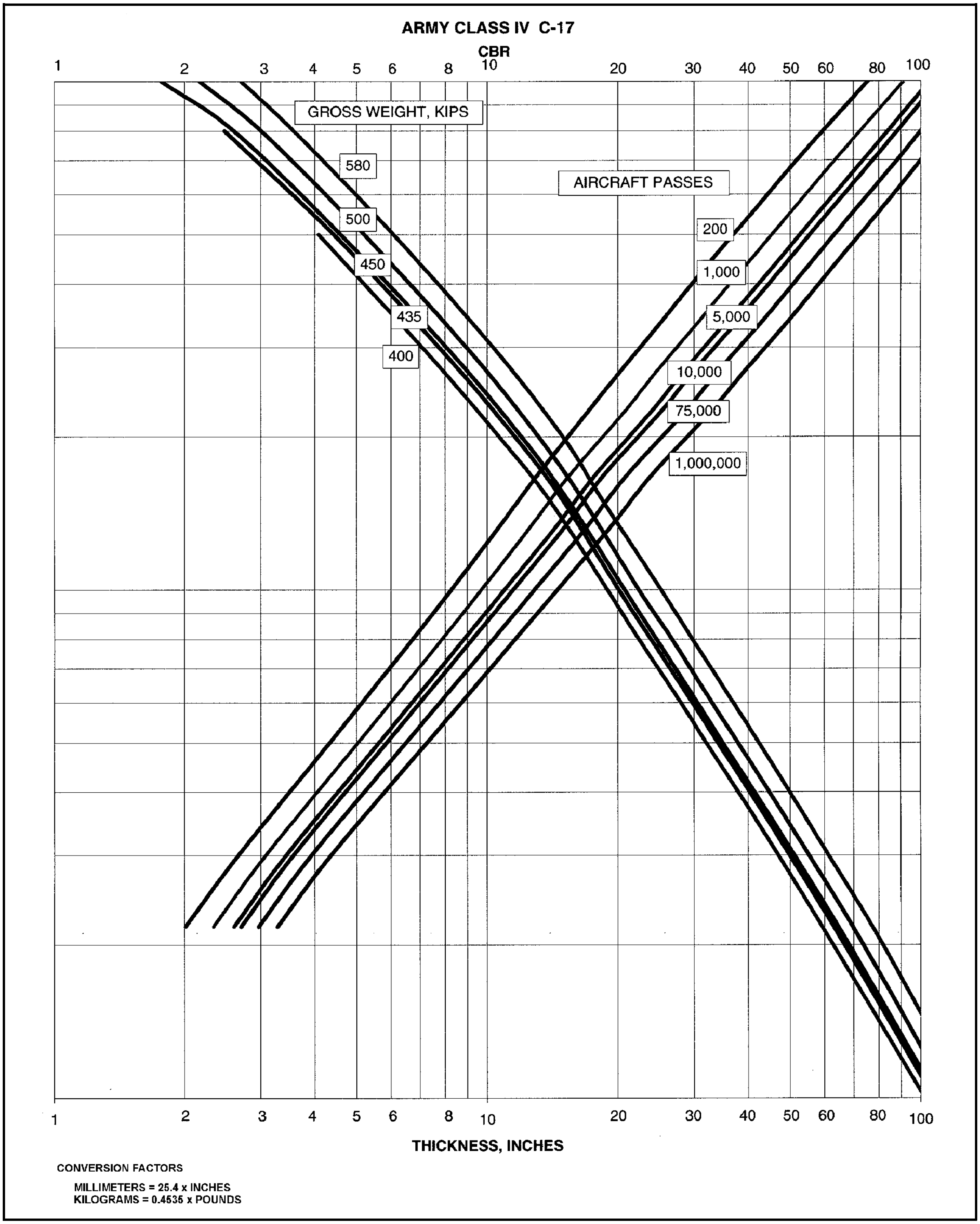


Figure 10-6.F lexible pavement design curves for Army Class IV airfields (C-17 aircraft) with runway > 1,525 meters (> 5,000 feet), type A traffic areas

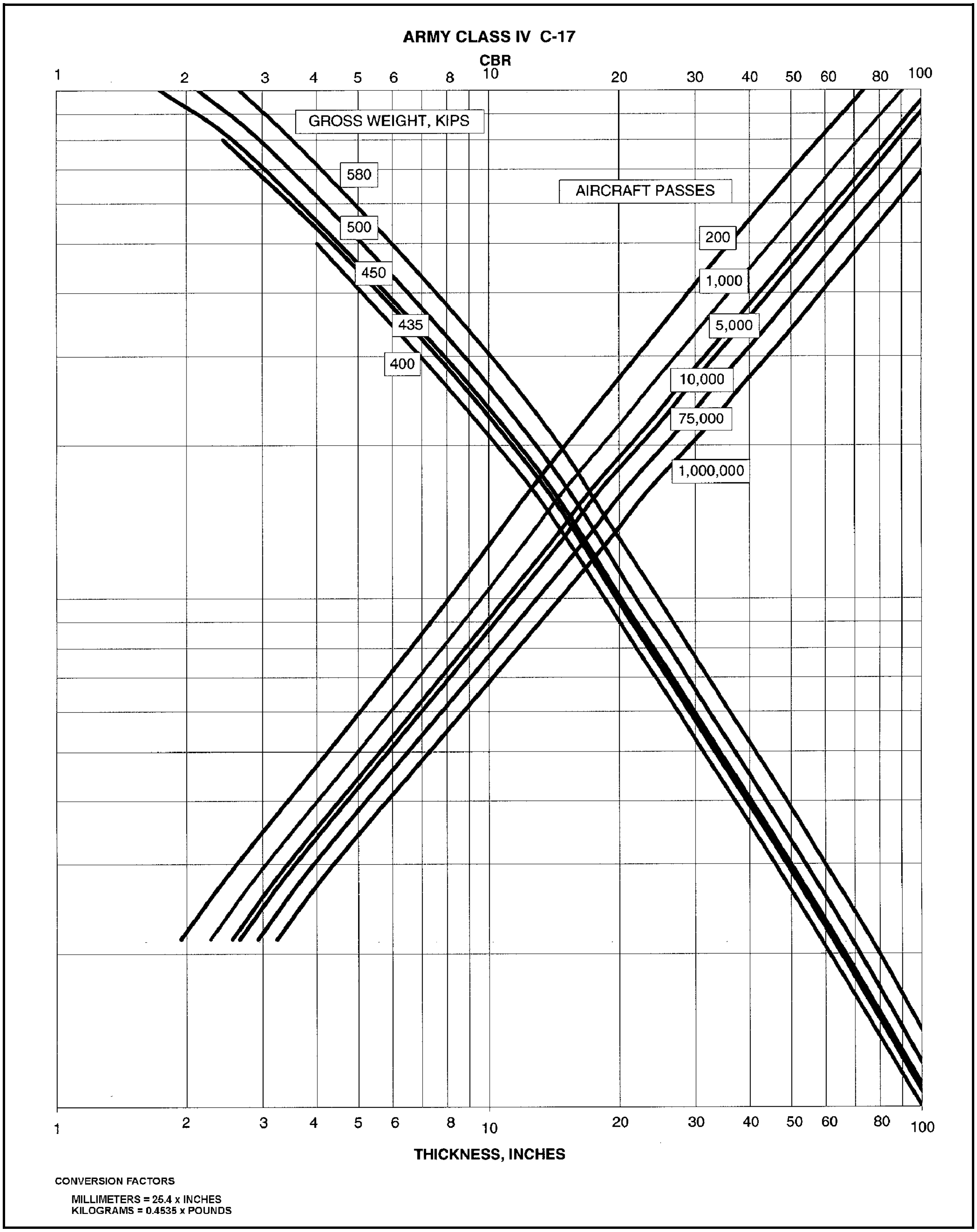


Figure 10-7.F lexible pavement design curves for Army Class IV airfields (C-17 aircraft) with runway > 1,525 meters (> 5,000 feet), types B and C traffic areas

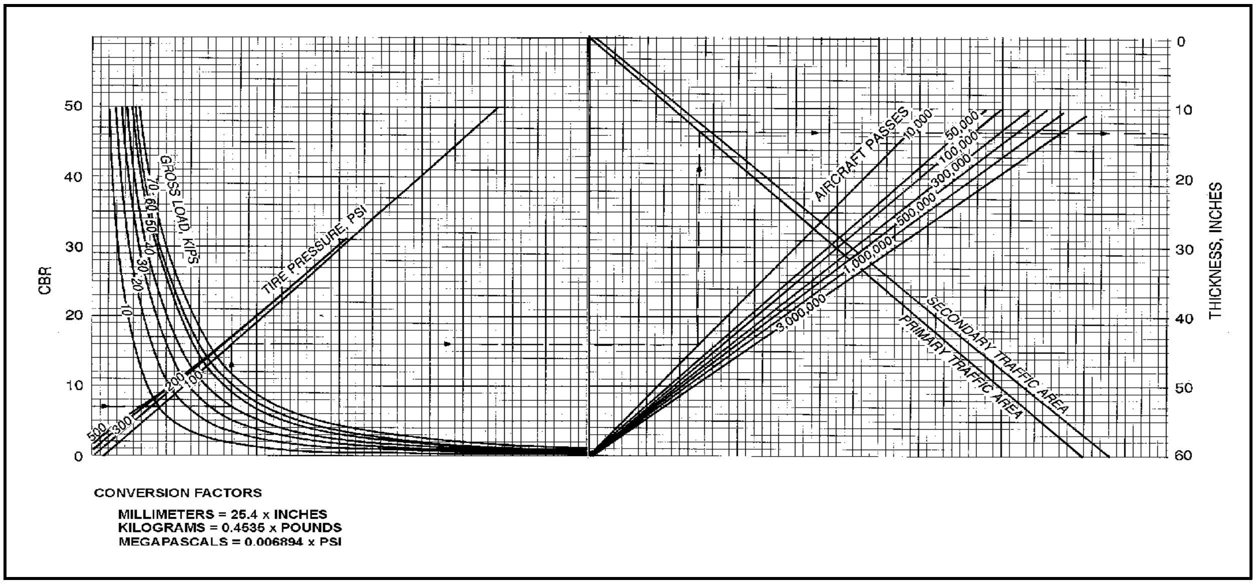


Figure 10-8. Flexible pavement design curves for Navy and Marine Corps single-wheel aircraft, primary and secondary traffic areas

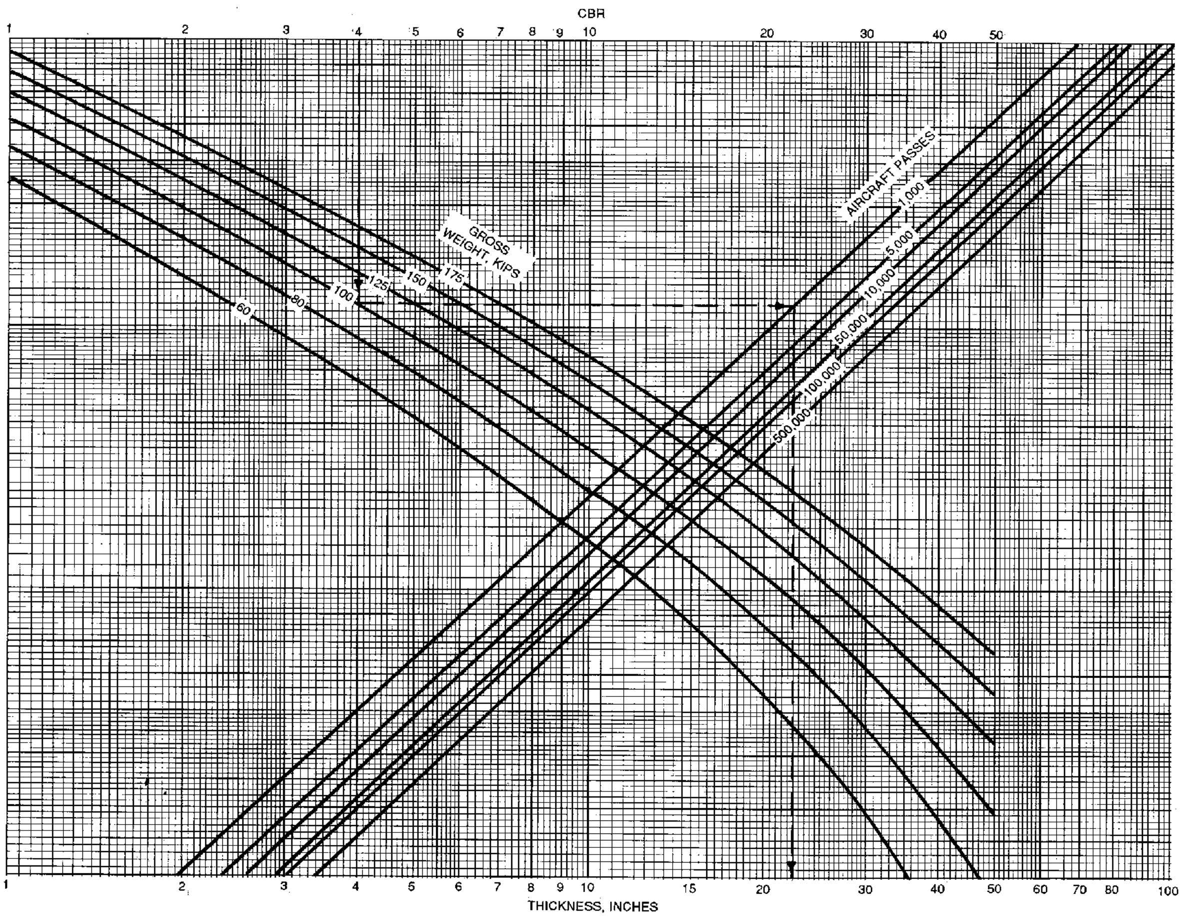


Figure 10-9. Flexible pavement design curve for Navy and Marine Corps dual-wheel aircraft, primary traffic areas

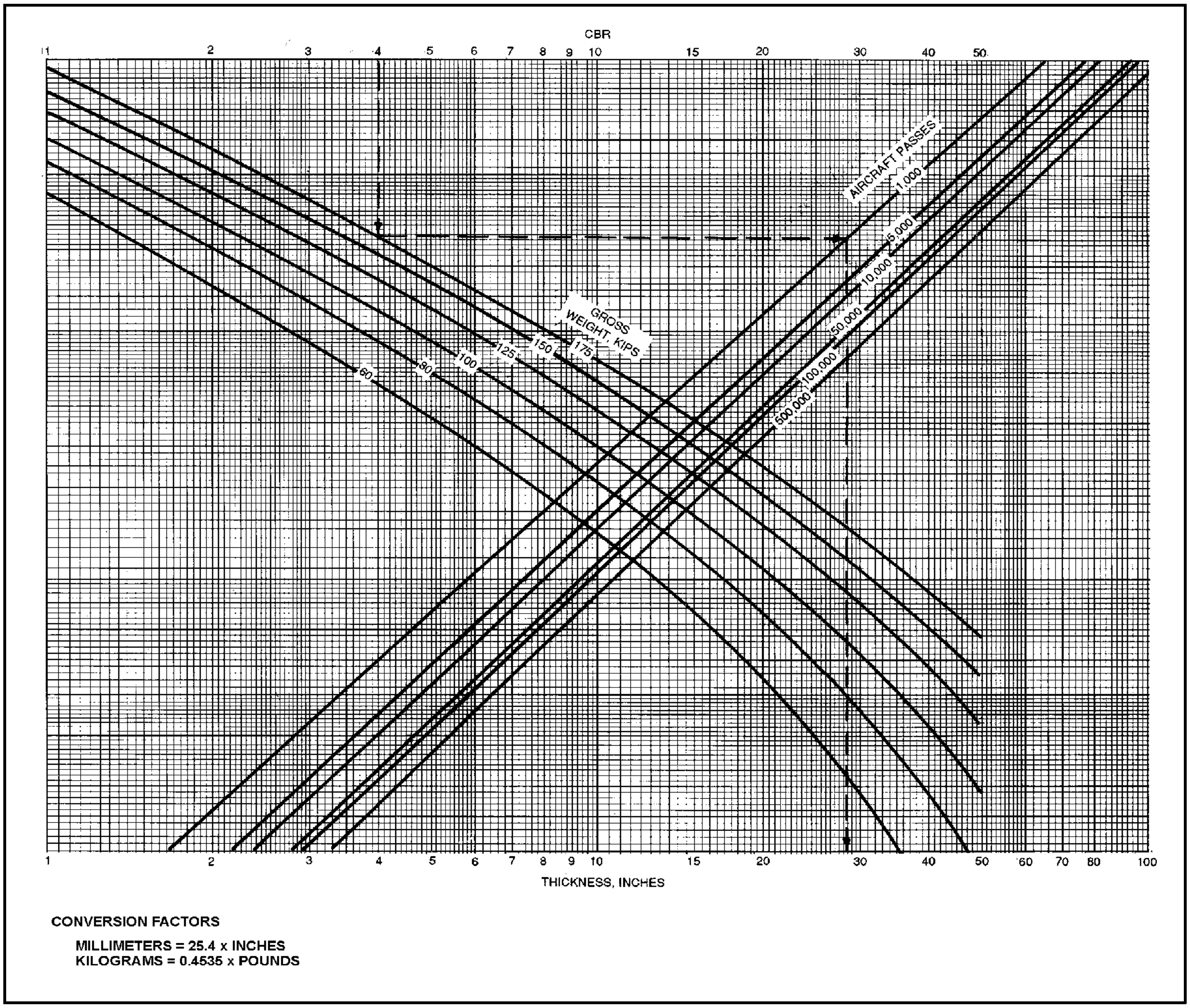


Figure 10-10. Flexible pavement design curve for Navy and Marine Corps dual-wheel aircraft, secondary traffic areas

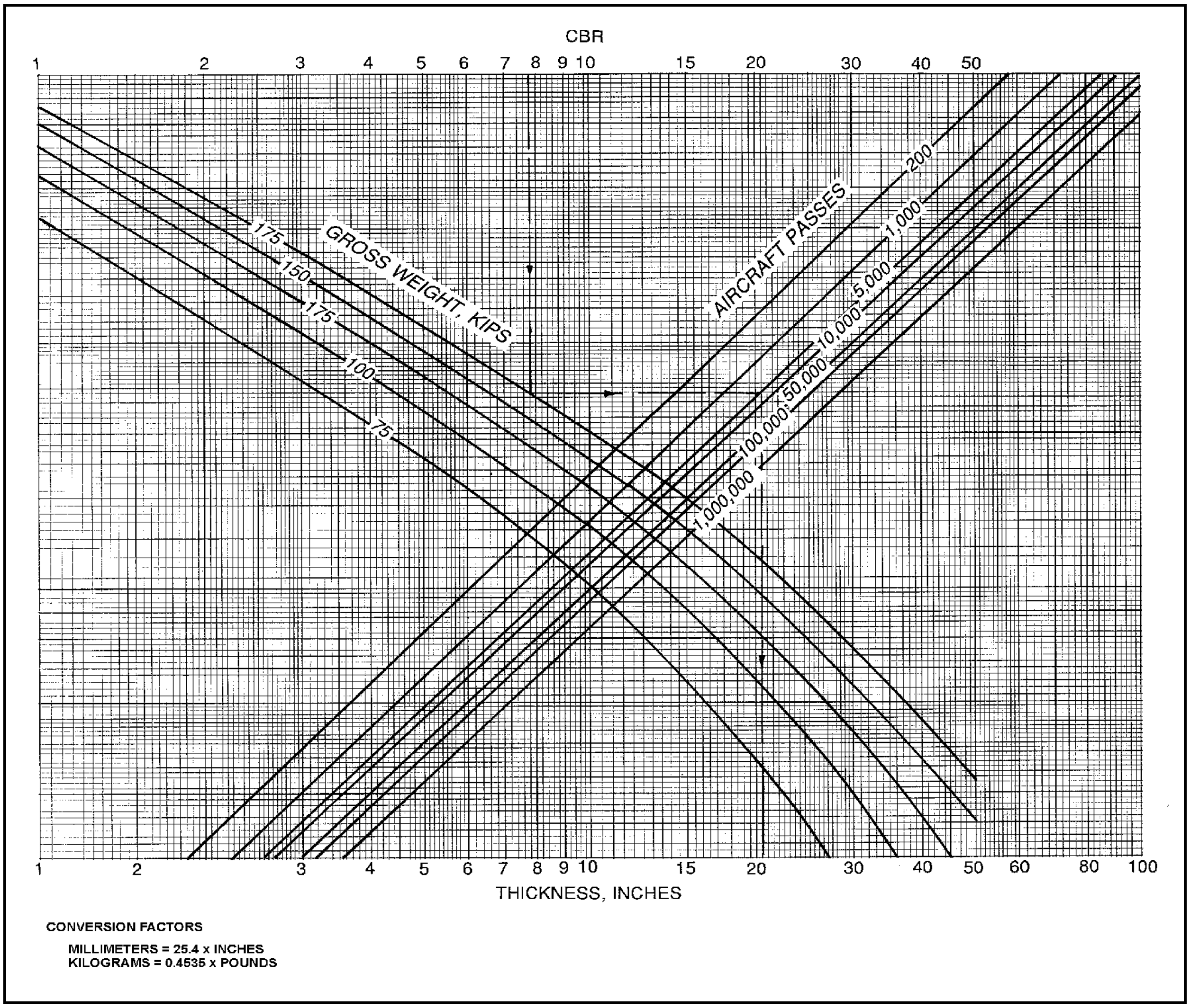


Figure 10-11. Flexible pavement design curve for Navy and Marine Corps C-130, primary traffic areas

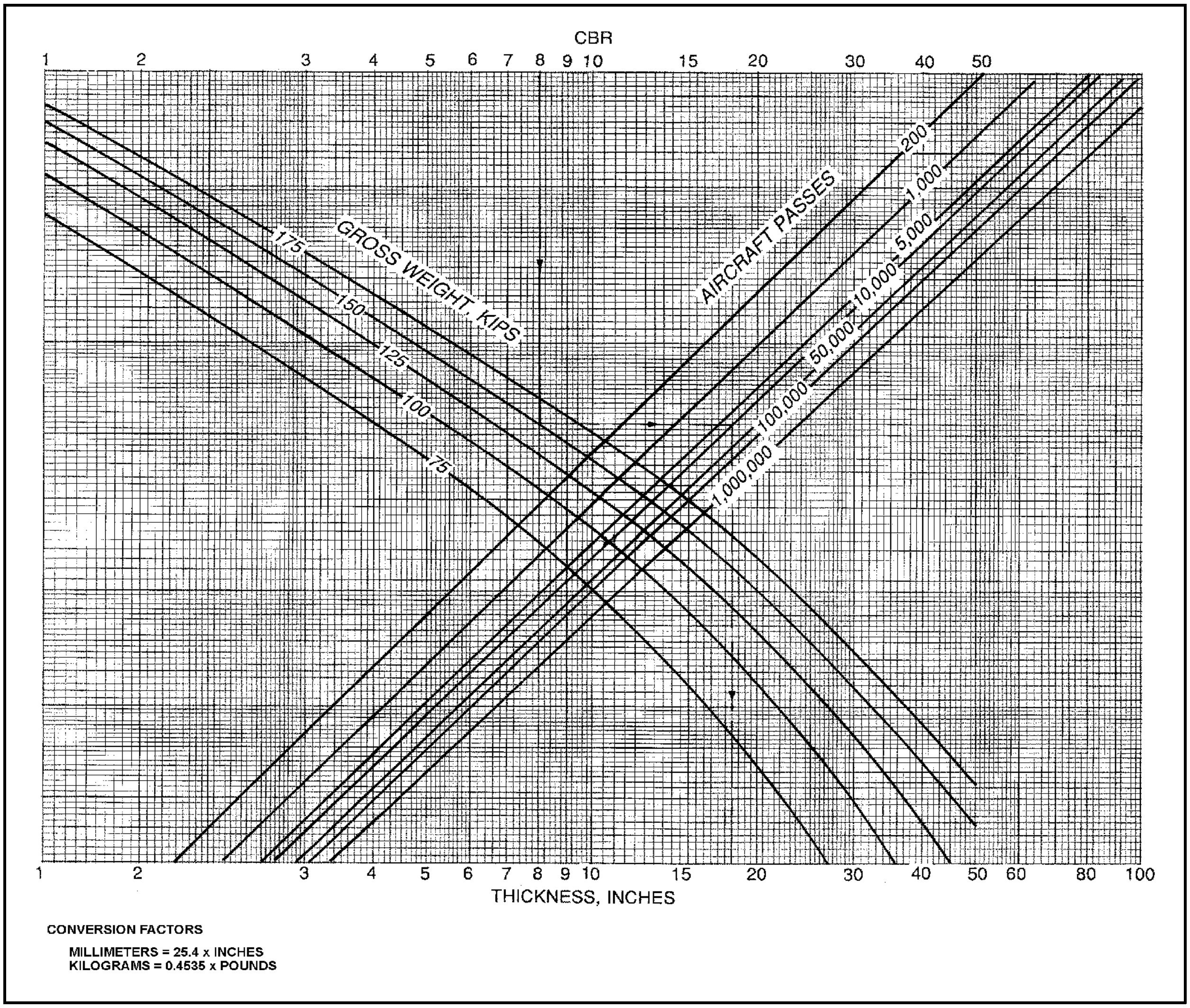


Figure 10-12. Flexible pavement design curve for Navy and Marine Corps C-130, secondary traffic areas

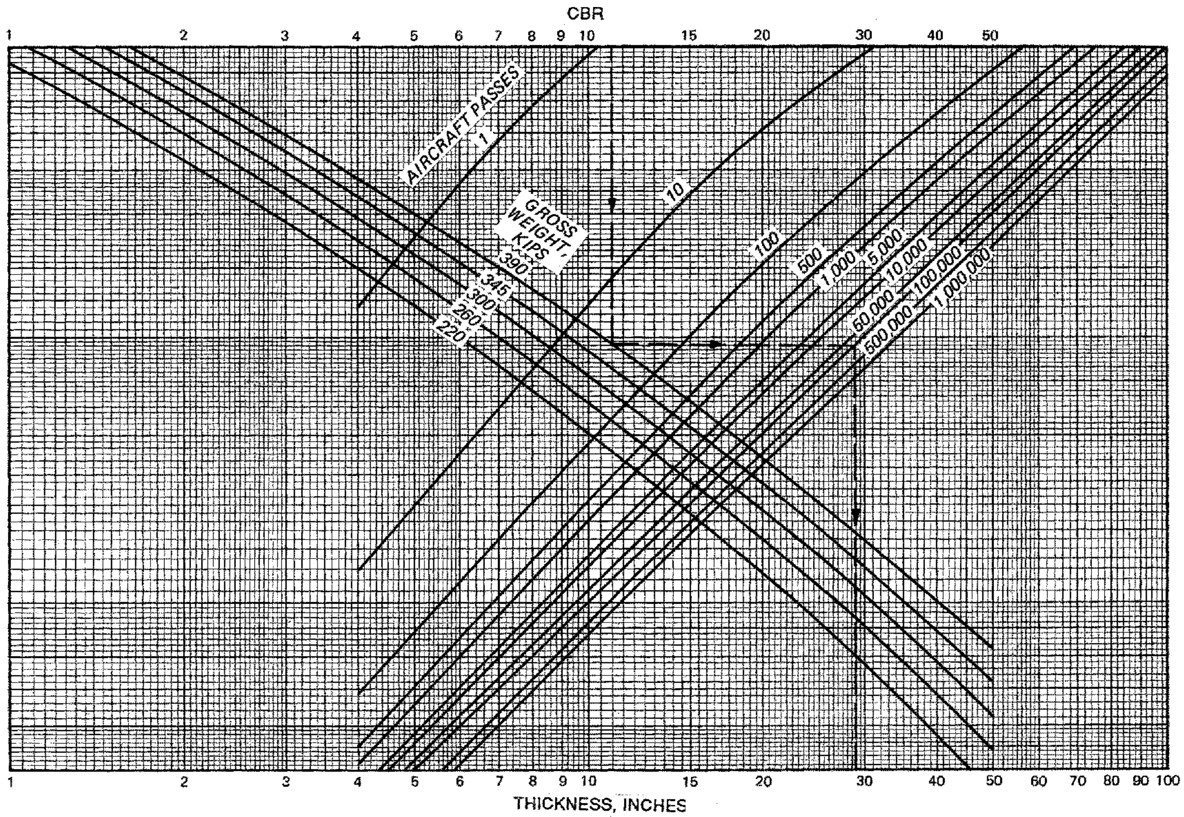


Figure 10-13. Flexible pavement design curve for Navy and Marine Corps C-141, primary traffic areas

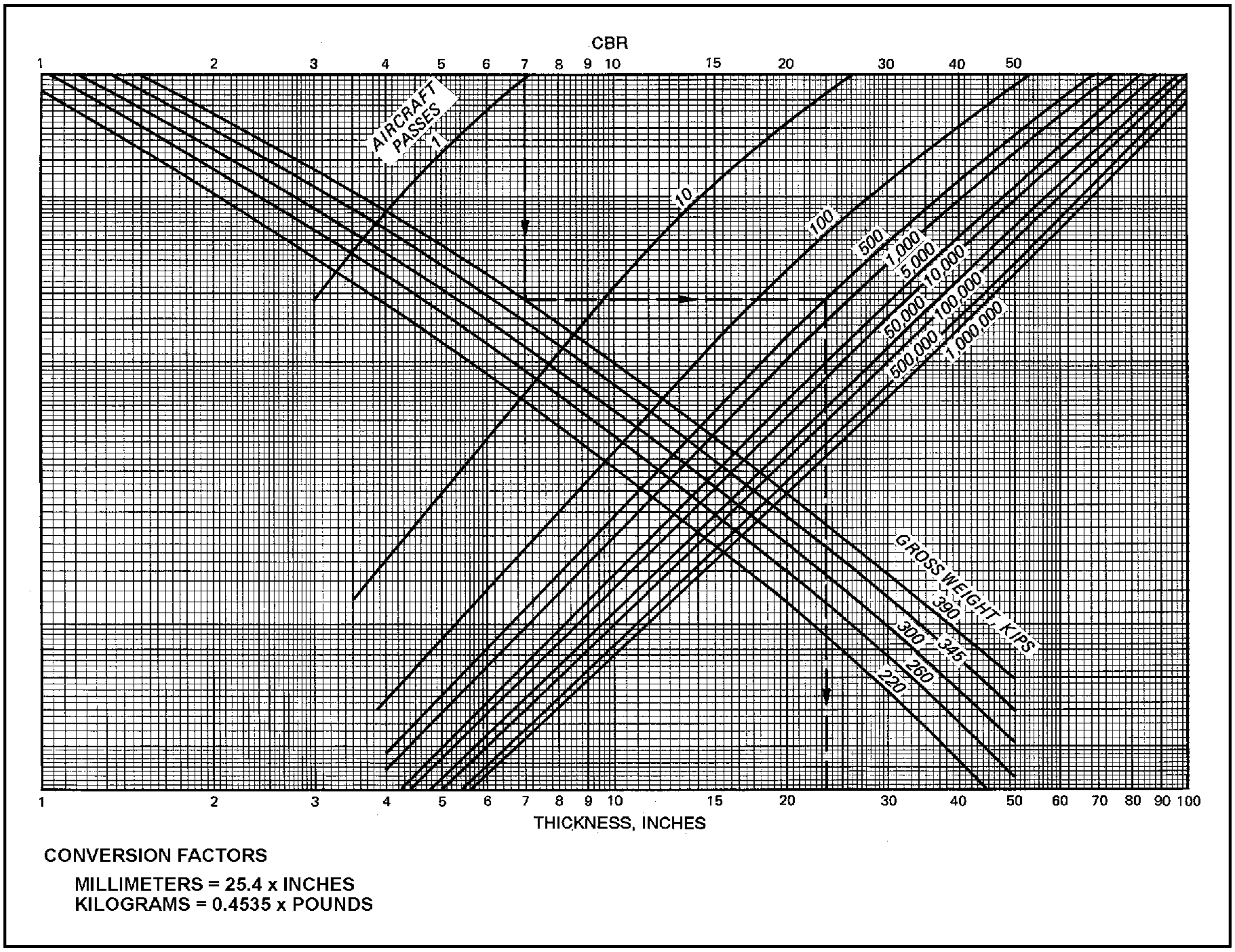


Figure 10-14. Flexible pavement design curve for Navy and Marine Corps C-141, secondary traffic areas

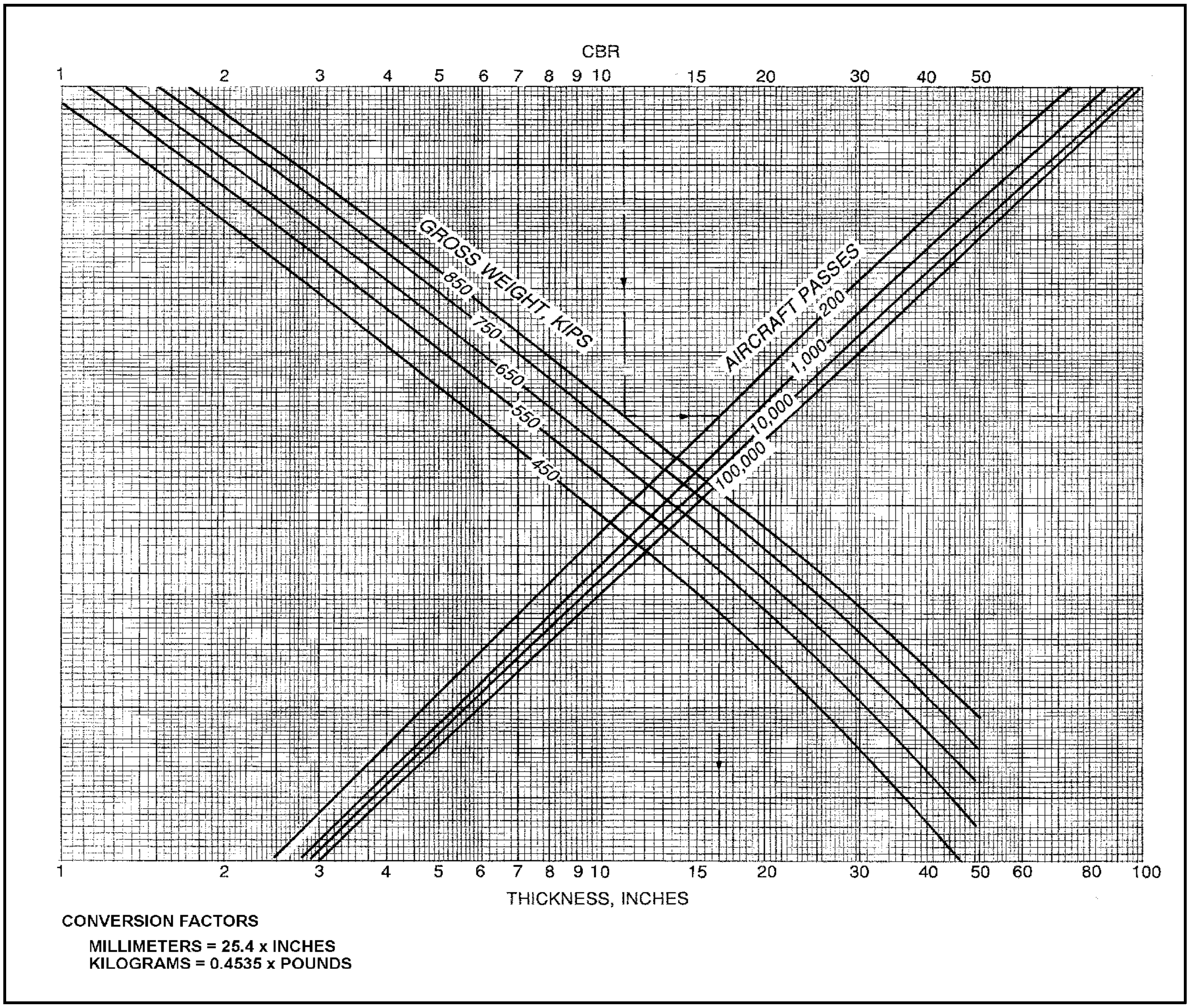


Figure 10-15. Flexible pavement design curve for Navy and Marine Corps C-5A, primary traffic areas

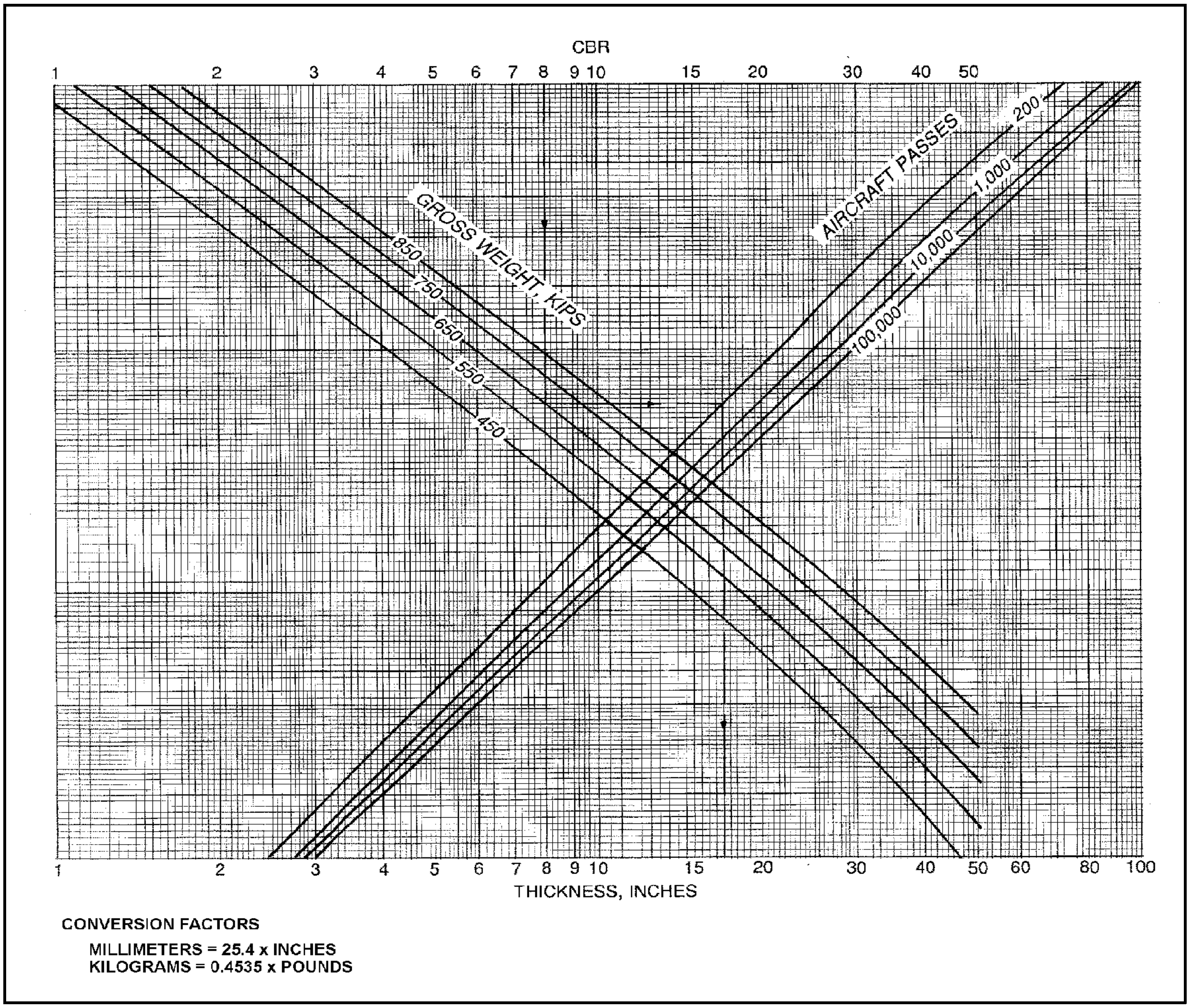


Figure 10-16. Flexible pavement design curve for Navy and Marine Corps C-5A, secondary traffic areas

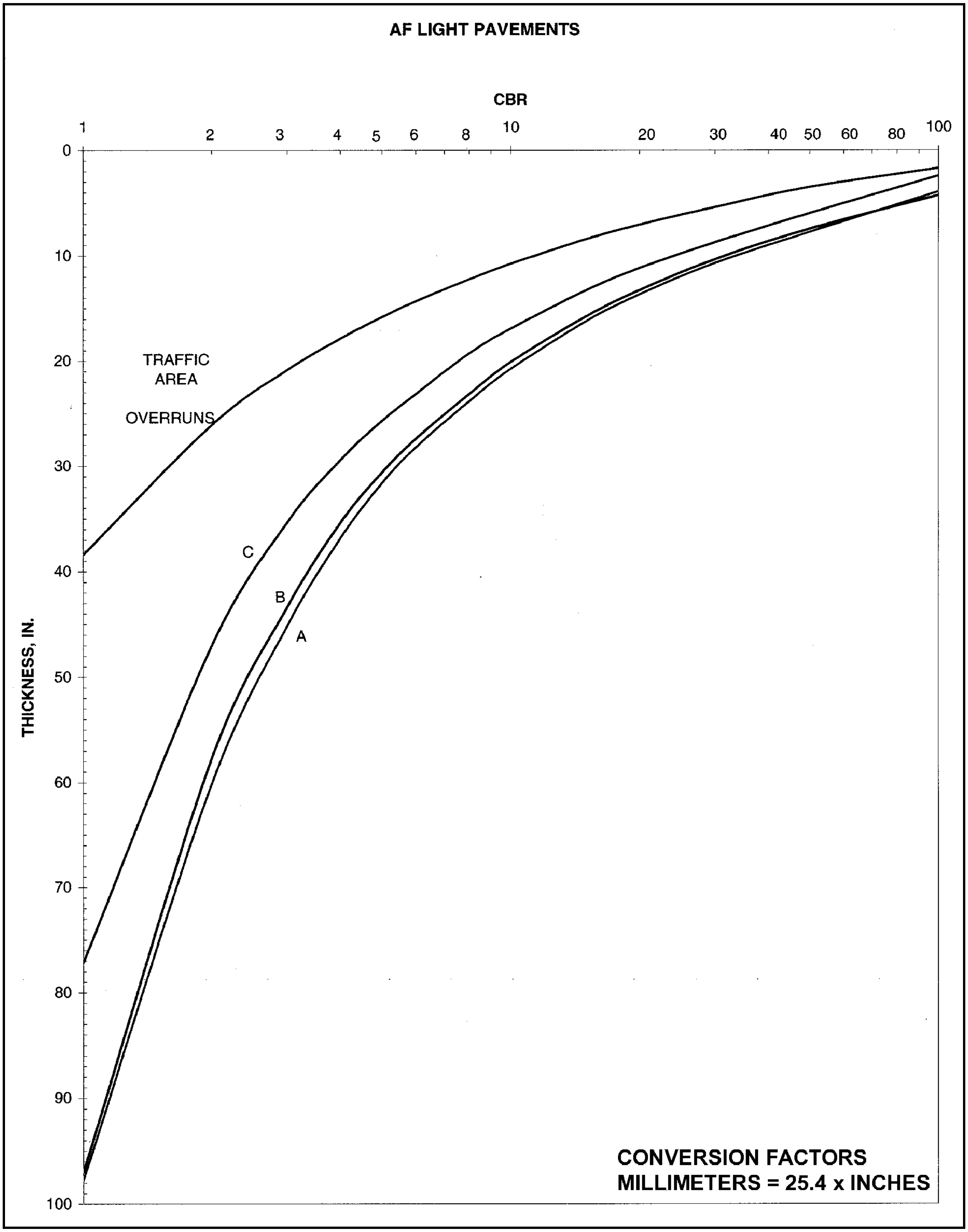


Figure 10-17.F lexible pavement design curve for Air Force light-load airfield

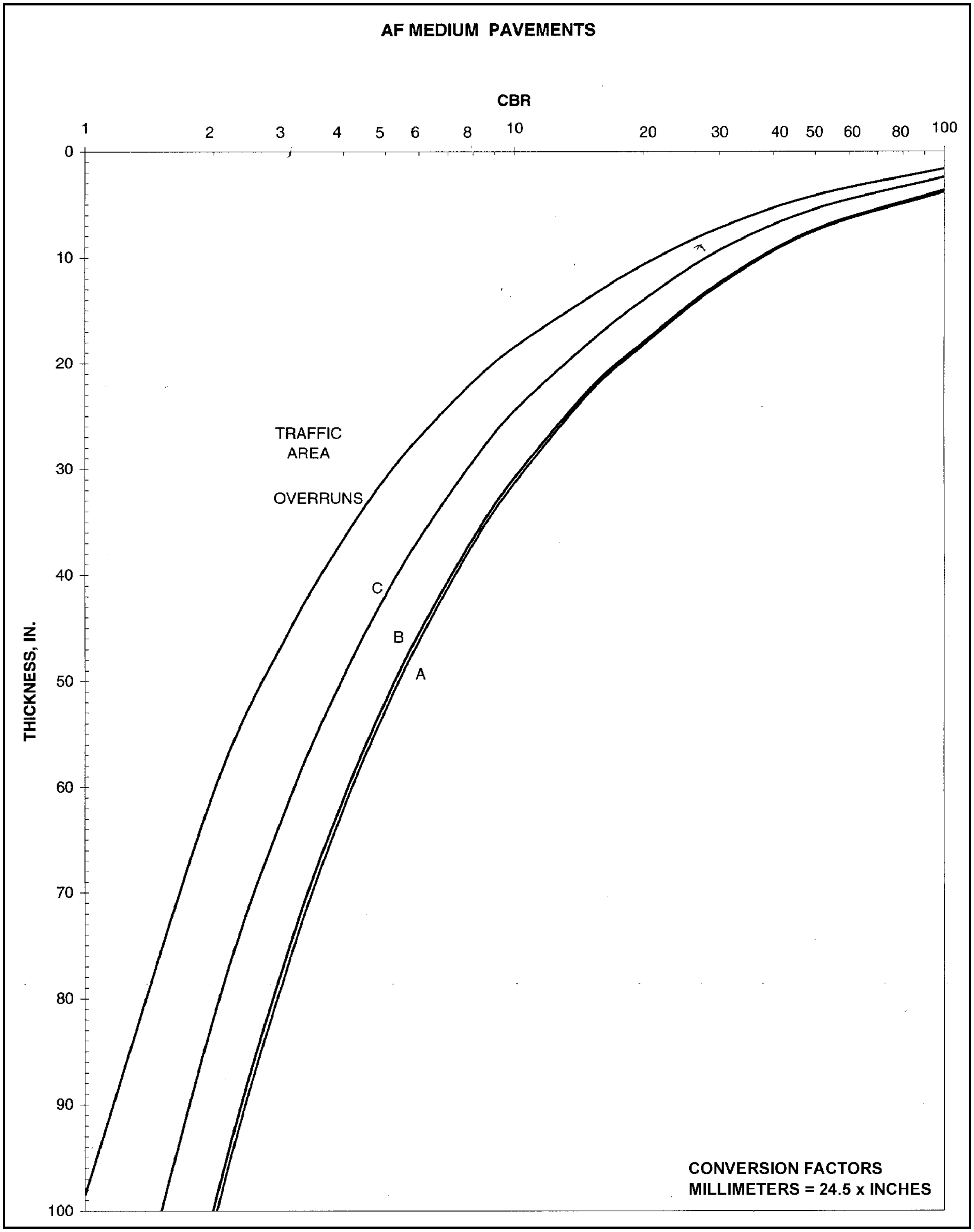


Figure 10-18.F lexible pavement design curve for Air Force medium-load airfield

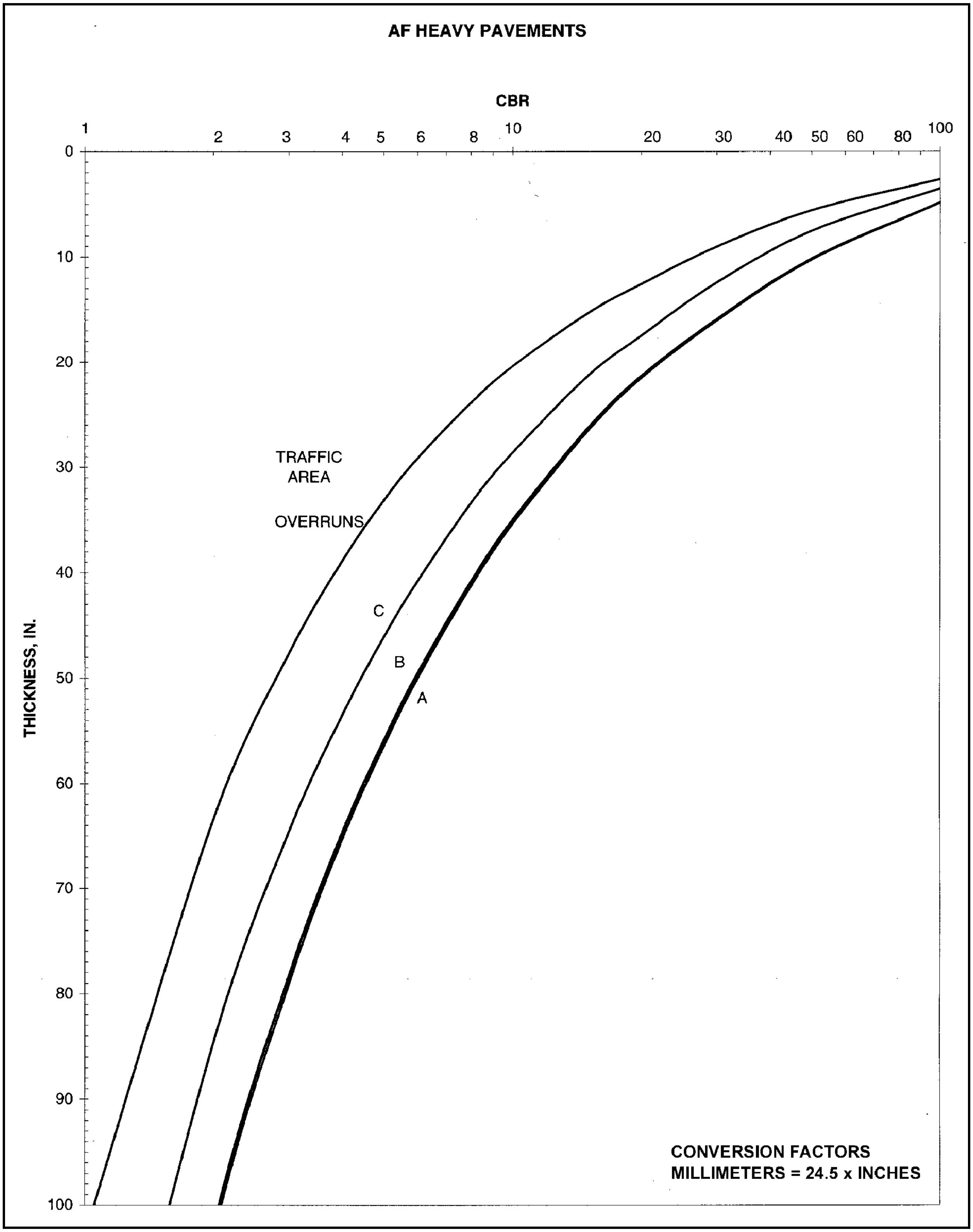


Figure 10-19.F lexible pavement design curve for Air Force heavy-load pavement

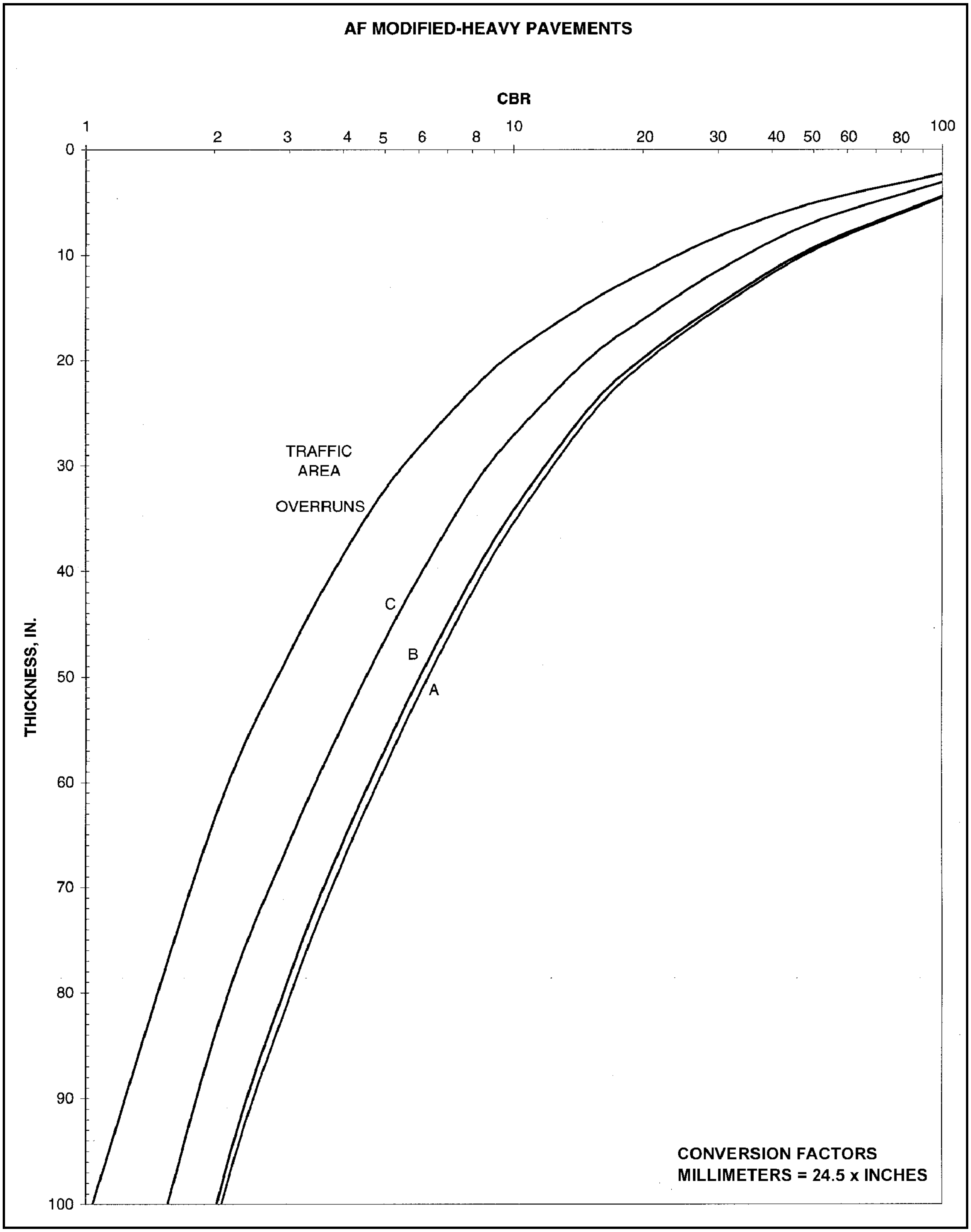


Figure 10-20.F lexible pavement design curve for Air Force modified heavy-load pavement

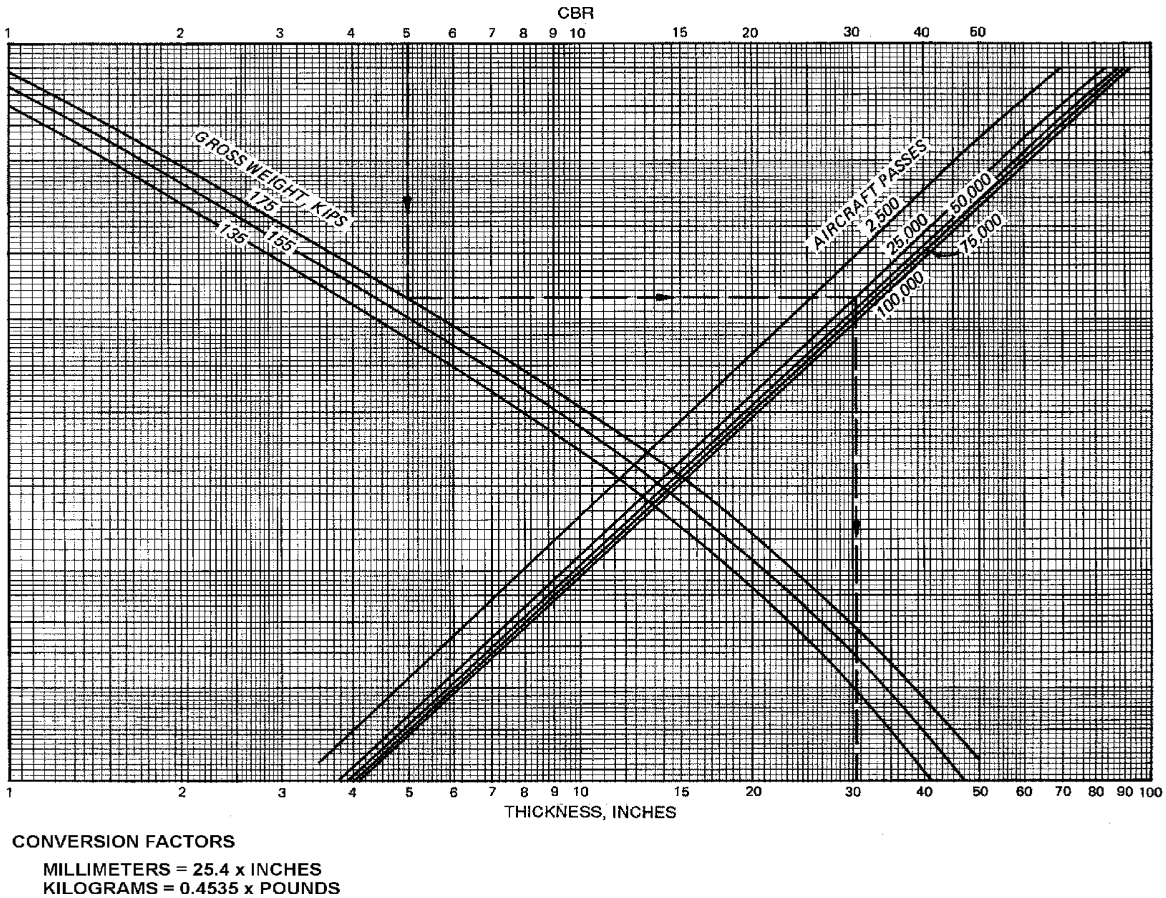
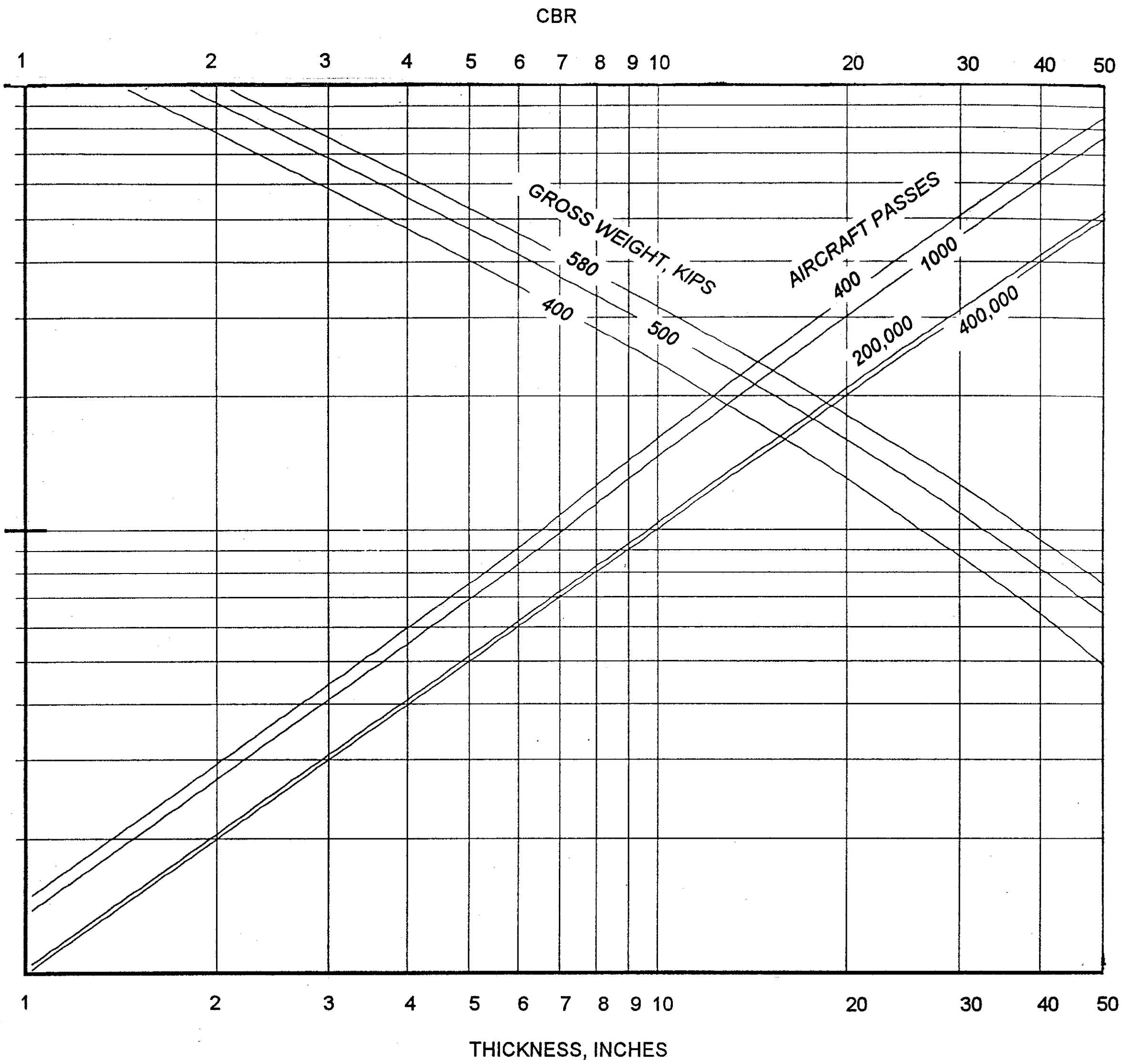
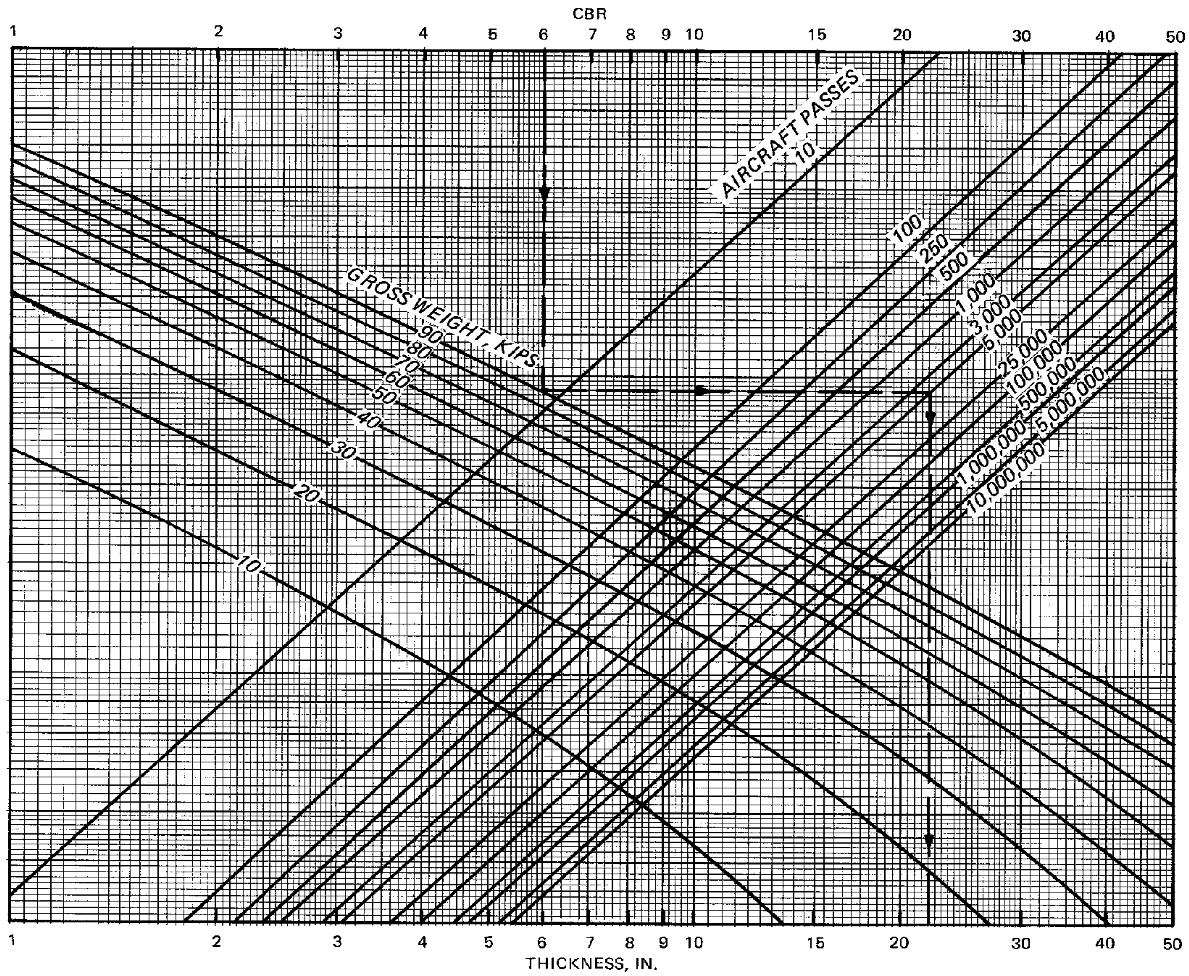


Figure 10-21a. Flexible pavement design curve for Air Force C-130 assault landing zone airfield



CONVERSION FACTORS
MILLIMETERS = 25.4 X INCHES
KILOGRAMS = 0.4535 X POUNDS

Figure 10-21b. Flexible pavement design curve for Air Force C-17 assault landing zone airfield

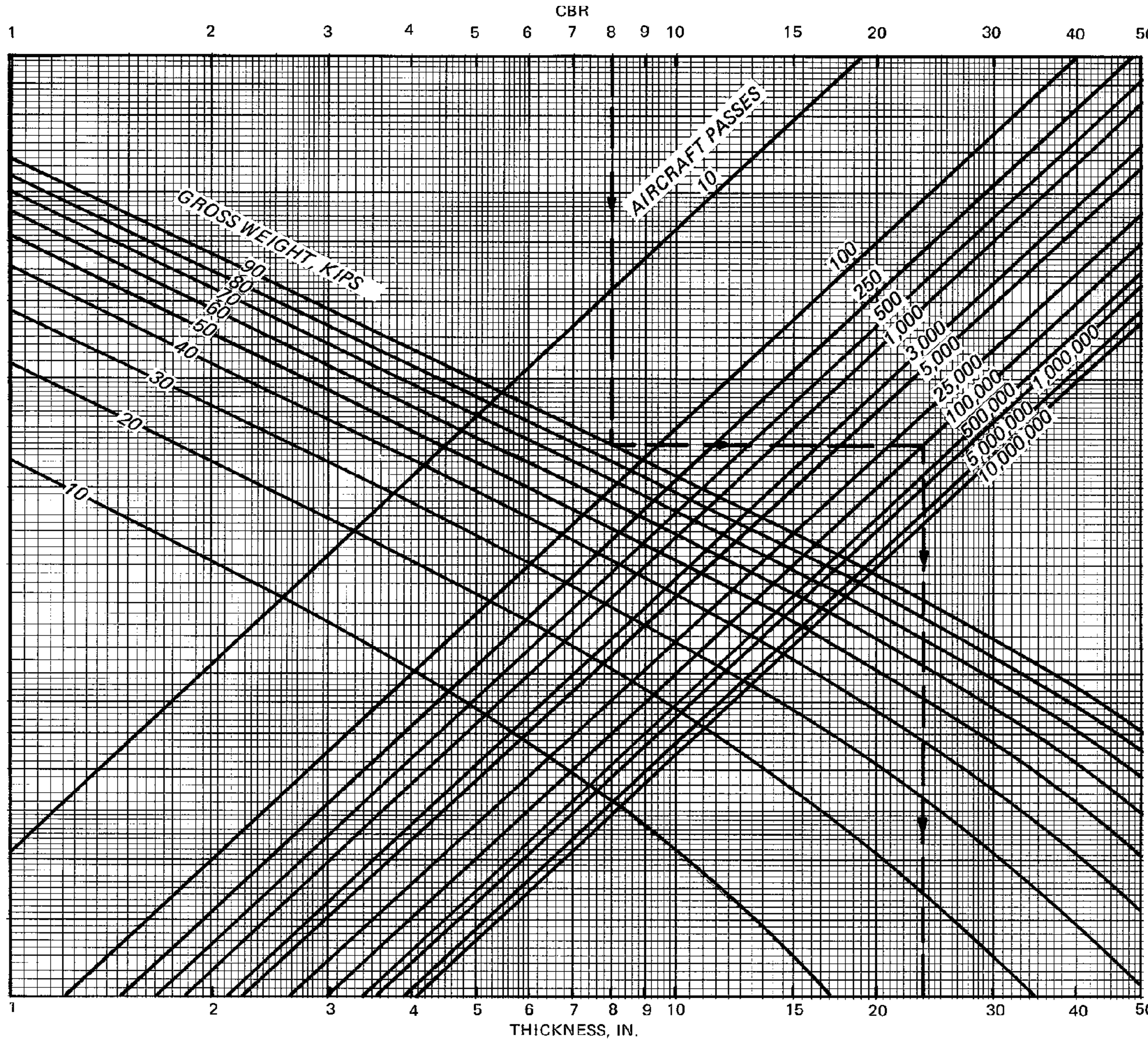


FLEXIBLE PAVEMENT DESIGN CURVE FOR F-15, TYPE A TRAFFIC AREA

CONVERSION FACTORS

MILLIMETERS = 25.4 x INCHES
KILOGRAMS = 0.4535 x POUNDS

Figure 10-22. Flexible pavement design curve for Air Force auxiliary airfield, type A traffic areas



FLEXIBLE PAVEMENT DESIGN CURVE FOR F-15, TYPE B AND C TRAFFIC AREAS

CONVERSION FACTORS

MILLIMETERS = 25.4 x INCHES
KILOGRAMS = 0.4535 x POUNDS

Figure 10-23. Flexible pavement design curve for Air Force auxiliary airfield, types B and C traffic areas

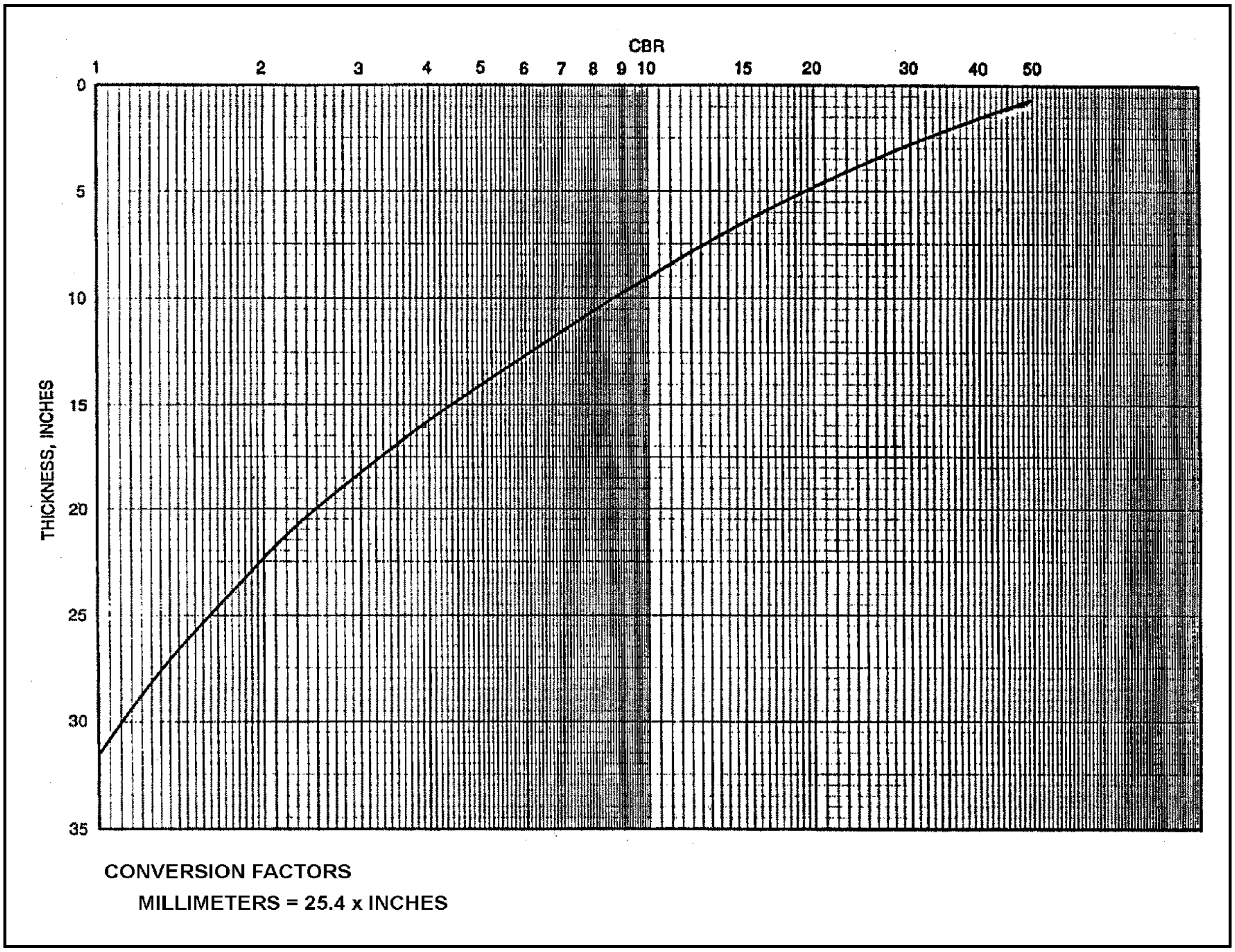


Figure 10-24. Flexible pavement design curve for shoulders on Army and Air Force pavements

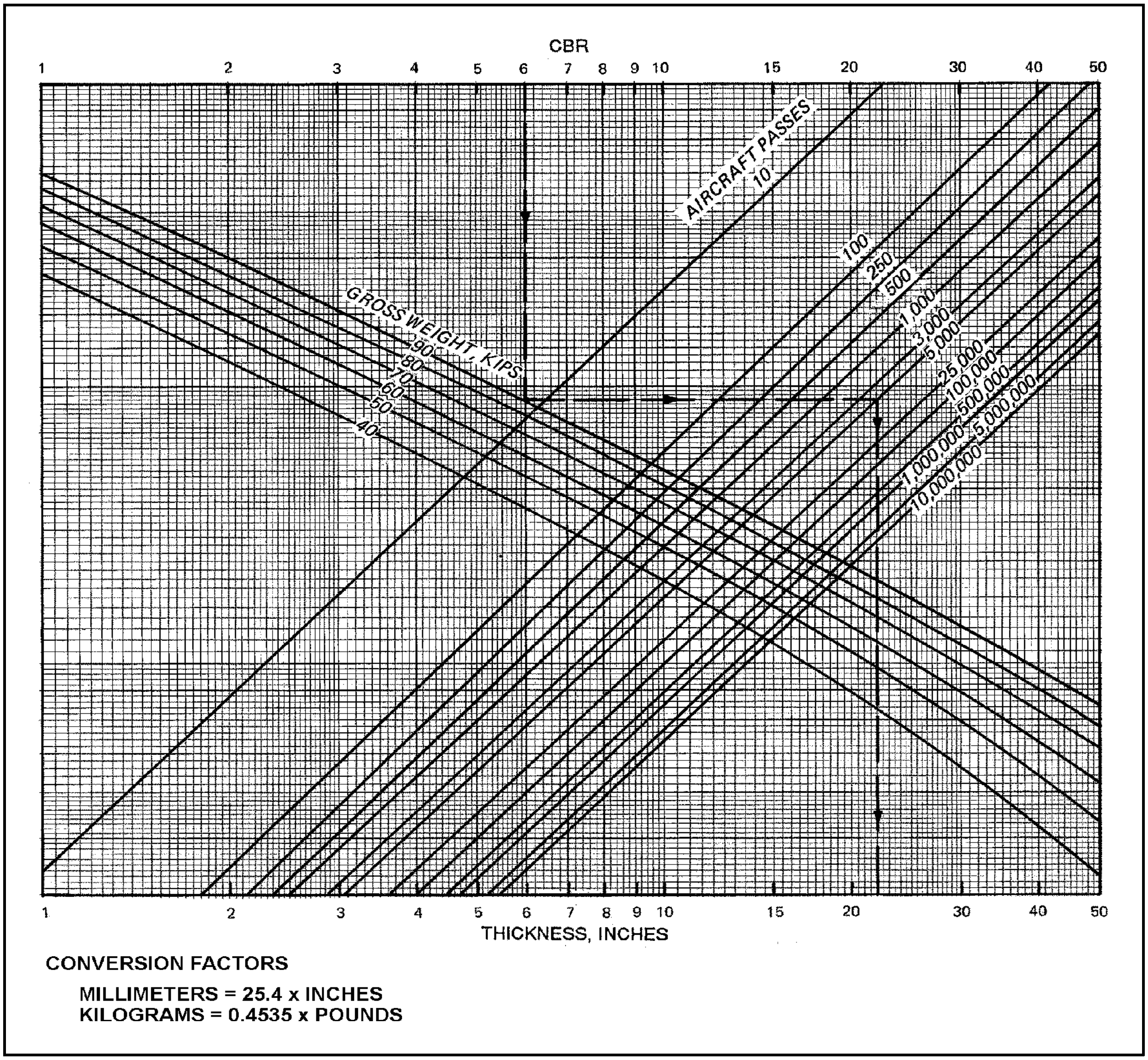


Figure 10-25. Air Force flexible pavement design curve for F-15, type A traffic areas

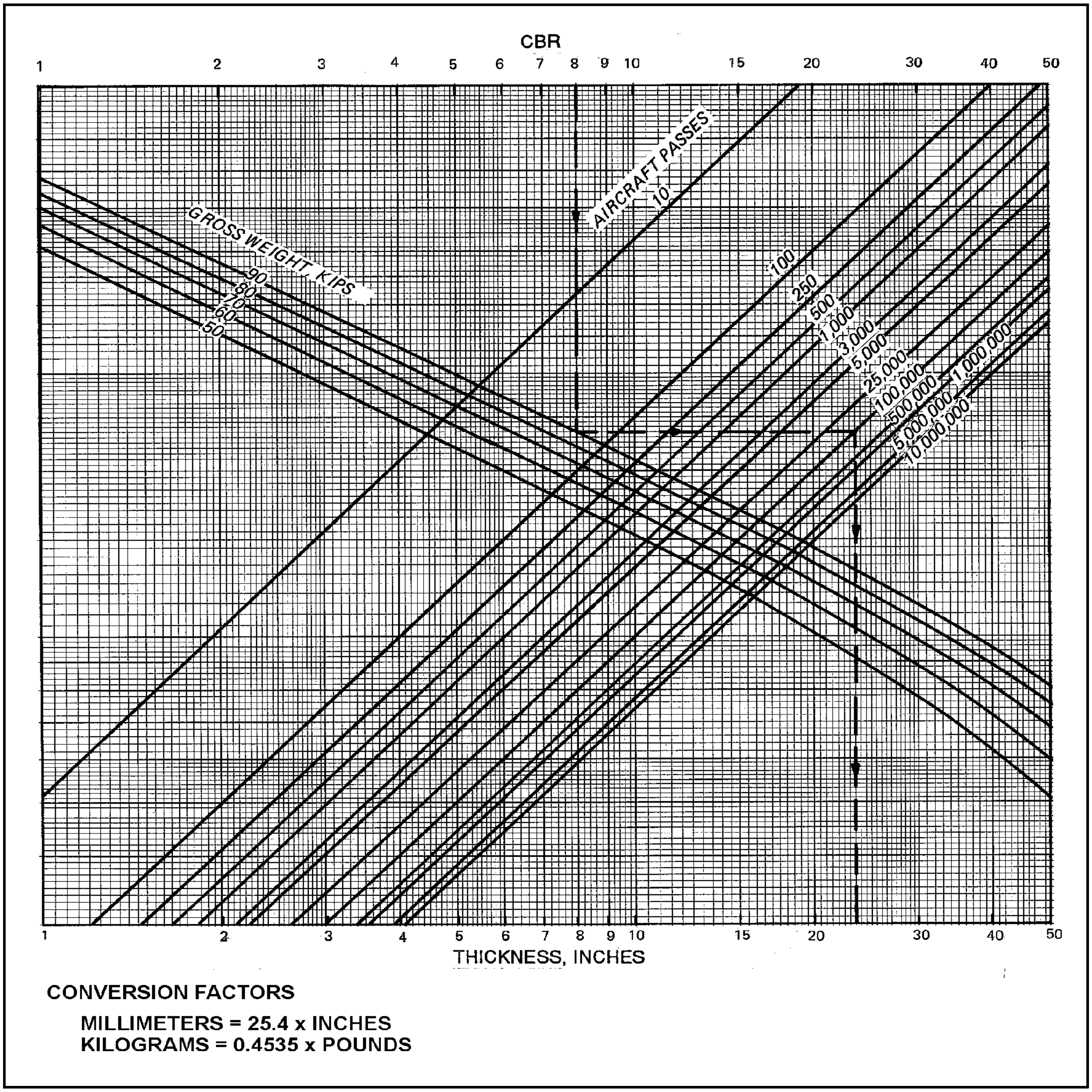


Figure 10-26. Air Force flexible pavement design curve for F-15, types B and C traffic areas

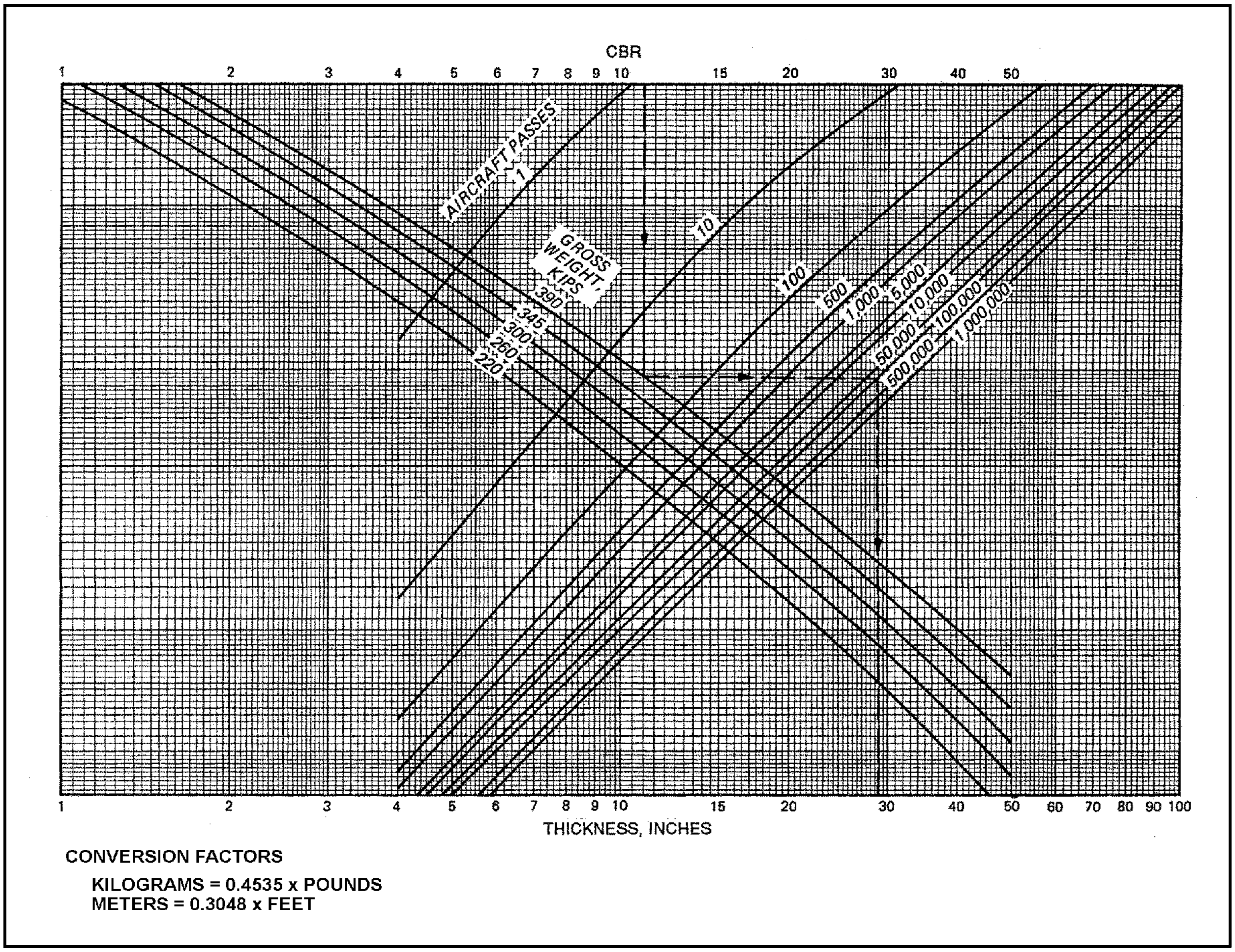
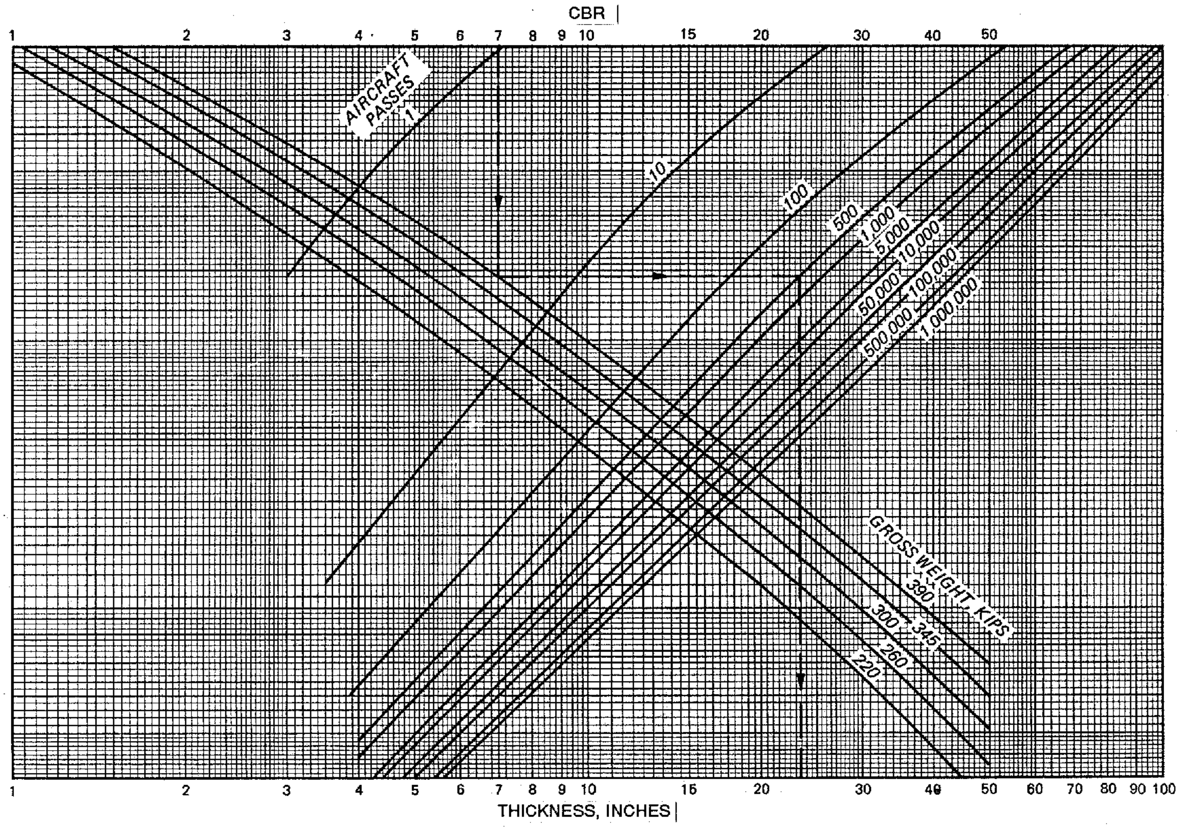


Figure 10-27. Air Force flexible pavement design curve for C-141, type A traffic areas



CONVERSION FACTORS

MILLIMETERS = 25.4 x INCHES
KILOGRAMS = 0.4535 x POUNDS

Figure 10-28. Air Force flexible pavement design curve for C-141, types B, C, and D traffic areas

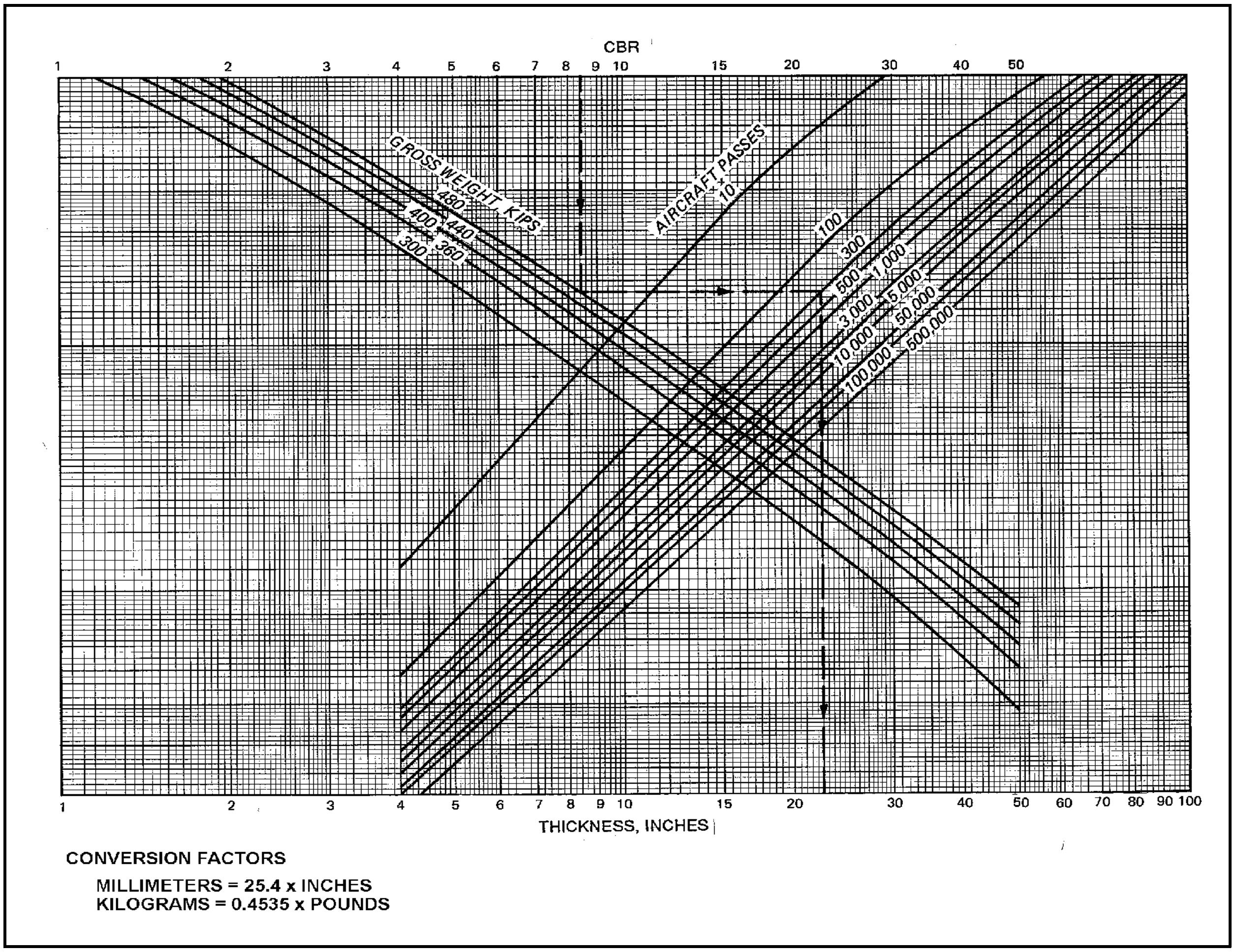
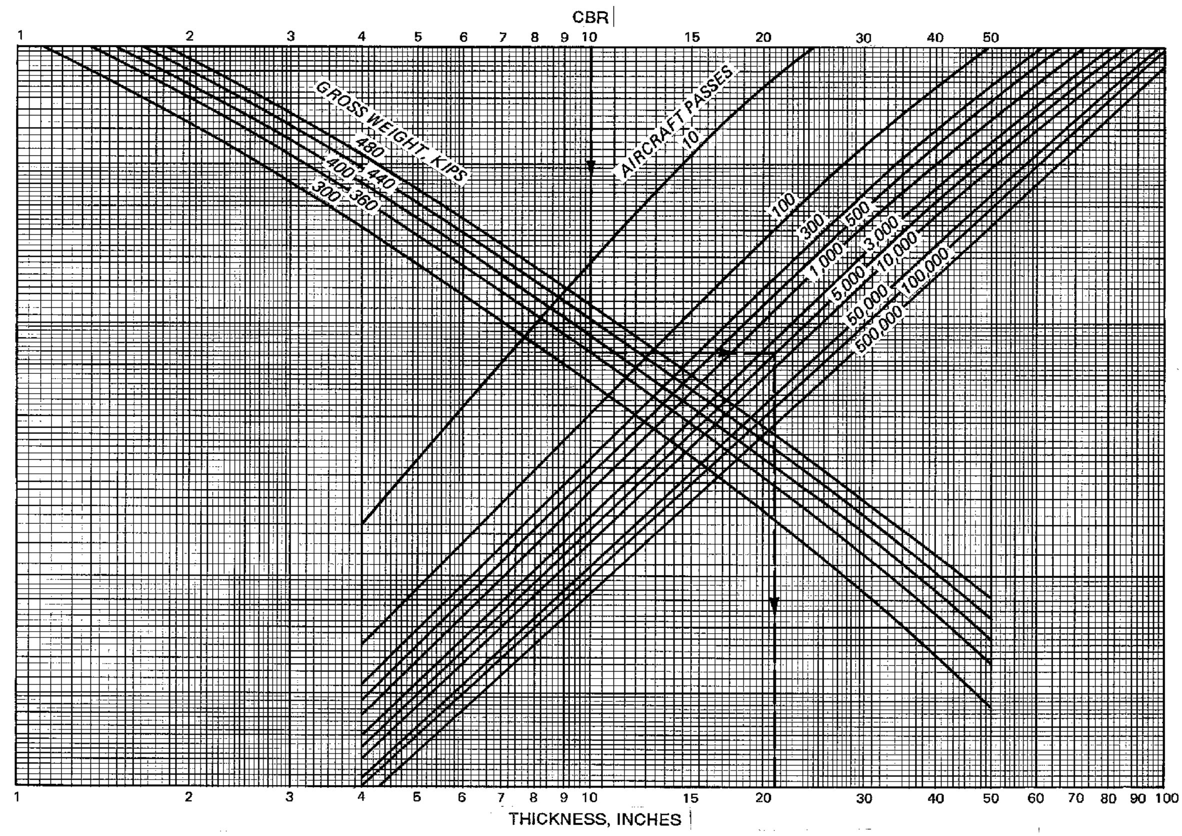


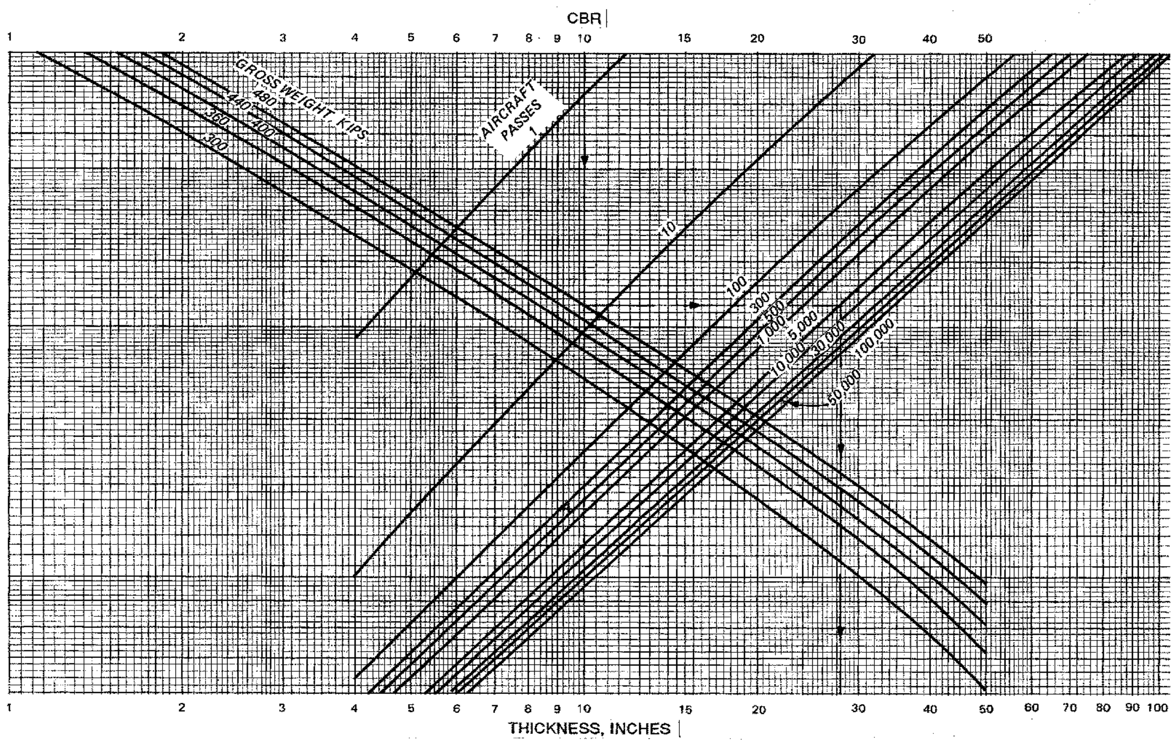
Figure 10-29. Air Force flexible pavement design curves for B-1, type A traffic areas



CONVERSION FACTORS

MILLIMETERS = 25.4 x INCHES
KILOGRAMS = 0.4535 x POUNDS

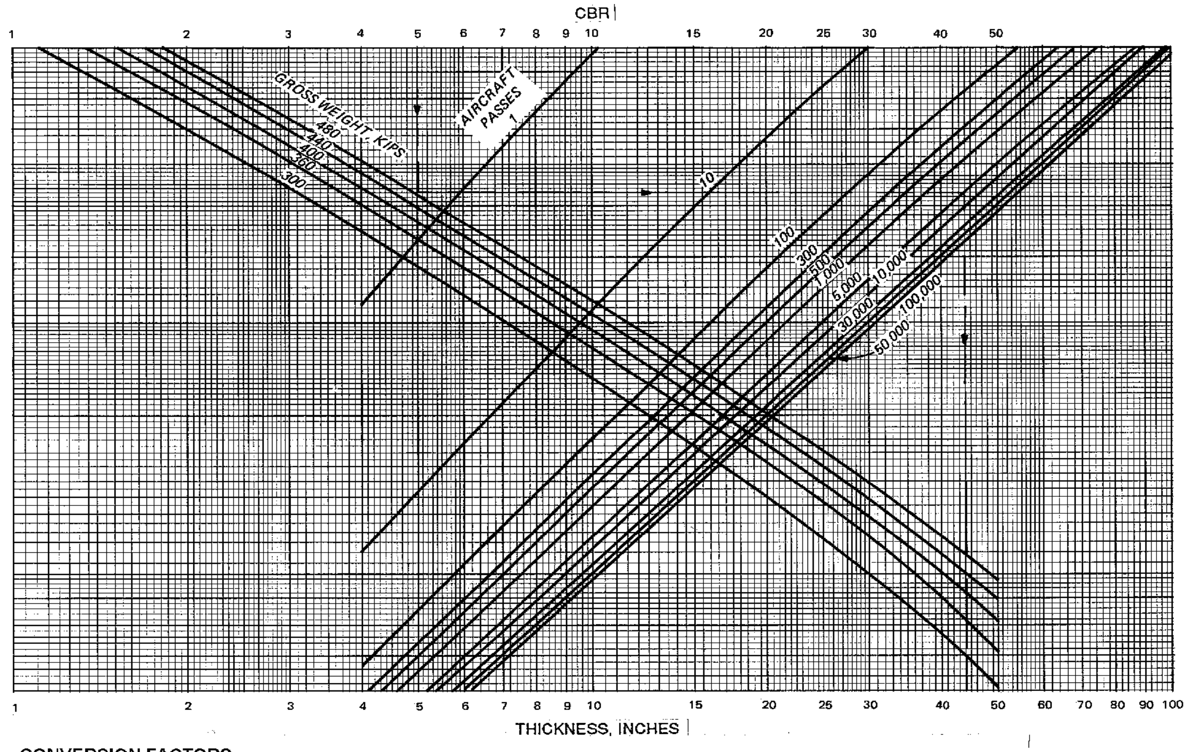
Figure 10-30. Air Force flexible pavement design curve for B-1, types B, C, and D traffic areas



CONVERSION FACTORS

MILLIMETERS = 25.4 x INCHES
KILOGRAMS = 0.4535 x POUNDS

Figure 10-31. Air Force flexible pavement design curve for B-52, type A traffic areas



CONVERSION FACTORS

MILLIMETERS = 25.4 x INCHES
KILOGRAMS = 0.4535 x POUNDS

Figure 10-32. Air Force flexible pavement design curve for B-52, types B, C, and D traffic areas

CHAPTER 11

LAYER ELASTIC DESIGN OF FLEXIBLE PAVEMENTS

1. DESIGN PRINCIPLES. The structural deterioration of a flexible pavement caused by traffic is normally evidenced by cracking of the bituminous surface course and development of ruts in the wheel paths. The design procedure handles these two modes of structural deterioration through limiting values of the strain at the bottom of the bituminous concrete and at the top of the subgrade. Use of a cumulative damage concept permits the rational handling of variations in the bituminous concrete properties and subgrade strength caused by cyclic climatic conditions. The strains used for entering the criteria are computed by the use of Burmister's solution for multilayered elastic continua. The solution of Burmister's equations for most pavement systems will require the use of computer programs and the characterization of the pavement materials by the elastic constants of the modulus of elasticity and Poisson's ratio.

2. FLEXIBLE PAVEMENT RESPONSE MODEL. The computer code recommended for computing the pavement response is the JULEA code. When the code is used, the following assumptions are made.

a. The pavement is a multilayered structure, and each layer is represented by a modulus of elasticity and Poisson's ratio.

b. The interface between layers is continuous; i.e., the friction resistance between layers is greater than the developed shear force.

c. The bottom layer is of infinite thickness.

d. All loads are static, circular, and uniform over the contact area.

3. DESIGN DATA.

a. Climatic Factors. In the design system, two climatic factors, temperature and moisture, are considered to influence the structural behavior of the pavement. Temperature influences the stiffness and fatigue of bituminous material and is the major factor in frost penetration. Moisture conditions influence the stiffness and strength of the base course, subbase course, and subgrade.

(1) Pavement temperature. The design procedure requires the determination of a design pavement temperature for consideration of vertical compressive strain at the top of subgrade and horizontal tensile strain at the bottom of cement- or lime-stabilized layers and a different design pavement temperature for consideration of the fatigue damage of the bituminous concrete surface. In either case, a design air temperature from Figure 11-1 is used to determine the design pavement temperature. Temperature data for computing the design air temperatures are available from the National Oceanic and Atmospheric Administration (NOAA) "Local Climatological Data Annual Summary with Comparative Data." These data may be obtained by requesting it from personnel at NOAA's web site: *http://www.noaa.gov/.* With respect to subgrade strain and fatigue of cement- and lime-stabilized base or subbase courses, the design air temperature is the average of the average daily mean temperature and the average daily maximum temperature during the traffic period. For consideration of the fatigue damage of bituminous materials, the design air temperature is the average daily mean temperature. Thus, for each traffic period, two design air temperatures are determined. Normally,

monthly traffic periods should be adequate. For design purposes, it is best to use the long-term averages such as the 30-year averages given in the annual summary. The determination of the design pavement temperatures for 254-millimeter (10-inch) bituminous pavement can be demonstrated by considering the climatological data for Jackson, MS. For the month of August, the average daily mean temperature is 27.5 degrees Celsius (81.5 degrees Fahrenheit) and the average daily maximum is 33.6 degrees Celsius (92.5 degrees Fahrenheit); therefore, the design air temperature for consideration of the subgrade strain is 30.5 degrees Celsius (87 degrees Fahrenheit), and the design pavement temperature (determined from Figure 11-1) would be approximately 37.8 degrees Celsius (100 degrees Fahrenheit). For consideration of bituminous fatigue, the design air temperature for August in Jackson is 27.5 degrees Celsius (81.5 degrees Fahrenheit), resulting in a design pavement temperature of approximately 33.3 degrees Celsius (92 degrees Fahrenheit). These design pavement temperatures are determined for each of the traffic periods. Temperature data for Jackson (from "Local Climatological Data Annual Summary with Comparative Data, Jackson, Mississippi") are shown in Table 11-1.

Table 11-1
Temperature Data for Jackson, Mississippi

	Temperature, degrees C (degrees F)	
Month	Average Daily Maximum	Average Daily Mean
January	14.7 (58.4)	8.4 (47.1)
February	16.5 (61.7)	9.9 (49.8)
March	20.4 (68.7)	13.4 (56.1)
April	25.7 (78.2)	18.7 (65.7)
May	29.4 (85.0)	22.6 (72.7)
June	32.8 (91.0)	26.3 (79.4)
July	33.7 (92.7)	27.6 (81.7)
August	33.6 (92.5)	27.5 (81.5)
September	31.1 (88.0)	24.4 (76.0)
October	26.7 (80.1)	18.8 (65.8)
November	20.3 (68.5)	12.9 (55.3)
December	15.8 (60.5)	9.4 (48.9)

(2) Thaw periods. The effects of temperature on subgrade materials are considered only with regard to frost penetration. The basic requirement of frost protection is given in Chapter 20. If the pavement is to be designed for a weakened subgrade condition, the design must consider a period of time during which the subgrade will be in a weakened condition.

(3) Subgrade moisture content for material characterization. In most design situations, pavement design will be predicated on the assumption that the moisture content of the subgrade will approach saturation. If sufficient data are available that indicate the subgrade will not reach saturation, then the design may be based on a lower moisture content. Sufficient data for basing the design on a

moisture content lower than saturation would normally consist of field moisture content measurements under similar pavements located in the area. These measurements should be made during the most critical period of the year when the water table is at its highest elevation. Extreme caution should be exercised when the design is based on other than the saturated condition.

b. Traffic Data. The traffic parameters to be considered are the type of design aircraft, aircraft loading, traffic volume, and traffic area.

(1) Traffic volume. The design traffic volume is expressed in terms of total operations of the design aircraft expected during the life of the pavement. This traffic volume must be converted to a number of expected strain repetitions. In converting operations to strain repetitions, the concept of effective gear print is introduced. The effective gear print is the width of pavement that sustains an effective strain repetition at a given depth in the pavement. The effective gear print is a function of the number of tires in a transverse line, the transverse spacing, the width of the contact area, and the effective thickness of pavement above the location of strain. The effective thickness of the pavement is the sum of the thickness of unbound material plus twice the thickness of bound material where a bound material is an asphalt concrete or stabilized layer. Thus, for a pavement having 76 millimeters (3 inches) of asphalt and 381 millimeters (15 inches) of unbound gravel, the effective thickness with reference to the strain at the top of the subgrade would be 381+(2×76) (15+(2×3)), or 533 millimeters (21 inches), and with respect to the strain at the bottom of the asphalt, the effective thickness would be 2×76 (2×3), or 152 millimeters (6 inches). With the determination of the effective thickness, the gear print is computed as illustrated in Figures 11-2 and 11-3. If the gear is composed of tracking tires such as tandem gear, then the number of strain repetitions may be somewhat greater than if the gear were not tandem. When the tracking tires are located far enough apart, two distinct strain pulses will occur and the multiplication factor for the tandem gear is 2. When the tires are sufficiently close, the strain pulses merge into a single pulse and the multiplication factor is 1. The computation of F is shown in Figure 11-4. In the figure, B is the spacing between tandem tires in the gear; t_e is the effective pavement thickness; and T_w is the length of the ellipse that is formed by the tire imprint. When t_e is less than $B - T_w$, F is 2. When t_e is greater than twice the difference between B and T_w, F is 1. For values of t_e between the two conditions, F is computed based on the equation:

$$F = \frac{3 \bullet (B - T_w) - t_e}{B - T_w} \qquad (11\text{-}1)$$

(a) The concept for conversion of aircraft operations to effective strain repetitions involves assuming that traffic distribution on the pavement can be represented by a normal distribution. For traffic on taxiways and runway ends (first 305 meters (1,000 feet)), the distribution has a wander width of approximately 178 millimeters (70 inches), and traffic on runway interiors has a wander width of approximately 355 millimeters (140 inches). (Note that wander width is defined as the width that contains 75 percent of the applied traffic.) From the normal distribution, the fraction of traffic for which the effective gear print will encompass a given point in the pavement can be computed. This fraction times F gives the number or fraction of the effective strain repetitions at a point in the pavement for each aircraft operation.

(b) The number of effective strain repetitions the pavement sustains at a point for every aircraft operation is the pass-to-strain conversion percentage. For an effective thickness of 0.00 millimeters (0 inches), the percentage is the inverse of the pass-to-coverage ratio multiplied by 100.

The procedure for computing the pass-to-strain conversion percentage has been computerized, and the factors can easily be computed for single, twin, single-tandem, twin-twin, twin-tandem, or other gears.

(c) The distribution of the pass-to-strain conversion percentages as a function of point location and effective thicknesses is given in Appendix E. These pass-to-strain conversion percentages can be used to convert, for any point location, the number of aircraft operations to effective strain repetitions.

(2) Aircraft loading. The aircraft loading and gear characteristics are used in the response model for computing the magnitude of strain. The information needed includes the number of tires, tire spacing, load per tire, and contact pressure. The radius of the loaded area is computed based on the assumption of a uniformly loaded circular area, i.e.,

$$r = \sqrt{\frac{L}{\pi p}} \tag{11-2}$$

where

r = radius of loaded area, millimeters (inches)

L = load per tire, Newtons (pounds)

p = contact pressure, MPa (psi)

Note: units should be consistent with units of the section parameters.

In principle, all main tires should be used in computing the strain, but usually only the tires on one landing gear need to be used. The distance between gears for common aircraft is sufficiently great to prevent interaction between gears. Within a main gear, some searching for the maximum strain may be needed. For most cases the maximum strain will occur under one of the tires, but for closely spaced tires or strains at a great depth, the maximum may move toward the center of the tire group.

(3) Traffic grouping. The traffic is grouped so that within each group each individual pass of an aircraft will cause damage similar a pass of any other aircraft in the group. That is, the pattern of strain of every pass of the group would be almost the same; then the value of the allowable number of passes (N) would be the same. For this to be true, the loading characteristics for aircraft within a group must be similar, and the single set of material properties must be applicable for all passes within the group. Grouping reduces considerably the design effort, and it is advantageous to reduce traffic to as few groups as possible. Grouping of the aircraft by similar pass-to-strain conversion percents has already been accomplished in Appendix E. Additional subgrouping would be necessary to account for other differences, such as load magnitude and tire pressure. Also, other groupings may be necessary to account for changes in material properties such as changes in subgrade modulus caused by thaw and changes in asphalt modulus caused by temperature. For pavements that are relatively unaffected by changes in temperature and are designed based on a single critical aircraft, it may be possible to reduce the aircraft operations to a single group. In this case, the design procedure simplifies to determining allowable strains for the design aircraft and to adjusting the pavement thicknesses to obtain the

allowable strain. Where the grouping cannot be reduced to a single group, then the concept of the cumulative damage must be used in the design process.

4. MATERIAL CHARACTERIZATION. Characterization of the pavement materials requires the quantification of the material stiffness as defined by the resilient modulus of elasticity and Poisson's ratio and, for selected pavement components, a fatigue strength as defined by a failure criterion. Inasmuch as possible, repeated load laboratory tests designed to simulate aircraft loading are used to determine the resilient stiffness of the materials. For some materials, such as unbound granular bases and subbases, an empirically based procedure was judged a better approach for obtaining usable material parameters. Failure criteria have been provided; thus, fatigue testing will not be necessary. In general, the use of layered elastic design procedures does not negate the material requirements set forth in Chapters 7, 8, and 9. In particular, the gradation, strength, and durability requirements as stated must be maintained.

a. Modulus of Elasticity.

(1) Bituminous mixtures. The term "bituminous mixtures" refers to a compacted mixture of bitumen and aggregate designed in accordance with standard practice. The modulus for these materials is determined by use of the repetitive triaxial test. The procedure for preparation of the sample is given in Appendix F with the procedure for the conduct of the repetitive triaxial test given in Appendix G.

(a) The stiffness of the bituminous mixtures will be greatly affected by both the rate of loading and by temperature. For runway design, a loading rate of 10 hertz is recommended. For taxiway and apron design, a loading rate of 2 hertz is suggested. These loading rates are appropriate for aircraft speeds of over 45 meters/second (100 miles/hour) on runways and less than 9 meters/second (20 miles/hour) on taxiways and aprons. Specimens should be tested at temperatures of 44, 21, and 38 degrees Celsius (40, 70, and 100 degrees Fahrenheit) so that a modulus-temperature relationship can be established. If temperature data indicate greater extremes than 4.4 and 38 degrees Celsius (40 and 100 degrees Fahrenheit), tests should be conducted at these extreme ranges if possible. The modulus value to be used for each strain computation would be the value applicable for the specific pavement temperature determined from the climatic data.

(b) An indirect method of obtaining an estimated modulus value for bituminous concrete is presented in detail in Appendix H. Use of this method requires that the ring-and-ball softening point and the penetration of the bitumen as well as the volume concentration of the aggregate and percent air voids of the compacted mixture be determined.

(2) Unbound granular base- and subbase-course materials. The terms "unbound granular base-course material" and "unbound granular subbase-course material" as used herein refer to materials meeting grading requirements and other requirements for base and subbase for airfield pavements, respectively. These materials are characterized by use of a chart in which the modulus is a function of the underlying layer and the layer thickness. The chart and the procedure for use of the chart are given in Appendix I.

(3) Stabilized material. The term "stabilized material" as used herein refers to soil treated with such agents as bitumen, portland cement, slaked or hydrated lime, and fly ash or a combination of such agents to obtain a substantial increase in the strength of the material. Stabilization with portland cement, lime, fly ash, or other agent that causes a chemical cementation to occur shall be referred to as chemical stabilization. Chemically treated soils having unconfined compressive strengths greater than the minimum strength specified for subbases are considered to be stabilized materials and should be tested

in accordance with the methods specified for stabilized materials. Chemically treated soils having unconfined compressive strengths less than that specified for subbases are considered to be modified subgrade soils and should be tested under the provisions for subgrade soils. Most likely this will result in using the maximum allowable subgrade modulus. Bituminous-stabilized materials should be characterized in the same manner as bituminous concrete. Stabilized materials other than bituminous-stabilized should be characterized using flexural beam tests or cracked-section criteria. Flexural modulus values determined directly from laboratory tests can be used when the effect of cracking is not significant and the computed strain based on this modulus does not exceed the allowable strain for the material being used.

(a) The general approach in the flexural beam test is to subject the specimen to repeated loadings at third points, measure the maximum deflection at the center of the beam (i.e., at the midpoint of the neutral axis), and calculate the values for the flexural modulus based on the theory of a simply supported beam. A correlation factor for stress is applied.

(b) Procedures for preparing specimens of and conducting flexural beam tests on chemically stabilized soils are presented in detail in Appendix J.

(c) The stabilized material for the base and subbase must meet the strength and durability requirement of TM 5-822-14/AFJMAN 32-1019. The strength requirements are as summarized in Chapter 9.

(4) Subgrade soils. The modulus of the subgrade is determined through the use of the repetitive triaxial test. For most subgrade soils, the modulus is greatly affected by changes in moisture content and state of stress. As a result of normal moisture migration, water table fluctuation, and other factors, the moisture content of the subgrade soil can increase and approach saturation with only a slight change in density. Since the strength and stiffness of fine-grained materials are particularly affected by such an increase in moisture content, these soils should be tested in the near-saturation state. Two methods are available to obtain a specimen with this moisture content: the soil can be molded at optimum moisture content and subsequently saturated or molded at the higher moisture content using static compaction methods. Evidence exists that the resilient properties of both specimen types are similar. It is not apparent whether this concept is valid for materials compacted at the higher densities; therefore, for the test procedures presented herein, back-pressure saturation of samples compacted at optimum is recommended for developing high moisture contents in test specimens.

(a) For cohesive subgrades, the resilient modulus of the subgrade will normally decrease with an increase in deviator stress, and therefore, the modulus is determined as a function of deviator stress. The modulus of granular subgrades will be a function of the first invariant. Procedures for specimen preparation, testing, and interpretation of test results for cohesive and granular subgrades are presented in Appendix K. For the layered elastic theory design procedure, however, the maximum allowable modulus for a subgrade soil should be restricted to 207 MPa (30,000 psi).

(b) In areas where the subgrade is to be subjected to freeze-thaw cycles, the subgrade modulus must be determined during the thaw-weakened state. Testing soils subject to freeze-thaw requires specialized test apparatus and procedures. Where commercial laboratories are not available, the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), 72 Lyme Road, Hanover, NH 03755, can conduct tests to characterize subgrade soils subjected to freeze-thaw.

(c) For some design situations, estimating the resilient modulus of the subgrade (M_R) based on available information may be necessary when conducting the repetitive load triaxial tests. An estimate of the resilient modulus in megapascals (pounds per square inch) can be made from the relationship of $M_R = 10.3 \times CBR$ ($M_R = 1{,}500 \times CBR$). The relationship does provide a method for checking the reasonableness of the laboratory results.

b. Poisson's Ratio. Because of the complexity of laboratory procedures involved in the direct determination of Poisson's ratio for pavement materials and because of the relatively minor influence on pavement design of this parameter when compared with other parameters, use of values commonly recognized as acceptable is recommended. These values for the four classes of pavement materials considered herein are presented in Table 11-2.

Table 11-2
Typical Poisson's Ratios for Four Classes of Pavement Materials

Pavement Materials	Poisson's Ratio v
Bituminous concrete	0.5 for E < 3,450 MPa (500,000 psi) 0.3 for E > 3,450 MPa (500,000 psi)
Unbound granular base- or subbase-course	0.3
Chemically stabilized base- or subbase-course	0.2
Subgrade	
Cohesive subgrade	0.4
Cohesionless subgrade	0.3

Note: E = elastic modulus of bituminous concrete (psi)

5. SUBGRADE EVALUATION. Chapter 6 provides for the evaluation of the subgrade for design by the CBR design procedure and also provides the background for evaluation of the subgrade modulus. After the establishment of the grade line, the pavement will be grouped as to soil type, strength, expected moisture content, compaction requirements, and other characteristics. For each soil group, a minimum of six resilient modulus tests should be conducted and the design modulus determined according to procedures given in Appendix K. The design modulus would be the average of the moduli obtained from the testing.

6. DESIGN CRITERIA. The damage factor (DF) is defined as $DF = \frac{n}{N}$, where n is the number of effective strain repetitions and N is the number of allowable strain repetitions. The cumulative damage factor is the sum of the damage factors for all aircraft. The value of n is determined from the number of aircraft operations. The value of N must be determined from the computed strain and the appropriate criteria. Basically, there are three criteria to determine N. These are the allowable number of repetitions as a function of the vertical strain at the top of the subgrade, the allowable number of repetitions as a function of the horizontal strain at the bottom of the bituminous concrete, and the allowable number of repetitions as a function of the horizontal strain at the bottom of a chemically stabilized base or chemically stabilized subbase. It should be noted that there is no strain criterion for unbound base. In the development of the procedure, it has been assumed that an unbound base and subbase that meets the specifications for quality will perform satisfactorily.

a. Subgrade Strain Criteria. The subgrade strain criteria were developed from the analysis of field test data and present the allowable number of strain repetitions as a function of strain magnitude. The data analysis indicated that the relationship between allowable repetitions and strain magnitude is slightly different for subgrades having different resilient moduli. The criteria are presented in graphic form in Figure 11-5 and can be approximated using the following equation:

$$allowable\ repetitions = 10{,}000 \cdot \left(\frac{A}{S_s}\right)^B \tag{11-3}$$

where

A = 0.000247 + 0.000245 log M_R

M_R = resilient modulus of the subgrade, psi

S_s = vertical strain at the top of the subgrade (in./in.)

B = 0.0658 $M_R^{0.559}$

b. Asphalt Strain Criteria.

(1) The primary means recommended for determining values of limiting horizontal tensile strain for bituminous concrete is the use of the repetitive load flexural beam tests on laboratory-prepared specimens. Procedures for the tests are presented in detail in Appendix L. Several tests are run at different stress levels and different sample temperatures such that the number of load repetitions to fracture can be represented as a function of temperature and initial stress. The initial stress is converted to initial strain to yield criteria based on the tensile strain of the bituminous concrete.

(2) An alternate method for determining values of limiting tensile strain for bituminous concrete is the use of the provisional laboratory fatigue data employed by Heukelom and Klomp. These data are presented in Appendix L in the form of a relationship between stress, strain, load repetitions, and elastic moduli of bituminous concrete. The allowable strain repetitions may be approximated by the equation

$$Allowable\ strain\ repetitions = 10^X \tag{11-4}$$

where

X = 2.68 - 5.0 log S_A - 2.665 log E

S_A = tensile strain of asphalt (in/in)

E = elastic modulus of the bituminous concrete (psi)

c. Chemically Stabilized Layers. For cement- and lime-stabilized materials, the criteria are to be developed using test procedures outlined in Appendix B. When flexural fatigue tests are not possible, then a preestablished relationship as shown in Figure 11-6 should be used.

d. Computer Programs for Computing Cumulative Damage Factor. Two computer codes are used for computing the subgrade and asphalt damage factors based on Equations 11-3 and 11-4. Both programs require material strains obtained by the running of the layered elastic computer programs. The listings of the programs contain an explanation of the input and instructions on the use of the programs. An example illustrating the use of the programs is given in this chapter in the paragraph entitled Example Design for Conventional Flexible Pavement.

7. CONVENTIONAL FLEXIBLE PAVEMENT DESIGN. Conventional flexible pavements consist of relatively thick aggregate layers with a 75- to 125-millimeter (3- to 5-inch) wearing course of bituminous concrete. In this type of pavement, the bituminous concrete layer is a minor structural element of the pavement, and thus, the temperature effects on the stiffness properties of the bituminous concrete may be neglected. Also, it must be assumed that if the minimum thickness of bituminous concrete is used as specified in Tables 8-2 through 8-5, then fatigue cracking will not be considered. Thus, for a conventional pavement, the design problem is one of determining the thickness of pavement required to protect the subgrade. The steps for determining the required thickness for nonfrost areas are:

a. The subgrade resilient modulus is determined based on the soil exploration, climatic conditions, and laboratory testing. The resilient modulus of the bituminous concrete is assumed to be 1,380 MPa (200,000 psi).

b. The traffic data determine the design loadings and repetitions of strain.

c. An initial pavement section is determined from the minimum thickness requirements as determined using Chapter 10 or by estimation. The resilient modulus of the base and of the subbase is determined based on the chart and the initial thickness.

d. The vertical strain at the top of the subgrade is computed for each aircraft being considered in the design.

e. The number of allowable strain repetitions for each computed strain is determined from the subgrade strain criteria.

f. The value of n/N is computed for each aircraft and summed to obtain the cumulative damage factor.

g. The assumed thicknesses are adjusted to make the value of the cumulative damage factor approach 1.0. This may be accomplished by first making the computations for three thicknesses and developing a plot of thickness versus damage factor. From this plot the thickness that gives a damage factor of 1.0 may be selected.

8. FROST CONDITIONS. Where frost conditions exist and the design is to be based on a base and subbase thickness less than the thickness required for complete frost protection, the design must be based on two traffic periods as described previously. In some cases, it may be possible to replace part of the subgrade with material not affected by cycles of freeze-thaw but which will not meet the specifications for a base or subbase. In this case, the material must be treated as a subgrade and characterized by the procedures given for subgrade characterization.

9. ASPHALT CONCRETE PAVEMENTS. The asphalt concrete pavement differs from the conventional flexible pavement in that the asphalt concrete is sufficiently thick to contribute significantly to the strength of the pavement. In this case, the variation in the stiffness of the asphalt concrete caused

by yearly climatic variations must be taken into account by dividing the traffic into increments during which variation of the resilient modulus of the asphalt concrete is at a minimum. One procedure is to determine the resilient modulus of the asphalt concrete for each month, then group the months when the asphalt concrete has a similar resilient moduli. Thus, it may be possible to reduce the traffic to three or four groups. Also, since the asphalt concrete is a major structural element, the failure of this element due to fatigue cracking must be checked. The flow diagram for design of the asphalt concrete pavements is given in Figure 11-7.

10. PAVEMENTS WITH A STABILIZED BASE COURSE. For a pavement having a chemically stabilized base course and an unbound aggregate subbase course, damage must be accumulated for subgrade strain, for horizontal tensile strain at the bottom of the bituminous concrete surfacing, and for horizontal tensile strain at the bottom of the chemically stabilized layer. Normally in this type of pavement, the base-course resilient modulus is sufficiently high (≥ 690 MPa (100,000 psi)) to prevent fatigue cracking of the bituminous concrete surface course (where the bituminous concrete surface course has a thickness equal to or greater than the minimum required in Tables 8-2 through 8-5), and thus this mode of failure is only a minor consideration. For most cases, a very conservative approach can be taken in checking for this mode of failure; i.e., all the traffic can be grouped into the most critical time period and the computed bituminous concrete strain compared with the allowable strain. If the conservative approach indicates that the surface course is unsatisfactory, then the damage should be accumulated in the same manner used for conventional flexible pavement. For the pavement having a stabilized base or subbase, checking the subgrade strain criteria becomes more complicated than for conventional flexible or bituminous concrete pavements. Two cases in particular should be considered. In the first case, the stabilized layer is considered to be continuous, with cracking due only to curing and temperature. In the second case, the stabilized layer is considered cracked because of load. The first step in evaluating the stabilized layer is to compute the horizontal tensile strain at the bottom of the stabilized layer and the vertical compressive strain at the top of the subgrade under assumptions that the stabilized layer is continuous and has a modulus value as determined by the flexural resilient modulus test. To account for the increase in stress due to loadings near shrinkage cracks, the computed strains should be multiplied by 1.5 for comparison with the allowable strains. If the analysis shows that the stabilized base will not crack under load, then it will be necessary to compare the adjusted value of subgrade strain with the allowable subgrade strain. If this analysis indicates that the adjusted strain is not less than or equal to the allowable strain, then the thickness should be increased and the process repeated, or the section should be checked under the assumption that the base course will crack and behave as a granular material. The cracked stabilized base course is represented by a reduced resilient modulus value, which is determined from the relationship between resilient modulus and unconfined compressive strength shown in Figure 11-8. When the cracked base concept is used, only the subgrade criteria need to be satisfied. The section obtained should not differ greatly from the section obtained by use of the equivalency factors in Table 9-1 or 9-2. A flow diagram for the design of this type of pavement is shown in Figure 11-9.

11. PAVEMENTS WITH STABILIZED BASE AND STABILIZED SUBBASE. This type of pavement is handled almost identically to a pavement with a stabilized base. If the base is a bituminous-stabilized material, then the cumulative damage procedure must be employed to determine if the subbase will crack. If the analysis indicates that the subbase will crack due to loading, an equivalent cracked-section modulus is determined from Figure 11-8, and the pavement is treated as a bituminous concrete pavement. If both the base and subbase courses are chemically stabilized, then both layers must be checked for cracking. A conservative approach is taken by checking for cracking of one layer by considering the other stabilized layer as cracked and having a reduced modulus. The vertical compressive strain at the top of the subgrade is computed by use of the flexural modulus or the reduced modulus, as appropriate. If either of the two layers is considered uncracked, then the computed

subgrade strain is multiplied by 1.5 to account for the shrinkage cracks that will exist. The basic flow diagram for this type of pavement is shown in Figure 11-10.

12. EXAMPLE DESIGN FOR CONVENTIONAL FLEXIBLE PAVEMENT. To illustrate the application of the design procedure, consider a design for an Army Class IV airfield. The subgrade is a lean clay classified as CL. The design is to be for 200,000 passes of the C-130 aircraft. The design loading for the C-130 on the taxiway is 70,310 kilograms (155,000 pounds) with a tire contact area of 0.258 square meters (400 square inches). For the runway interior the loading is 75 percent of the taxiway loading. The reduction is accomplished by reducing the contact area, giving a contact area of 0.194 square meters (300 square inches). The design process may best be illustrated in steps. The basic steps are material investigation, determination of trial pavement sections, computation of critical strains, determination of applied strain repetitions, and computation of damage factors.

a. Step 1 - Material Investigation.

(1) The evaluation of the subgrade is to be accomplished by field and laboratory studies. The subgrade is to be classified according to different material types and material processing. For this example, it is assumed that the subgrade is fairly uniform and consists of a compacted lean clay placed according to existing compaction requirements. The subgrade evaluation involves conducting a series of resilient modulus tests according to the procedures given in Appendix L. For a location such as Shreveport, LA, it must be assumed that the subgrade would become saturated and thus the resilient modulus tests are conducted on saturated samples. A minimum of six samples should be tested and a design modulus determined for each sample. For determination of a design modulus, the data from the laboratory tests are plotted on a log-log plot of M_R versus σ_d and overlaid on the design curves as shown in Figure 11-11. For the design example, the design modulus obtained using this process is assumed to be 62 MPa (9,000 psi) for both taxiway and runway designs. Base and subbase materials must be obtained that meet the requirements of Chapters 7 and 8. The modulus values for the base and subbase are to be determined by the procedures given in Appendix J. Because the modulus of these materials depends on layer thicknesses, the modulus cannot be obtained until the trial sections are determined.

(2) The bituminous surfacing must meet the requirements of Chapter 9 as to minimum thickness and composition. The modulus-temperature relationship is determined according to the test procedures given in Appendix H or by the provisional procedure given in Appendix I. Assume for the example problem that the relationship as shown in Figure 11-12 is obtained from laboratory test data. (For simplicity, these data will be used for both taxiway and runway.) From the climatic data, the design air temperature is obtained and the design modulus values are determined as shown in Tables 11-3 and 11-4. To reduce the number of computations, the 12 groups are reduced to four groups as shown in Table 11-5. The Poisson's ratio for all materials is selected from Table 11-2.

b. Step 2 - Determination of Initial Section.

(1) From Chapter 10 the total thickness of pavement required for a gross aircraft load of 70,310 kilograms (155,000 pounds), 200,000 passes, and a subgrade CBR of 6 is determined to be 710 millimeters (28 inches). For the runway interior design, the thickness would be based on a gross aircraft load of 52,730 kilograms (116,250 pounds) and would result in an estimated thickness of 610 millimeters (24 inches). For taxiway design, subgrade damage factors will be computed for pavement thicknesses of 680, 760, and 840 millimeters (27, 30, and 33 inches) in an attempt to bracket the final required pavement thickness. The total thickness of pavement is made up of the asphalt

Table 11-3
Bituminous Concrete Moduli for Each Month for Conventional Flexible Pavement Design Based on Subgrade Strain

Month (1)	Average Daily Mean Air Temperature,[1] degrees F (2)	Average Daily Maximum Air Temperature,[2] degrees F (3)	Design Air Temperature,[2] degrees F (4)	Design Pavement Temperature,[3] degrees F (5)	Dynamic Modulus[4] |E*| 10^3 psi (6)
Jan	47.5	56.4	52	60	1,270
Feb	50.7	60.1	55	64	1,060
Mar	58.0	68.0	63	72	700
Apr	66.1	76.0	71	81	420
May	73.3	83.2	78	90	250
Jun	80.5	90.4	85	97	160
Jul	83.1	92.9	88	100	130
Aug	82.7	92.8	88	100	130
Sep	77.3	87.4	82	94	190
Oct	67.2	78.1	73	83	380
Nov	56.2	66.4	61	71	720
Dec	49.3	58.3	54	61	1,200

[1] Determined from local climatological data for Shreveport, LA.
[2] Average of values from columns 2 and 3.
[3] Estimated from 5-inch bituminous concrete thickness curve in Figure 6-1. (Figure 6-1 is entered with the appropriate design air temperature.)
[4] Determined by laboratory testing of bituminous concrete.
Conversion Factors: degrees C = degrees F - 32/1.8, megapascals = 0.006894 × psi

thickness, base thickness, and subbase thickness. The section for a thickness of 760 millimeters (30 inches) is shown in Figure 11-13 as an example.

(2) For runway design, thicknesses of 510, 610, and 660 millimeters (20, 24, and 26 inches) are assumed for the initial sections for computing the subgrade damage factor. The section for 610 millimeters (24 inches) is shown in Figure 11-14. In the initial section, a 13-millimeter (5-inch) asphalt layer is assumed for the taxiway design, and a 10-millimeter (4-inch) asphalt layer is assumed for the runway design. After determining the total thickness required for these asphalt thicknesses, the design can be refined for other asphalt thicknesses.

c. Step 3 - Computation of Strains.

Table 11-4
Bituminous Concrete Moduli for Each Month for Conventional Flexible Pavement Design Based on Bituminous Concrete Strain

Month	Average Daily Mean Air Temperature,[1] degrees F	Design Pavement Temperature,[2] degrees F	Dynamic Modulus |E*| 10^3 psi
Jan	47.5	56	1,500
Feb	50.7	60	1,270
Mar	58.0	67	920
Apr	66.1	76	570
May	73.3	84	360
Jun	80.5	92	220
Jul	83.1	95	180
Aug	82.7	95	180
Sep	77.3	89	260
Oct	67.2	77	540
Nov	56.2	65	1,000
Dec	49.3	57	1,400

[1] Determined from local climatological data for Shreveport, LA.
[2] Estimated from 5-inch bituminous concrete thickness curve in Figure 6-1. (In design for bituminous concrete strain, the average daily mean air temperature is used as the design air temperature for entering Figure 6-1.)
Conversion Factors: degrees C = degrees F - 32/1.8, millimeters = 25.4 × inches

(1) The horizontal strain at the bottom of the asphalt layer and the vertical strain at the top of the subgrade are computed for each traffic grouping shown in Table 11-5. The data needed for input into the JULEA computer program for the computation of asphalt and subgrade strains for the 760-millimeter (30-inch) pavement structure for a taxiway design are given in Table 11-6. Note that the input contains data for one run, but four runs would be required to compute the subgrade data, i.e., one run for each grouping to account for variation in asphalt modulus. The strain is computed considering only two of the four main tires; the transverse spacing of the tires is sufficiently large to prevent an overlapping effect for the other two tires. The individual tire loading is computed by considering 90 percent of the gross load on the main gear, equally distributed between the four tires of the main gear, resulting in a weight on each tire of 15,820 kilograms (34,875 pounds). The radius of the loaded area is computed as a circle having an area equal to the tire contact area. A contact area of 0.258 square meters (400 square inches) results in a radius of the contact area of 28.6 millimeters (11.28 inches). The pavement system is a five-layer system having full friction between layers. For a

Table 11-5
Grouping Traffic into Traffic Groups According to Similar Asphalt Moduli

		Modulus Values, kips per square inch				
		For Computation of Asphalt Damage		For Computation of Subgrade Damage		
Group	Month	Monthly Values	Group Average	Monthly Values	Group Average	Percent of Total Traffic
1	Jan	1,500	1,390	1,270	1,180	25.0
	Dec	1,400		1,200		
	Feb	1,270		1,060		
2	Nov	1,000	960	720	710	16.7
	Mar	920		700		
3	Apr	570	490	420	400	25.0
	Oct	540		380		
	May	360		250		
4	Sep	260	210	190	150	33.3
	Jun	220		160		
	Jul	180		130		
	Aug	180		130		

Conversion Factors: megapascals = 6.894 × kips per square inch

flexible pavement system, the rough computational procedure is sufficiently accurate. The subgrade vertical strain is computed at the top of the subgrade layer and under the center of one of the tires and midway between the tires. The maximum strain is found to occur under the tire. Results of computer runs for the example problem are shown in Table 11-7.

(2) A similar set of runs is made for the computation of the horizontal strain at the bottom of the asphalt layer. This set of runs will use the asphalt moduli determined for consideration of asphalt strains and given in Table 11-5. For computing the strains for the runway design, the load and contact area are reduced by 75 percent. The resulting tire loading is 11,850 kilograms (26,125 pounds) applied over a circular contact area having a radius of 248 millimeters (9.77 inches).

d. Step 4 - Determination of Applied Repetitions.

(1) The design is for 200,000 passes of the aircraft over the life of the pavement. The pavement life has been divided into four periods as shown in Table 11-5. Considering that the traffic is to be equally distributed throughout the year would result in 25, 16.7, 25, and 33.3 percent of the traffic to be applied in the first, second, third, and fourth periods, respectively.

(2) The 200,000 passes will result in a total number of effective strain repetitions that will be a function of transverse location on the pavement and on the depth at which the strain is being considered.

Table 11-6
Structure Data File for Input into the JULEA Computer Program

STRUCTURE Data File
Job Title
TM EXAMPLE 1
Number of Pavements
1
Number Thickness and Moduli Variations
1 1
Pavement Description
Flexible Pavement
Slab Flexural Strength (only for rigid pavements)
.00000000

No. of Layers
6

Layer Number	Thicknesses (in.)	Modulus of Elasticity (psi)	Poisson's Ratio	Interface Condition	Layer Code
1	5.00	1,180,000.00	0.300	0.00	0
2	6.00	58,000.00	0.300	0.00	0
3	7.00	32,000.00	0.300	0.00	0
4	6.00	25,000.00	0.300	0.00	0
5	6.00	17,000.00	0.300	0.00	0
6		9,000.00	0.400		0

No. of Depths
2

Depth No.	Depth (in.)
1	-5.00000000
2	30.00000000

(Continued)

Table 11-6 (Concluded)

LOAD Data File
Job Title
TM EXAMPLE
No. of Aircraft
1
Aircraft Identification Number 1
C-130
Gross Load
39750.00
Fraction of Gross Load on the Gear to be analyzed
1.000

No. of Tires
2

Tire No.	Radius (in.)	Cont. Area (sq in.)	Cont. Press. (psi)	Tire Load (pounds)	X-Coord. (in.)	Y-Coord. (in.)
1	11.28	400.00	87.19	34,875.00	-30.00	.00
2	11.28	400.00	87.19	34,875.00	30.00	.00

No. of Evaluation Points (X, Y Sets)
5

Point No.	X-Coord. (in.)	Y-Coord. (in.)
1	0.00	0.00
2	7.50	0.00
3	15.00	0.00
4	22.50	0.00
5	30.00	0.00

Table 11-7
Results of Computer Runs for the Example Problem. (Horizontal Strain for the Asphalt and Vertical Strains for the Subgrade)

Traffic Group or Season	Percent Traffic	Strains, in./in.					
		33-in. Pavement, 4-in. AC		30-in. Pavement, 5-in. AC		27-in. Pavement, 6-in. AC	
		Asphalt	Subgrade	Asphalt	Subgrade	Asphalt	Subgrade
1	25.0	0.000217	0.000654	0.000218	0.000733	0.000200	0.000831
2	16.7	0.000228	0.000698	0.000234	0.000789	0.000227	0.000908
3	25.0	0.000247	0.000741	0.000267	0.000844	0.000270	0.000980
4	33.3	0.000219	0.000806	0.000263	0.000927	0.000295	0.001080

From plots in Appendix E showing the conversion from passes to strain repetitions for the taxiway and runway, the conversion percentages are determined. For the taxiway and depth to the top of subgrade of 760 millimeters (30 inches), the maximum conversion percentage for converting passes to effective strain repetitions from Figure E-10 is approximately 100. This maximum occurs at a distance of 26 meters (86 inches) from the centerline of the taxiway. Thus, the effective number of subgrade repetitions would be 200,000. For consideration of the asphalt strain at a depth of 130 millimeters (5 inches), the conversion percentage is approximately 50, resulting in 100,000 strain repetitions. From Figure E-9, the conversion percentages for the runway are 60 and 30 for consideration of subgrade strain and asphalt strain, respectively.

(3) The effective number of strain repetitions for a traffic group then is determined by multiplying the total strain repetitions by the factor of traffic occurring in a group.

e. Step 5 - Computation of Damage Factors.

(1) The damage factor for one traffic group is defined as n/N where n represents the effective strain repetitions for that group and N equals the allowable numbers of strain repetitions as computed from Equations 11-3 and 11-4. The damage factors for the different periods are summed to obtain the cumulative damage factor.

(2) The computations were performed by use of the computer programs SUBGRADE for the subgrade damage and ASPHALT for the asphalt damage. The data file, SDATA1, required by the program SUBGRADE for computing the subgrade damage factor for 840-, 760-, and 685-millimeter (33-, 30-, and 27-inch) pavements is given in Table 11-8 and the output is given in Table 11-9. The data file ADATA1 required by the program ASPHALT for computing the asphalt damage factor for the asphalt is given in Table 11-10 and for the output in Table 11-11.

(3) To speed the design procedure, the subgrade damage factor was computed for several pavement thicknesses, and the results for the taxiway pavement were plotted as shown in Figure 11-15. For pavements having an asphalt concrete thickness of 130 millimeters (5 inches), the subgrade damage factor was computed for thicknesses of 685, 760, and 840 millimeters (27, 30, and 33 inches). From the plot of damage factor versus pavement thickness, it is determined that the required thickness for the taxiway pavement would be 735 millimeters (29 inches). Using the 735-millimeter (29-inch) overall thickness as a constant thickness, the subgrade damage factor can be computed for varying thickness of asphalt concrete. Lines can then be constructed that will provide the total thickness for each asphalt concrete thickness. Alternate designs, rounded to the nearest inch, might be 152-millimeter (6-inch) asphalt concrete with 710 millimeters (28 inches) in total thickness or 102-millimeter (4-inch) asphalt concrete with 762 millimeters (30 inches) in total thickness. The relationship between pavement thickness and subgrade damage factors for the runway is given in Figure 11-16.

(4) For these designs, the asphalt damage must be computed. Plots of asphalt damage versus asphalt thickness for both the taxiway and runway are given in Figure 11-17. The asphalt damage factor would not control the asphalt thickness since the damage factor for this case is always less than 1.0. The minimum thickness of the asphalt layer would be dictated by the minimum thickness criterion in the basic manual.

Table 11-8
Data File for Computing Subgrade Damage for Pavement Thicknesses of 840, 760, and 685 millimeters (33, 30, and 27 inches)

List SDATA1

100	Taxiway design subgrade damage thickness = 33 inches
110	4 200000
120	.25 .16666667 .25 .333333
130	9000. 9000. 9000. 9000.
140	.000654 .000698 .000741 .00806
150	Taxiway design subgrade damage thickness = 30 inches
160	4 200000
170	.25 .1666667 .25 .333333
180	9000. 9000. 9000. 9000.
190	.000733, .000789 .000844 .000927
200	Taxiway design subgrade damage thickness = 27 inches
210	4 200000
220	.25 .166667 .25 .33333
230	9000. 9000. 9000. 9000.
240	.000831 .000908 .000980 .001080
250	End of data
260	0 0

13. EXAMPLE DESIGN FOR ALL BITUMINOUS CONCRETE (ABC) PAVEMENT.

a. The thickness of the ABC pavement required for the taxiway design is estimated by considering the thickness of conventional pavement, i.e., 130 millimeters (5 inches) of asphaltic concrete and 610 millimeters (24 inches) of granular base and subbase. For this conventional pavement the effective thickness would be 865 millimeters (34 inches) which when converted to an ABC pavement would give an estimated thickness of 430 millimeters (17 inches) (computed by using the equivalence of 2 for bound materials). For computation of the fatigue damage and subgrade damage, monthly time periods are used as shown in Tables 11-12 and 11-13, respectively. Normally for ABC designs, the subgrade damage will be the controlling criteria and thus the thickness for satisfying the subgrade criteria is first determined. The subgrade strains are computed for six time periods so as to produce a plot as shown in Figure 11-18. From this plot, the subgrade strains for each time period are determined and are given in Tables 11-14 and 11-15. The data shown in Table 11-14 are input into the computer program SUBGRADE to compute the subgrade damage factor. It is noted that an equivalent thickness of 865 millimeters (34 inches) is used to determine the applied strain repetitions, resulting in the same number of strain repetitions as was used for the design of the conventional pavement. Damage factors were computed for pavement thicknesses of 405, 430, 480, and 535 millimeters (16, 17, 19, and 21 inches) from which the plot of damage factor versus pavement thickness (Figure 11-19) was

Table 11-9
Program Output for Subgrade Damage for Pavement Thicknesses of 840, 760, and 685 millimeters (33, 30, and 27 inches)

* Run SUBGRAD

00 Taxiway Design Subgrade Damage Thickness = 33 inches

Damage based on subgrade strain criteria and on 200,000 total strain repetitions

Sub Modulus	Subg Strain	Allow Reps	Applied Reps	Damage
9000.	0.000654	7523438.	5000.	0.665-02
9000.	0.000698	3758888.	3333.	0.895-02
9000.	0.000741	1981678.	50000.	0.258-01
9000.	0.000806	807168.	66667.	0.835-01

Total Damage = 0.1235E+00

50 Taxiway Design Subgrade Damage Thickness = 30 inches

Damage based on subgrade strain criteria and on 200,000 total strain repetitions

Sub Modulus	Subg Strain	Allow Reps	Applied Reps	Damage
9000.	0.000733	8885301.	50000.	0.825-01
9000.	0.000789	1018577.	33333.	0.338-01
9000.	0.000844	493454.	50000.	0.10E+00
9000.	0.000927	181174.	66667.	0.37E+00

Total Damage = 0.5256E+00

20 Taxiway Design Subgrade Damage Thickness = 27 inches

Damage based on subgrade strain criteria and on 200,000 total strain repetitions

Sub Modulus	Subg Strain	Allow Reps	Applied Reps	Damage
9000.	0.000831	582449.	50000.	0.86E-01
9000.	0.000908	231418.	33333.	0.14E+00
9000.	0.000980	100039.	50000.	0.50E+00
9000.	0.001080	32112.	66666.	0.21E+00

Total Damage = 0.281E+01

Table 11-10
Data File for Computing Asphalt Damage

List ADATA1

100	Taxiway Design; A5. Thickness = 4 inches
110	4 100000
120	.25 .16667 .25 .33333
130	1390000. 960000. 490000. 210000.
140	.000217 .000228 .000247 .000219
150	Taxiway Design; A5. Thickness = 5 inches
160	4 100000
170	.25 .16667 .25 .33333
180	1390000. 960000. 490000. 210000.
190	.000218 .000234 .000267 .000263
200	Taxiway Design; A5. Thickness = 6 inches
210	4 100000
220	.25 .166667 .25 .3333
230	1390000. 960000. 490000. 210000.
240	.000200 .000227 .000270 .000295
250	End of data
260	0 0

developed. From Figure 11-19, the taxiway thickness for a damage factor of 1.0 is determined to be 430 millimeters (16.9 inches). The fatigue damage factor based on the asphalt criteria is then computed for a pavement thickness of 430 millimeters (16.9 inches). Also, from Figure 11-19 the runway thickness for a damage factor of 1.0 is determined to be 345 millimeters (13.6 inches).

b. The plot of asphalt strain versus asphalt modulus is shown in Figure 11-20. The asphalt strain for each time period is given in Table 11-14. Using the computer program ASPHALT, the fatigue damage factor is computed to be 0.15, which is considerably less than 1.0. Thus, a pavement thickness of 430 millimeters (16.9 inches) meets both the subgrade criteria and the asphalt fatigue criteria.

c. The runway design is accomplished in the same manner as the taxiway design. The conventional runway section of 102 millimeters (4 inches) of asphaltic concrete and 635 millimeters (25 inches) of granular base and subbase converted to a 840-millimeter (33-inch) effective thickness. An ABC pavement of 370 millimeters (14.5 inches) would be required to give the same effective thickness. Based on the estimated thickness, the subgrade damage factor was computed for pavement thicknesses of 330, 355, and 405 millimeters (13, 14, and 16 inches). The aircraft wheel load and the number of load repetitions for the computations were the same as used in the design for the conventional section. The subgrade strains and the asphalt strains as a function of pavement thickness are given in Figures 11-21 and 11-22, respectively. The data for computing the damage factors are

Table 11-11
Program Output for Asphalt Damage

* Run ASPHALT

00 Taxiway Design; A5. Thickness = 4 inches

Damage based on asphalt strain criteria and on 100,000 total strain repetitions

Asp Modulus	Asph Strain	Allow Reps	Applied Reps	Damage
1390000.	0.000217	42328.	25000.	0.59E+00
960000.	0.000228	88688.	16687.	0.19E+00
490000.	0.000247	356568.	25000.	0.70E-01
210000.	0.000219	6333934.	33333.	0.54E-03

Total Damage = 0.854E+00

50 Taxiway Design; A5. Thickness = 5 inches

Damage based on asphalt strain criteria and on 100,000 total strain repetitions

Asp Modulus	Asph Strain	Allow Reps	Applied Reps	Damage
1390000.	0.000218	47554.	25000.	0.52E+00
960000.	0.000234	77834.	16667.	0.21E+00
490000.	0.000267	241586.	25000.	0.10E+00
210000.	0.000263	2491763.	33333.	0.13E-01

Total Damage = 0.857E+00

20 Taxiway Design; A5. Thickness = 6 inches

Damage based on asphalt strain criteria and on 100,000 total strain repetitions

Asp Modulus	Asph Strain	Allow Reps	Applied Reps	Damage
1390000.	0.000200	63638.	25000.	0.39E+00
960000.	0.000227	90598.	16667.	0.18E+00
490000.	0.000270	228459.	85000.	0.11E+00
210000.	0.000295	1403381.	33333.	0.84E-00

Total Damage = 0.710E+00

Table 11-12
Bituminous Concrete Moduli for Each Month for ABC Pavement Design Based on Bituminous Concrete Strain

Month	Average Daily Mean Air Temperature degrees F	Design Pavement Temperature degrees F	Dynamic Modulus $\|E^*\|$ 10^3 psi
Jan	47.5	54	1,600
Feb	50.7	57	1,400
Mar	58.0	64	1,060
Apr	66.1	72	700
May	73.3	80	460
Jun	80.5	88	280
Jul	83.1	91	230
Aug	82.7	91	230
Sep	77.3	85	340
Oct	67.2	73	670
Nov	56.2	61	1,200
Dec	49.3	56	1,500

Conversion Factors: Degrees C = degrees F - 32/1.8, Megapascals = 0.006894 × PSI

given in Table 11-15. The plot of the subgrade damage factor versus thickness is given in Figure 11-20. From the plot, it is determined that a 345-millimeter (13.5-inch) ABC pavement would satisfy the subgrade criteria. The asphalt fatigue damage factor for a 330-millimeter (13-inch) pavement was computed to be 0.24, thus determining that the 345-millimeter (13.5-inch) pavement satisfies both criteria.

Table 11-13
Bituminous Concrete Moduli for Each Month for ABC Pavement Design Based on Subgrade Strain

Month	Average Daily Mean Air Temperature, degrees F	Average Daily Maximum Air Temperature, degrees F	Design Air Temperature, degrees F	Design Pavement Temperature, degrees F	Dynamic Modulus |E*| 10^3 psi
Jan	47.5	56.4	52	57	1,400
Feb	50.7	60.1	55	62	1,150
Mar	58.0	68.0	63	70	790
Apr	66.1	76.0	71	77	540
May	73.3	83.2	78	86	320
Jun	80.5	90.4	85	95	180
Jul	83.1	92.9	88	97	160
Aug	82.1	92.8	88	97	160
Sep	77.3	87.4	82	91	230
Oct	67.2	78.1	73	82	400
Nov	56.2	66.4	61	69	830
Dec	49.3	58.3	54	61	1,200

Conversion Factors: degrees C = degrees F - 32/1.8, megapascals = 0.006894 × psi

Table 11-14
Data for Computing Damage Factors for Taxiway Design

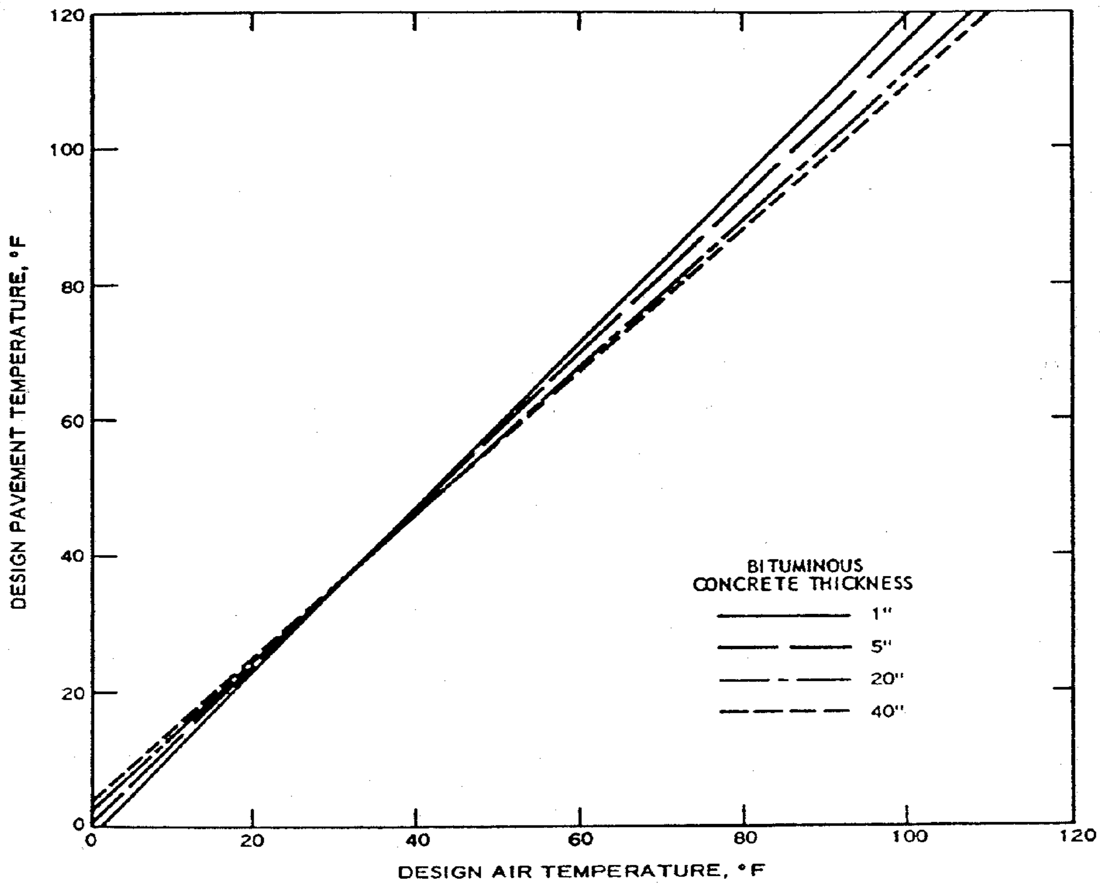
Month	Strain Repetitions	Subgrade Modulus, psi	Subgrade Strain, inches/inch × 10^{-5}				Asphalt Modulus kips per square inch	Asphalt Strain inches/inch × 10^{-5}
			t = 16 inches	t = 17 inches	t = 19 inches	t = 21 inches		
Jan	16,666	9,000	35	31	26	23	1,600	87
Feb	16,666	9,000	40	35	30	26	1,400	96
Mar	16,666	9,000	50	44	37	32	1,060	118
Apr	16,666	9,000	64	56	47	41	700	161
May	16,666	9,000	78	68	59	50	460	194
Jun	16,666	9,000	112	94	82	74	280	275
Jul	16,666	9,000	120	104	89	78	230	315
Aug	16,666	9,000	120	104	89	78	230	315
Sep	16,666	9,000	96	84	72	62	340	240
Oct	16,666	9,000	68	60	53	48	670	167
Nov	16,666	9,000	49	43	37	31	1,200	108
Dec	16,666	9,000	39	34	29	25	1,500	91

Conversion Factors:
Megapascals = 0.006894 × psi
Megapascals = 6.894 × kips per square inch
Millimeters = 25.4 × inches

Table 11-15
Data for Computing Damage Factors for Runway Design

Month	Strain Repetitions	Subgrade Modulus	Subgrade Strain, inches/inch × 10^{-5} t = 13 inches	t = 14 inches	t = 16 inches	Asphalt Modulus, kips psi	Asphalt Strain, inches/inch × 10^{-5} t = 13 inches	t = 14 inches
Jan	10,000	9,000	36	32	26	1,600	99	91
Feb	10,000	9,000	40	36	30	1,400	110	100
Mar	10,000	9,000	51	46	38	1,060	134	123
Apr	10,000	9,000	64	58	48	700	186	167
May	10,000	9,000	79	71	59	460	220	200
Jun	10,000	9,000	113	100	84	280	310	285
Jul	10,000	9,000	121	106	91	230	357	325
Aug	10,000	9,000	121	106	91	230	357	325
Sep	10,000	9,000	97	86	73	340	372	248
Oct	10,000	9,000	69	62	51	670	190	172
Nov	10,000	9,000	49	45	37	1,200	122	112
Dec	10,000	9,000	39	35	29	1,500	105	95

Conversion Factors:
Megapascals = 0.006894 × psi
Millimeters = 25.4 × inches



CONVERSION FACTOR

°C = 0.555 x (°F - 32)
MILLIMETERS = 25.4 x INCHES

Figure 11-1. Temperature relationships for selected bituminous concrete thickness

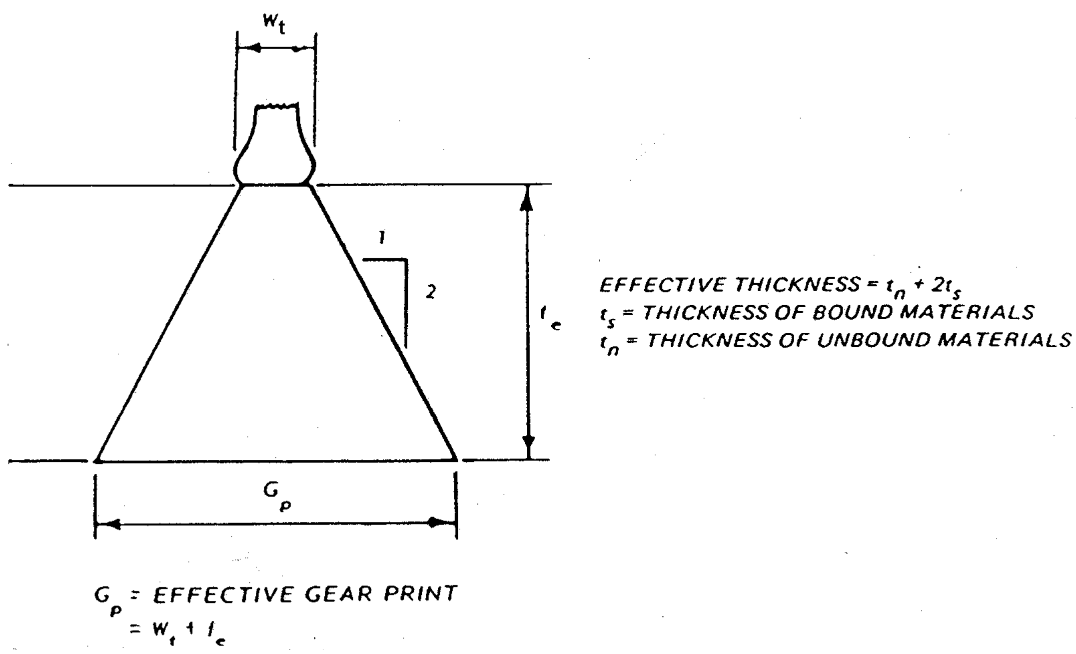


Figure 11-2. Computation of effective gear print for single gear

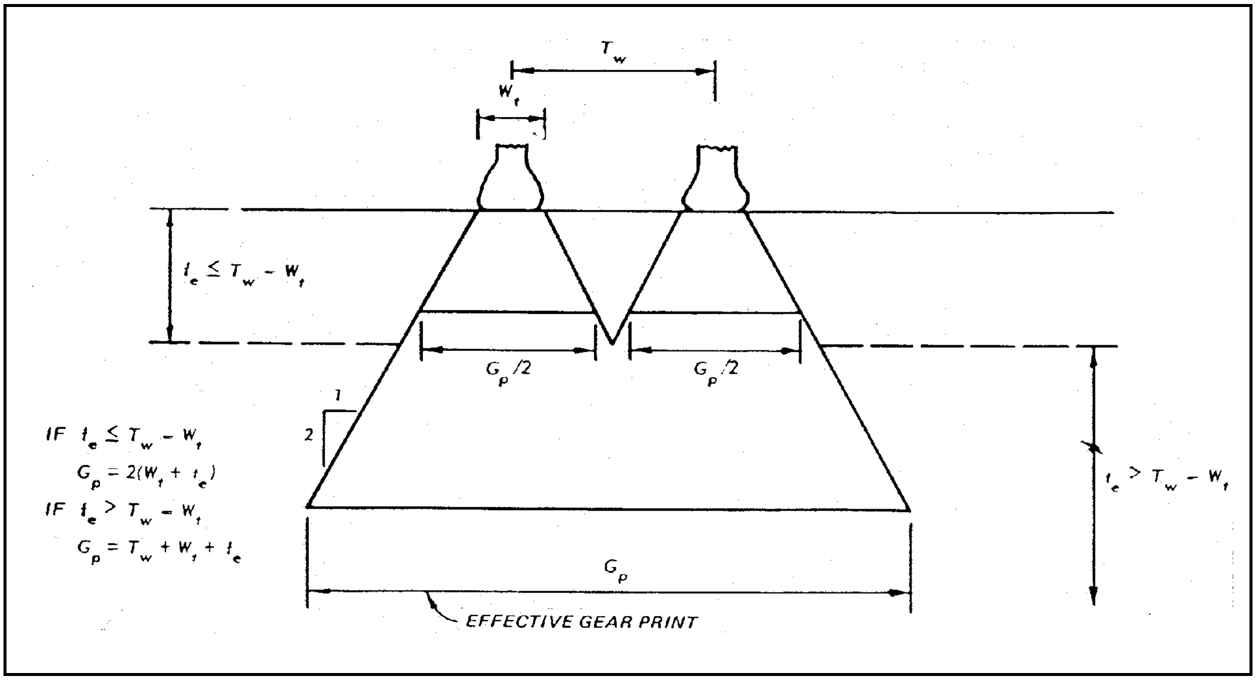


Figure 11-3. Computation of effective gear print for twin gear

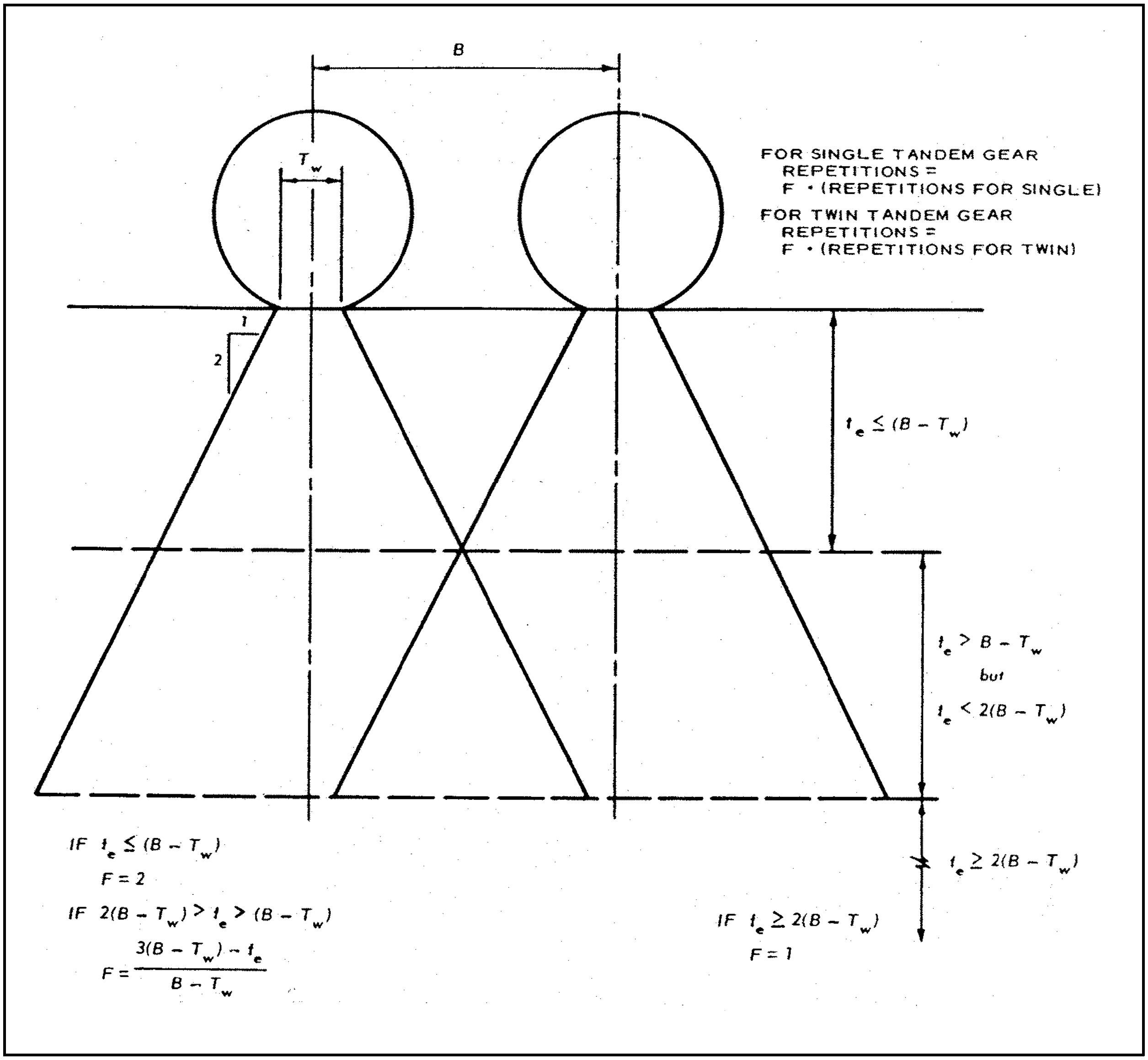


Figure 11-4. Computation of repetition factor for tandem gear

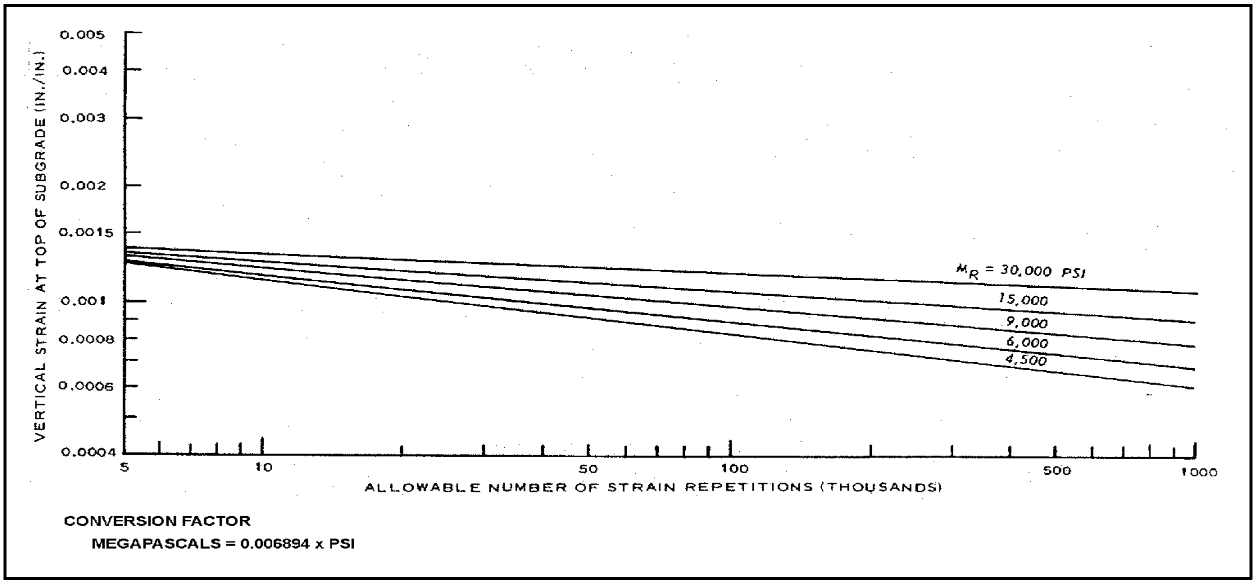


Figure 11-5. Design criteria based on subgrade strain

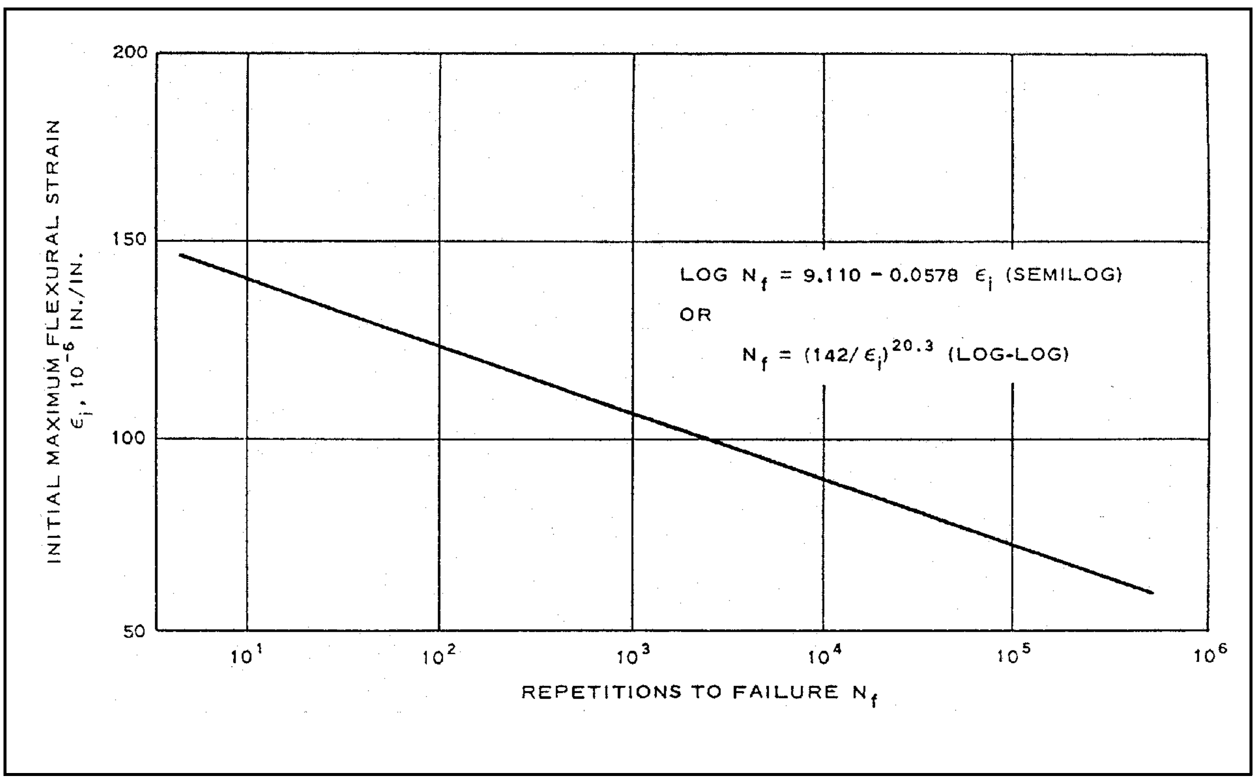


Figure 11-6. Fatigue life of flexural specimens

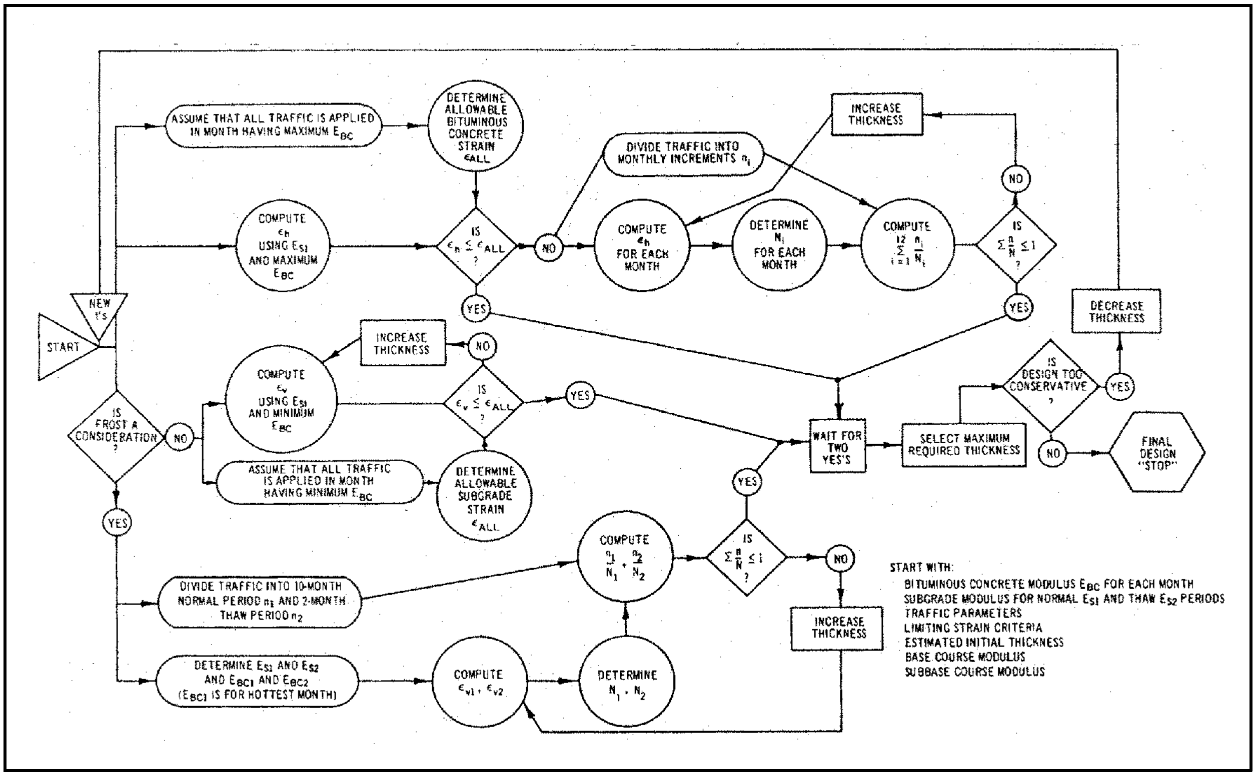
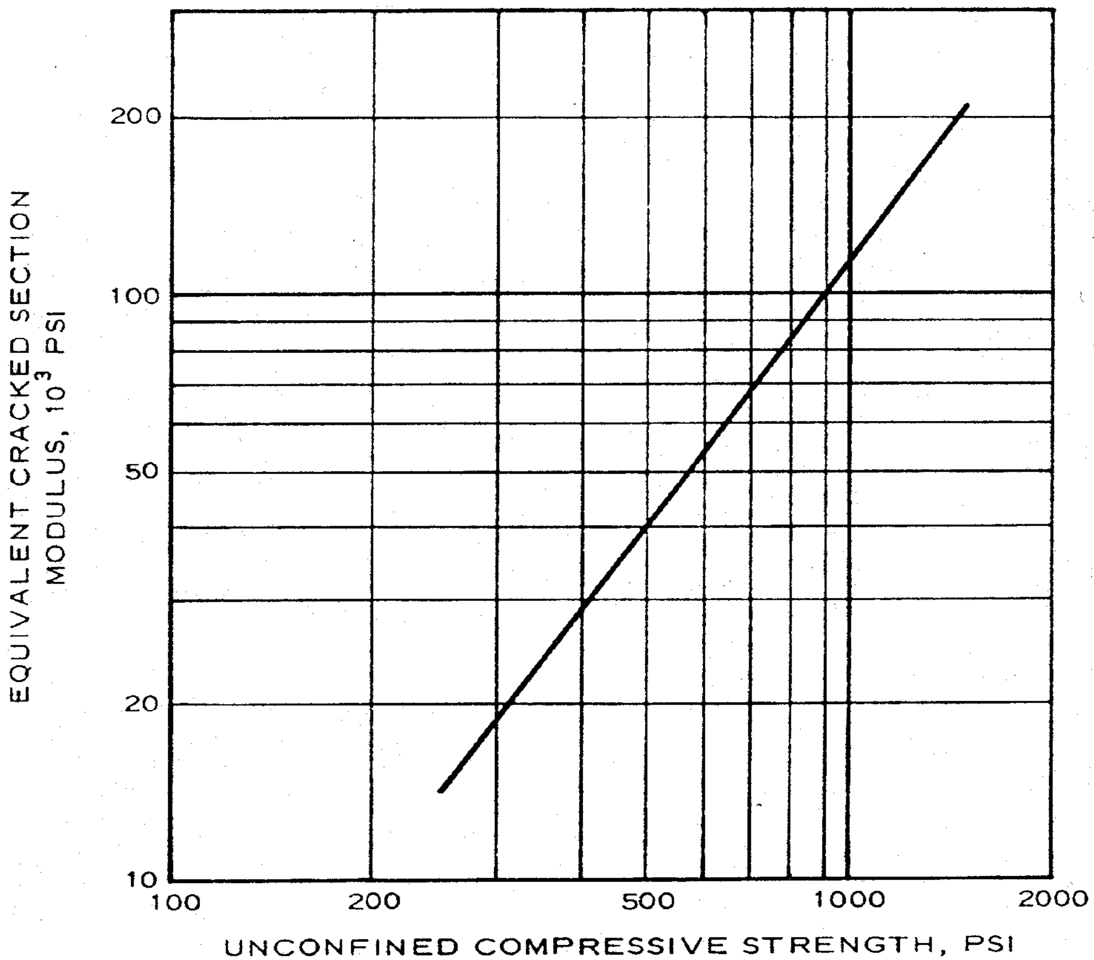


Figure 11-7. Flow diagram of important steps in design of bituminous concrete pavement



CONVERSION FACTOR

MEGAPASCALS = 0.006894 x PSI

Figure 11-8. Relationship between cracked section modulus and unconfined compressive strength

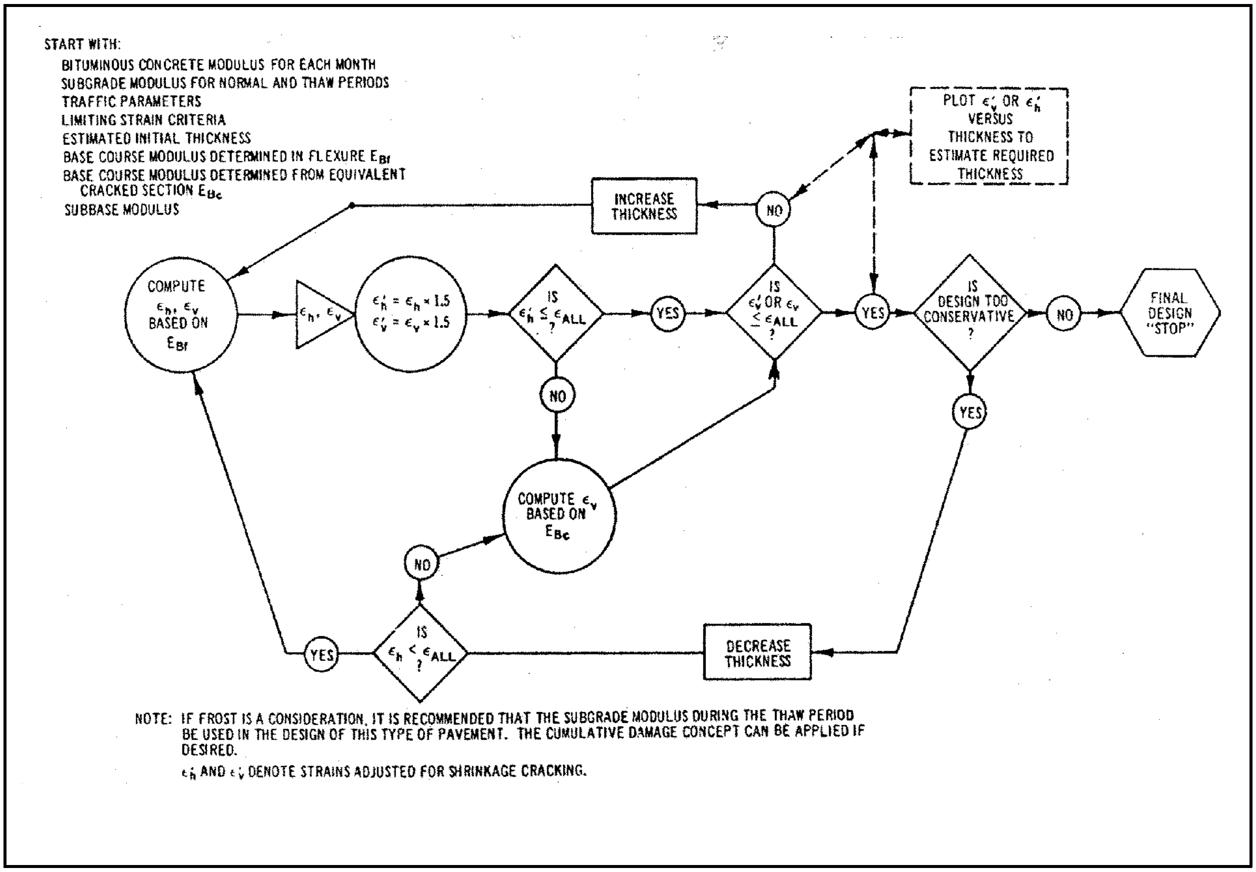


Figure 11-9. Flow diagram of important steps in design of pavements having chemically stabilized base course and unstabilized subbase course

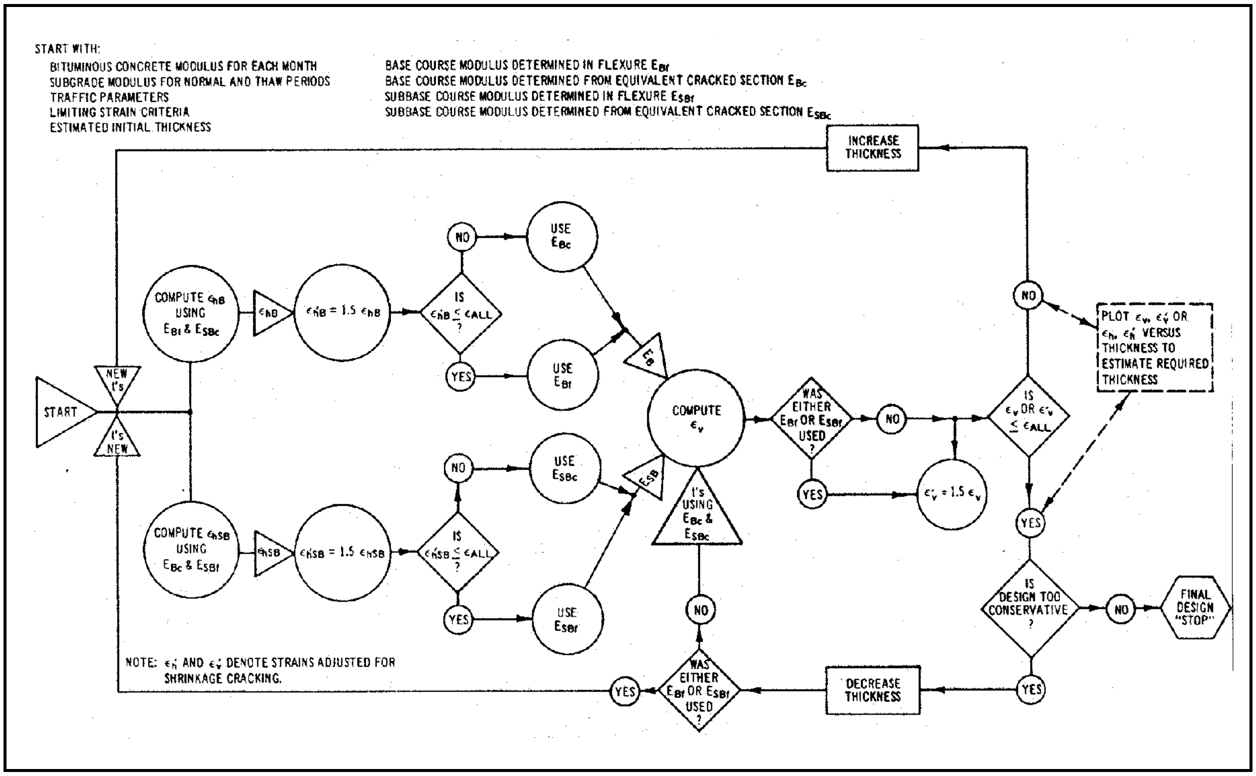
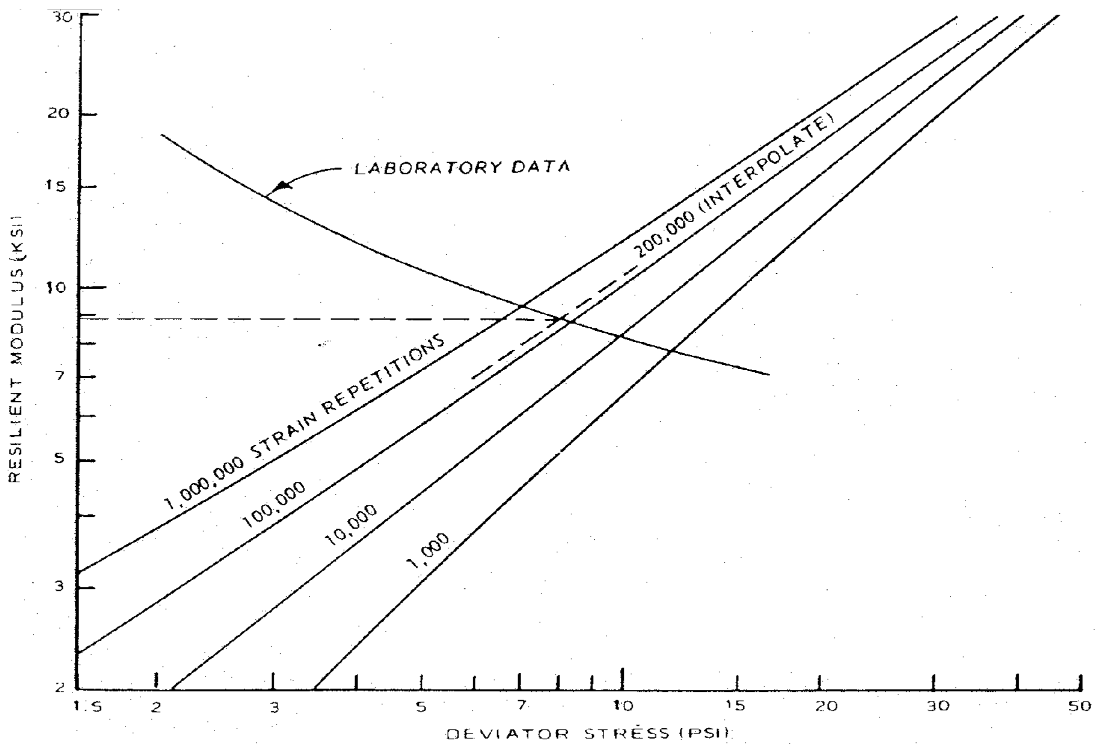


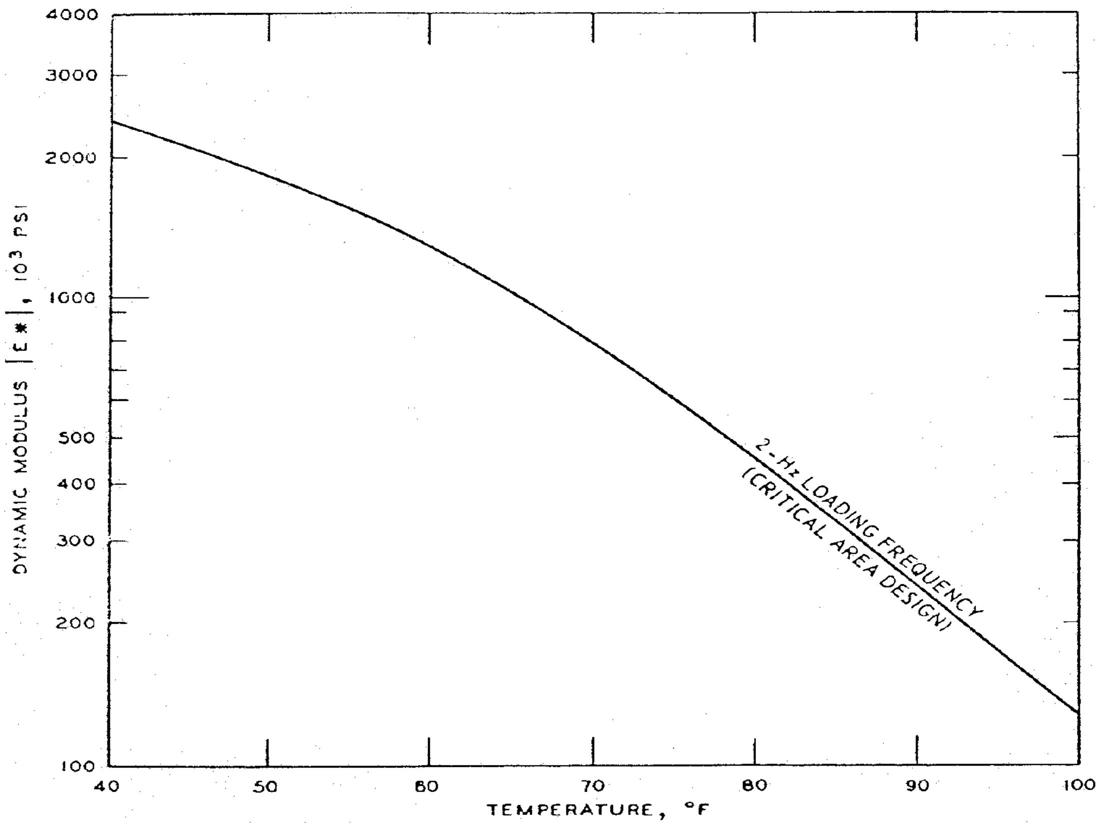
Figure 11-10. Flow diagram of important steps in design of pavements having stabilized base and chemically stabilized subbase courses



CONVERSION FACTORS

MEGAPASCALS = 0.006894 x PSI
MEGAPASCALS = 6.894 x KSI

Figure 11-11. Estimation of resilient modulus M_R



CONVERSION FACTORS

MEGAPASCALS = 0.006894 x PSI
°C = 0.555 (°F = 32)

Figure 11-12. Results of laboratory tests for dynamic modulus of bituminous concrete

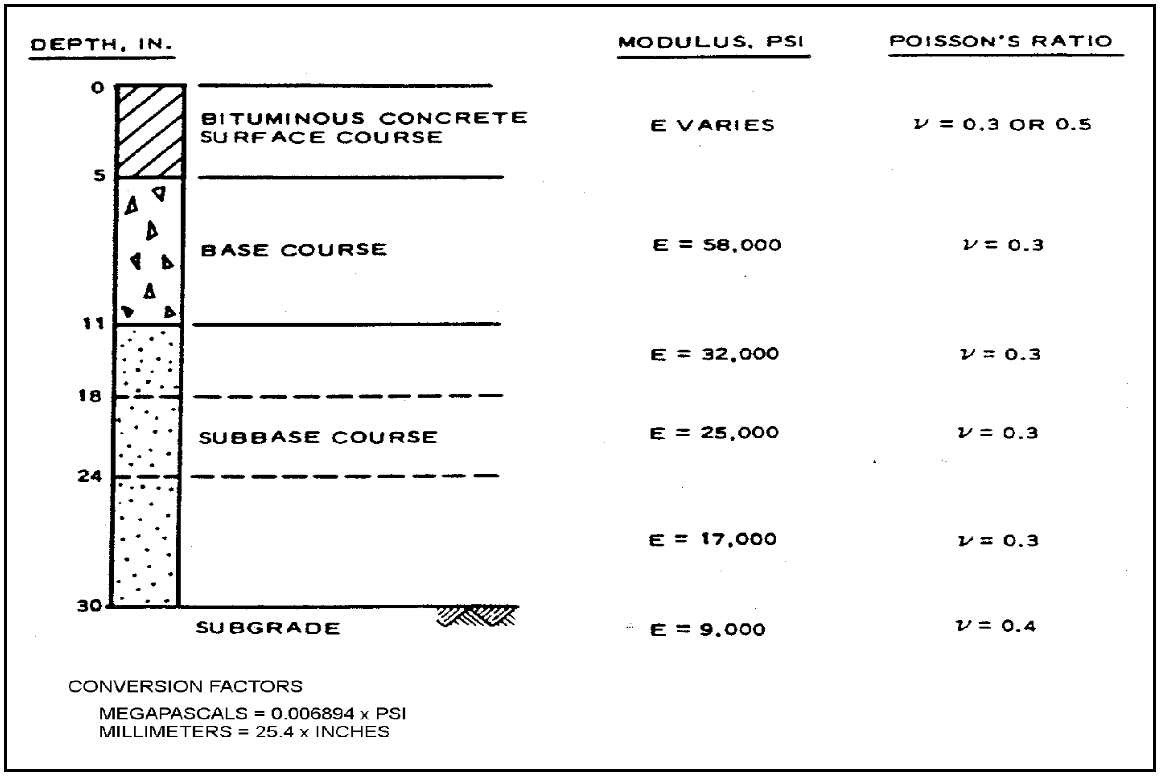


Figure 11-13. Section for pavement thickness of 760 millimeters (30 inches) for initial taxiway design

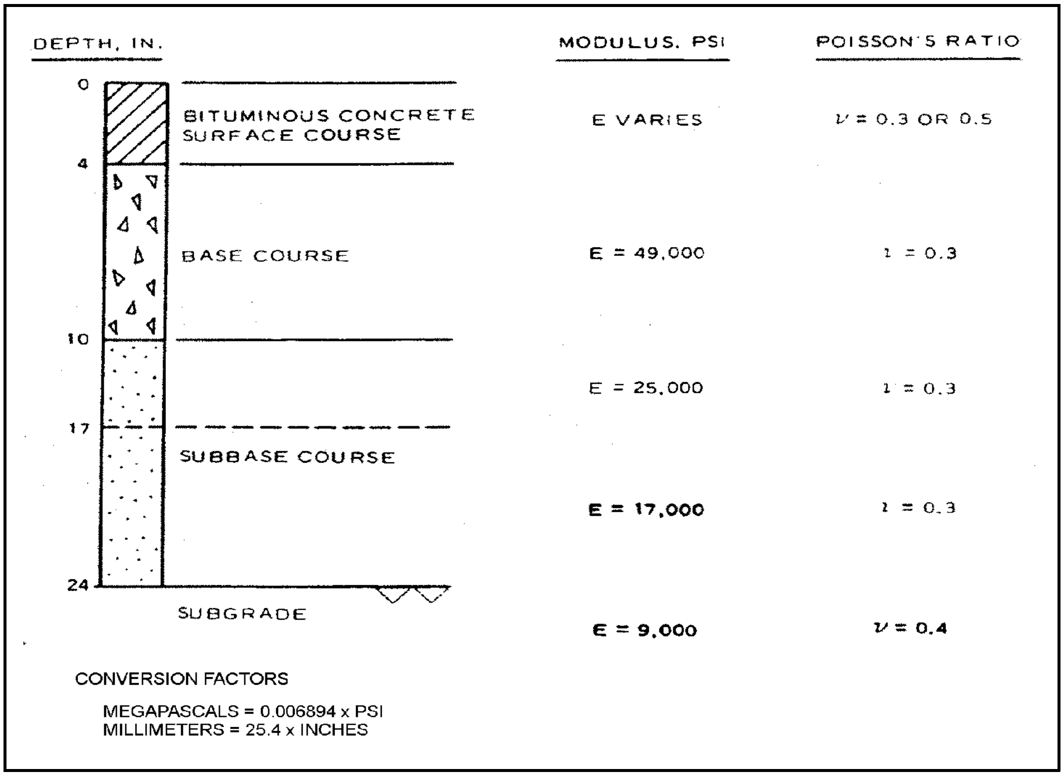
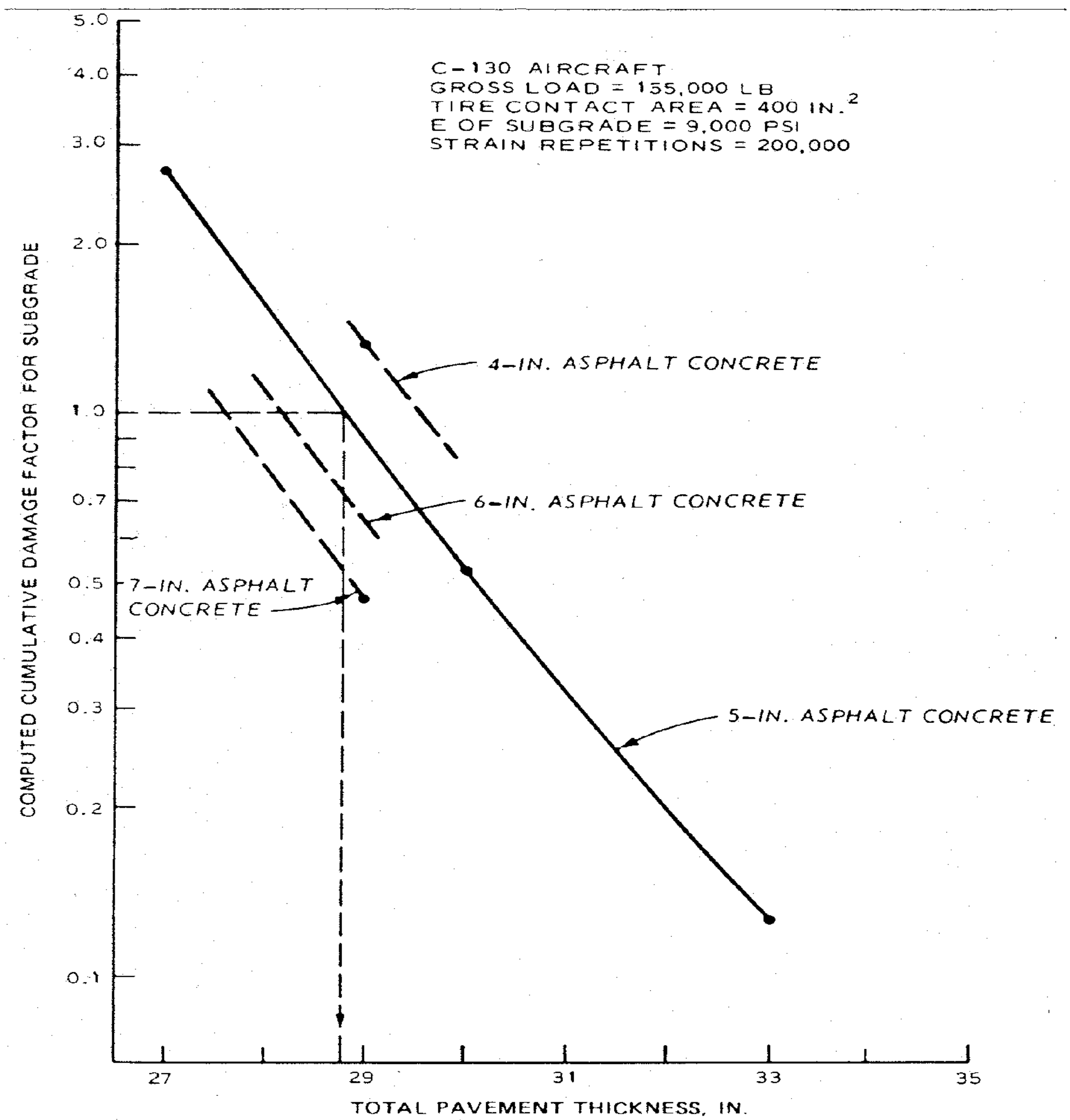


Figure 11-14. Section for pavement thickness of 610 millimeters (24 inches) for initial runway design



CONVERSION FACTORS

KILOGRAMS = 0.4535 x POUNDS
MEGAPASCALS = 0.006894 x PSI
SQUARE MILLIMETERS = 645 x SQUARE INCHES
MILLIMETERS = 25.4 x INCHES

Figure 11-15. Pavement design for taxiways

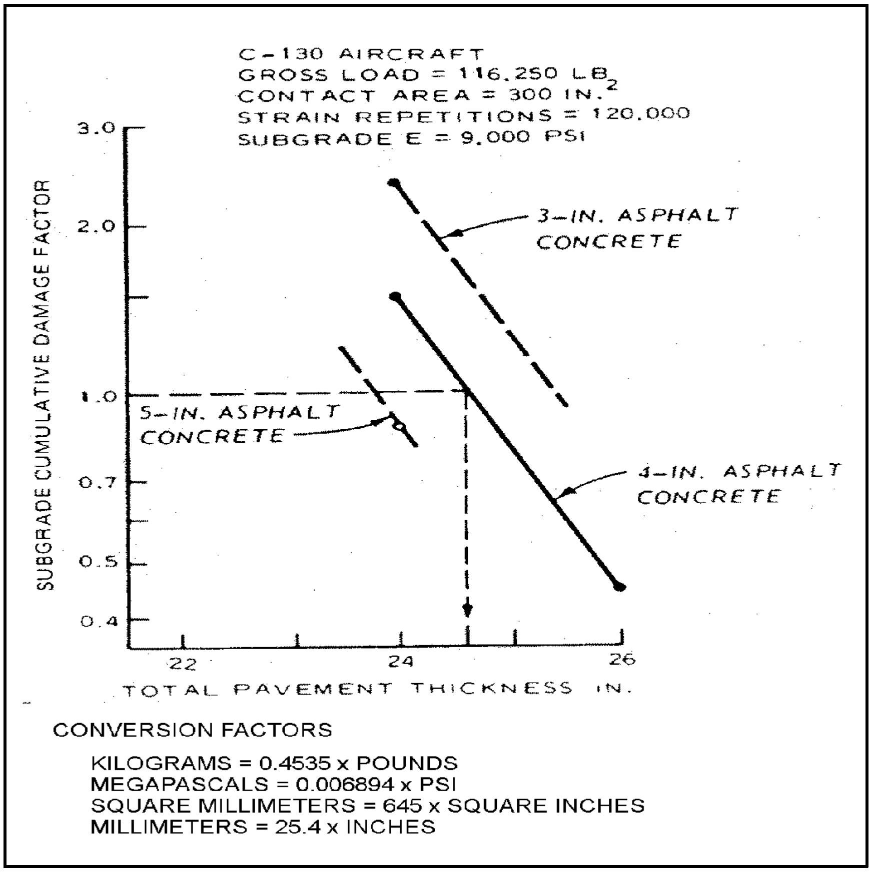
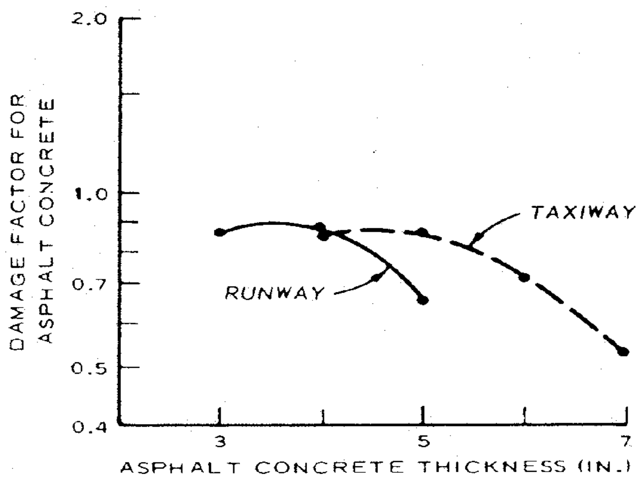


Figure 11-16. Design for runways

C-130 AIRCRAFT

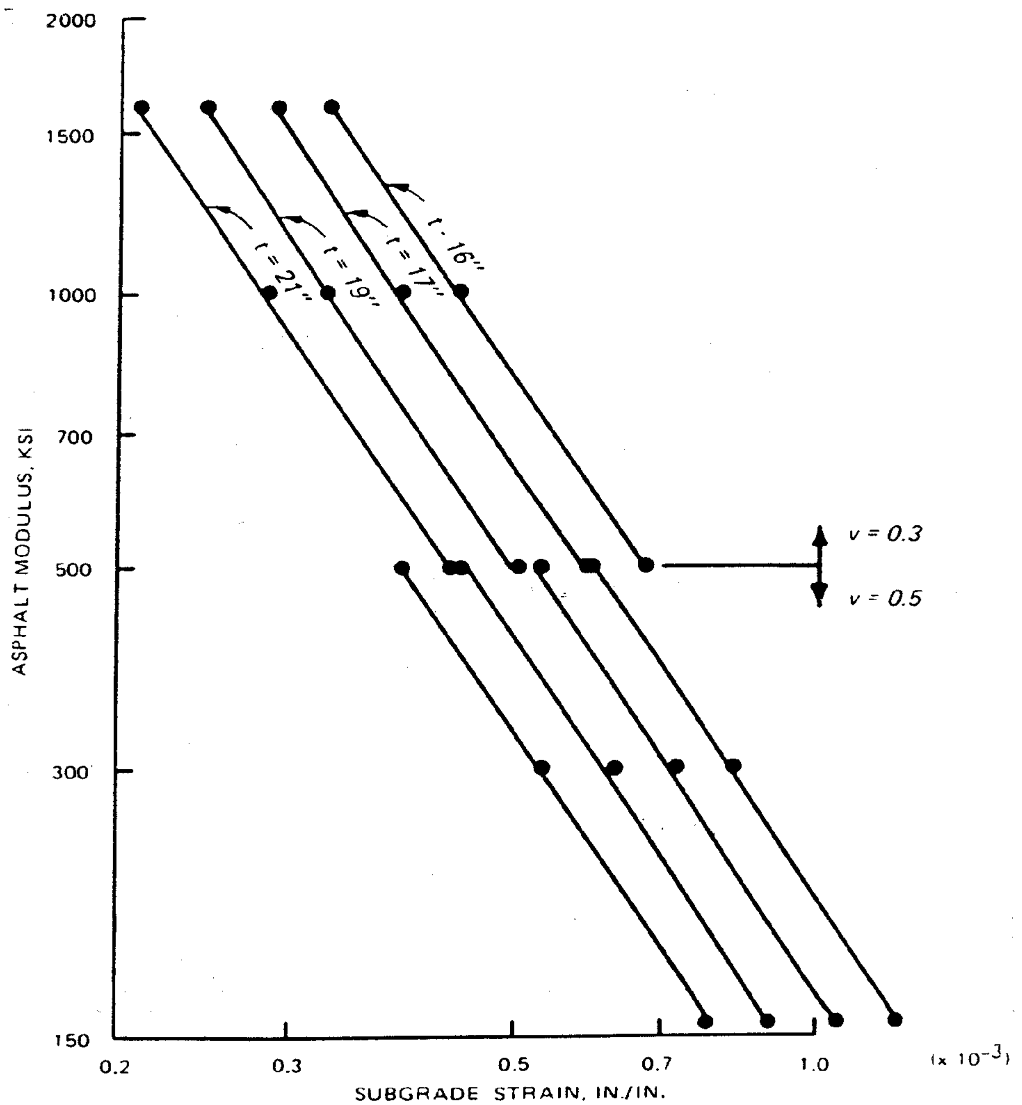
	TAXIWAY	RUNWAY
GROSS LOAD, LB	155,000	116,250
CONTACT AREA, IN.^{2}	400	300
STRAIN REPETITIONS	100,000	60,000



CONVERSION FACTORS

KILOGRAMS = 0.4535 x POUNDS
SQUARE MILLIMETERS = 645 x SQUARE INCHES
MILLIMETERS = 25.4 x INCHES

Figure 11-17. Design for asphalt concrete surface



CONVERSION FACTORS

MILLIMETERS = 25.4 x INCHES
MEGAPASCALS = 6.894 x KSI

Figure 11-18. Computed strain at the top of the subgrade for taxiway design

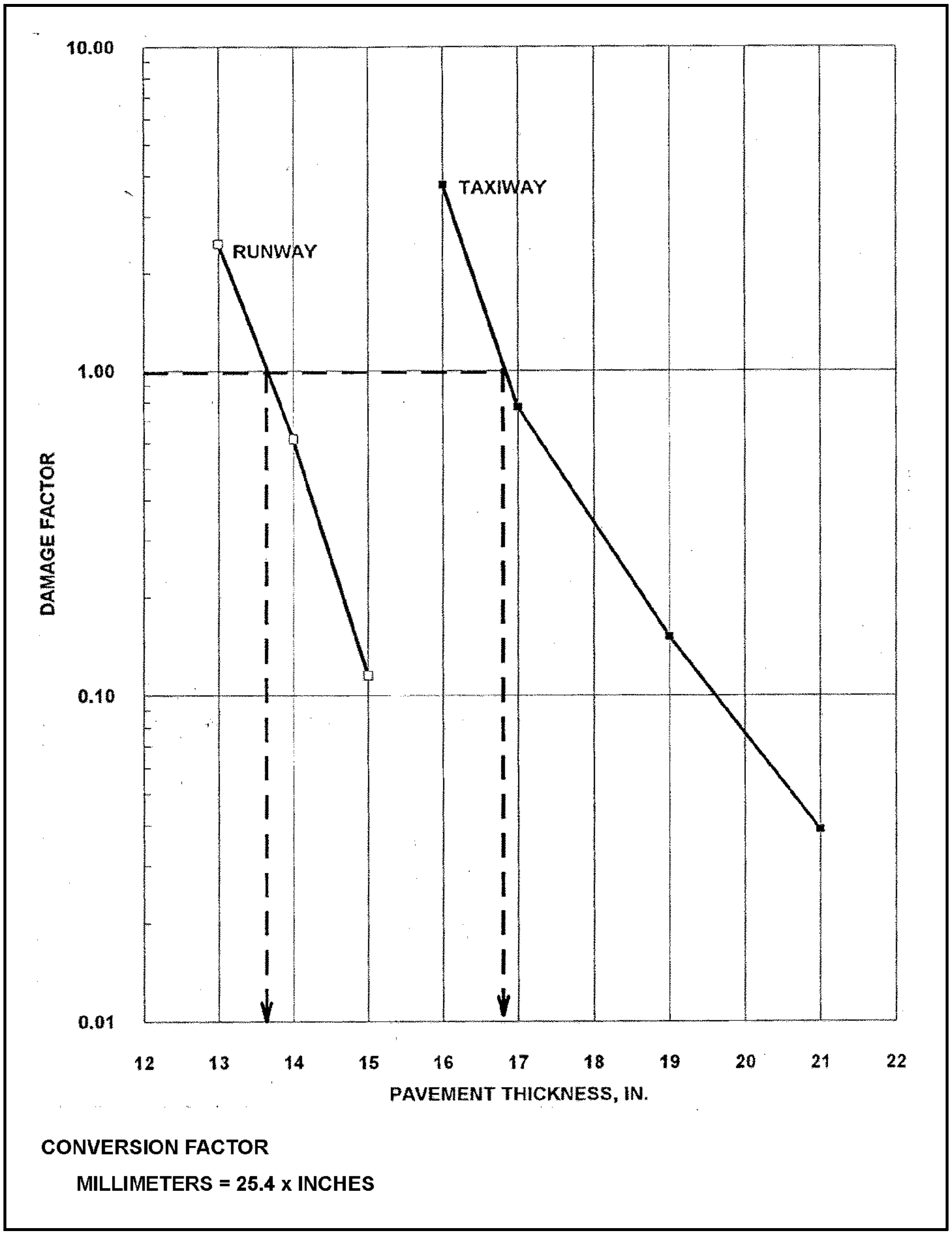
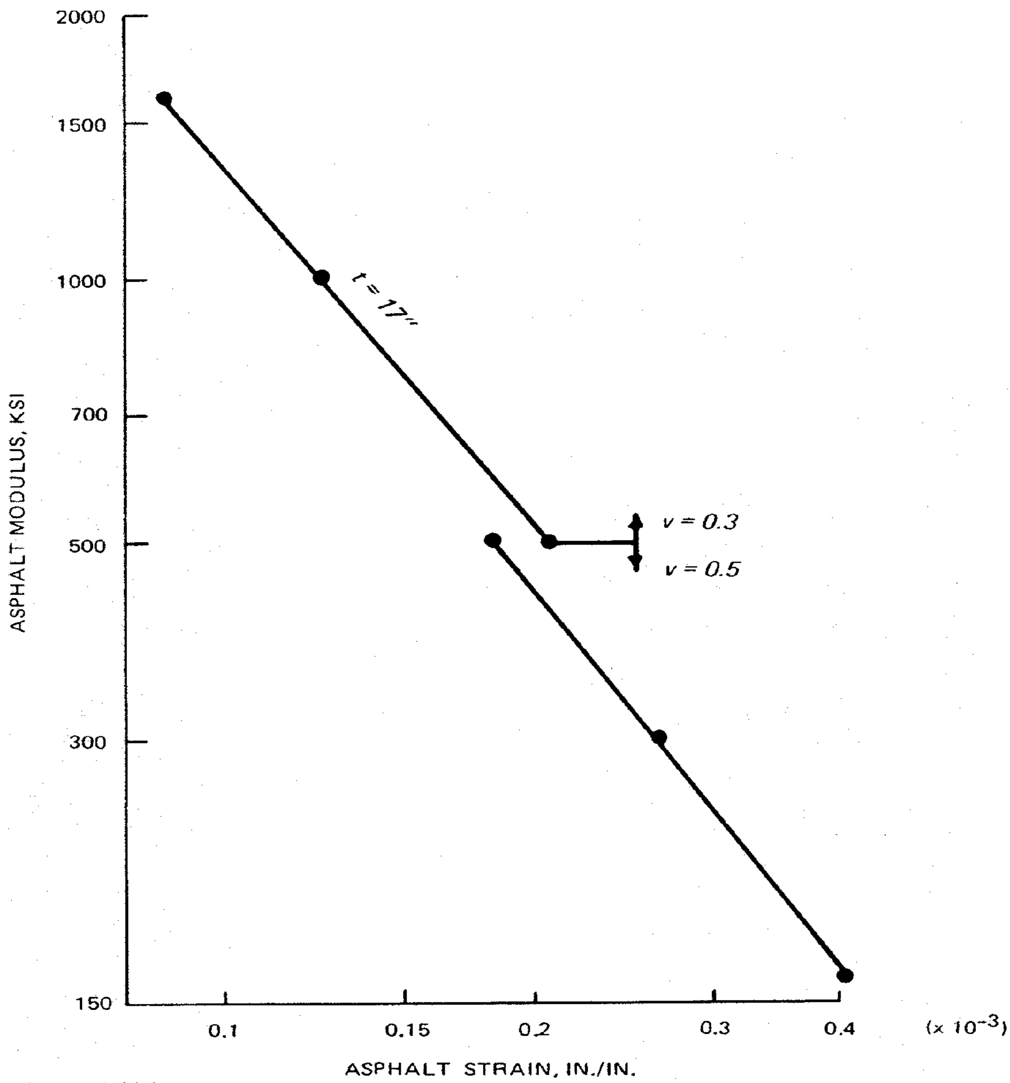


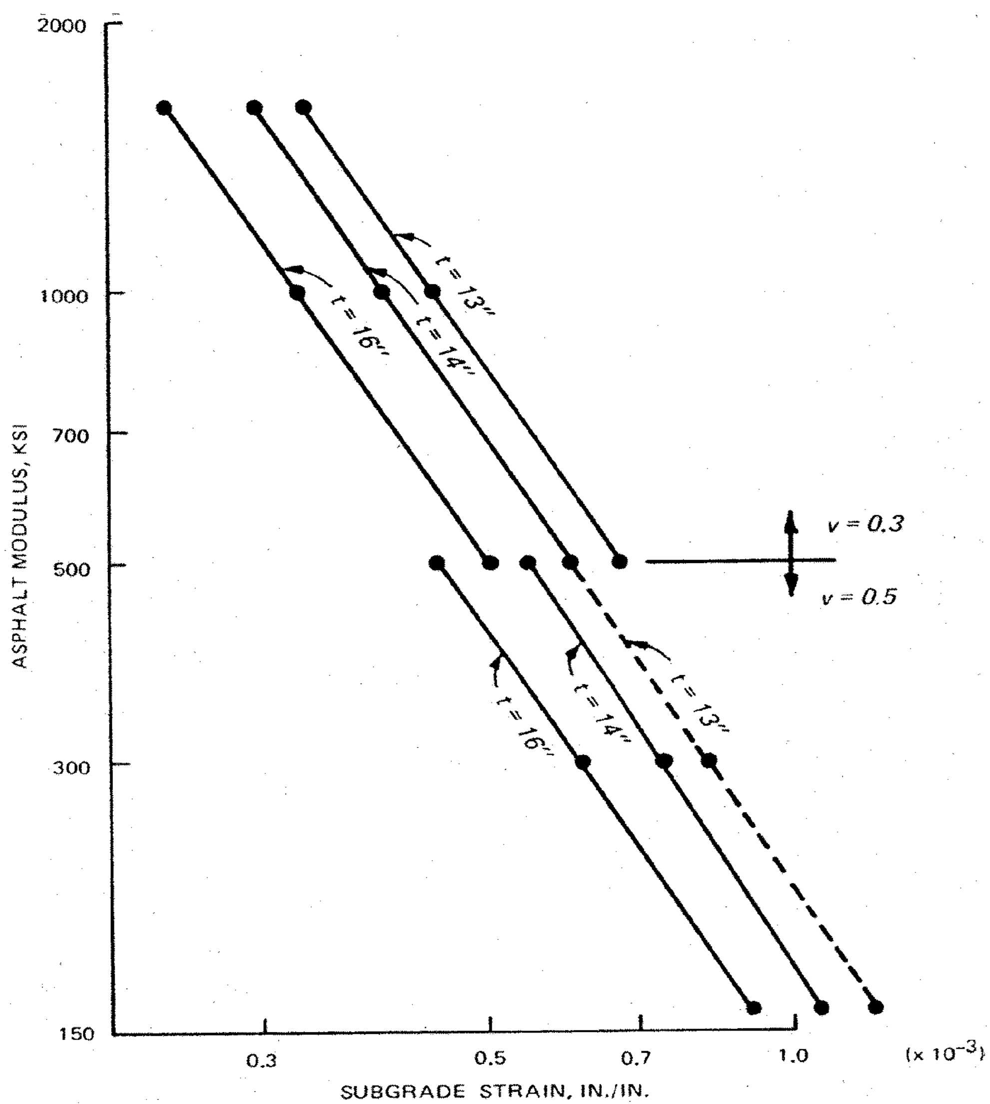
Figure 11-19. Damage factor versus pavement thickness



CONVERSION FACTORS

MILLIMETERS = 25.4 x INCHES
MEGAPASCALS = 6.894 x KSI

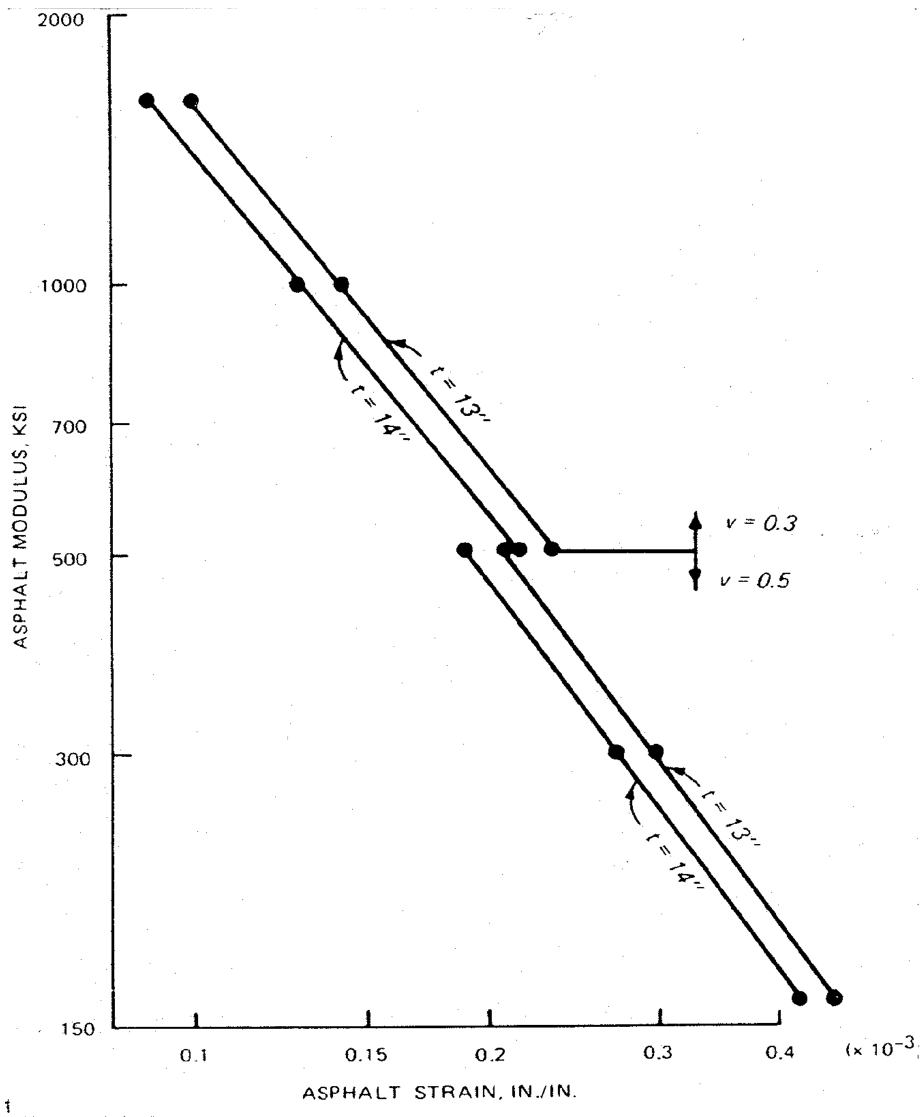
Figure 11-20. Computed strain at the bottom of the asphalt for taxiway design



CONVERSION FACTORS

MILLIMETERS = 25.4 x INCHES
MEGAPASCALS = 6.894 x KSI

Figure 11-21. Computed strain at the top of the subgrade for runway design



CONVERSION FACTORS

MILLIMETERS = 25.4 x INCHES
MEGAPASCALS = 6.894 x KSI

Figure 11-22. Computed strain at the bottom of the asphalt for runway design

CHAPTER 12

PLAIN CONCRETE PAVEMENTS

1. BASIS OF DESIGN – ARMY AND AIR FORCE. The pavement thickness requirement is calculated using a mechanistic fatigue analysis. Stresses under design aircraft are calculated using the Westergaard edge-loaded model. These calculated edge stresses are related to the concrete flexural strength and repetitions of traffic through a field fatigue curve based on full-scale accelerated traffic test of aircraft loads. A wide variety of model tests, theoretical analyses, and field measurements over the years have demonstrated that part of the load applied to the edge of a pavement slab is transferred to and carried by the adjacent slab through dowels, aggregate interlock, etc. For design, a load transfer value of 25 percent is routinely used as a reasonable approximation of the load transfer measured over time on the types of joints approved for use in Army and Air Force airfields. The actual load transfer at a joint will vary depending on joint type, quality of construction, slab length, number of load repetitions, temperature conditions, etc. The design charts in this chapter were developed based on a 25 percent load transfer value. If adequate load transfer is not provided at the joints of trafficked slabs, the pavement should be designed for no load transfer using the PCASE pavement design program that allows direct input of the load transfer value or the gross load used in the design charts in this chapter should be increased by 1/3 to remove the load transfer effect. Alternatively, a thickened edge detail can be used at joints without adequate load transfer. This design method also includes a thickness reduction for high-strength subgrades (modulus of subgrade reaction, k, > 54 kPa/mm (200 pci) in recognition that after the initial flexural fatigue crack forms (classical design failure condition for this design method) the continued slab deterioration through additional cracking and spalling proceeds more slowly on high-strength subgrades than on low-strength subgrades.

2. BASIS OF DESIGN – NAVY. The pavement thickness requirement is calculated using a mechanistic fatigue analysis. Stresses under design aircraft are calculated using the Westergaard interior load model for light traffic or training base commands. For medium to heavy loaded pavements, the Army and Air Force design procedure described above should be considered. The Navy recognizes edge stress design as a way to reduce pavement life cycle costs for bases with medium to heavy traffic missions. These calculated interior stresses are related to the concrete flexural strength and repetitions of traffic through a fatigue curve based on a conservative laboratory beam test relation originally developed by the Portland Cement Association. Adequate quality joints at short joint spacing are required to provide load transfer with the Navy assumptions. Alternate thickness design methods are allowed for Navy pavements if the method is approved by the NAVFAC.

3. USES FOR PLAIN CONCRETE. Military airfield experience has found that plain, unreinforced concrete is generally the most economical concrete airfield surface to build and maintain. Unreinforced concrete will be used for concrete military airfield pavements unless special circumstances exist. The most common exception will be for cases requiring conventional reinforcing as noted in Chapter 1, paragraph 7 and Chapter 13. Other reinforcing for which design techniques are provided in this manual are for special circumstances and their use must be approved by TSMCX, AF MAJCOM pavements engineer, or NAVFAC as appropriate.

4. THICKNESS DESIGN - ARMY AND AIR FORCE PAVEMENTS.

a. General. Figures 12-1 through 12-22 are design curves to be used in designing plain concrete pavements as defined in Chapters 2, 3, and 4. Figures 12-1 through 12-5 are for Army Class I to IV airfields, and Figures 12-6 to 12-17 are for Air Force (Figures 12-6 to 12-11 are for standard mixed traffic designs.). Figure 12-17 is a design curve for shoulders and is applicable to all airfields requiring concrete shoulders. Figures 12-6 to 12-12 are design curves for the six Air Force standard airfield types, and Figures 12-13 to 12-16 are individual design curves for various aircraft to be used in designing pavements for conditions other than the basic airfield types. Thicknesses may also be determined using the computer programs referenced in Chapter 1.

b. Plain Concrete Pavements on Nonstabilized or Modified Soil Foundations. For plain concrete pavements that will be placed directly on nonstabilized or modified base courses or subgrade, the thickness requirement will be determined from the appropriate design curve using the design parameters of concrete flexural strength, R; modulus of soil reaction, k; gross weight of aircraft; aircraft pass level; and pavement traffic area type (except for shoulder design). The design gross aircraft weight and pass level may vary depending upon the type of traffic area or pavement facility. When using English units and the thickness from the design curve indicates a fractional value, it will be rounded up to the nearest full- or half-inch thickness. The minimum thickness of plain concrete pavement will be 150 millimeters (6.0 inches). When it is necessary to change from one thickness to another within a pavement facility, such as from one traffic area to another, the transition will be accomplished in one full paving lane width or slab length. SI thickness values will be rounded up to the nearest 10 millimeters.

c. Plain Concrete Pavements on Stabilized Base and/or Subgrade. Stabilized base and/or subgrade layers meeting the strength requirements of Chapter 9 and lean concrete base will be treated as low-strength base pavements, and the plain concrete pavement will be considered an overlay with a thickness determined using the following modified, partially bonded rigid overlay pavement design equation:

$$h_o = \sqrt[1.4]{h_d^{1.4} - \left[\left(\sqrt[3]{\frac{E_b}{E_c}}\right) h_b\right]^{1.4}} \qquad (12\text{-}1)$$

where

h_o = thickness of plain concrete overlay, millimeters (inches)

h_d = design thickness of equivalent single slab placed directly on foundation, millimeters (inches)

E_b = modulus of elasticity of base MPa (psi)

E_c = modulus of elasticity of concrete, usually taken as 27,575 MPa (4×10^6 psi)

h_b = thickness of stabilized layer or lean concrete base, millimeters (inches)

5. EXAMPLES OF PLAIN CONCRETE PAVEMENT DESIGN FOR ARMY AND AIR FORCE.

a. General. It is required that an airfield be designed as a medium-load pavement. Types A and B traffic areas are designed for the F-15 at 36,740 kilograms (81,000 pounds), the C-17 at 263,100 kilograms (580,000 pounds), and the B-52 at 181,400 kilograms (400,000 pounds). Types C and D traffic areas and overruns are designed for the F-15 at 27,555 kilograms (60,750 pounds), the C-17 at 197,100 kilograms (435,000 pounds), and the B-52 at 136,080 kilograms (300,000 pounds). Types A, B, and C traffic areas are designed for 100,000 passes of the F-15, 400,000 passes of the C-17, and 400 passes of the B-52. Type D traffic areas and overruns are designed for 1,000 passes of the F-15, 4,000 passes of the C-17, and 4 pass of the B-52. (Since the B-52 is included in the design, the runway must be 61 meters (200 feet) wide.) On-site and laboratory investigations have yielded the following data required for design: (1) the subgrade material is classified as a silty sand (SM); (2) the modulus of soil reaction, k, of the subgrade is 54 kPa/mm (200 pci); (3) a nearby source of crushed gravel meets the requirements for base course; (4) frost does not enter subgrade material; and (5) 90-day concrete flexural strength, R, is 4.8 MPa (700 psi).

b. Example Design, Slab on Grade. Figure 12-8 is entered with the subgrade k = 200 pci, concrete design flexural strength R = 700 psi, and the pavement thickness is determined for the various traffic areas and overruns as follows:

Traffic Area	**Thickness, mm (in.)**[1]
A	406 (16.0)[1]
B	406 (16.0)
C	302 (12.0)
D and overruns	229 (9.0)

[1] Fractional values would be rounded up to the nearest full- or half-inch for design.

c. Example Design, Slab on Unbound Base. For comparison purposes, designs are developed below for three base-course thicknesses. Field plate bearing tests conducted in a test section to establish the modulus of soil reaction for three thicknesses of base course give k values of 68 kPa/mm (250 pci) for a 152-millimeter (6-inch) base, 81 kPa/mm (300 pci) for a 305-millimeter (12-inch), and 95 kPa/mm (350 pci) for 460-millimeter (18-inch) base. These values are supported by Figure 8-1 and are thus selected for design. Figure 12-8 is entered with the design flexural strength, modulus of soil reaction, and traffic areas to determine the required concrete pavement thicknesses. Thicknesses for shoulders were determined from Figure 12-17. The thicknesses for this example are summarized as follows:

Foundation Condition	**Modulus of Soil Reaction kPa/mm (pci)**	**Thickness, mm (in.)**				
		A	**B**	**C**	**D & Overruns**	**Shoulders**[1]
(1)	(2)	(3)	(4)	(5)	(6)	(7)
150-mm (6-in.) base	68 (250)	370 (14.5)	370 (14.5)	290 (11.5)	215 (8.5)	150 (6)
300-mm (12-in.) base	81 (300)	340 (13.5)	340 (13.5)	260 (10.5)	200 (8.0)	150 (6)
460-mm (18-in.) base	95 (350)	330 (13)	320 (12.5)	250 (10)	200 (8.0)	150 (6)

Note: Final thickness should be rounded values.
[1] Use minimum thickness of 150 millimeters (6 inches) for shoulders.
The final selection of concrete pavement thickness must be based upon a study of the cost of importing and placing base course versus savings in concrete pavements.

d. Example Design, Slab on Stabilized Base. Assume that a cement-stabilized base course will be used. Laboratory tests on base-course material have shown that a cement content of 7 percent by weight will yield a 7-day compressive strength of 6.89 MPa (1,000 psi) and a flexural modulus of elasticity E_b of 3,450 MPa (500,000 psi) at an age of 90 days. According to TM 5-822-14/ AFJMAN 32-1019, the compressive strength of 6.89 MPa (1,000 psi) qualifies as a stabilized layer (that is, permits a thickness reduction), and the design is made using Equation 12-1. The single slab thickness h_d of plain concrete is determined from Figure 12-7 using R = 4.8 MPa (700 psi) and k = 54 kPa/mm (200 pci) for the design load and pass level for each type traffic area. The thicknesses of plain concrete overlay determined with Equation 12-1 for several thicknesses of stabilized layer are shown in the following tabulation:

Type Traffic Area	Thickness of Stabilized Layer h_b, mm (in.)	Thickness of Slab on Grade h_d, mm (in.)	Overlay Thickness h_o, mm (in.)
A	150 (6)	406 (16.0)	380 (15.0)
	300 (12)	406 (16.0)	330 (13.0)
	450 (18)	406 (16.0)	267 (10.5)
B	150 (6)	406 (16.0)	370 (14.5)
	300 (12)	406 (16.0)	330 (13.0)
	450 (18)	406 (16.0)	254 (10.0)
C	150 (6)	300 (12.0)	280 (11.0)
	300 (12)	300 (12.0)	215 (8.5)
	450 (18)	300 (12.0)	150 (6.0)
D & Overrun	150 (6)	229 (9.0)	200 (8.0)
	300(12)	229 (9.0)	150 (6.0)[1]
	450 (18)	229 (9.0)	150 (6.0)[1]

Note: Final design overlay thicknesses should be rounded in accordance with paragraph 4b.
[1] Minimum thickness of plain concrete pavement.

The final selection of plain concrete pavement and stabilized base thicknesses will be based upon the economics involved.

e. Design Example for Mixed Traffic.

(1) General. The design of rigid airfield pavements has been based on a standard definition of aircraft mixture, load, and pass levels. However, pavements may be designed for a mixture of aircraft type, loadings, and repetitions other than the standard. This design example presents a procedure for the design of pavements which will be subjected to a mixture of traffic types and loadings based upon equivalent aircraft loadings.

(2) Procedure. The design of a concrete pavement to accommodate a mixture of aircraft traffic is accomplished using the following steps:

(a) Determine the aircraft traffic that is anticipated to use the pavements during the life of the pavements. Arrange this traffic in accordance with aircraft type, gross weight, and number of passes.

(b) Select the pavement thickness required for each aircraft at the design gross weight, pass level, and pavement characteristics.

(c) Select the controlling aircraft as the one requiring the maximum thickness.

(d) Evaluate the controlling thickness in terms of allowable passes for each aircraft in the design mix using the appropriate design curves from Figures 12-1 to 12-17. Those curves are entered from the left with the flexural strength, modulus of subgrade reaction, and load and from the right with controlling thickness and traffic. The intersection point of these two lines will estimate the allowable number of passes of an aircraft. An example of this operation is shown in Figure 12-18.

(e) Determine the number of each aircraft equivalent to one pass of the controlling aircraft by dividing the allowable passes of each aircraft by the allowable pass level of the controlling aircraft.

(f) The number of design passes for each aircraft is then divided by the equivalent passes to determine the total number of equivalent passes of the controlling aircraft to be considered for final design.

(3) Example problem solution.

(a) Determine the thickness of pavement required for a taxiway having the mixture of aircraft, gross weights, and number of passes as shown in columns 1-3 in Table 12-1. The concrete design flexural strength R is 4.48 MPa (650 psi), and the modulus of soil reaction k is 54 kPa/mm (200 pci).

(b) The pavement thickness required for each aircraft is shown in column 4 as determined from appropriate design curves. (Figures 12-3, 12-4, 12-13 through 12-15)

(c) Determine the allowable number of passes of each aircraft for the controlling thickness in column 4 of 363 millimeters (14.3 inches) for the C-141. These allowable passes are determined from the aircraft respective design curve and listed in column 5.

(d) Divide the allowable number of passes (column 5) by the allowable number of passes for the C-141 (10,000). This gives the number of equivalent passes of each aircraft in terms of one pass of the C-141 and is shown in column 6. For example, one pass of the C-141 is equivalent to 780 passes of the F-15 at the design weights.

(e) Divide the number of design passes in column 3 by the number of equivalent passes in column 6 to determine the total number of equivalent C-141 passes for design. These values are shown in column 7.

(f) Determine the total number of equivalent C-141 passes by totaling the values in column 7. Enter the C-141 design curve (Figure 12-14) with the total number of equivalent passes (20,129), the design load of 156,490 kilograms (345 kips), R of 4.48 MPa (650 psi), k of 54 kPa/mm (200 pci), and traffic area A to determine the final design thickness of 381 millimeters (15.0 inches). These values will be rounded to 380 millimeters (15.0 inches).

Table 12-1
Example of Mixed Traffic Design

(1) Aircraft	(2) Gross Weight, kg (kips)	(3) Aircraft Passes	(4) Preliminary Thickness, in.	(5) Allowable Passes at 14.3 in.	(6) Column 5 Divided by 10,000	(7) Column 3 Divided by Column 6
B-52	181,400 (400)	300	14.2	336	0.03	10,000
C-141	156,490 (345)	10,000	14.3	10,000	1.00	10,000
C-130	70,310 (155)	5,000	9.3	53,000,000	5,300	1
F-15	30,840 (68)	100,000	12.2	7,800,000	780	128
OV-1	8,160 (18)	1,000,000	6.0	Unlimited	--	--
					Total Passes on Basis of C-141 Aircraft	20,129

Conversion Factors:
Millimeters = 25.4 × inches

6. THICKNESS DESIGN - NAVY AND MARINE CORPS PAVEMENTS.

a. General. Figures 12-19 to 12-23 are design curves for various aircraft to be used in determining thickness requirements for individual aircraft. Figures 12-24 to 12-28 are design curves to be used for mixed aircraft traffic in determining thickness requirements. Thicknesses may also be determined using the computer program DESIGN OF RIGID AIRFIELD PAVEMENTS. See paragraph 8 in Chapter 4 for design policy.

b. Fatigue Damage. Repeated aircraft loading results in fatigue damage in the concrete slabs which results in microcracks at the bottom of the slab. These cracks work their way to the surface of the slab, eventually dividing the slab into two or more pieces. In addition, if pumping and loss of support occur at slab corners, the critical stress could increase until a corner break develops. As the proportion of cracked slabs increases, the airfield pavement requires increasing maintenance and repair.

c. Structural Characterization. The slab and foundation are characterized using the Westergaard theory of a slab loaded at the interior resting on a uniformly supported foundation (as modeled using the k value). Stresses may be computed using the computer program RPDESIGN. A major design assumption is that adequate load transfer is provided at the joints so that the load stresses that occur at the joints are not significantly higher than the stresses at the interior of the slab. Adequate load transfer must be provided by a stabilized base, keyways, mechanical load transfer devices or aggregate interlock.

d. Structural Slab Cracking from Aircraft Loadings. The cracking of a nonreinforced jointed concrete slab with relatively short joint spacing is controlled by:

(1) The magnitude of flexural stress caused by aircraft traffic.

(2) The flexural strength of the concrete.

(3) The number of stress applications.

The number of allowable stress applications to crack the concrete slab is controlled by the ratio of critical stress to flexural strength of the concrete. The relationship used in this design procedure to relate stress/flexural strength ratio to the number of stress applications to cracking was developed by the PCA and is shown in Table 12-2. The lower the ratio of critical stress to flexural strength, the larger the number of load applications that the slab can carry before cracking occurs.

e. Structural Slab Cracking and Mixed Aircraft Loading. When two or more aircraft will utilize a given pavement, each may cause a certain amount of fatigue damage in the concrete slab. The effect of mixed traffic can be provided for in the pavement design by using Miner's cumulative fatigue damage procedure. Fatigue damage is defined as the ratio of the number of loading cycles actually applied (at a given stress level) to the number of allowable load applications to cracking failure (at the same stress level). The resulting fraction represents the proportion of the useful life of the concrete that is consumed by repeated loading.

$$Cumulative\ Fatigue\ Damage = \sum \frac{n_i}{N_i} \qquad (12\text{-}1)$$

where

n_i = number of applied loads (coverages) at a given stress level (as denoted by i)

N_i = number of allowable loads (coverages) at the same stress level to cracking of the concrete

The fatigue damage can be accumulated over any number of stress levels (or different aircraft loadings) as indicated by the summation sign.

f. Thickness Design Inputs. Five key design inputs are needed to determine the required slab thickness.

(1) Design concrete flexural strength. The 28-day third-point loading flexural strength is used for pavement design. The design flexural strength should be as high as practicable and economical but not less than 4.48 MPa (650 psi). The actual mean flexural strength in the field will be greater than the design flexural strength.

(2) Value of k at top of base. The k value on the subgrade and at the top of the base layers will be determined using the procedure presented in Chapter 5. The value used for design is that obtained at the top of the base. The combined base and subgrade should have a minimum design k value of

54 kPa/mm (200 pci) to prevent excessive permanent deformation of the subgrade due to slab corner deflections. A base course of sufficient thickness and quality should be used to achieve this modulus. However, in no case should design be based on a k value greater than 135 kPa/mm (500 pci). A stabilized base or lean concrete base may be used as a substitute for a granular base course on a 1:1.5 thickness replacement ratio. However, the k value used for design remains the same as that determined at the top of the granular base. The design k value is not increased due to the use of a stabilized or lean concrete base. An unbonded stabilized or lean concrete base does not increase the effective k value greatly due to slippage between the slab and base.

Table 12-2
Stress-Strength Ratios and Allowable Coverages

Stress-Strength[1] Ratio	Allowable Coverages	Stress-Strength[1] Ratio	Allowable Coverages
0.45	2,300,000	0.63	14,000
0.46	1,700,000	0.64	11,000
0.47	1,300,000	0.65	8,000
0.48	1,000,000	0.66	6,000
0.49	720,000	0.67	4,500
0.50	540,000	0.68	3,500
0.51	400,000	0.69	2,500
0.52	300,000	0.70	2,000
0.53	240,000	0.71	1,500
0.54	180,000	0.72	1,100
0.55	130,000	0.73	850
0.56	100,000	0.74	650
0.57	75,000	0.75	480
0.58	57,000	0.76	370
0.59	42,000	0.77	280
0.60	32,000	0.78	210
0.61	24,000	0.79	160
0.62	18,000	0.80	120

[1] Interior or edge stress and design flexural strength.

(3) Type and design gear load of aircraft using facility. Pavement thickness design can be determined for a single design aircraft or for a mix of aircraft traffic. Determine the design gear load for a given aircraft by first selecting the design gross aircraft weight. This is normally the maximum gross aircraft weight at departure. Then estimate the design gear load by assuming that 95 percent of the gross weight is carried by the main gears. Design values are given in Chapter 4.

(4) Number of Aircraft Passes. Forecast the total number of passes (not coverages) of each aircraft that is expected to use the pavement feature over its design life. The "number of passes" is normally the number of departures. The exception to this is in touchdown areas on runways where the impact due to aircraft performing touch-and-go operations will cause pavement damage. On pavements that are to be used for touch-and-go operations, add the expected number of touch-and-go operations over the design life to the number of departures to arrive at the design traffic passes. Minimum pass levels for design are given in Chapter 4.

(5) Primary or Secondary Traffic Area. Guidance on determining if the pavement feature is a primary or secondary traffic area is given in Chapter 4.

g. Thickness design procedure for a single design aircraft. Use Figures 12-19 to 12-23 to determine the concrete slab thickness for single-design aircraft. This procedure will provide the required slab thickness for a specified type of aircraft when the flexural strength, k value, gear load, tire pressure for single-wheel gear aircraft, number of passes, and type of design traffic area are specified. The design chart for aircraft with single wheel gear is shown in Figure 12-19 and is used by entering the design flexural strength and the tire load and projecting as shown by the dashed example lines until the required slab thickness is obtained. The design charts shown in Figures 12-20 through 12-23 are also entered with the design concrete flexural strength and projecting as shown by the dashed example lines until the required slab thickness is obtained. The calculated slab thickness is then rounded to obtain the design thickness.

h. Thickness Design Procedure for Mixed Traffic. When an airfield pavement will be loaded by two or more aircraft, the combined damage caused by the aircraft mix must be used in the design. The required slab thickness may be determined for a mix of aircraft types using Miner's damage hypothesis and data on forecasted operations of different aircraft types operating at the facility. The slab thickness design for mixed traffic is an iterative procedure in which the designer selects a trial slab thickness that is normally the thickness required for the most critical aircraft using the feature plus 25 millimeters (1 inch). The designer then computes the proportion of the fatigue life of the pavement consumed as the sum of the individual damage contributions of the forecasted volume of each aircraft type, and subsequently varies the slab thickness until less than 100 percent of the fatigue life of the pavement is consumed by the forecasted mix of traffic. This procedure is described in the following sections and is facilitated by the use of a table for computations as shown in Table 12-3.

(1) Required Inputs. The specific aircraft types and their design gear load (typically 95 percent of the maximum gross departure gear load) are entered in columns 1 and 2 of Table 12-3. The projected number of passes (departures) over the selected design period are entered in column 3 of Table 12-3. Divide the projected passes by the appropriate pass-coverage ratio from Table 12-4 to obtain projected coverages for each aircraft. If the forecasted number of passes is not available, use the minimum pass levels given in Chapter 4. Use the pass-coverage ratios given for primary (channelized) traffic areas when designing for runway ends, primary taxiways, and aprons. Use the pass-coverage ratios given for secondary (unchannelized) traffic areas when designing for other areas. Enter the pass-coverage ratio selected for each aircraft in column 4 of Table 12-3, and the number of coverages computed in column 5. The other required inputs are the concrete flexural strength, the effective k value on top of the base, and the tire pressure for each single wheel aircraft, which should be recorded in the spaces provided at the top of Table 12-3.

(2) Determination of interior flexural stresses. Select a trial slab thickness and record it in the space provided for the iteration being performed. For the initial trial, use the required thickness for the expected critical aircraft (determined from Figures 12-19 through 12-23) plus 25 millimeters (1 inch).

Table 12-3
Fatigue Damage Summary Sheet for Mixed Traffic

PAVEMENT IDENTIFICATION ________ TRAFFIC AREA ________
SLAB THICKNESS: ________ SINGLE WHEEL AIRCRAFT TIRE PRESSURE, psi
BASE K: ________ 1. ________ 1. ________
FLEXURAL STRENGTH ________ 2. ________ 2. ________

① AIRCRAFT	② DESIGN GEAR LOAD	③ PROJECTED PASSES	④ P/C	⑤ PROJECTED COVERAGES (n)	⑥ INTERIOR STRESS	⑦ STRESS/F S	⑧ ALLOWABLE COVERAGES (N)	⑨ FATIGUE LIFE CONSUMED (n/N)
							$\sum$ n/N =	

Table 12-4
Pass-to-Coverage Ratios

Aircraft	Rigid Pavements		Flexible Pavements	
	Traffic Area A	Traffic Area B	Traffic Area A	Traffic Area B
B-1	3.41	5.65	1.71	2.82
B-52	1.58	2.15	1.58	2.15
B-727	3.32	5.87	3.32	5.87
C-5A	1.66	2.11	0.83	1.05
C-9	3.73	6.89	3.73	6.89
C-12	7.07	13.89	7.07	13.89
C-17	2.74	3.80	1.37	1.90
C-130	4.40	8.54	2.20	4.27
C-141	3.49	6.23	1.75	3.12
CH-46E	8.01	15.22	8.01	15.22
CH-47	4.38	7.64	4.38	7.64
CH-53E	5.23	9.53	5.23	9.53
CH-54	4.31	8.51	4.31	8.51
DC-10-10	3.64	5.80	1.82	2.87
DC-10-30	3.77	5.59	1.88	2.80
E-2C	8.58	17.00	4.29	8.50
E-4	3.62	5.12	1.81	2.56
F-4C	8.77	17.37	8.77	17.37
F-14	7.78	15.34	7.78	15.34
F-15 C&D	9.30	15.34	9.30	15.34
F-15E	8.10	13.36	8.10	13.36
F/A-18	9.57	17.04	9.57	17.04
F-111	5.63	9.77	5.63	9.77
KC-135	3.48	6.14	1.74	3.07
L-1011	3.58	5.44	1.79	2.72
ORBITER	3.60	6.49	3.60	6.49
OV-1	10.36	17.28	10.36	17.28
P-3	3.58	6.66	3.58	6.66
S-3A	10.43	20.87	10.43	20.87
UH-60	11.94	19.49	11.94	19.49

Determine the flexural stress at the bottom of the slab caused by each particular aircraft gear for the interior loading position, using Figures 12-24 through 12-20. For each single wheel gear aircraft, enter Figure 12-24 with the trial slab thickness, tire load, and tire pressure, move either up or down to the base effective k value and continue horizontally to the flexural stress. For each of the multiwheel gear aircraft types listed, enter the appropriate Figures 12-25 through 12-28 with the trial slab thickness, project a horizontal line left to the effective k value, move either up or down to the design gear load, and continue horizontally to the flexural stress. Record the stress values in column 6 of Table 12-3.

(3) Fatigue life consumption. The stress-strength ratio recorded for each aircraft in column 7 of Table 12-3 is the flexural stress in column 6 divided by the design concrete flexural strength. Select from Table 12-2 the allowable number of coverages corresponding to the stress-strength ratio computed for each aircraft type, and record the allowable number of coverages in column 8 of Table 12-3. For each aircraft type, divide the projected number of coverages in column 5 by the allowable number of coverages in column 8 to determine the portion of fatigue life consumed by the forecasted volume of each aircraft type and record in column 9. The sum of the values in column 9 is the total damage, the proportion of total fatigue life of the slab consumed by the forecasted volumes of the aircraft types listed. If this number is considerably less than 1.00 (100 percent), indicating that the slab has considerable remaining fatigue life at the end of the design period not consumed by the forecasted mix of traffic, then the trial slab thickness may be reduced in the next iteration. If the total damage is greater than 1.00 (100 percent), indicating that the fatigue life of the slab will be consumed by lower traffic volumes than those projected over the design period, then the trial slab thickness must be increased in the next iteration. The process of selecting a slab thickness, determining the flexural stress, and calculating the fatigue life consumption is repeated until the slab thickness which corresponds to an acceptable value for damage (less than 1.00 or 100 percent) is determined.

i. Minimum Thickness. The minimum allowable new concrete pavement thickness is 200 millimeters (8 inches) in primary and secondary traffic areas and 100 millimeters (4 inches) in blast protective areas not subject to aircraft loading. For helicopter and basic training fields the minimum thickness in primary and secondary traffic areas is 150 millimeters (6 inches).

7. DESIGN EXAMPLES FOR NAVY AND MARINE CORPS PLAIN CONCRETE PAVEMENTS.

a. Thickness Design for a Single Aircraft. It is desired to design a plain rigid pavement for the following conditions.

Aircraft = C-141
Design gear load = 70,300 kilograms (155,000 pounds)
Design flexural strength = 4.48 MPa (650 psi)
Effective k value at top of base course = 54 kPa/mm (200 pci)
Total departures over 20-year design life = 25,000
Traffic area = primary taxiway (channelized traffic)

Using Figure 12-22, the required slab thickness is 340 millimeters (13.4 inches). This thickness would then be rounded upward to 350 millimeters (14.0 inches).

b. Thickness Design for Mixed Traffic. A new runway is to be designed to serve frequent operations of C-141, C-130, C-17, and C-5A aircraft. In addition to these aircraft, the new facility will be used by F-14 and P-3 aircraft. The runway is located in a warm climatic region where frost penetration does not need to be considered in the design process. Use the following general design procedure when designing the rigid pavement for this runway.

(1) Subgrade evaluation and testing. A subgrade investigation was performed to evaluate the support of the subgrade soil. Prior to the actual field survey, previous soils investigations, soils maps, climatic data, etc., were collected to provide background information on the soil conditions. Soil borings were then obtained to aid in evaluating the physical properties of the soil. Soil borings were taken at 60-meter (200-foot) intervals along the location of the proposed runway. Soil tests show that the subgrade soil can be classified as CL according to the Unified Soil Classification System. Test results show that there is no significant soil variation in the area for the new runway. Swelling soils are not a problem at the site. Plate load-bearing tests were performed according to ASTM D 1196 to determine the modulus of subgrade reaction (k value). Because of the uniform soils throughout the area, only three plate load tests were taken. The results are summarized below:

Test Number	k Value, kPa/mm (pci)
1	27 (100)
2	41 (150)
3	35 (130)
Average = 34 kPa/mm (127 pci)	

Because of the uniform soil conditions throughout the site, a design k value of the average of the three tests, or 34 kPa/mm (127 pci), is used.

(2) Base course design. Results of a field survey and soil tests indicate that the subgrade soil has a high degree of saturation and low permeability. Thus, very little bottom drainage is likely. Therefore, a base material that is resistant to the detrimental effects of moisture should be used. A free-draining granular base course may be used to increase the subgrade k value to the minimum acceptable k value of 54 kPa/mm (200 pci) on top of the base course. According to Figure 8-1, a 203-millimeter (8-inch) granular base course will raise the k value on top of the base to 54 kPa/mm (200 pci). To prevent intrusion of subgrade fines into the base course, a filter course is included in the design.

(3) Traffic projections. The following tabulations summarize the projected traffic for the new runway over a 20-year design period and the design gear loads.

	Passes	Pass-Coverage Ratio		Coverages, 20 Years	
Aircraft	**20 Years**	**Channelized**	**Nonchannelized**	**Channelized**	**Nonchannelized**
C-141	12,500	3.49	6.23	3,582	2,006
C-130	50,000	4.40	8.54	11,364	5,855
C-5	25,000	1.66	2.11	15,060	11,848
C-17	12,500	1.37	1.90	9,124	6,579
P-3	100,000	3.58	6.66	27,933	15,015
F-14	100,000	7.78	15.34	12,854	6,519

Aircraft	Design Gear Load, kg (lb)
C-141	70,300 (155,000)
C-130	38,100 (84,000)
C-5	86,180 (190,000)
C-17	1,179,360 (260,000)
P-3	30,845 (68,000)
F-14[1]	13,600 (30,000)

[1] The design tire pressure for the F-14 is 1.65 MPa (240 psi).

(4) Slab thickness and joints. The k value of 54 kPa/mm (200 pci) as determined above and a design flexural strength of 4.48 MPa (650 psi) are used to determine the required slab thickness. Results of the mixed traffic analysis for the channelized traffic areas are summarized in Table 12-5. Results for the unchannelized traffic areas are summarized in Table 12-6. This shows that a 345-millimeter (13.6-inch) concrete slab is required in areas of channelized traffic to serve the projected aircraft over a design life of 20 years. This is rounded up to a recommended thickness of 350 millimeters (14.0 inches). A 330-millimeter (13.0-inch) concrete slab is required in areas with unchannelized traffic.

8. JOINT USES. Joints are provided to permit contraction and expansion of the concrete resulting from temperature and moisture changes, to relieve warping and curling stresses due to temperature and moisture differentials, to prevent unsightly irregular breaking of the pavement, and to act as a construction expedient to separate sections or strips of concrete placed at different times. The three general types of joints are contraction, construction, and expansion. A typical jointing layout of the three types is illustrated in Figure 12-29.

9. SELECTION OF JOINT TYPES. Joints are either construction or contraction joints. Construction joints are used because there is a physical limit on the concrete placement such as the beginning or end of a placement lane (transverse construction joint) or at the edges of the placement lane (longitudinal construction joint). Concrete is a dynamic material that changes volume throughout its life as chemical reactions occur and as temperature and moisture fluctuations occur. Either joints must be provided to accommodate these natural volume changes in concrete or the concrete will crack. Such joints are contraction joints and are formed by sawing partial depth into the concrete at early ages before cracking can occur. This sawing must be done as soon as the concrete has hardened sufficiently to allow saw cutting without raveling or damage to the concrete. The exact timing of the saw cutting depends on the characteristics of the concrete mixture and the environmental conditions. This cutting occurs on the same day as placing except under very unusual circumstances. Waiting overnight to cut these joints generally will result in uncontrolled cracking. Contraction joints made by inserts forced into the plastic concrete or by manually grooving the plastic concrete surface are unacceptable for military airfields. The most common contraction joints are the regularly spaced transverse joints (transverse contraction joints) placed down the length of the concrete placement lane. The maximum spacing between joints is a function of the slab thickness and allowable limits are provided in paragraph 10. When the concrete placement lane width exceeds these allowable limits between joints, a longitudinal contraction joint will be placed to bring the joint spacing within the maximum limits. The resulting slabs should be square. If the ratio of length to width falls outside of the range of 0.75 to 1.25 or if the geometry of the pavement dictates an irregular shaped slab (e.g., filet slabs), the slabs will have to be reinforced as required in Chapters 1 and 13. Expansion joints are special construction joints that are used to isolate structures from the concrete pavement movement (e.g., isolate hangar from an apron) or to separate two intersecting pavements (e.g., a taxiway intersecting a runway at right angles). Expansion joints often are

Table 12-5
Design Example for Primary (Channelized) Traffic Areas

PAVEMENT IDENTIFICATION New E-W Runway TRAFFIC AREA Channelized
SLAB THICKNESS: 13.0
BASE K: 200 pci
FLEXURAL STRENGTH 650 psi

SINGLE WHEEL AIRCRAFT: 1. F-14 2.
TIRE PRESSURE, psi: 1. 240 2.

① AIRCRAFT	② DESIGN GEAR LOAD	③ PROJECTED PASSES	④ P/C	⑤ PROJECTED COVERAGES (n)	⑥ INTERIOR STRESS	⑦ STRESS/FS 650	⑧ ALLOWABLE COVERAGES (N)	⑨ FATIGUE LIFE CONSUMED (n/N)
C-141	155,000	12,500	3.49	3,582	430	0.66	6,000	0.60
C-130	84,000	50,000	4.40	11,364	330	0.51	400,000	0.03
C-5	190,000	25,000	1.66	15,060	360	0.55	130,000	0.12
P-3	68,000	100,000	3.58	27,934	370	0.57	75,000	0.37
F-14	30,000	100,000	7.78	12,853	260	0.40	--	--
C-17	260,000	12,500	1.37	9,124	375	0.58	56,700	0.16
	Conversion Factors:							
	kilograms = 0.453 × pounds							
	megapascals = 0.006894 × psi							
							$\sum$ n/N =	1.28

Table 12-5 (Continued)

PAVEMENT IDENTIFICATION New E-W Runway TRAFFIC AREA Channelized
SLAB THICKNESS: 13.8
SINGLE WHEEL AIRCRAFT: 1. F-14 2.
TIRE PRESSURE, psi: 1. 240 2.
BASE K: 200 pci
FLEXURAL STRENGTH 650 psi

① AIRCRAFT	② DESIGN GEAR LOAD	③ PROJECTED PASSES	④ P/C	⑤ PROJECTED COVERAGES (n)	⑥ INTERIOR STRESS	⑦ STRESS/FS 650	⑧ ALLOWABLE COVERAGES (N)	⑨ FATIGUE LIFE CONSUMED (n/N)
C-141	155,000	12,500	3.49	3,582	400	0.62	18,000	0.20
C-130	84,000	50,000	4.40	11,364	300	0.46	1,700,000	0.01
C-5	190,000	25,000	1.66	15,060	340	0.52	300,000	0.05
P-3	68,000	100,000	3.58	27,934	330	0.51	400,000	0.07
F-14	30,000	100,000	7.78	12,853	230	0.35	Unlimited	--
C-17	260,000	12,500	1.37	9,124	346	0.53	230,000	0.04
	Conversion Factors:							
	kilograms = 0.453 × pounds							
	megapascals = 0.006894 × psi							
							$\sum$ n/N =	0.37

Table 12-6
Design Example for Secondary (Unchannelized) Traffic Areas

PAVEMENT IDENTIFICATION New E-W Runway TRAFFIC AREA Unchannelized
SLAB THICKNESS: 12.5 inches SINGLE WHEEL AIRCRAFT TIRE PRESSURE, psi
BASE K: 200 pci 1. F-14 1. 240
FLEXURAL STRENGTH 650 psi 2. 2.

① AIRCRAFT	② DESIGN GEAR LOAD	③ PROJECTED PASSES	④ P/C	⑤ PROJECTED COVERAGES (n)	⑥ INTERIOR STRESS	⑦ STRESS/F S	⑧ ALLOWABLE COVERAGES (N)	⑨ FATIGUE LIFE CONSUMED (n/N)
C-141	155,000	12,500	6.23	2,006	455	0.70	2,000	1.00
C-130	84,000	50,000	8.54	5,855	350	0.54	180,000	0.03
C-5	190,000	25,000	2.11	11,848	370	0.57	75,000	0.16
P-3	68,000	100,000	6.66	15,015	390	0.60	32,000	0.47
F-14	30,000	100,000	15.34	6,519	270	0.42	Unlimited	--
C-17	260,000	12,500	1.90	6,579	395	0.61	24,000	0.27
	Conversion Factors:							
	kilograms = 0.453 × pounds							
	megapascals = 0.006894 × psi							
							$\sum$ n/N =	1.93

Table 12-6 (Continued)

PAVEMENT IDENTIFICATION New E-W Runway TRAFFIC AREA Unchannelized
SLAB THICKNESS: 13.0
BASE K: 200 pci
FLEXURAL STRENGTH 650 psi

SINGLE WHEEL AIRCRAFT: 1. F-14 2.
TIRE PRESSURE, psi: 1. 240 2.

① AIRCRAFT	② DESIGN GEAR LOAD	③ PROJECTED PASSES	④ P/C	⑤ PROJECTED COVERAGES (n)	⑥ INTERIOR STRESS	⑦ STRESS/F S	⑧ ALLOWABLE COVERAGES (N)	⑨ FATIGUE LIFE CONSUMED (n/N)
C-141	155,000	12,500	6.23	2,006	430	0.66	6,000	0.33
C-130	84,000	50,000	8.54	5,855	330	0.51	400,000	0.01
C-5	190,000	25,000	2.11	11,848	360	0.55	130,000	0.09
P-3	68,000	100,000	6.66	15,015	370	0.57	75,000	0.20
F-14	30,000	100,000	15.34	6,519	260	0.40	Unlimited	--
C-17	260,000	12,500	1.90	6,579	375	0.58	56,700	0.12
	Conversion Factors:							
	kilograms = 0.453 × pounds							
	megapascals = 0.006894 × psi							
							$\sum$ n/N =	0.75

the source of maintenance headaches so they are used only when concrete movement has to be isolated. The old practice of automatically placing expansion joints at prescribed intervals down a pavement feature is unnecessary and has been discontinued since the 1950s. Doweled construction joints and saw-cut contraction joints without dowels will be the default joints used for military airfield pavement construction. Other joints will be used for special circumstances if needed or with the specific approval of the AF MAJCOM pavements engineer, TSMCX, or NAVFAC as appropriate. These other special application joints include:

a. Thickened-edge expansion or doweled expansion joints where isolation from concrete movement is required.

b. Thickened-edge construction joint where load transfer cannot be provided by dowels and aircraft traffic will cross or be adjacent to the joint.

c. Doweled contraction joint where load transfer from aggregate interlock might be lost due to slab movement (e.g., last three contraction joints on a runway are commonly doweled because of possible joint opening from accumulated slab movements or on long reinforced slabs where environmental changes may result in excessive joint opening).

d. Butt longitudinal construction joints but this requires special design for no load transfer for Army and Air Force airfield pavements.

e. Tied joints (Navy only) where relative movement and separation between slabs must be restricted. Such situations are rare on airfield pavements.

f. Doweled construction joints will normally be used at the intersection of new and old concrete, or alternatively the new concrete may have a thickened edge. Note that this latter situation will leave the old concrete slab without load transfer and its premature failure should be anticipated and planned for. Special junctures that require undercutting and placing concrete below the old slab require approval from the AF MAJCOM pavements engineer, TSMCX, or NAVFAC as appropriate before use.

10. JOINTS FOR ARMY AND AIR FORCE PAVEMENTS.

a. Contraction Joints.

(1) General. Weakened-plane contraction joints are provided to control cracking in the concrete and to limit curling or warping stresses resulting from drying shrinkage and contraction and from temperature and moisture gradients in the pavement. Shrinkage and contraction of the concrete causes slight cracking and separation of the pavement at the weakened planes, which will provide some relief from tensile forces resulting from foundation restraint and compressive forces cause by subsequent expansion. Contraction joints will be required transversely and may be required longitudinally depending upon pavement thickness and spacing of construction joints. A typical contraction joint is shown in Figure 12-30. Instructions regarding the use of saw cuts to form the weakened plane are contained in TM 5-822-7/AFM 88-6, Chapter 8.

(2) Width and Depth of Weakened-Plane Groove. The width of the weakened-plane groove will be a +3 millimeters (+1/8 inch) or greater. The depth of the weakened plane groove must be great enough to cause the concrete to crack under the tensile stresses resulting from the shrinkage and contraction of the concrete as it cures. Experience, supported by analyses, indicates that this depth should be at least one-fourth of the slab thickness for pavements less than 300 millimeters (12 inches),

75 millimeters (3 inches) for pavements 300 to 450 millimeters (12 to 18 inches) in thickness, and one-sixth of the slab thickness for pavements greater than 450 millimeters (18 inches) in thickness. In no case will the depth of the groove be less than the maximum nominal size of aggregate used. Concrete placement conditions may influence the fracturing of the concrete and dictate the depth of groove required. For example, concrete placed early in the day, when the air temperature is rising, may experience expansion rather than contraction during the early life of the concrete with subsequent contraction occurring several hours later as the air temperature drops. The concrete may have attained sufficient strength before the contraction occurs so that each successive weakened plane does not result in fracturing of the concrete. As a result, excessive opening may result where fracturing does occur. If this situation occurs, increase the depth of the initial groove by 25 percent to assure the fracturing and proper functioning of each of the scheduled joints.

(3) Width and depth of sealant reservoir. The width and depth of the sealant reservoir for the weakened plane groove will conform to dimensions shown in Figure 12-31. The dimensions of the sealant reservoir are critical to satisfactory performance of the joint sealing materials.

(4) Spacing of transverse contraction joints. Transverse contraction joints will be constructed across each paving lane, perpendicular to the centerline, at intervals of not less than 3.8 meters (12.5 feet) and generally not more than 6 meters (20 feet) for the Navy and 6 meters (20 feet) for the Army and Air Force. The joint spacing will be uniform throughout any major paved area, and each joint will be straight and continuous from edge to edge of the paving lane and across all paving lanes for the full width of the paved area. Staggering of joints in adjacent paving lanes can lead to sympathetic cracking and will not be permitted unless reinforcement is used. The maximum spacing of transverse joints that will effectively control cracking will vary appreciably depending on pavement thickness, thermal coefficient and other characteristics of the aggregate and concrete, climatic conditions, and foundation restraint. It is impractical to establish limits on joint spacing that are suitable for all conditions without making them unduly restrictive. The joint spacings in Table 12-7 have given satisfactory control of transverse cracking in most instances and may be used as a guide, subject to modification based on available information regarding the performance of existing pavements in the vicinity or unusual properties of the concrete. For the best pavement performance, the number of joints should be kept to a minimum by using the greatest allowable joint spacing that will control cracking. Experience has shown, however, that oblong slabs, especially in thin pavements, tend to crack into smaller slabs of nearly equal dimensions under traffic. Therefore, it is desirable, insofar as practicable, to keep the length and width dimensions as nearly equal as possible. In no case should either dimension exceed the other dimension by more than 25 percent. Under certain climatic conditions, joint spacings different from those in Table 12-7 may be satisfactory. Where it is desired to change the joint spacing, a request will be submitted to the Transportation System Mandatory Center of Expertise, TSMCX (CENWO-ED-TX) for Army projects, or the appropriate Air Force Major Command for Air Force projects, regardless of who performs the design.

Table 12-7
Recommended Spacing of Transverse Contraction Joints

Pavement Thickness, millimeters (inches)	Spacing, meters (feet)
Less than 230 (9)	3.8 to 4.6 (12.5 to 15)
230 to 305 (9 to 12)	4.6 to 6 (15 to 20)
Over 305 (12)[1]	6 (20 max)

[1] 6-meter (20-foot) maximum spacing for Army and Air Force pavements.

(5) Spacing of longitudinal contraction joints. Contraction joints will be placed along the centerline of paving lanes that have a width greater than the determined maximum spacing of transverse contraction joints in Table 12-7. Contraction joints may also be required in the longitudinal direction of overlays, regardless of overlay thickness, to match joints existing in the base pavement unless a bond-breaking medium is used between the overlay and base pavement or the overlay pavement is reinforced.

(6) Doweled contraction joints. Dowels will be required in the last three transverse contraction joints back from the ends of all runways to provide positive load transfer in case of excessive joint opening due to cumulative shrinkage of the pavement. Similar dowel requirements may be included in the transverse contraction joints at the end of other long paved areas, such as taxiways or aprons where local experience indicates that excessive joint opening may occur. In rigid overlays in Air Force and Army Type A traffic areas, longitudinal contraction joints that would coincide with an expansion joint in the base pavement will be doweled. Dowel size and spacing will be as specified in Table 12-8.

(7) Aggregate Interlock. Aggregate interlock can provide adequate load transfer across joints when the pavement is originally constructed during hot weather. However, as joint movements due to temperature variation and load applications increase and the joint begins to open, aggregate interlock is lost and load transfer is greatly reduced. The effectiveness of aggregate interlock may be improved by increasing base strength and the angularity of coarse aggregate and shorter spacing of joints.

b. Construction Joints. Centerline longitudinal construction joints should be used on runways and taxiways.

(1) General. Construction joints may be required in both the longitudinal and transverse direction. Longitudinal construction joints (generally spaced 6 meters (20 feet) apart but may be more than one lane wide depending on construction equipment capability) will be required to separate successively placed paving lanes. Transverse construction joints will be installed when it is necessary to stop concrete placement within a paving lane for a length of time that will allow the concrete to start to set. All transverse construction joints will be located in place of other regularly spaced transverse joints (contraction or expansion types) and will normally be doweled butt joints. There are several types of construction joints available for use as shown in Figure 12-32 and as described below. The selection of the type of construction joint will depend on such factors as the concrete placement procedure (formed or slipformed), airfield type, adjacent existing pavement, and foundation conditions.

Table 12-8
Dowel Size and Spacing for Construction, Contraction, and Expansion Joints

Pavement Thickness mm (in.)	Minimum Dowel Length mm (in.)	Maximum Dowel Spacing mm (in.)	Dowel Diameter and Type
Less than 203 (8)	406 (16)	305 (12)	20-mm (3/4-in.) bar
203-292 (8-11.5)	406 (16)	305 (12)	25-mm (1-in.) bar
305-394 (12-15.5)	508 (20)	381 (15)	25- to 30-mm (1- to 1-1/4-in.) bar or 25-mm (1-in.) extra-strength pipe
406-521 (16 - 20.5)	508 (20)	457 (18)	25- to 40-mm (1- to 1-1/2-in.) bar or 25- to 60-mm (1- to 1-1/2-in.) extra-strength pipe
533-648 (21 - 25.5)	610 (24)	457 (18)	50-mm (2-in.) bar or 50-mm (2-in.) extra-strength pipe
660 (26) or more	762 (30)	457 (18)	75-mm (3-in) bar or 75-mm (3-in.) extra-strength pipe

(2) Doweled butt joint. The doweled butt joint is considered to be the best joint for providing load transfer and maintaining slab alignment. Therefore, it is the desirable joint for the most adverse conditions, such as heavy loading, high traffic intensity, and lower strength foundations. However, because the alignment and placement of the dowel bars are critical to satisfactory performance, the dowels must be carefully aligned, especially for slipformed concrete. The doweled butt joint is required for all transverse construction joints.

(3) Thickened-edge joint. Thickened-edge-type joints may be used in lieu of other types of joints employing load-transfer devices. The thickened-edge joint is constructed by increasing the thickness of the concrete at the edge to 125 percent of the design thickness. The thickness is then reduced by tapering from the free-edge thickness to the design thickness at a distance 1.5 meters (5 feet) from the longitudinal edge. The thickened-edge butt joint is considered adequate for the load-induced concrete stresses. The thickened-edge joint may be used at free edges of paved areas to accommodate future expansion of the facility or where aircraft wheel loadings may track the edge of the pavement.

c. Expansion Joints.

(1) General. Expansion joints will be used at all intersections of pavements with structures and may be required within the pavement features. A special expansion joint required at pavement intersections is the slip joint. The types of expansion joints are the thickened-edge, the thickened-edge slip joint, and the doweled type (Figures 12-33 and 12-34). Filler material for the thickened-edge and doweled-type expansion joint will be a nonextruding type. Bituminous filler material will not be used when the sealer is non-bituminous. The type and thickness of filler material and the manner of its installation will depend upon the particular case. Usually a preformed material of 19-millimeter (3/4-inch) thickness will be adequate, but in some instances a greater thickness of filler material may be required. Filler material for slip joints will be either a heavy coating of bituminous material not less than

6 millimeters (1/4 inch) in thickness when joints match or normal nonextruding-type material not less than 6.3 millimeters (1/4 inch) in thickness when joints do not match. Where large expansions may have a detrimental effect on adjoining structures, such as at the juncture of rigid and flexible pavements, expansion joints in successive transverse joints back from the juncture should be considered. The depth, length, and position of each expansion joint will be sufficient to form a complete and uniform separation between the pavements and between the pavement and the structure concerned and, unless doweled, must be completely straight from end to end so translation can occur. The designer should dowel expansion joints only under special conditions. (Use thickened edge expansion joints.) Expansion joint filler must cover the full depth of the joint surface so there is no point-to-point contact of concrete.

(2) Between pavement and structures. Expansion joints will be installed to surround, or to separate from the pavement, any structures that project through, into, or against the pavements, such as at the approaches to buildings or around drainage inlets and hydrant refueling outlets. The thickened-edge-type expansion joint will normally be best suited for these places.

(3) Within pavements.

(a) Expansion joints within pavements must be carefully constructed. Except for protecting abutting structures and taxiways intersecting at an angle, their use will be kept to the absolute minimum necessary to prevent excessive stresses in the pavement from expansion of the concrete or to avoid distortion of a pavement feature through the expansion or translation of an adjoining pavement. The determination of the need for and spacing of expansion joints will be based upon pavement thickness, thermal properties of the concrete, prevailing temperatures in the area, temperatures during the construction period, and the experience with concrete pavements in the area.

(b) Longitudinal expansion joints within pavements will be of the thickened-edge type (Figure 12-33). Dowels are not recommended in longitudinal or most transverse expansion joints because differential expansion and contraction and subgrade movement parallel with the joints may develop undesirable localized strains and possibly failure of the concrete, especially near the corners of slabs at transverse joints.

(c) Transverse expansion joints within pavements will often be the doweled type (Figure 12-33). There may be instances when it will be desirable to allow some slippage in the transverse joints, such as at the angular intersection of pavements to prevent the expansion of one pavement from distorting the other. In some of these instances, instead of a transverse expansion joint, a thickened-edge slip joint may be used (Figure 12-34). When a thickened-edge joint (slip joint) is used at a free edge not perpendicular to a paving lane, a doweled transverse expansion joint will be provided as shown in Figure 12-32.

d. Dowels. The important functions of dowels or any other load-transfer device in concrete pavements are to help maintain the alignment of adjoining slabs and to transmit loads across the joint. Different sizes of dowels will be specified for different thicknesses of pavements (Table 12-8). When extra-strength pipe is used for dowels, the pipe will be filled with either a stiff mixture of sand-asphalt or portland cement mortar, or the ends of the pipe will be plugged. If the ends of the pipe are plugged, the plug must fit inside the pipe and be cut off flush with the end of the pipe so that there will be no protruding material to bond with the concrete and prevent free movement of the dowel. Figures 12-30, 12-32, and 12-33 show the dowel placement. All dowels will be straight, smooth, and free from burrs at the ends. One end of the dowel will be painted and oiled to prevent bonding with the concrete. Dowels used at expansion joints will be capped at one end, in addition to painting and oiling, to permit further penetration of the dowels into the concrete when the joints close.

e. Special Provisions of Slipforming Paving.

(1) Provisions must be made for slipform pavers when there is a change in longitudinal joint configuration. The thickness may be varied without stopping the paving train, but the joint configuration cannot be varied without modifying the side forms, which will normally require stopping the paver and installing a header. The requirements discussed as follows shall apply.

(2) The header may be set on either end of the transition slab with the transverse construction joint doweled as required. As an example, for the transition between the type A and type D areas on a medium-load pavement, the header could be set at the end of either type pavement. The dowel size and location in the transverse construction joint should be commensurate with the thickness of the pavement at the header.

f. Joint Sealing. All joints will be sealed with a suitable sealant to prevent infiltration of surface water and solid substances. The Army and Air Force do not require all joints to be sealed with preformed compression seals. Jet-fuel-resistant (JFR) sealants will be used in the joints of aprons, warm-up holding pads, hardstands, washracks, and other paved areas where fuel may be spilled during the operation, parking, maintenance, and servicing of aircraft. In addition, heat-resistant JFR joint sealant materials will be used for runway ends and other areas where the sealant material may be subject to prolonged heat and blast of aircraft engines. Non-JFR sealants will be used in the joints of all other airfield pavements. JFR sealants will conform to Federal Specification SS-S-200 or ASTM D 3569 and D 3581. Non-JFR sealants will conform to ASTM D 3405, D 3406, D 1190, and CRD-C-525. Silicone sealants meeting ASTM D 5893 may also be used in both JFR and non-JFR areas. When heat- and blast-resistant JFR sealants are required, they will conform to Federal Specification SS-S-200. An optimal sealant, meeting both the heat- and blast-resistant JFR and non-JFR sealant requirements, is a preformed compression seal conforming to ASTM D 2628 and D 2835. As a general rule, compression-type preformed sealants must have an uncompressed width of not less than twice the width of the joint reservoir. However, the maximum and minimum dimensions for the seal width should be based on the joint opening and expected movement. The selection of a pourable or preformed sealant should be based upon the economics involved and the service life desired. Compression seals will remain effective five to seven times as long as liquid sealants.

g. Special Joints and Junctures. Situations will develop where special joints or variations of the more standard-type joints will be needed to accommodate movements that will occur and to provide a satisfactory operational surface. Some of these special joints or junctures as shown in Figure 13-2 are discussed in the following paragraphs and in particular, paragraph 11.

11. JOINTS FOR NAVY AND MARINE CORPS PAVEMENT.

a. Expansion Joints. Expansion joints allow for the expansion of the pavement and the reduction of high compressive stresses at critical locations in the concrete pavement in hot weather. Expansion joints are placed the full depth of the slab. Expansion joints should be used at all intersections of pavements with fixed structures, at nonperpendicular pavement intersections, and between existing and new concrete pavements when the joints in the adjacent slabs are not aligned. Expansion joints are not otherwise required within the nonreinforced concrete pavement. See Figure 12-34 for expansion joint details.

b. Contraction (Weakened Plane) Joints. Contraction joints should be used to control cracking in the pavement due to volume changes resulting from a temperature decrease or a moisture decrease and to limit curling and warping stresses from temperature and moisture gradients in the pavement. Contraction joints are formed in concrete by partial depth sawing or by installing sawable inserts. The saw cut joint or formed groove provides a weakened plane which will crack through the full slab depth during shrinkage and contraction of the concrete as it cures. Contraction joints are required in the transverse direction and also in the longitudinal direction depending upon slab thickness and spacing of the construction joints. See Figure 12-30 for contraction joint details.

c. Construction Joints. Construction joints are used between paving lanes or when abutting slabs are placed at different times. Longitudinal and transverse construction joints may be required. Transverse construction joints will be required when it is necessary to stop concrete placement for a length of time sufficient to allow the concrete to begin to set. Longitudinal construction joints are generally spaced 6 meters (20 feet) apart but may be multiple lane width, depending on the construction equipment.

(1) Transverse construction joints. When possible, locate all transverse construction joints at the same location as regularly spaced transverse joints. Provide for load transfer or a thickened edge.

(2) Longitudinal construction joints. Construct longitudinal construction joints as shown in Figure 12-32 and indicated below.

(a) Keyed joint. Keyways have been used extensively to provide load transfer along longitudinal joints. However, there has been a substantial amount of keyway failure under heavy aircraft loading on thinner slabs. Keyed joints may only be used on slabs 225 mm (9 in.) thick or greater.

(b) Butt joint. A butt joint may be used for longitudinal construction joints on pavements less than 229 mm (9 in.) thick constructed with a stabilized base.

(c) Thickened-edge joint. A thickened-edge joint may be used for longitudinal construction joints. The thickened-edge joint may be used for any pavement thickness and base type.

d. Joint Spacing. The standard slab size for pavements is 3.8 by 4.6 meters (12.5 by 15 feet). Transverse joint spacing is 4.6 meters (15.0 feet) and longitudinal joint spacing is 3.8 meters (12.5 feet). For slabs having a thickness greater than 300 millimeters (12 inches), joint spacing can be increased to a maximum of 6.1 meters (20 feet). The transverse joint spacing shall not vary from the longitudinal joint spacing by more than 25 percent. Figure 12-29 shows standard joint spacings.

e. Load Transfer Design. A properly designed joint must provide adequate load-transfer across the joint. Load transfer efficiency is normally defined as the ratio of deflection of the unloaded side to the deflection of the loaded side of the joint. Good load transfer will aid in preventing deterioration such as corner breaks, transverse and longitudinal cracking, faulting, pumping, and spalling. Different amounts of load transfer can be obtained through the use of aggregate interlock, dowel bars, keyways, a stabilized base, or a combination of these.

(1) Aggregate interlock. Aggregate interlock can provide adequate load transfer across joints when the pavement is originally constructed or during hot weather. However, as joint movements due to temperature variation and load applications increase and the joint begins to open, aggregate interlock is lost and load transfer is greatly reduced. The effectiveness of aggregate interlock may be improved by increasing base strength and the angularity of coarse aggregate and shorter spacing of joints.

(2) Dowel bars. Dowel bars are used to provide load transfer and prevent excessive vertical displacements of adjacent slabs. There are some situations where the use of dowels is appropriate, such as for creating load transfer where tying in to existing pavements.

(3) Stabilized base. A stabilized base can be used to improve load transfer effectiveness by reducing joint deflections through increased support across a joint. Use a stabilized base for all pavements less than 225 millimeters (9 inches) thick to provide improved load transfer and lower deflections and stresses. A stabilized base may also be used for pavements greater than 225 millimeters (9 inches) thick to provide additional load transfer. Where thickened-edge joints are used, the stabilized base is not required.

f. Joint Sealants. Joint sealants are used to provide a seal to reduce infiltration of water and incompressibles. An effective joint seal will help retard and reduce distress related to free water and incompressibles, such as pumping, spalling, faulting, and corrosion of mechanical load transfer devices. Several pavement areas require fuel-resistant or blast-resistant joint sealants. Use jet fuel-resistant sealants for all aprons. Use blast-resistant sealants for the first 305 meters (1,000 feet) of runways and exits at runway ends. Use sealing compounds meeting ASTM D 1190, D 3405, or D 3406 for taxiways and runway interiors.

(1) Types of sealant materials. The three major types of sealant materials are (a) field poured, hot applied; (b) field poured, cold applied; and (c) preformed compression seals. These materials may be jet fuel resistant (tar-based) or nonjet fuel resistant (typically asphalt based).

(a) Field poured, hot applied. This group of sealants includes rubberized asphalt sealant and rubberized tar sealant. Rubberized asphalt joint sealants must meet ASTM D 1190, D 3405, or D 3406. Rubberized tar sealants must meet ASTM D 3569 or D 3581.

(b) Field poured, cold applied. These are two-component, polymer-based, cold-applied heat and jet fuel-resistant joint sealants. These sealants must meet Federal Specification SS-S-200E. The Air Force and Navy recommends the use of silicone sealants that conform to NFGS 02522, 02562, and ASTM 5893 in lieu of sealants that meed Federal Specification SS-S-200E.

(c) Preformed compression seals. The most common type of preformed compression seal is the neoprene compression seal. Neoprene compression seals must satisfy ASTM D 2628. Preformed compression seals may be used in the areas designated in NFGS-02522. Preformed compression seals are designed to be in compression for their entire life. There is little bond between the compression seal and the sidewalls of the joint to sustain tension.

(2) Joint reservoir design. The joint reservoir must be properly designed so that the joint sealant can withstand compressive and tensile strains.

(a) Field poured sealants. The shape factor, which is defined as the ratio of the depth of the sealant to the width of the joint, should be between 1.0 and 1.5. Dimensions of the joint sealant and reservoir are shown in Figure 12-30. A backer rod or bond breaking tape must be used to help obtain a proper shape factor and to prevent the joint sealant from bonding to the bottom of the joint reservoir. Most field poured liquid joint sealants can withstand strains of approximately 25 percent of their original width. Joint reservoir and sealant dimensions shown in Figure 12-30 are based on a slab size of 3.8 by 4.5 meters (12.5 by 15.0 feet).

(b) Preformed compression seals. The reservoir width for preformed compression seals must be designed to keep the sealant in compression at all times. The depth of the reservoir must exceed the depth of the seal but is not related directly to the width of the joint. The width of the compression seal should be approximately twice the width of the joint. The limits on the compression seal are normally 20 percent minimum and 50 percent maximum compression strain of the original sealant width. For example, the working range of a 25-millimeter (1-inch) wide neoprene compression seal is from 13 to 20 millimeters (0.5 to 0.8 inches). If the seal is subjected to compression greater than the 50 percent level for extended periods of time, the seal may take a compression set, and the webs may bond to each other. If this happens, the seal will not open as the joint opens, and the seal will no longer be effective. The joint dimensions for the standard size slab are shown in Figure 12-30. Design sealant dimensions based on the actual joint spacing. Choose preformed neoprene compression seal dimensions so that the working range of the joint is within the working range of the sealant.

12. JOINTING PATTERN FOR RIGID AIRFIELD PAVEMENTS. Proper jointing pattern for rigid airfield pavement is a critical item of design and construction for all services. Not only is it important for a quality product, but it can and should promote efficiency for the construction contractor, and thus cost savings. Criteria for type of joints, their location, and maximum allowable spacing have been given in the previous paragraphs. This paragraph focuses on appropriate and efficient layout of the jointing pattern. Laying out a good jointing pattern depends on experience working at it and is more of an art than a science. The designer must learn to play with it and try various combinations until the optimum layout is reached. Every productive hour spent on this produces appreciable cost savings.

a. General. All project joint layout drawings should have a prominent note on them saying "No changes in the jointing pattern shall be made without the written approval of the design engineer." The design engineer must make every effort to provide an efficient layout for construction, consistent with the limits of criteria. However, once the joint layout is finalized, no change whatever should be made by field personnel unless examined and approved in writing by the designer to be sure that it does not compromise his plan or violate criteria.

b. Layout. Joint layouts should be as simple and as uniform as possible and meet all criteria of the preceding paragraphs. Except for unusual circumstances, all joints should have straight lines with the longitudinal and transverse joints at right angles. Careful study must always be made to ensure that the paving lanes (longitudinal construction joints vs transverse joints) are laid out in the right direction for the contractor's efficient work--particularly where the area has irregular boundaries.

c. Spacing. Longitudinal construction joints should be spaced such that the widths of pioneer (pilot) lanes are all equal and any variability in total distance is taken care of in a few fill-in lanes, where setting the paver width is not such a problem. Except where impractical, the jointing pattern should not require slabs that have one side exceeding the other by more than 25 percent; if any slab exceeds this, it must be reinforced--an extra expense.

d. Longitudinal Construction Joints. Never should longitudinal construction joints be spaced by simply dividing the overall distance into a whole number of lanes of equal width, unless that width comes out to an easily used value for the paving operations. If practical, pioneer lanes should have widths in multiples of 6 inches, or, if metric is used for the project, multiples of 250 millimeters. Extensions to the paver are easily made in these intervals. Other, odd intervals can be used, but they are more expensive for the contractor to adjust. Fill-in lane widths should be reasonably close to the pioneer lanes, and all fill-in lanes can be made the same width as necessary to accommodate the total distance. However, if the take-up distance is small, it is usually better to provide it in just one or two lanes and make the rest of the fill-in lanes uniform in width--simply to reduce the chance of measurement error during construction.

e. Transverse Contraction Joints. For transverse contraction joints, the spacing should be the same as the longitudinal construction joints, or close to the same. Again, it is usually not appropriate to design the transverse joints all with the same spacing, unless this comes out with easily measured spacing. Otherwise, make spacing an easily remembered and an easily measured distance, with any take-up distance provided in one or two spaces. One main objective is to provide spacings that are easy for the joint saw crew (usually working at night) to follow and not get confused (no fractional inches, or odd metric units, and as little variation as possible).

f. Replacements and Additions. Much of the present airfield paving work consists of replacement areas and additions to existing pavement. This often results in odd-shaped areas with irregular boundaries, proving difficult to provide a really good jointing pattern. As much as possible, the guidelines in the previous subparagraphs should be followed, modified as absolutely necessary. Care should be taken to, as much as possible, prevent small slabs and odd-shaped slabs requiring reinforcement. When working with areas having irregular boundaries, it becomes a process of trial and error to provide the best fit to the area, following criteria and minimizing as much as possible the need for odd-shaped reinforced slabs--an expense to be avoided. When abutting existing PCC pavement, an attempt should be made to match the existing joint pattern, where possible. Older pavements will often have 7.6-meters (25-foot) joint spacing, when now we are usually allowed a maximum of 6 meters (20 feet). For jobs of moderate size, if it is possible to match the existing joint pattern, the new joint spacing can be made 7.6 meters (25 feet), provided the existing has shown no distress because of the 7.6-meter (25-foot) spacing. Otherwise, use 3.8-meter (12.5-foot) spacing. Either is acceptable, but the Using Service should be contacted to get their preference--some like one and some the other.

g. Expansion Joints and Slip Joints.

(1) New PCC to New PCC. Where pavements abut buildings and other fixed objects, an expansion joint should be provided. Where two new PCC pavements meet a an angle, an expansion joint is necessary. If they meet at a 90-degree angle, the intersection should be a, thickened-edge expansion joint. If they meet at other than a 90-degree angle, it should be a thickened-edge joint, either expansion joint or slip joint. If the joints on new-to-new construction do not match and no expansion or slip joint is used, 900-millimeter (3-foot) wide strips of reinforcing should be installed along each side of the joint to prevent sympathetic cracks from forming in line with mismatched joints. Normally, expansion joints of any kind should not be doweled if load transfer can be provided in another way. There have been projects where doweled expansion joints have been successfully used, but this should be used only where no translation movements or stresses are expected.

(2) New PCC to Old PCC. Where new PCC pavement meets old (existing) PCC pavement at an angle, an attempt should be made to provide load transfer. At a 90-degree intersection, an ordinary thickened edge (one side) expansion joint can be used if no load transfer is necessary (existing pavement so understrength that it will not match the new pavement). At a 90-degree intersection and at an intersection other than 90 degrees, it usually will be best to put in a doweled construction joint at the intersection, and then install a thickened-edge expansion joint far enough back on the new pavement to totally clear any fillets and give the shortest unobstructed (straight) line across the pavement. .

(3) Slip Joints. Slip joints, 6-millimeter (1/4-inch) minimum thickness, can be used in lieu of expansion joints in places where only translation is expected, and no movement perpendicular to the joint is expected. At 6-millimeter (1/4-inch) thickness, they are sufficient to prevent sympathetic cracking across the joint, and thus eliminate the need for the 900-millimeter (3-foot) strip of reinforcing on each side of new-to-new construction.

h. Special Joint. A "special joint", as shown in Figure 12-32 (Sheet 3 of 3), can be used to provide load transfer on the existing side of a new PCC to old PCC joint. This can be used under the conditions listed below. Although somewhat expensive, this is an excellent joint when constructed properly, but requires close supervision in the field to ensure that the constructor builds it properly. Note that considerable handwork is required in grading the undercut and placing concrete and reinforcement. (Never should the contractor be allowed to attempt to fill the undercut with concrete spread by the paver.) Special joint (undercut) between new and existing pavements. A special joint (undercut) (Figure 12-32 (Sheet 2 of 3)) may be used at the juncture of new and existing pavements for the following conditions:

(1) When load-transfer devices (keyways or dowels) or a thickened edge was not provided at the free edge of the existing pavement.

(2) When load-transfer devices or a thickened edge was provided at the free edge of the existing pavement, but neither met the design requirements for the new pavement.

(3) For any joints, when removing and replacing slabs in an existing pavement if the existing load-transfer devices are damaged during the pavement removal, and if other types of joints are suitable.

The special joint design need not be required if a new pavement joins an existing pavement that is grossly inadequate to carry the design load of the new pavement or if the existing pavement is in poor structural condition. If the existing pavement can only carry a load that is 50 percent or less of the new pavement design load, special efforts to provide edge support for the existing pavement may be omitted. However, if the provisions for edge support are omitted, accelerated failures in the existing pavement may be experienced. Any load-transfer devices in the existing pavement should be used at the juncture to provide as much support as possible to the existing pavement. The new pavement will simply be designed with a thickened edge at the juncture. Drilling and grouting dowels in the existing pavement for edge support may be considered, if structurally suitable, as an alternative to the special joint, but a thickened-edge design will be used for the new pavement at the juncture.

i. Tied Joints (Navy Only). Tied joints are seldom used for airfield pavement. However, two instances occur:

(1) As required and shown in Figure 12-29, "Typical Jointing". (The situation must be evaluated and existing service experience observed to prevent tying two slabs that have conditions (dimensions or aggregate properties) which may cause a crack to form between the tied joint and the next adjacent joint.)

(2) Where half a slab is removed across a paving lane halfway between transverse joints (at least 3 meters (10 feet) must be removed and not less than 3 meters (10 feet) remain). In this instance, the new construction joint of new to existing, at mid-slab, must be tied (with drilled and epoxied reinforcing bars). No joint reservoir should be sawed, or sealant applied.

j. Portland Cement Concrete to Asphalt Concrete Intersections. Figures 12-35, 12-36, 12-37, and 12-38 show various types of joints to use for the juncture of PCC and AC pavements.

(1) Figure 12-35. This joint is to be used for most transverse joints that will receive aircraft traffic at Army installations and for all transverse joints that will receive aircraft traffic at Air Force installations.

(2) Figure 12-36. This detail can be used for transverse joints in areas where high-speed aircraft traffic is expected. It is a more conservative joint, but also more expensive. The Using Service should be contacted to determine which joint they prefer. This joint should no be used for Air Force jobs.

(3) Figures 12-37 and 12-38 show joints that can be used where no appreciable aircraft traffic is expected to cross. (Such as longitudinal joints on the outer edges of PCC keel sections in an AC pavement and similar locations.)

(4) Normally, the joint between PCC pavement and AC shoulder pavement should be a plain butt joint. Depending on local experience, it may be well to saw a reservoir in this joint and apply joint sealer.

k. Sample Joint Layouts. Figures 12-39 through 12-43 are samples of various typical jointing patterns. An explanation of the significance and details of each is in the following subparagraphs.

(1) Figure 12-39. This shows a perfect jointing pattern for a rectangular pavement with easily divided boundary dimensions. Unfortunately such regular dimensions and shapes do not often occur--particularly in all the replacement and repair work being required now.

(2) Figure 12-40. Metric.

(a) This figure shows the same 30.4 meters (100 feet) by 42.7 meters (140 feet) pavement as Figure 12-39, but everything is in metric (SI). It can be seen at the bottom of the page that the longitudinal construction joints have been evenly spaced across the 30.4 meters (100 feet.) This may look nice on paper, but it requires the contractor to set the width of his paver for an odd width--more expensive. If there were a large number of longitudinal lanes, it could be appropriate to make them all the same width, even if this were an odd dimension for all the lanes, since this would require only one odd setting of the paver width. At the top of the page is a layout showing four lanes at 6.0-meter (19.7-foot) width and a single fill-in lane at an odd width. (The width of the fill-in lanes is not so critical.)

(b) At the right-hand side of the figure is shown a spacing for transverse contraction joints--an odd spacing obtained by dividing the total distance into a series of equal width spacing. This is, of course, feasible to construct a series of very odd cumulative spacings. This makes it more likely that the joint sawing crew (usually working at night) may make a mistake in adding the cumulative distance, and thus get a joint out of line. The spacing shown on the left side of the page, with six spaces at 6.0 meters (19.7 feet) and one takeup space of 6.56 meters (21.5 feet), is much easier for the joint sawing crew to work with, and thus much less likely to get out of line. Always make joint layouts as simple as possible, within criteria.

(3) Figure 12-41.

(a) This figure, for a 54-meter (180-foot) wide pavement, shows nice, easy spacing of longitudinal and transverse joints, if everything is in the inch-pound system. See the spacing of 6 meters (20 feet) by 6 meters (20 feet), at the top and right side of the drawing. However, if the same overall width has to be designed in metric, it gets more complicated. Still, there is a variety of spacing that can be feasibly used for transverse contraction joints.

(b) Longitudinal construction joints are a problem, however. At the bottom of the figure are shown three possible solutions. The top one of the three is very pretty and easy to design, but it requires the contractor to adjust his paver to an odd width for the pioneer lanes--an extra expense. The middle line of the three shows a good jointing pattern with nine lanes at 6.0 meters (20 feet) and two fill-in lanes at 6.36 meters (20.9 feet)--well within criteria for shape. The bottom one of the three is also a good jointing pattern with five pioneer lanes at 6.0 meters (20 feet) and four fill-in lanes at 6.18 meters (20.3 feet). Neither of these two last systems requires the contractor to adjust his paver to anything other than an even width or to make any changes in adjustment.

(4) Figure 12-42. This is simply a further explanation of Figure 13-2b, with more details. See also subparagraph 12g.

(a) This figure shows a new PCC pavement intersecting an existing PCC pavement at an angle (90 degrees). Such an intersection requires a joint that can tolerate movement, both at right angles to the joint and along the joint, as well as providing load transfer across the joint.

(b) One approach would be to drill and grout dowels in the existing PCC and put in a doweled expansion joint at the intersection. This is not desirable, because it locks the two pavements together and does not permit any translation movement along the joint. This is particularly significant if the angle of intersection is other than 90 degrees.

(c) Another approach would be to put in a thickened-edge expansion joint at the intersection. But often the existing pavement will not have a thickened edge--and thus no true load transfer across the joint can take place.

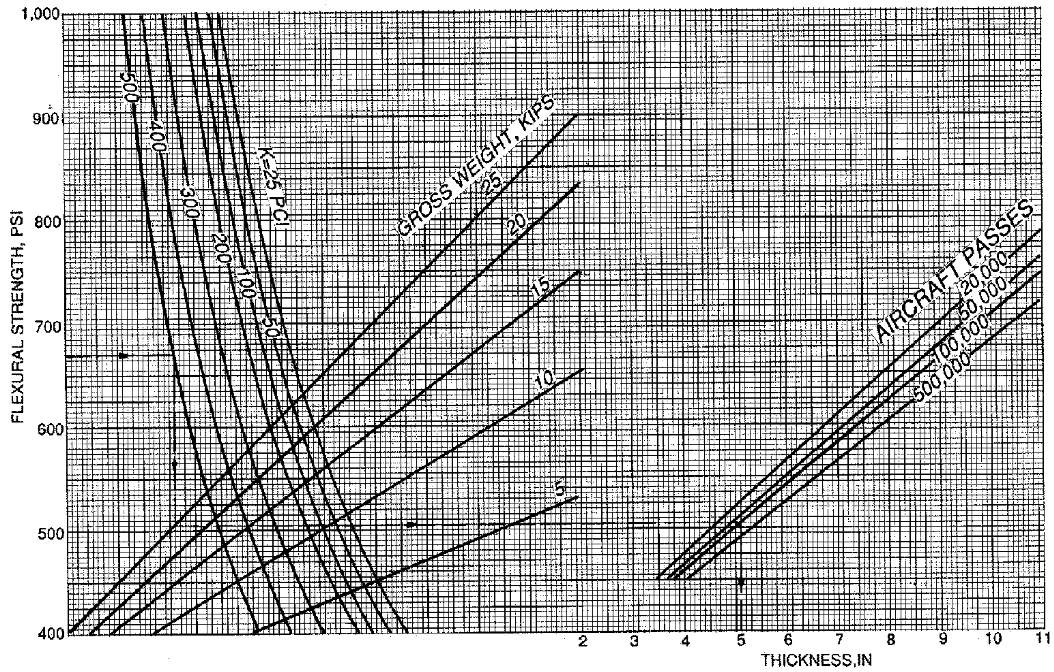
(d) The usual approach is to provide joints as shown. A doweled construction joint is installed at the intersection of the two pavements--dowels drilled and grouted into the existing PCC. This provides load transfer but no chance for translation movement. Opportunity for movement is provided by installing a thickened-edge expansion joint at a transverse joint in the new pavement. This should be just far enough back to provide a straight joint from edge to edge of the pavement (primarily to get past the end of the fillet). Note that transverse joints within the fillet area are not straight lines and would prohibit any movement along the joint.

(e) Note that the existing joints and the joints in the new area between the intersection and the expansion joint are at the same spacing. This prevents the need for any other action to prevent sympathetic cracking from any mismatched joints at the intersection. (Not always is it feasible to line up these joints, but an attempt to should be made.) At the expansion joint it is not necessary to line up joints on both sides. This permits making an easy change from the existing joint spacing to a different spacing in the new pavement.

(f) Also note that the 900-millimeter (3-foot) ends of joints intersecting curved fillets must be angled to be perpendicular to the curve at their intersection.

(5) Figure 12-43. This figure illustrates what can happen when a good jointing pattern is messed up by the joint sawing crew. This occurred on a big PCC apron at a military base. What happened was that the crew sawing transverse contraction joints (at night of course) spaced the sawed transverse joints as intended in about 85 percent of the longitudinal paving lanes, with 37 uniformly spaced joints at the left end of the apron, and 3 lesser spaced joints at the right end. But, on the other 15 percent of the longitudinal lanes, they measured the transverse joints backward, with uniform spacing at the right end and lesser spacing at the left end. Outside of the fact that there will be sympathetic cracking at the mismatched joints, structurally the pavement is excellent with a good surface finish.

(6) To reiterate, regardless of the shape and dimensions of the pavement to be constructed, the simplest jointing pattern, conforming to criteria, will be best.



RIGID PAVEMENT DESIGN CURVE FOR ARMY CLASS I HELIPORTS AND HELIPADS.

CONVERSION FACTORS

KILOPASCALS PER MILLIMETER = 0.271 x PCI
KILOGRAMS = 0.453 x POUNDS
MILLIMETERS = 25.4 x INCHES
MEGAPASCALS = 0.006894 x PSI

Figure 12-1. Plain concrete design curves for Army Helipads, Class I

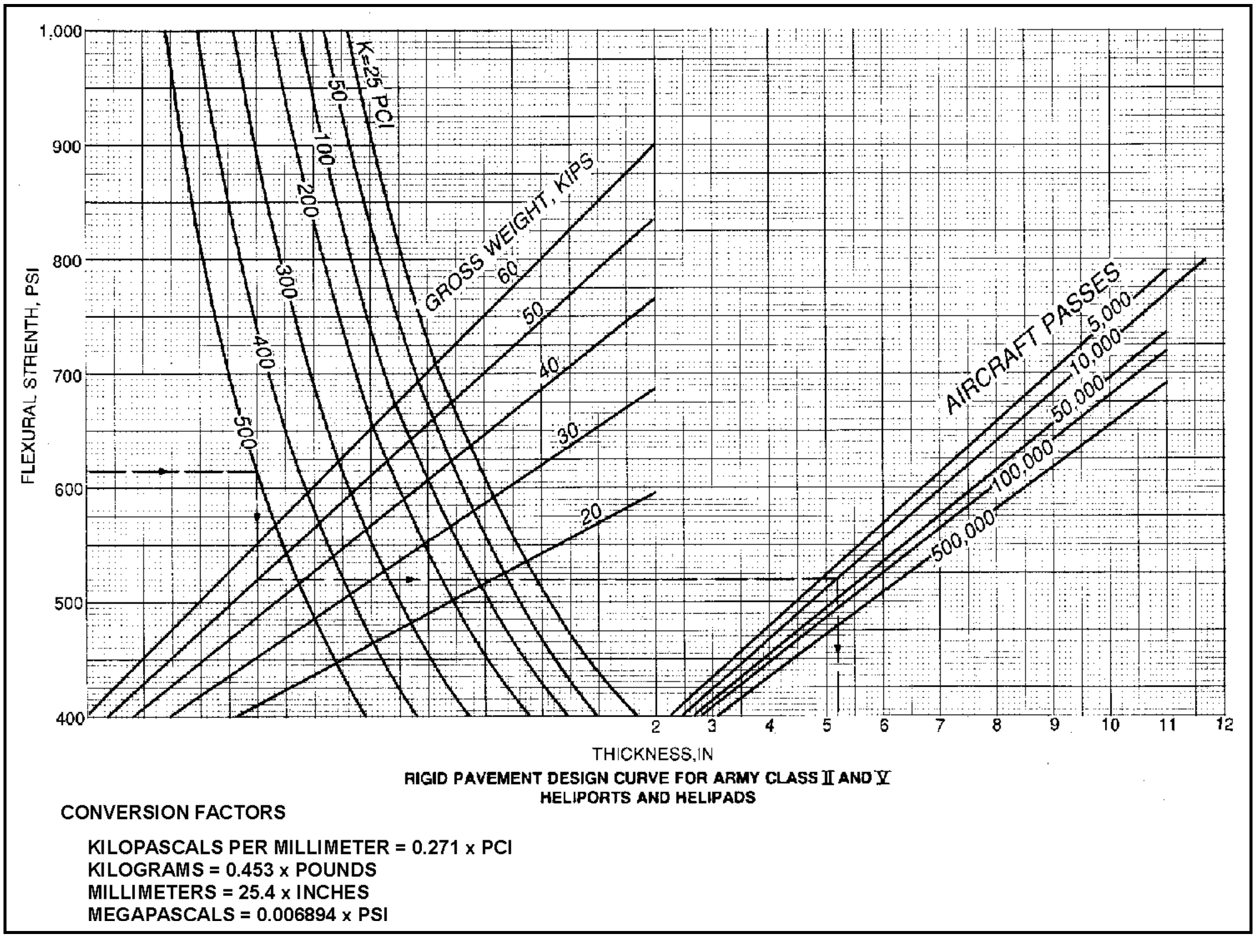
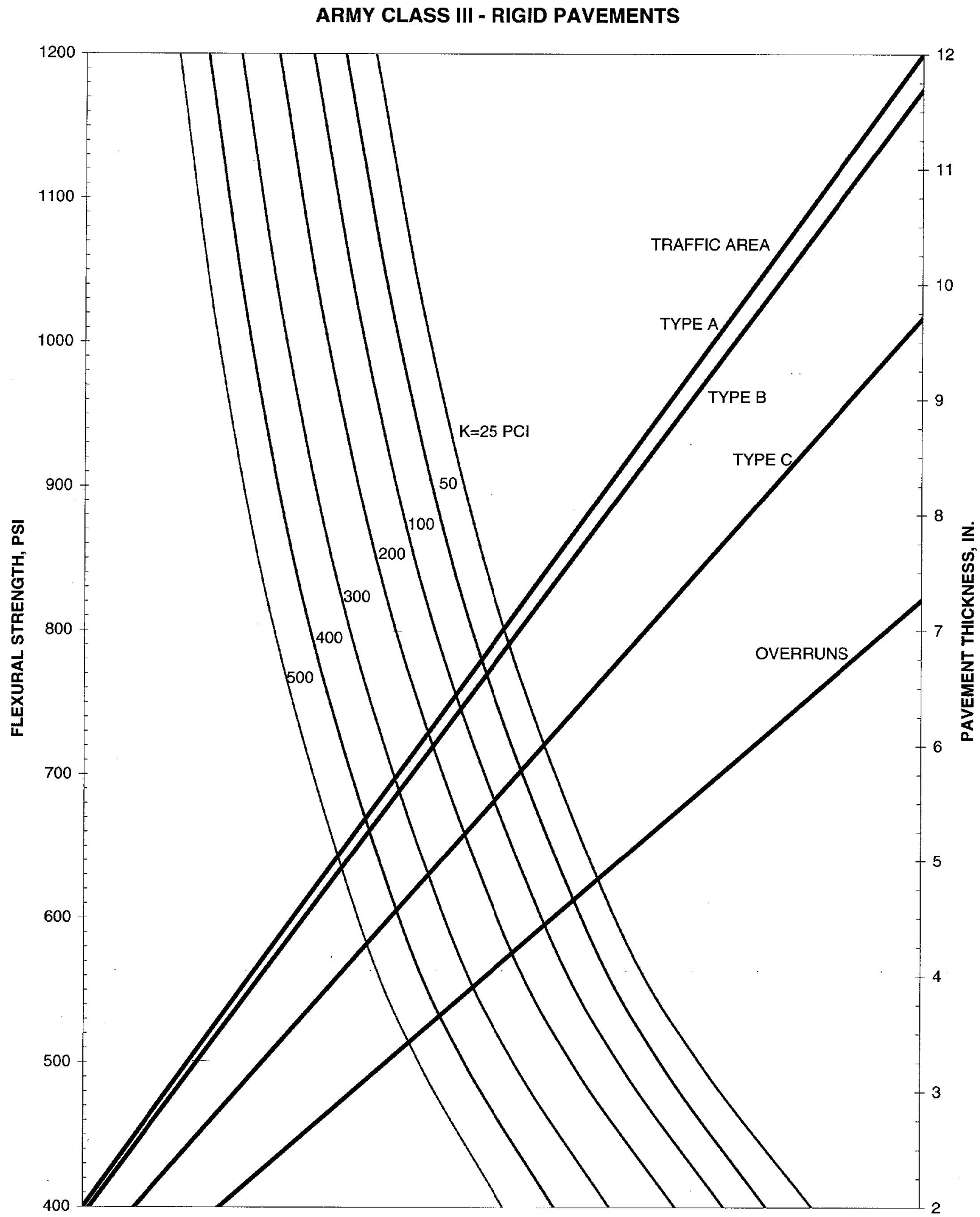


Figure 12-2. Plain concrete design curves for Army Class II airfields



CONVERSION FACTORS

KILOPASCALS PER MILLIMETER = 0.271 x PCI
KILOGRAMS = 0.453 x POUNDS
MILLIMETERS = 25.4 x INCHES
MEGAPASCALS = 0.006894 x PSI

Figure 12-3. Plain concrete design curves for Army Class III airfields as defined in paragraph 4.c of Chapter 2

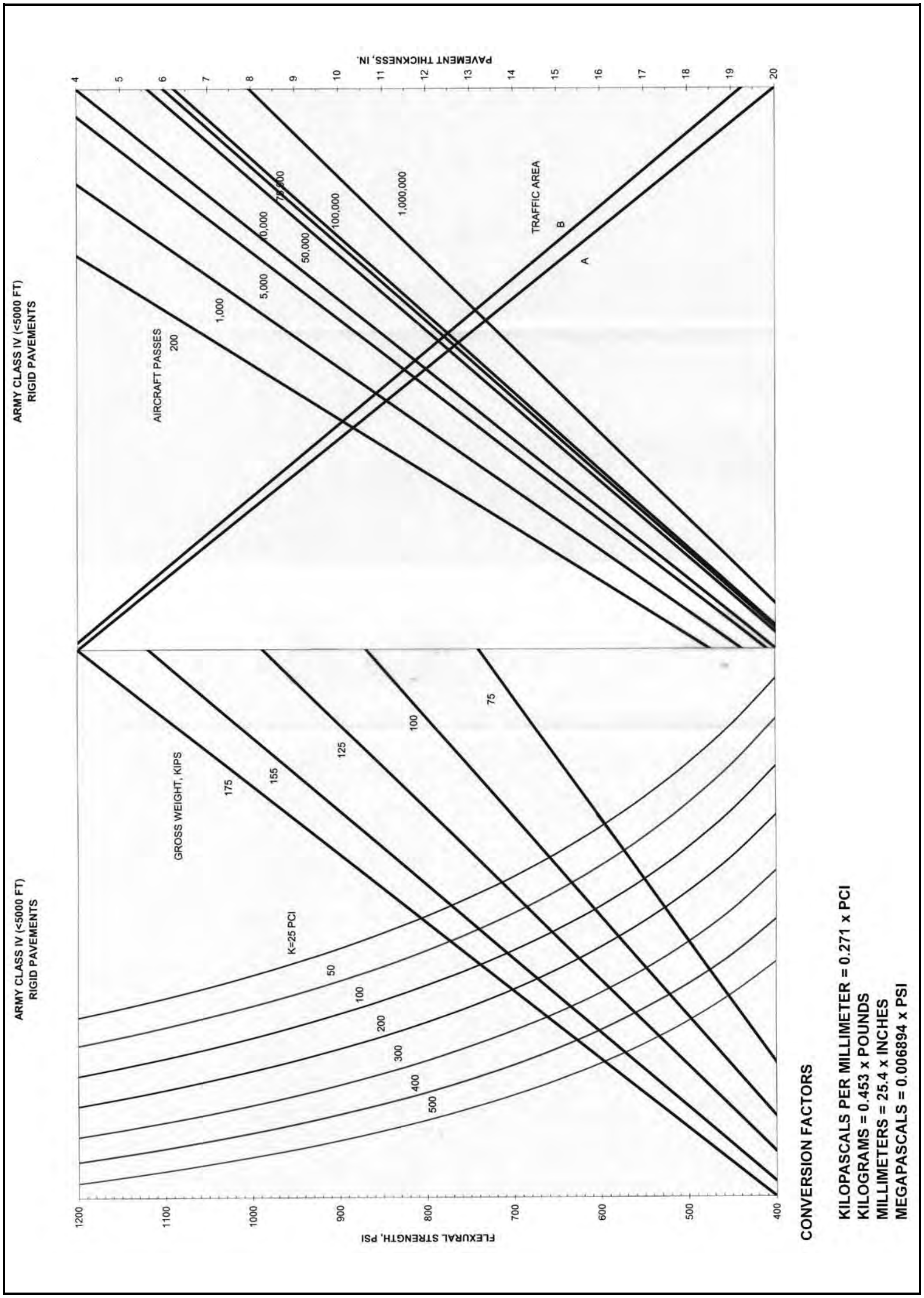


Figure 12-4. Plain concrete design curves for Army Class IV airfields (C-130 aircraft) with runway ≤ 1,525 meters (5,000 feet)

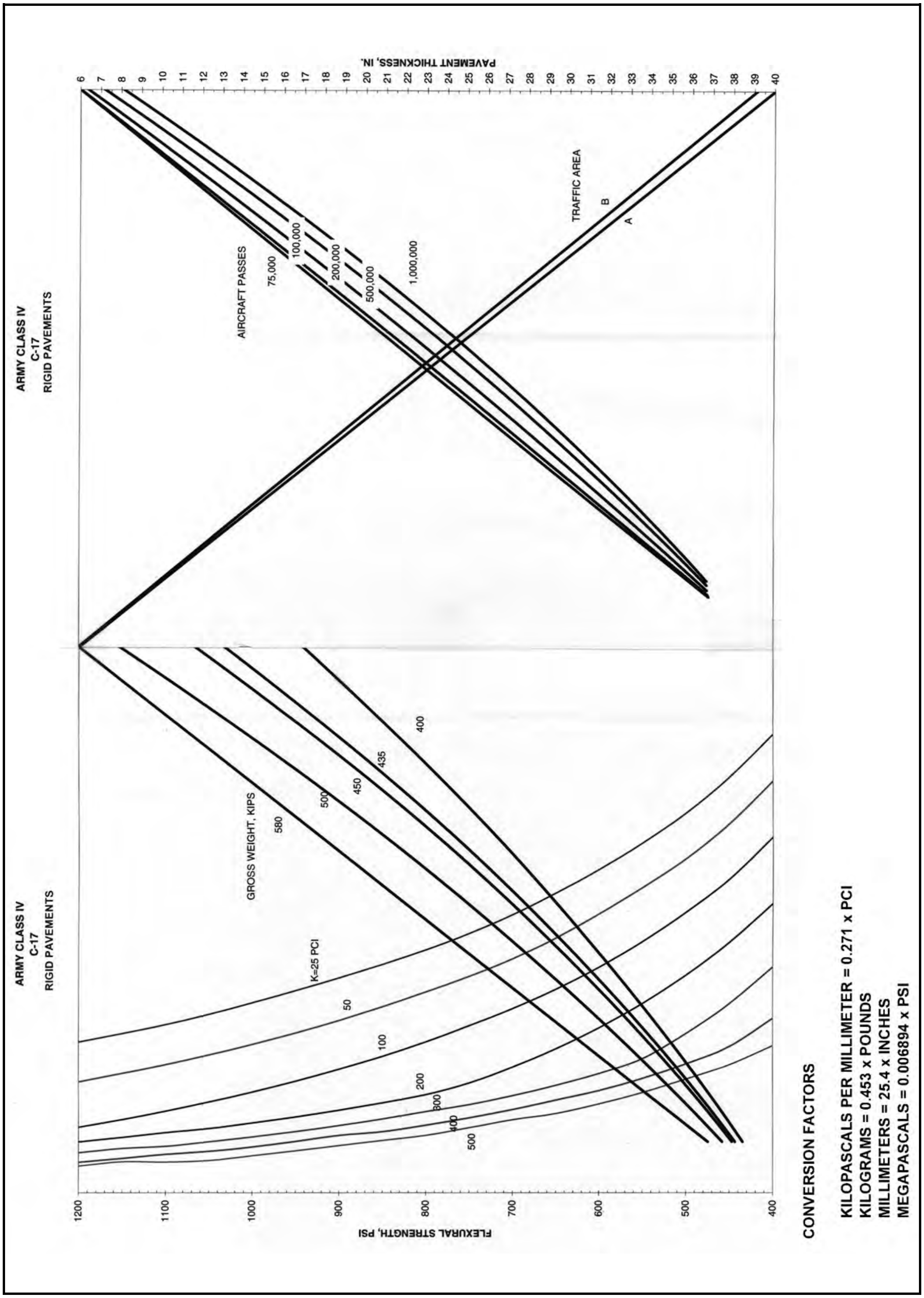
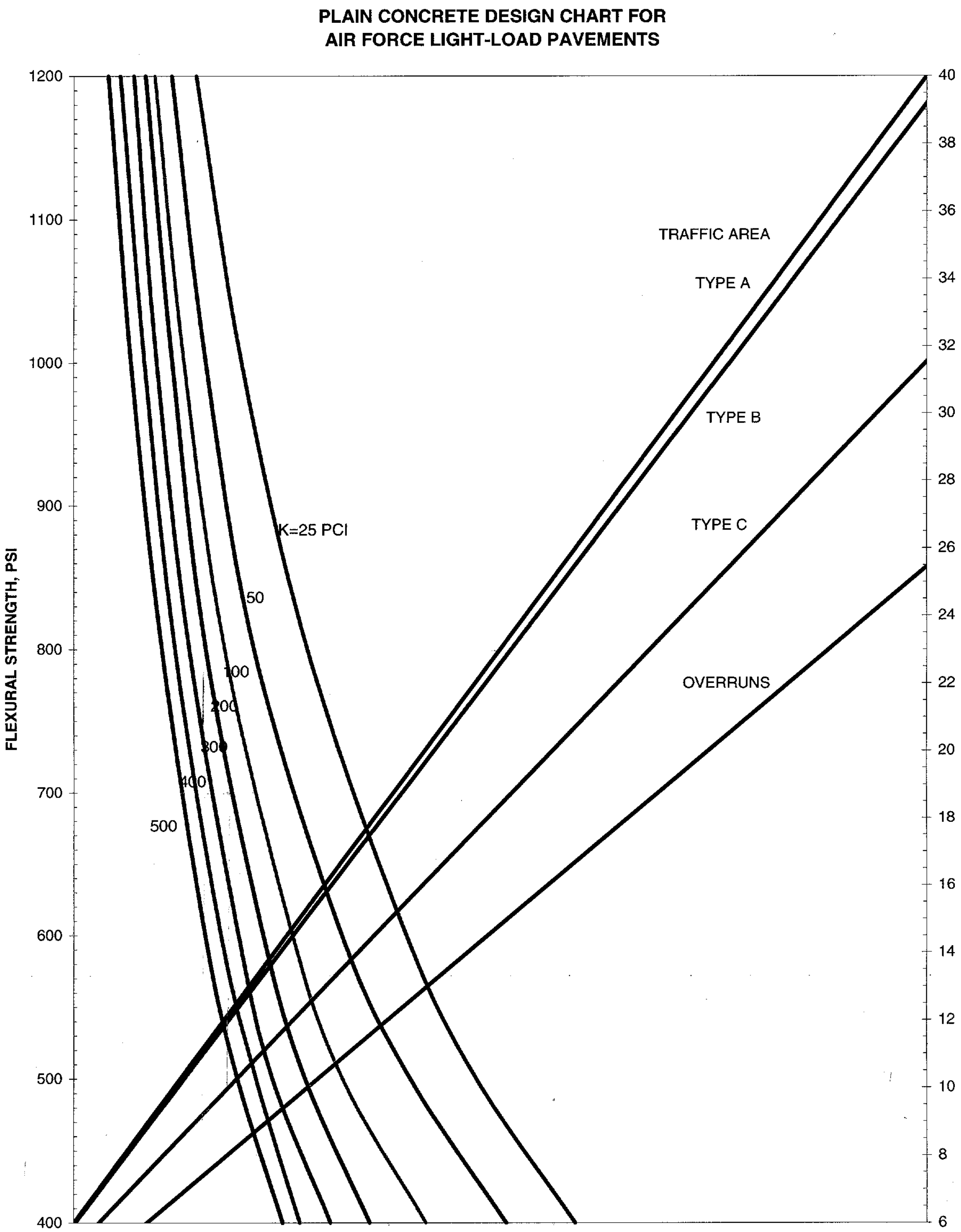


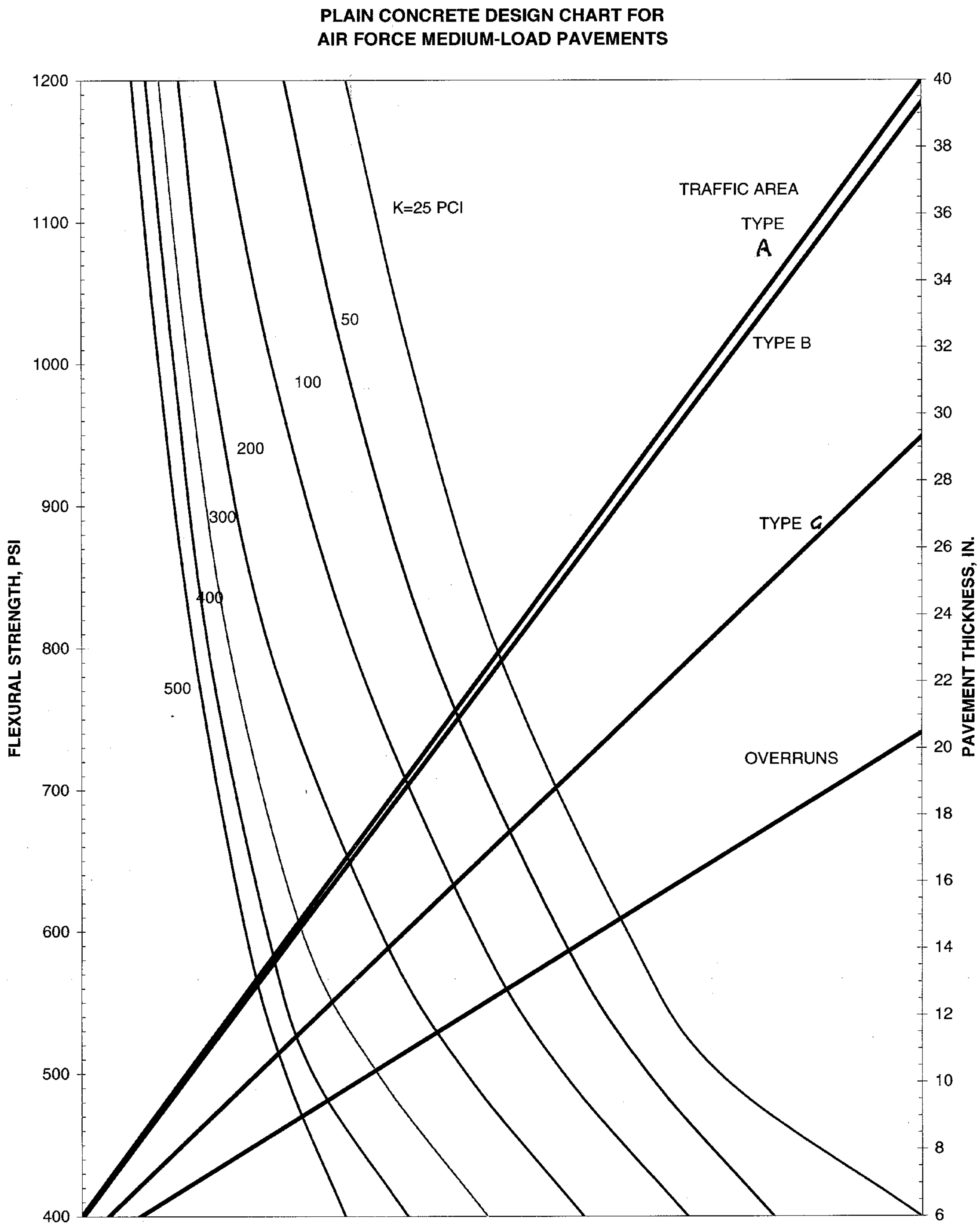
Figure 12-5. Plain concrete design curves for army Class IV airfields (C-17 aircraft) with runway > 2,745 meters (9,000 feet)



CONVERSION FACTORS

KILOPASCALS PER MILLIMETER = 0.271 x PCI
MILLIMETERS = 25.4 x INCHES
MEGAPASCALS = 0.006894 x PSI

Figure 12-6. Plain concrete design curves for Air Force light-load pavements



CONVERSION FACTORS

KILOPASCALS PER MILLIMETER = 0.271 x PCI
MILLIMETERS = 25.4 x INCHES
MEGAPASCALS = 0.006894 x PSI

Figure 12-7. Plain concrete design curves for Air Force medium-load pavements

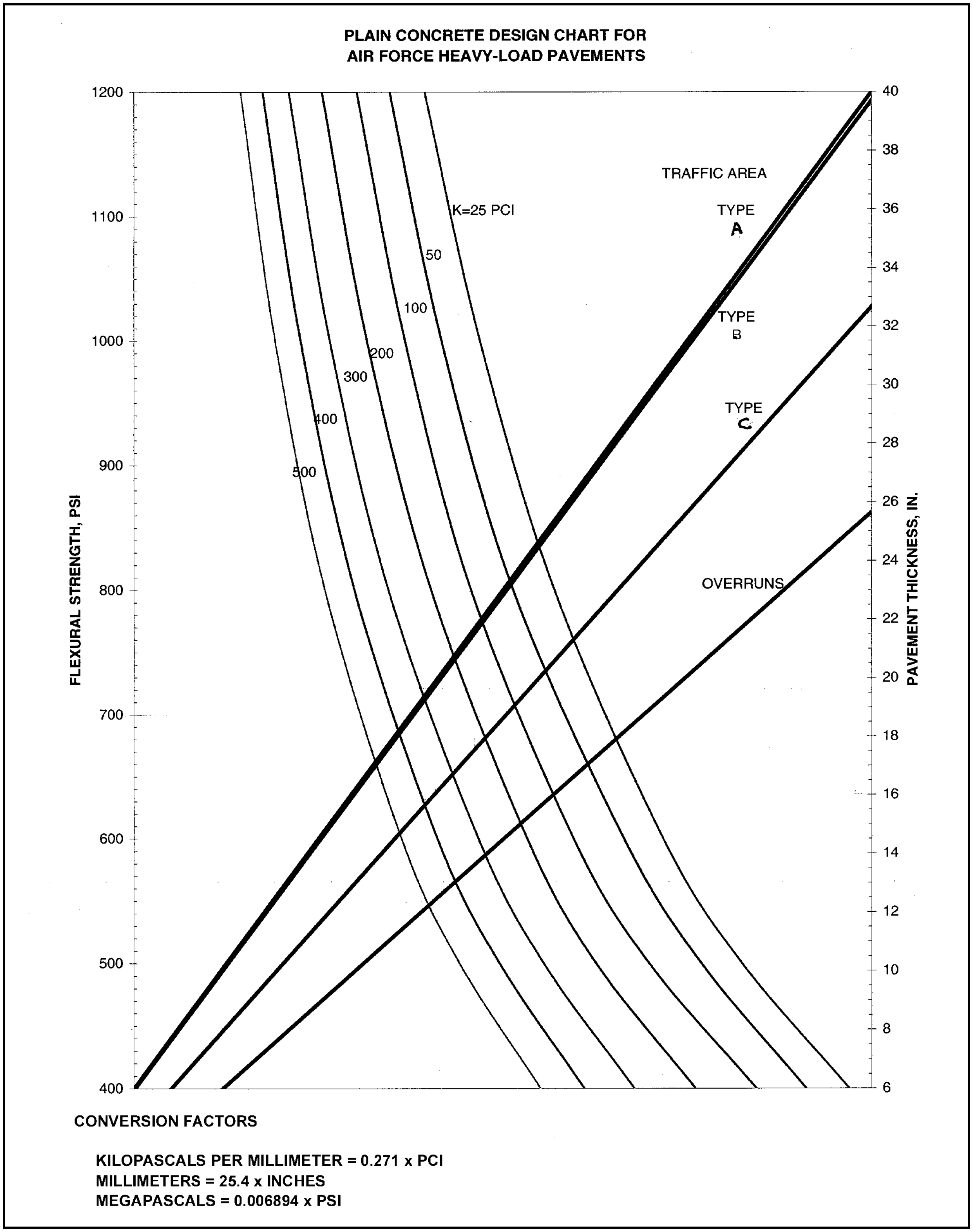


Figure 12-8. Plain concrete design curves for Air Force heavy-load pavements

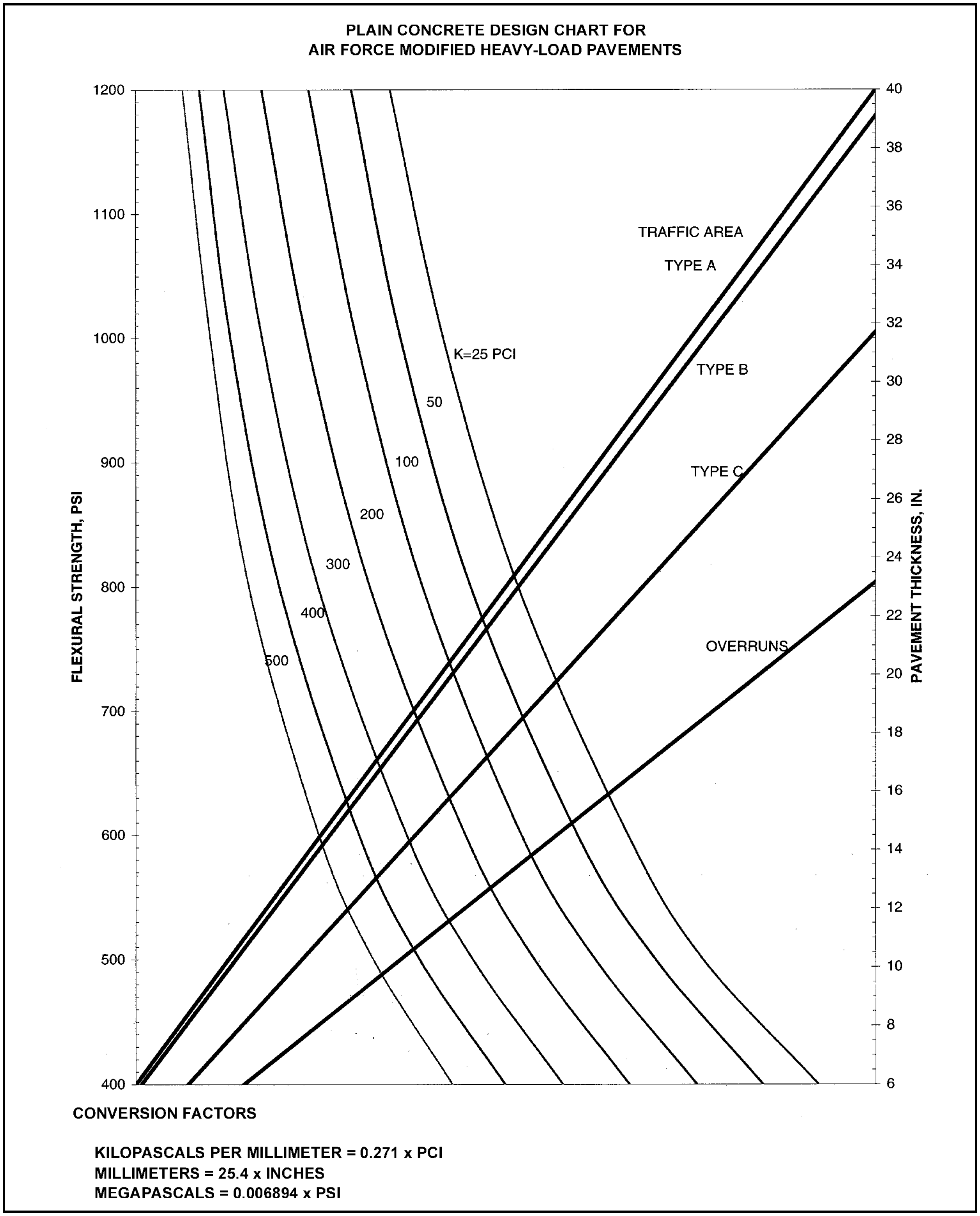
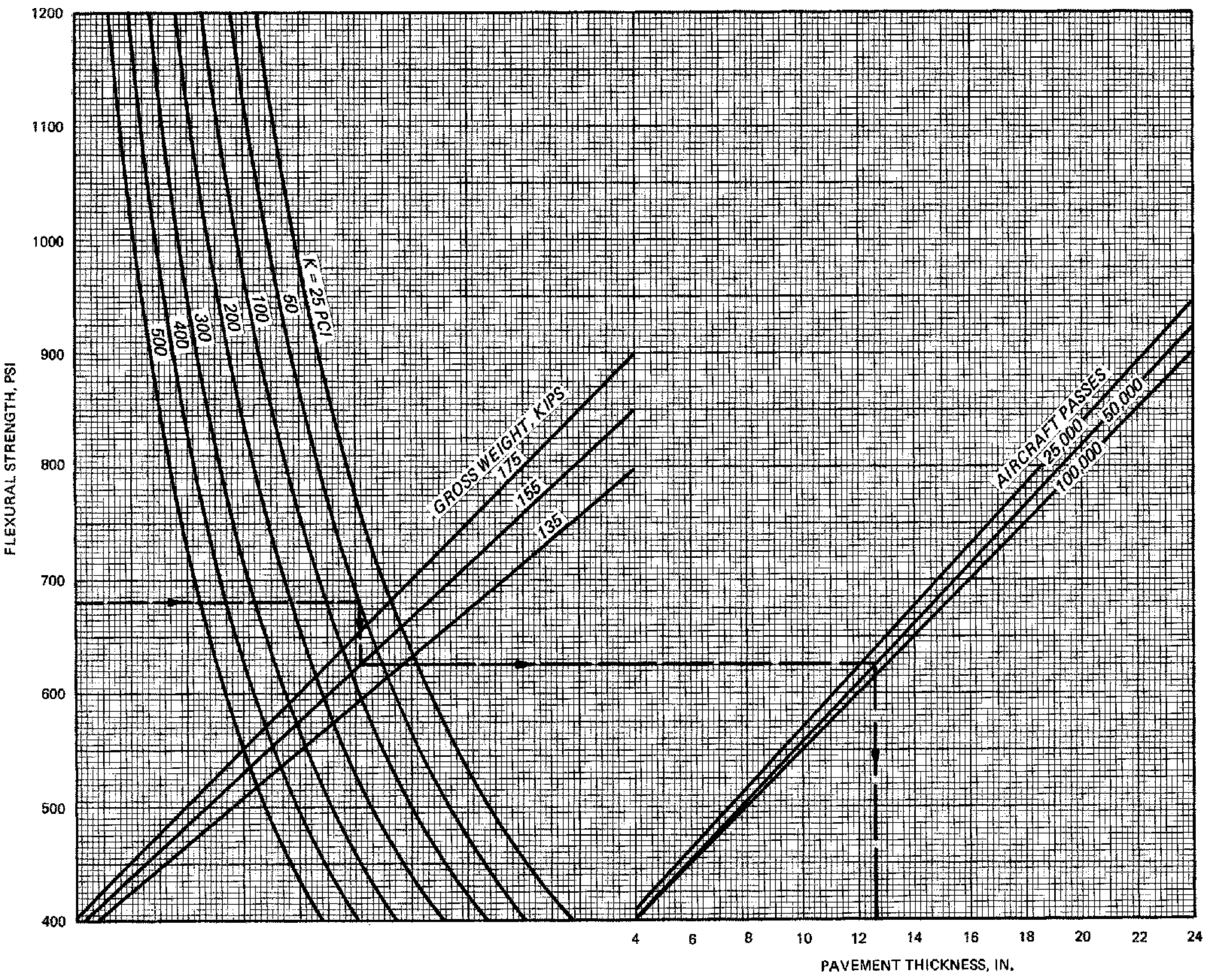


Figure 12-9. Plain concrete design curves for Air Force modified heavy-load pavements



RIGID PAVEMENT DESIGN CURVES FOR C-130 ASSAULT LANDING ZONE PAVEMENT

CONVERSION FACTORS

KILOPASCALS PER MILLIMETER = 0.271 x PCI
KILOGRAMS = 0.453 x POUNDS
MILLIMETERS = 25.4 x INCHES
MEGAPASCALS = 0.006894 x PSI

Figure 12-10. Plain concrete design curves for Air Force C-130 assault landing zone pavements

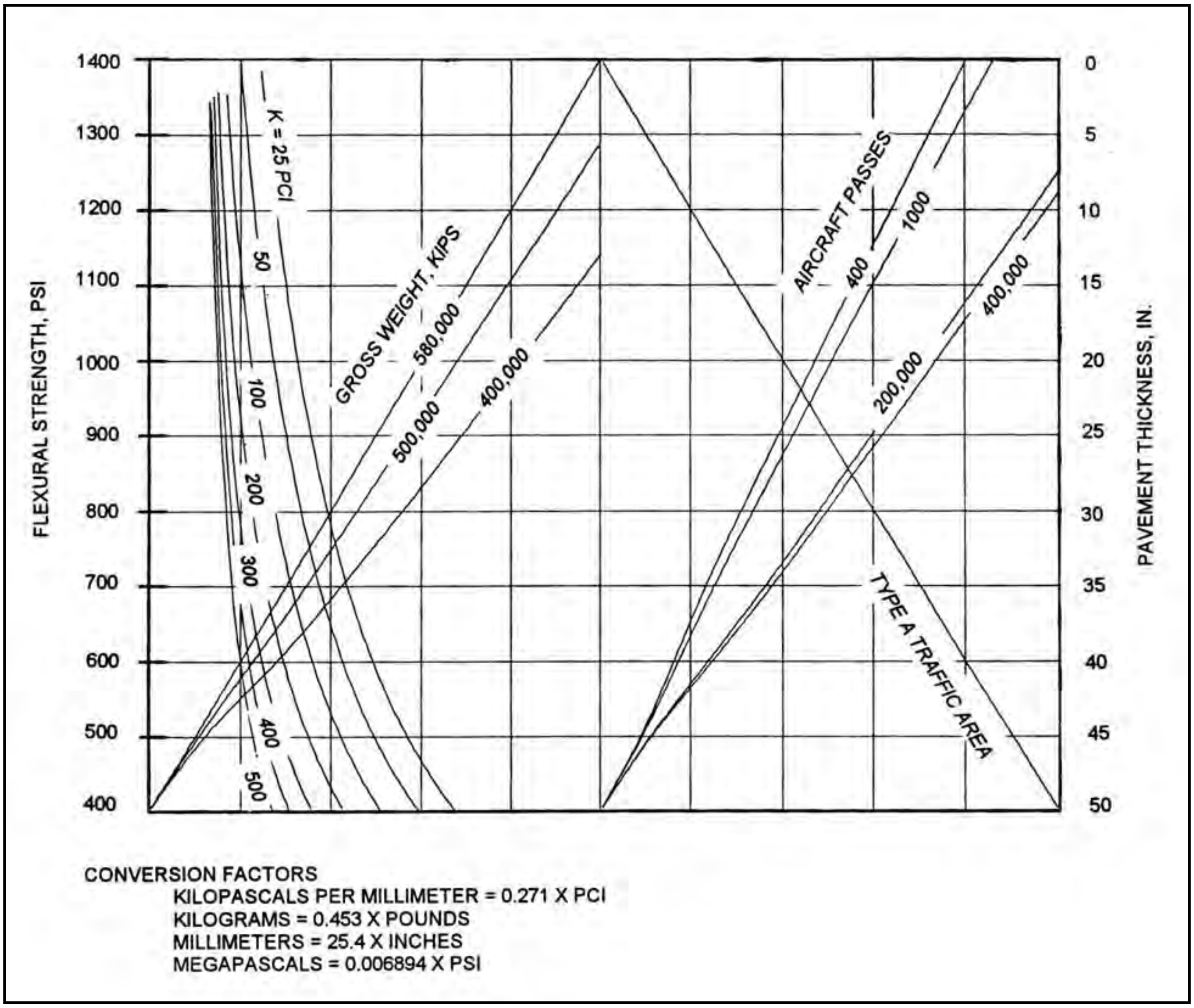


Figure 12-11. Plain concrete design curves for Air Force C-17 assault landing zone

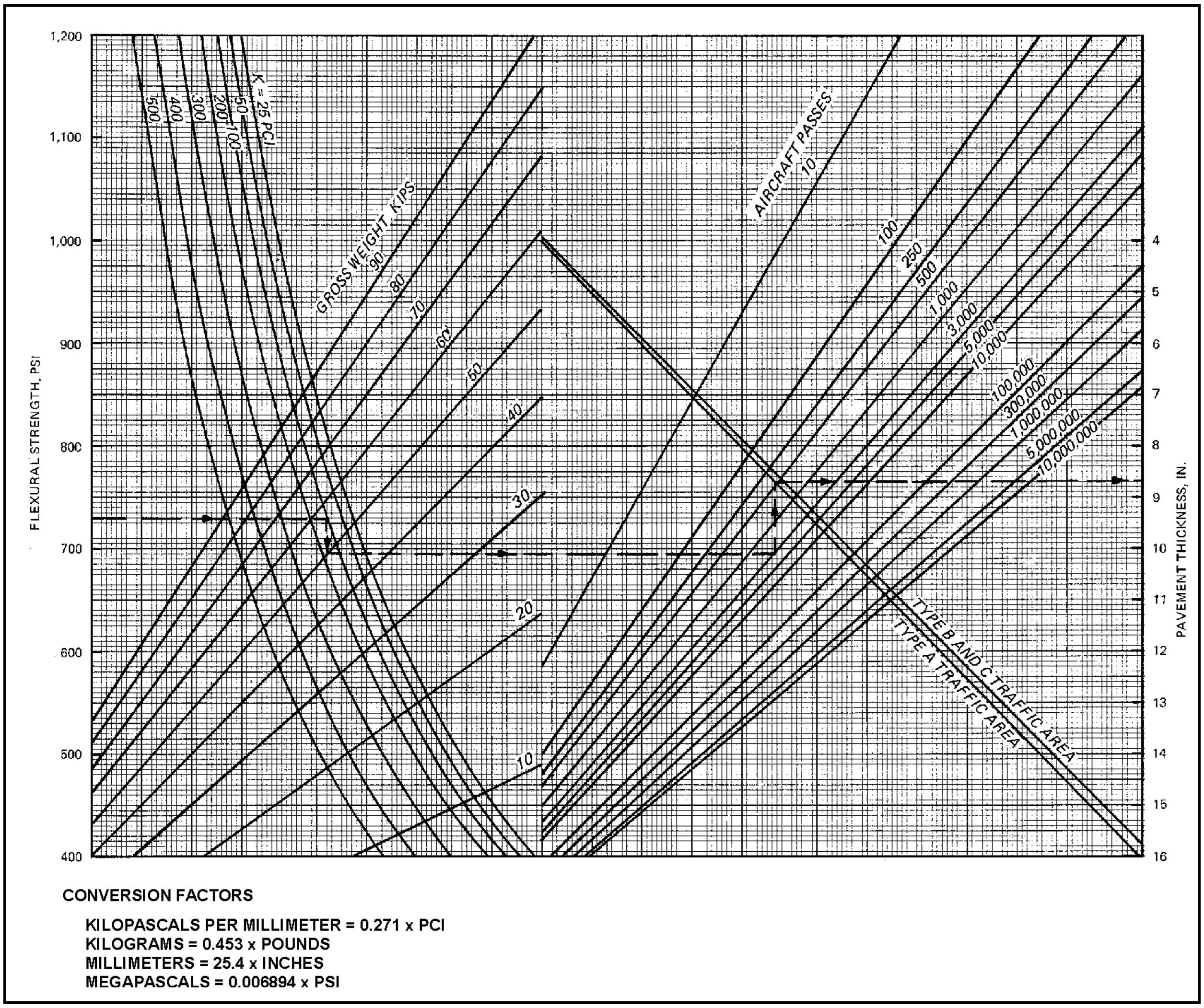
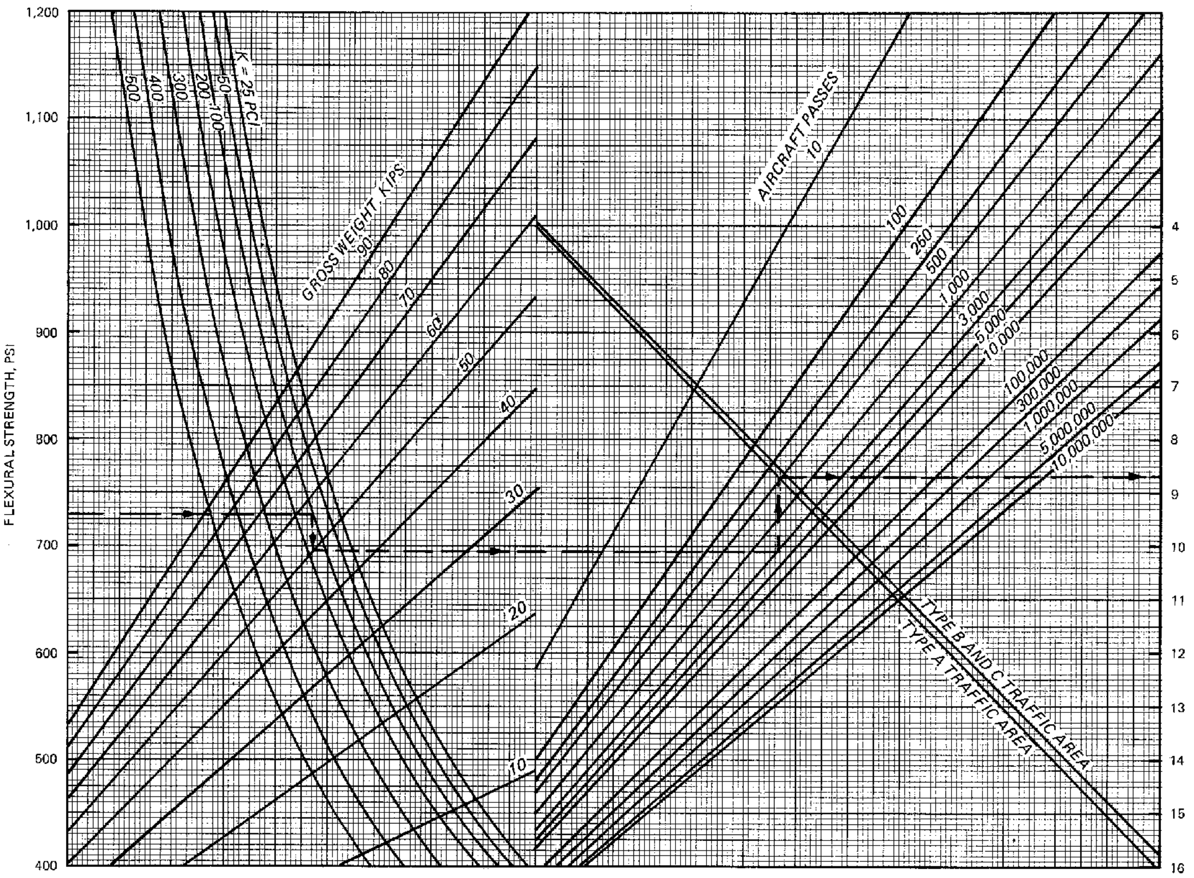


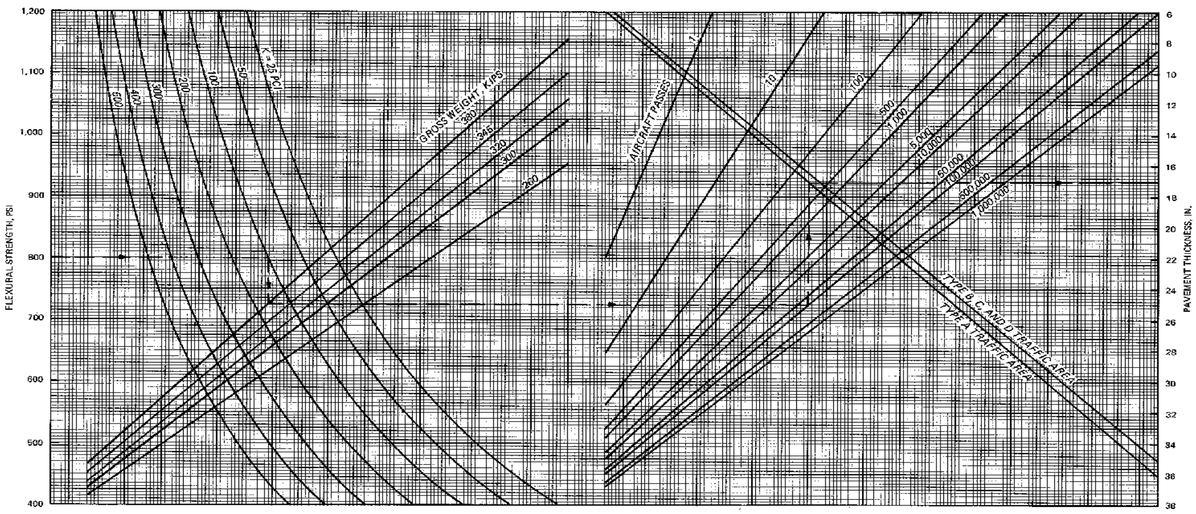
Figure 12-12. Plain concrete design curves for Air Force auxiliary pavements



CONVERSION FACTORS

KILOPASCALS PER MILLIMETER = 0.271 x PCI
KILOGRAMS = 0.453 x POUNDS
MILLIMETERS = 25.4 x INCHES
MEGAPASCALS = 0.006894 x PSI

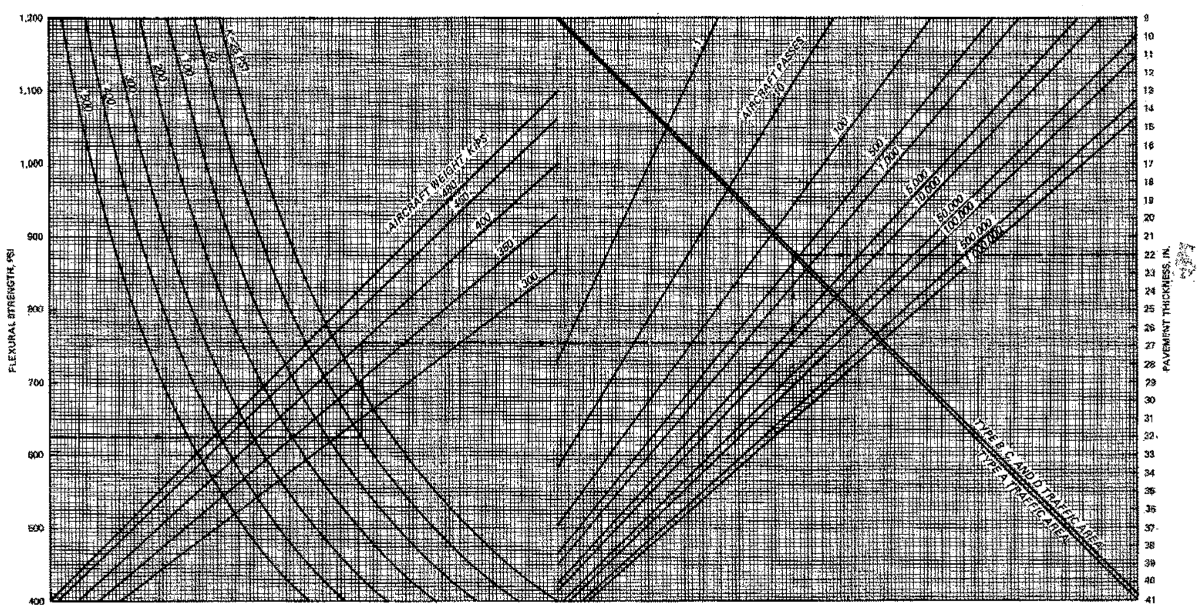
Figure 12-13. Plain concrete design curves for F-15 aircraft



CONVERSION FACTORS

MEGANEWTONS PER CUBIC METER = 0.0271 x PCI
KILOGRAMS = 0.453 x POUNDS
MILLIMETERS = 25.4 x INCHES
MEGAPASCALS = 0.006894 x PSI

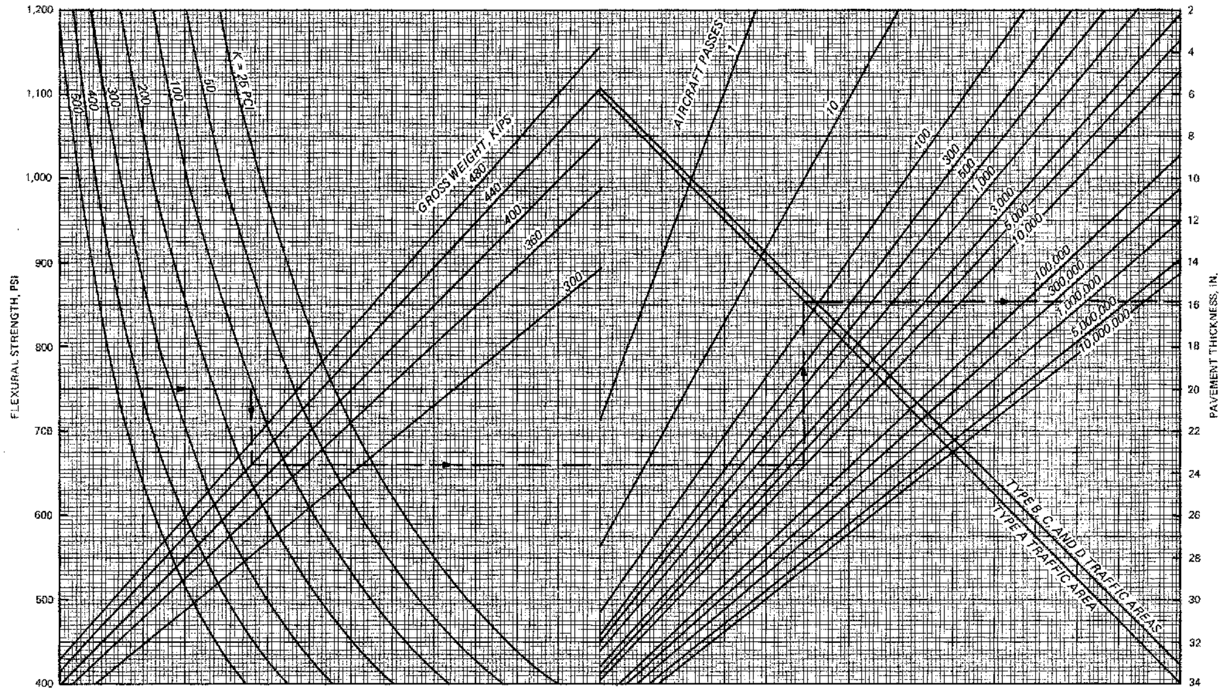
Figure 12-14. Plain concrete design curves for C-141 aircraft



CONVERSION FACTORS

KILOPASCALS PER MILLIMETER = 0.271 x PCI
KILOGRAMS = 0.453 x POUNDS
MILLIMETERS = 25.4 x INCHES
MEGAPASCALS = 0.006894 x PSI

Figure 12-15. Plain concrete design curves for B-52 aircraft

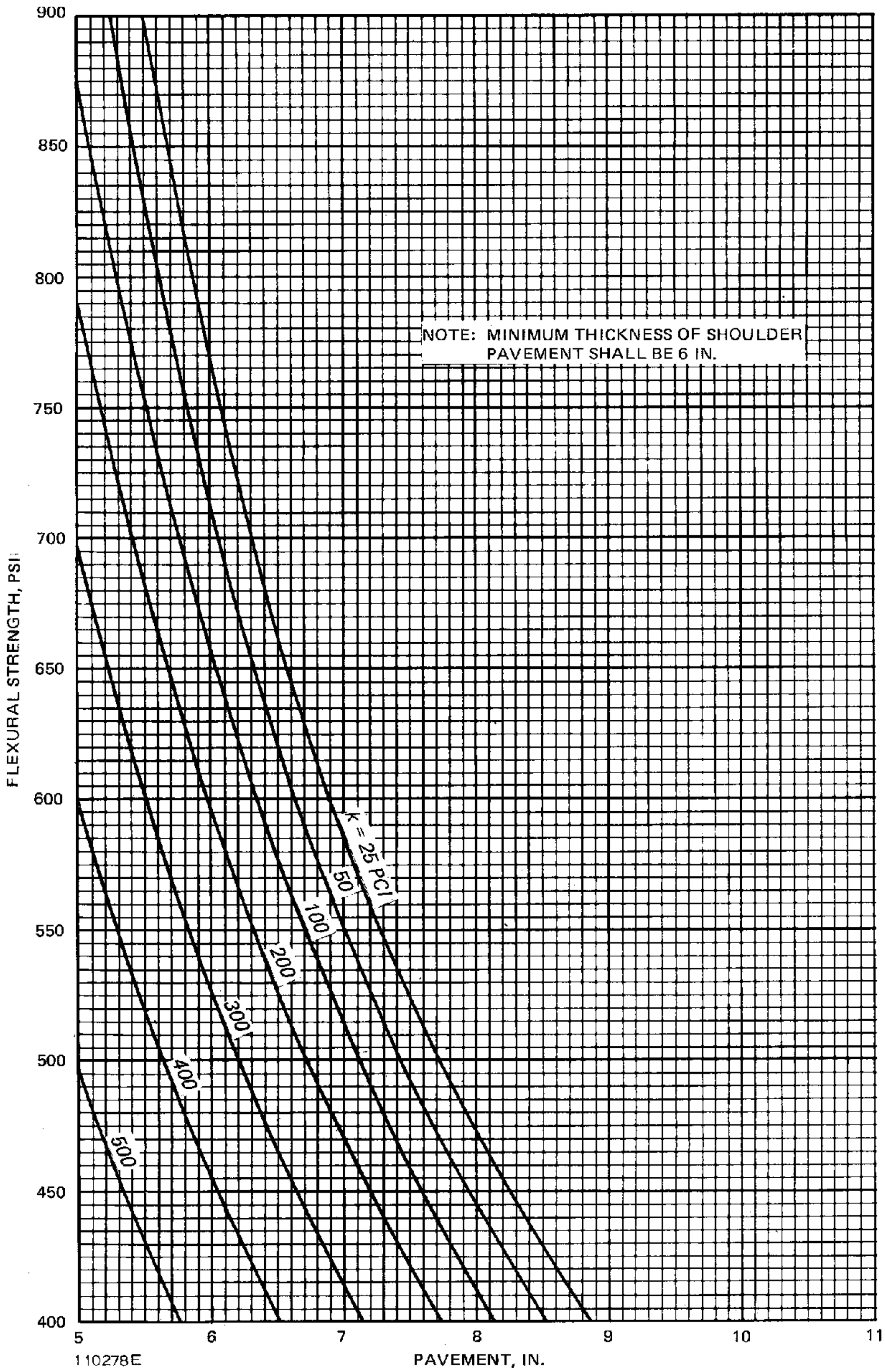


RIGID PAVEMENT DESIGN CURVE FOR B-1 AIRCRAFT

CONVERSION FACTORS

KILOPASCALS PER MILLIMETER = 0.271 x PCI
KILOGRAMS = 0.453 x POUNDS
MILLIMETERS = 25.4 x INCHES
MEGAPASCALS = 0.006894 x PSI

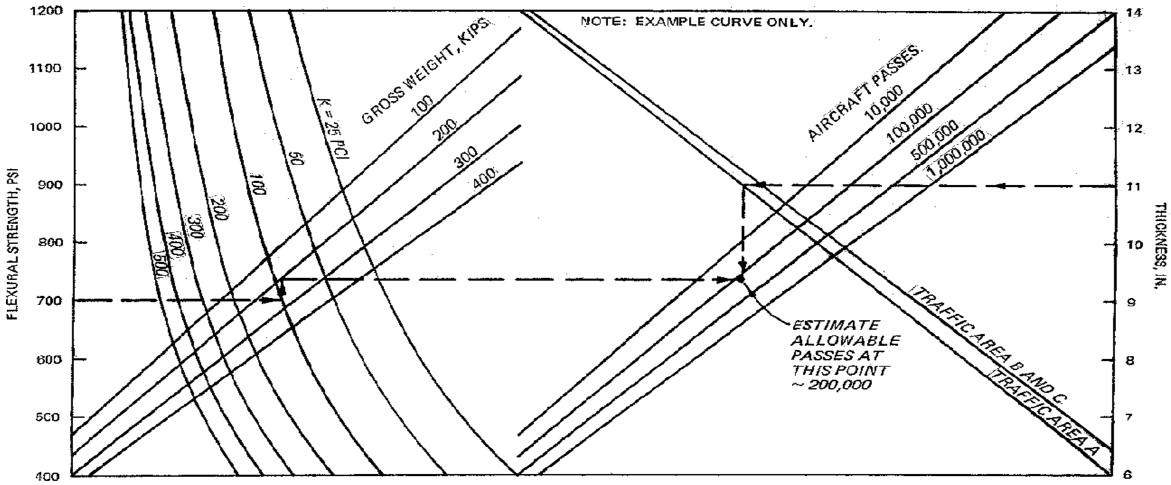
Figure 12-16. Plain concrete design curves for B-1 aircraft



CONVERSION FACTORS

KILOPASCALS PER MILLIMETER = 0.271 x PCI
MILLIMETERS = 25.4 x INCHES
MEGAPASCALS = 0.006894 x PSI

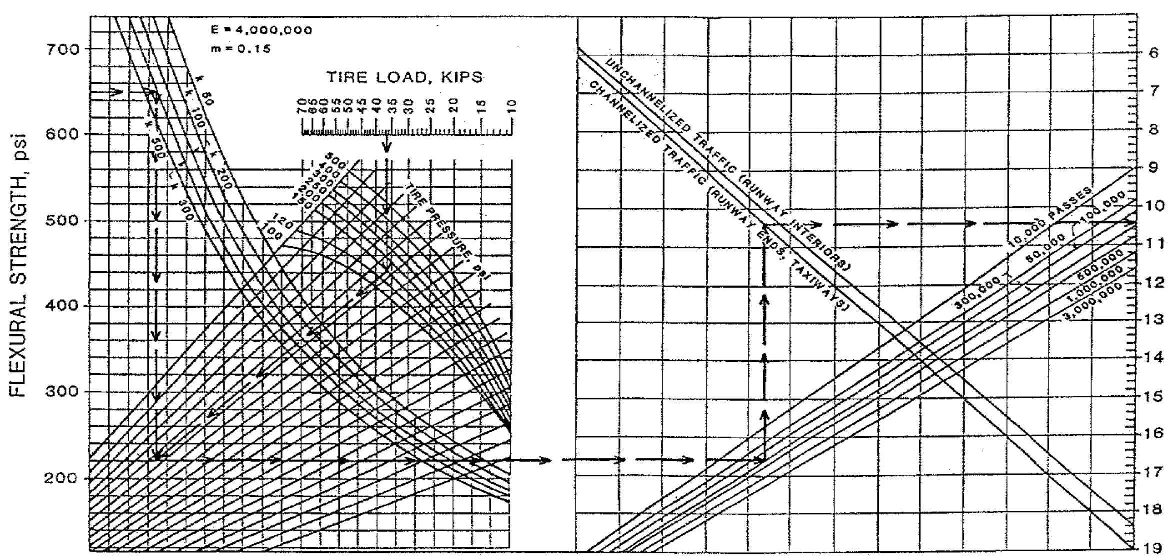
Figure 12-17. Plain concrete design curves for shoulders



CONVERSION FACTORS

KILOPASCALS PER MILLIMETER = 0.271 x PCI
KILOGRAMS = 0.453 x POUNDS
MILLIMETERS = 25.4 x INCHES
MEGAPASCALS = 0.006894 x PSI

Figure 12-18. Example of allowable passes determination



CONVERSION FACTORS

MEGANEWTONS PER CUBIC METER = 0.0271 x PCI
KILOGRAMS = 0.453 x POUNDS
MILLIMETERS = 25.4 x INCHES
MEGAPASCALS = 0.006894 x PSI

Figure 12-19. Rigid pavement thickness design chart for single-wheel load (Navy)

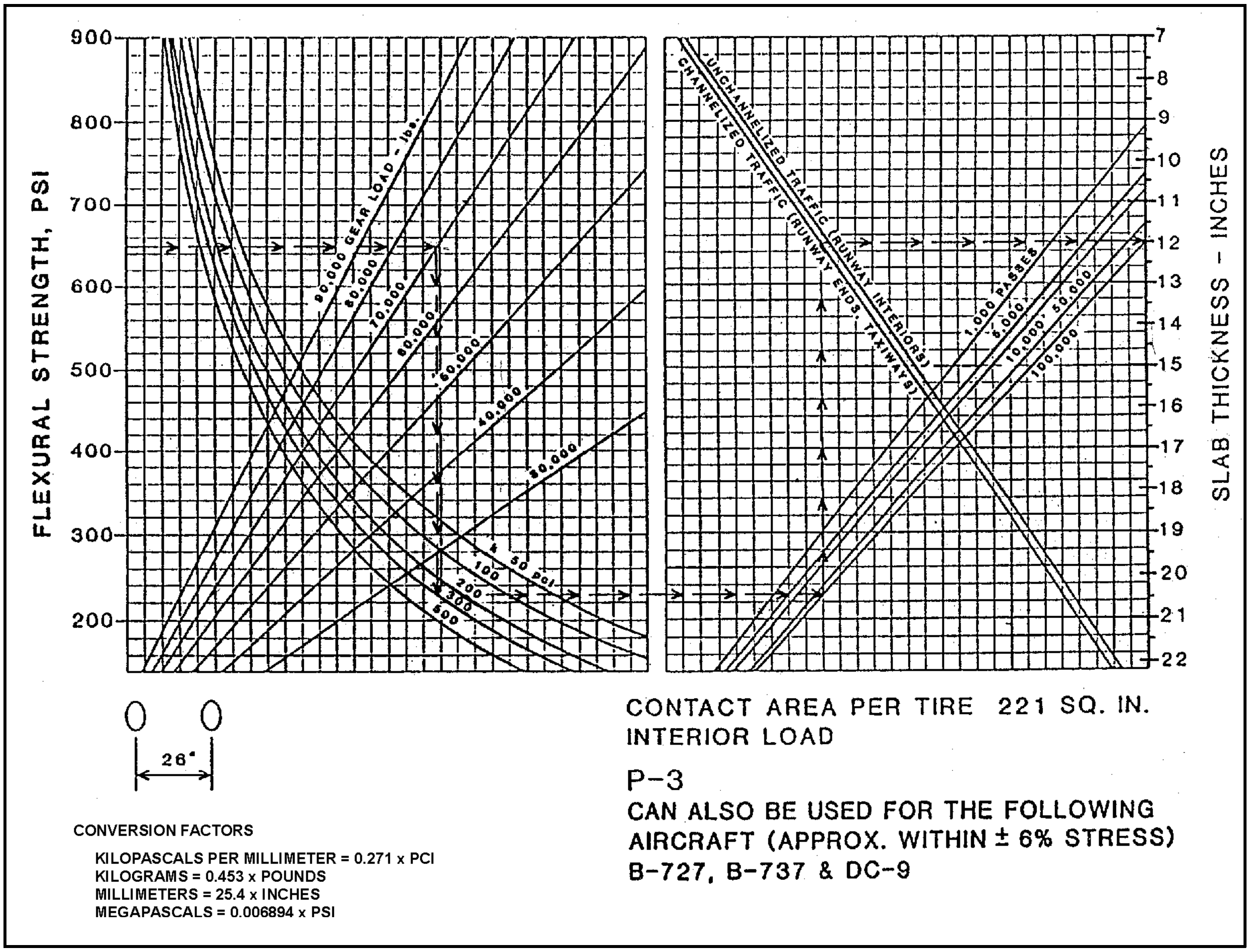


Figure 12-20. Rigid pavement thickness design chart for P-3 aircraft (Navy)

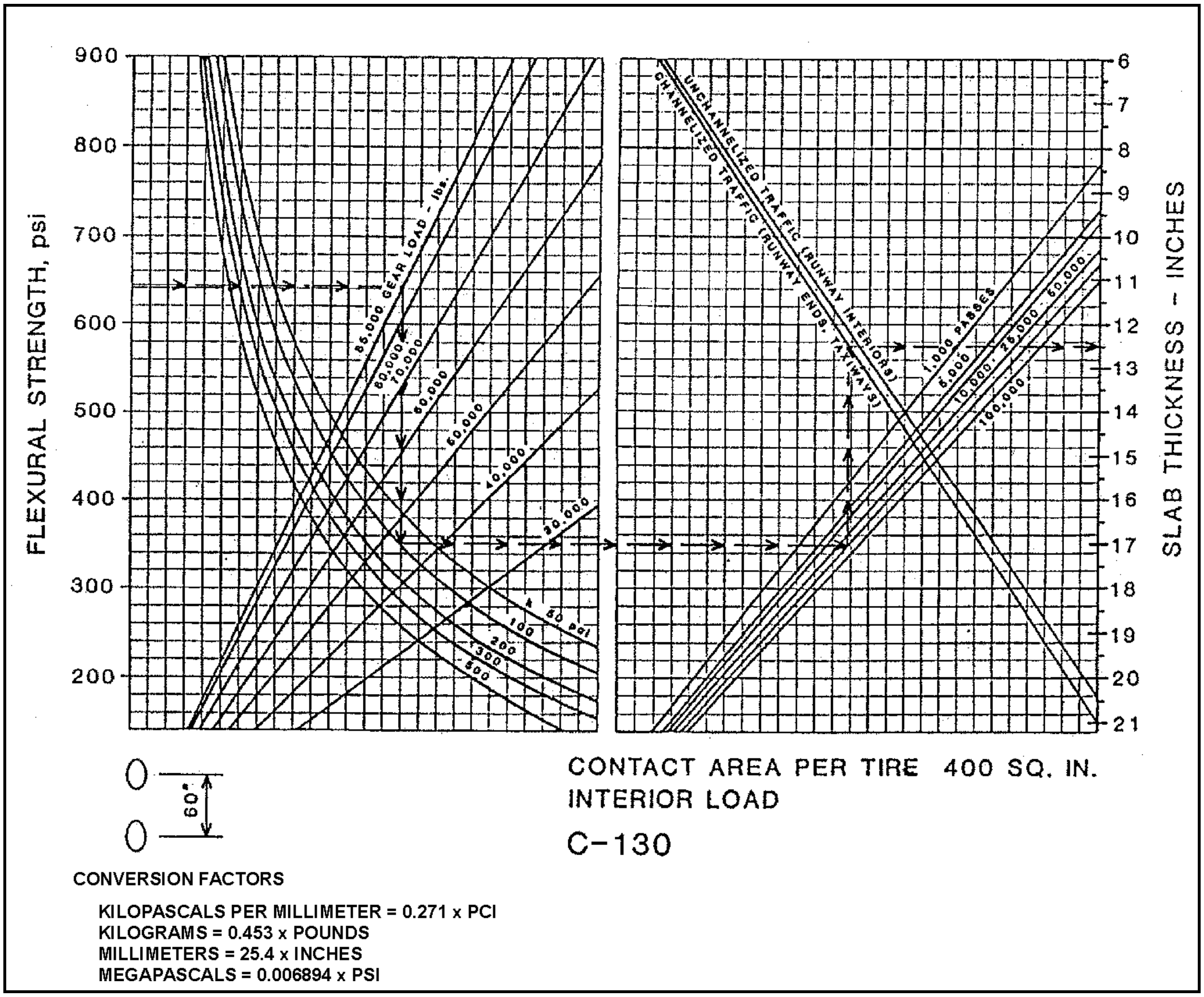


Figure 12-21. Rigid pavement thickness design chart for C-130 aircraft (Navy)

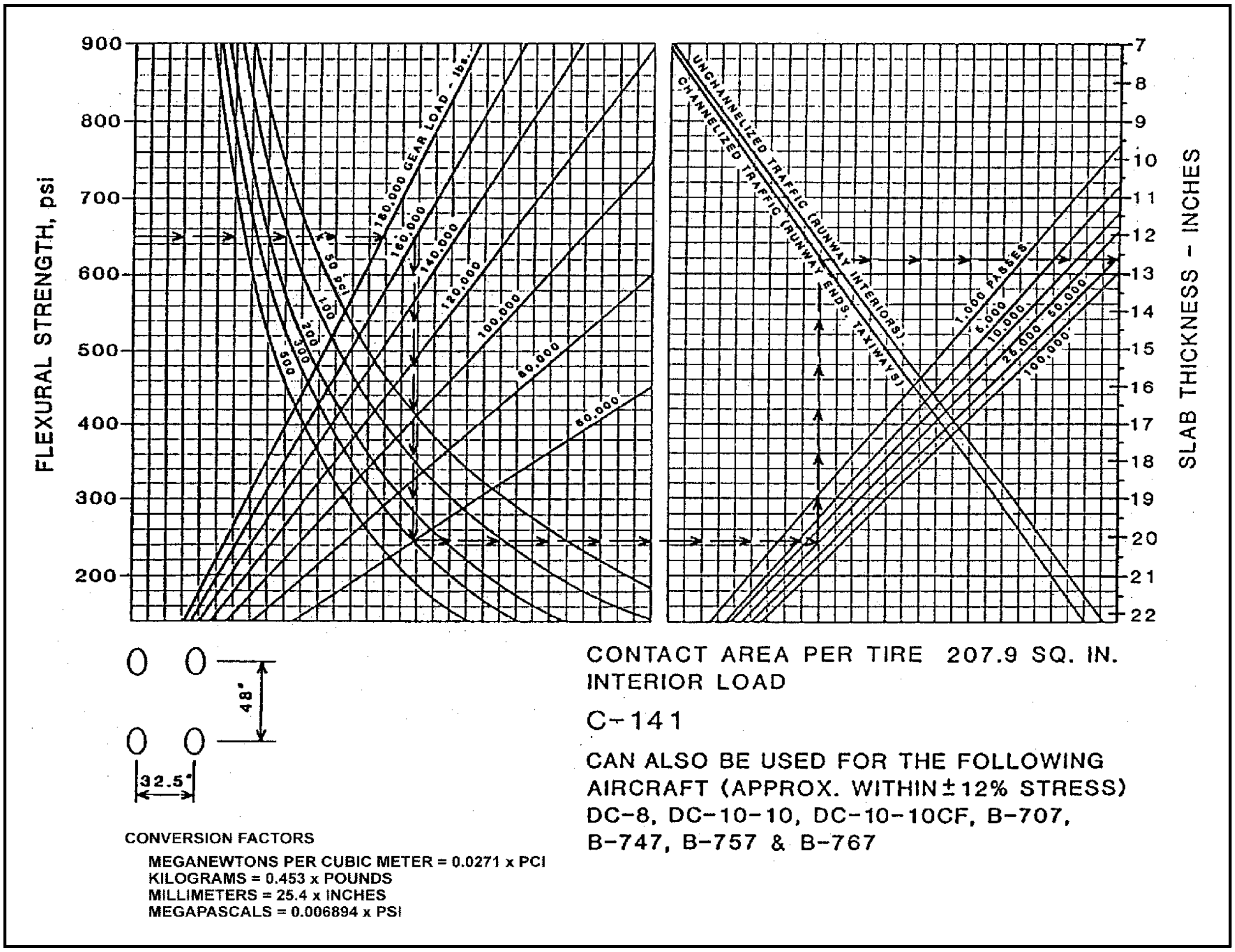


Figure 12-22. Rigid pavement thickness design chart for C-141 aircraft (Navy)

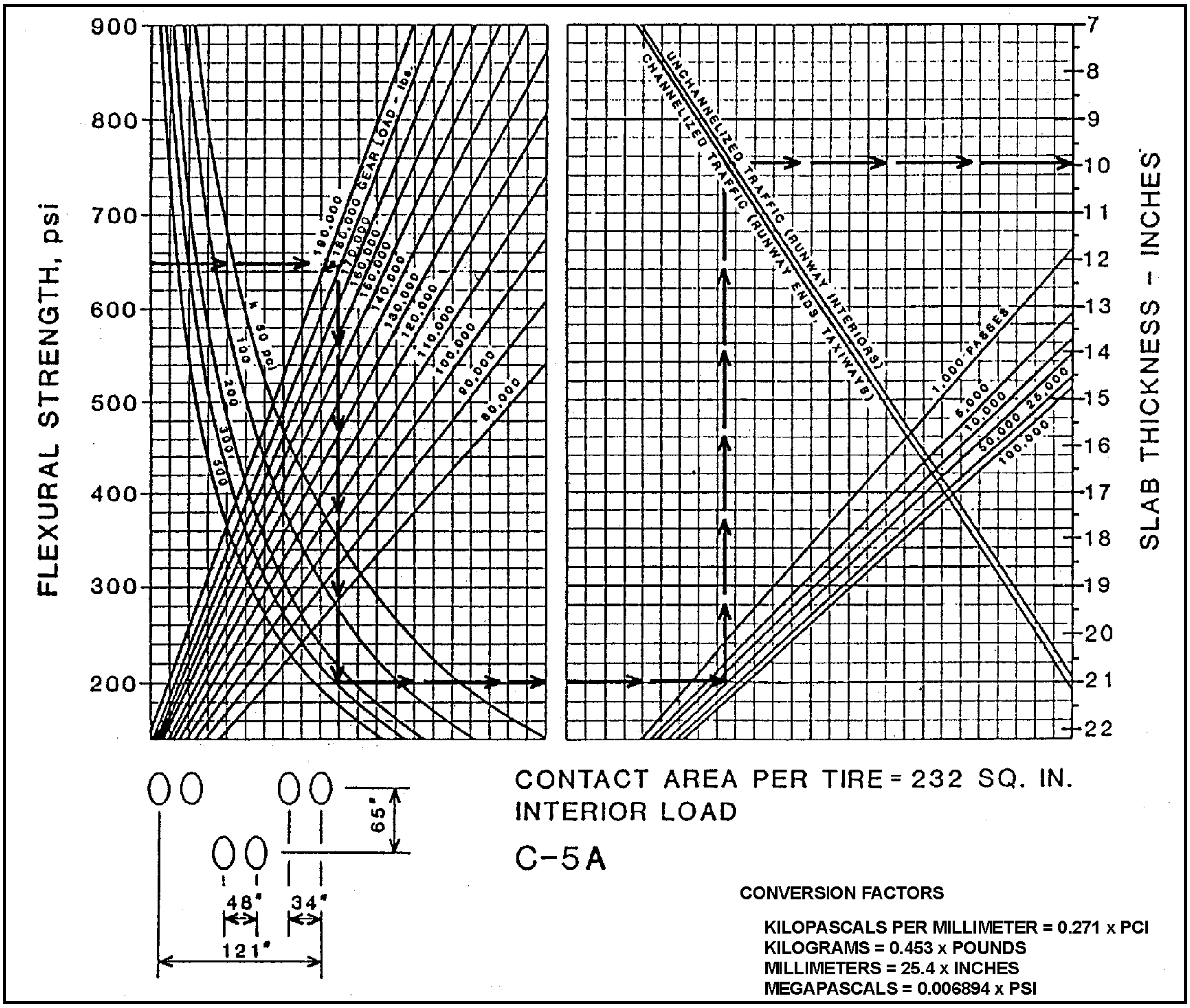
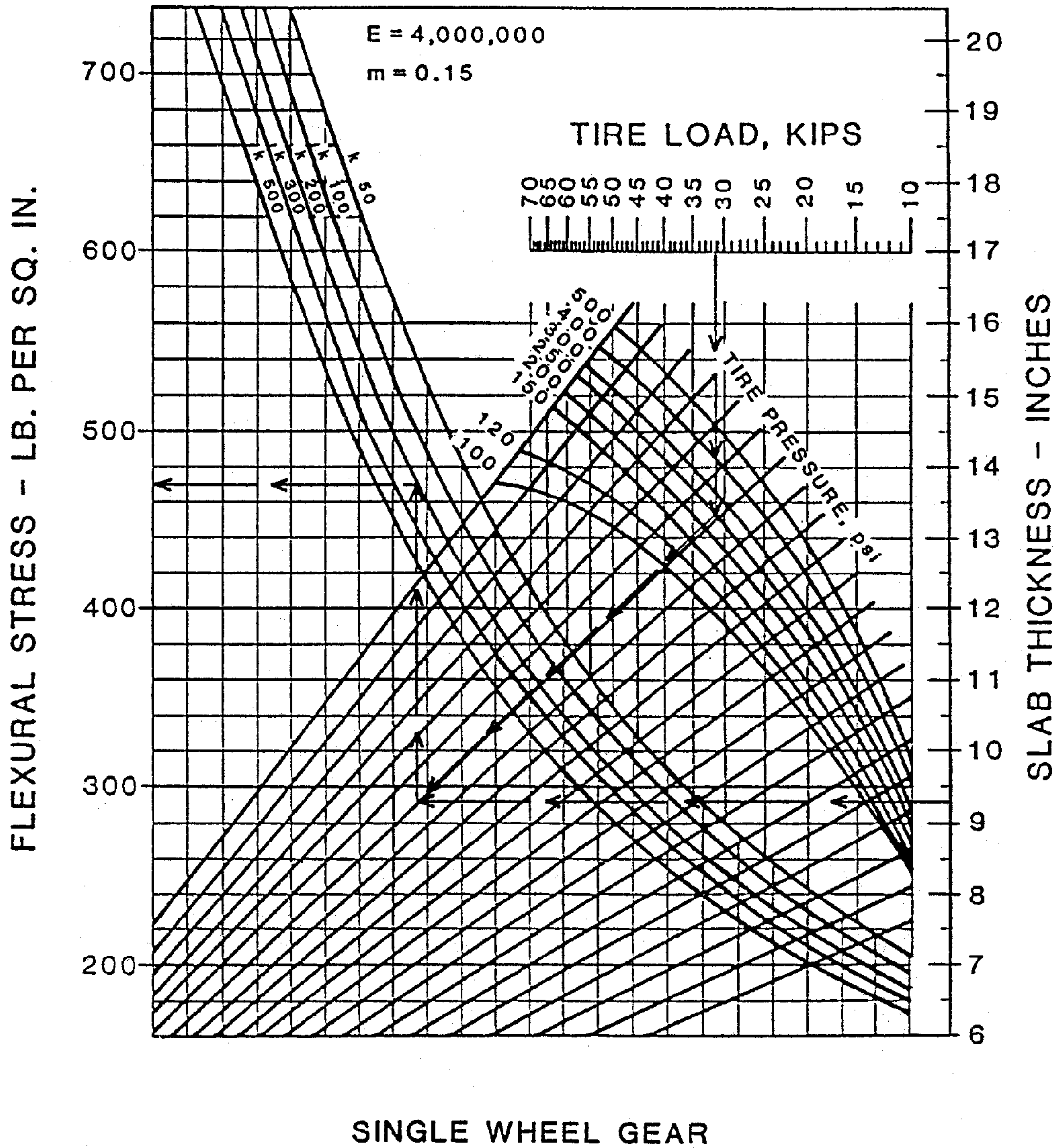


Figure 12-23. Rigid pavement thickness design chart for C-5A aircraft (Navy)



CONVERSION FACTORS

KILOPASCALS PER MILLIMETER = 0.271 x PCI
KILOGRAMS = 0.453 x POUNDS
MILLIMETERS = 25.4 x INCHES
MEGAPASCALS = 0.006894 x PSI

Figure 12-24. Chart for determining flexural stress for single-wheel gear (Navy)

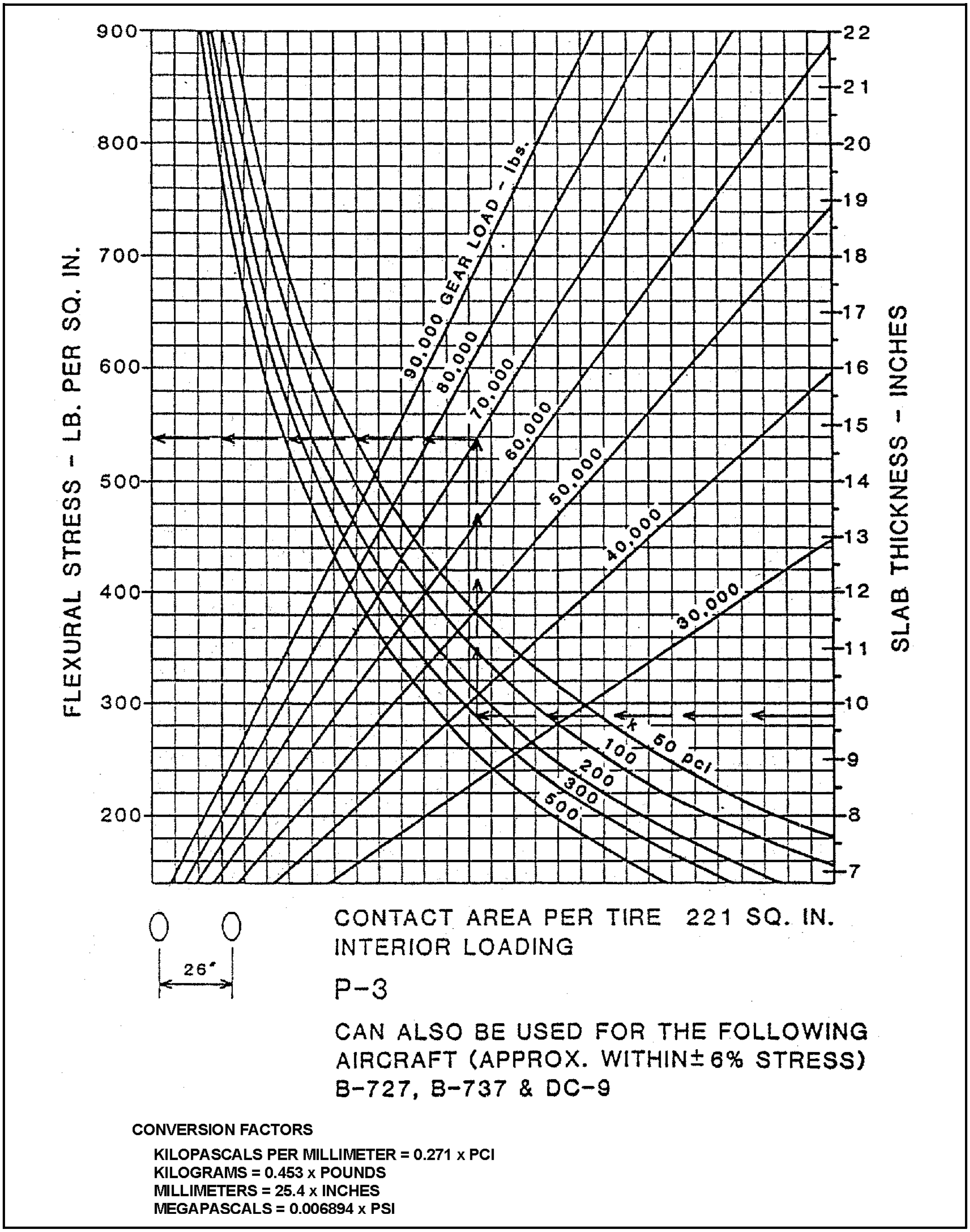
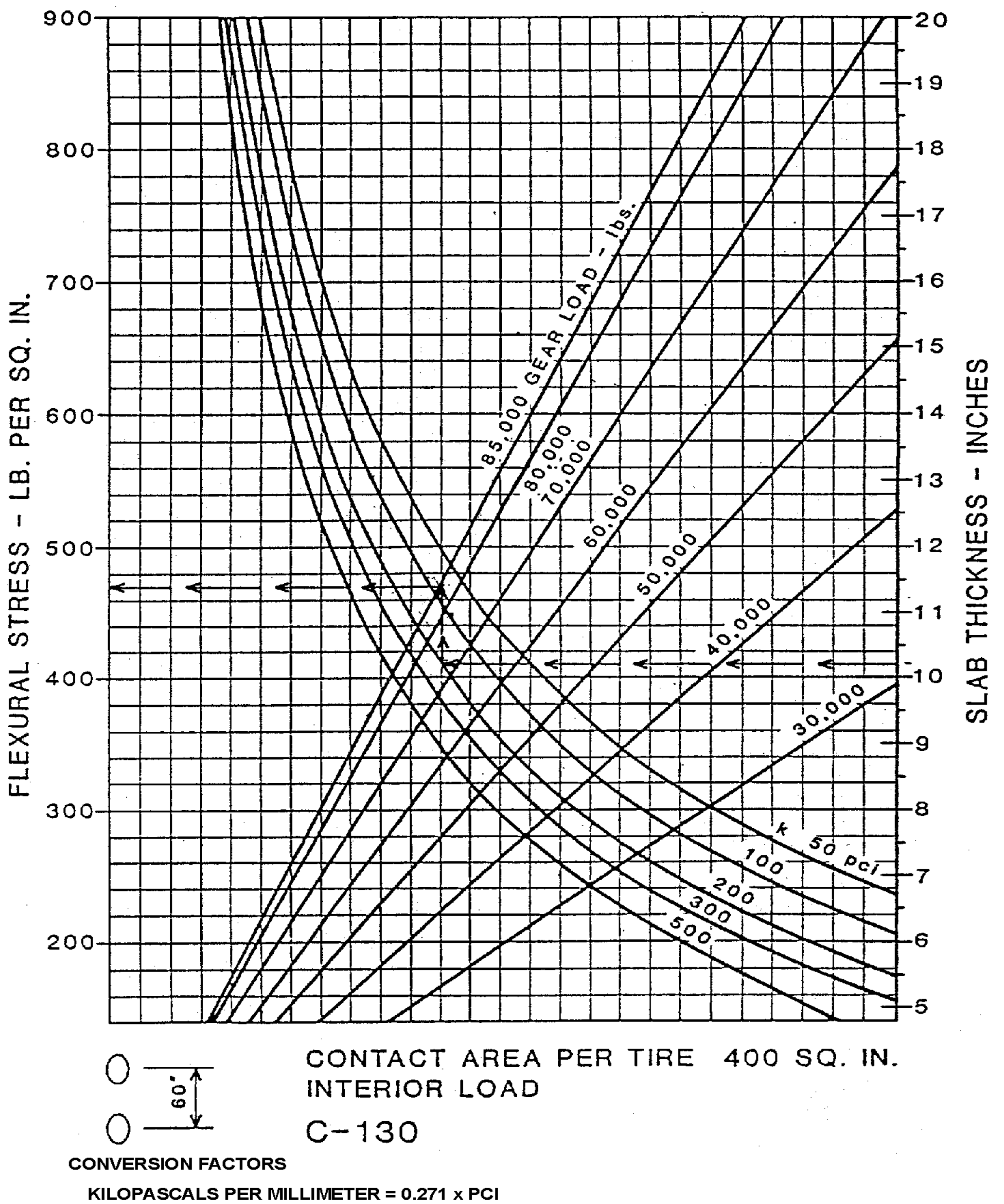


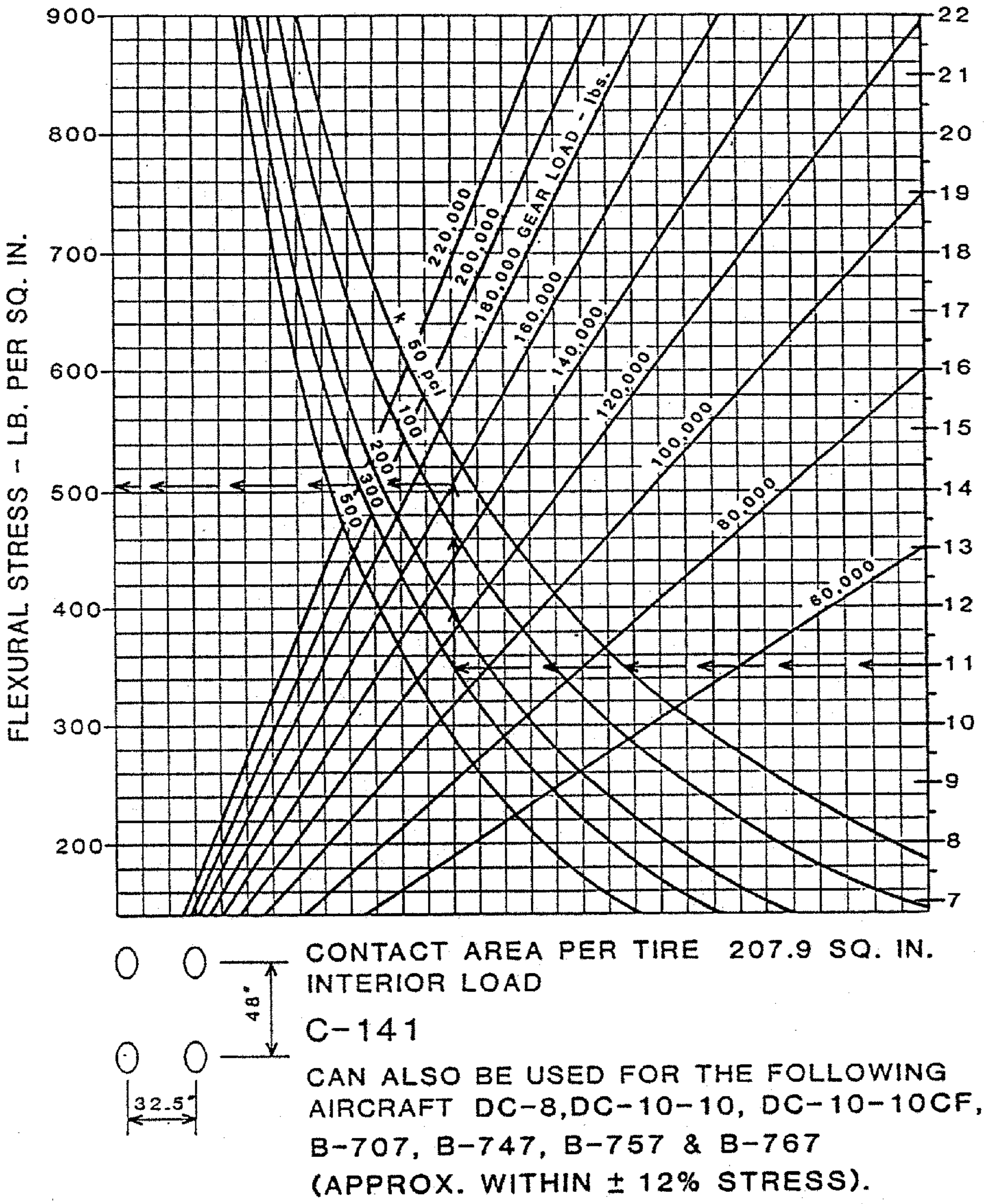
Figure 12-25. Chart for determining flexural stress for P-3 aircraft (Navy)



CONVERSION FACTORS

KILOPASCALS PER MILLIMETER = 0.271 x PCI
KILOGRAMS = 0.453 x POUNDS
MILLIMETERS = 25.4 x INCHES
MEGAPASCALS = 0.006894 x PSI

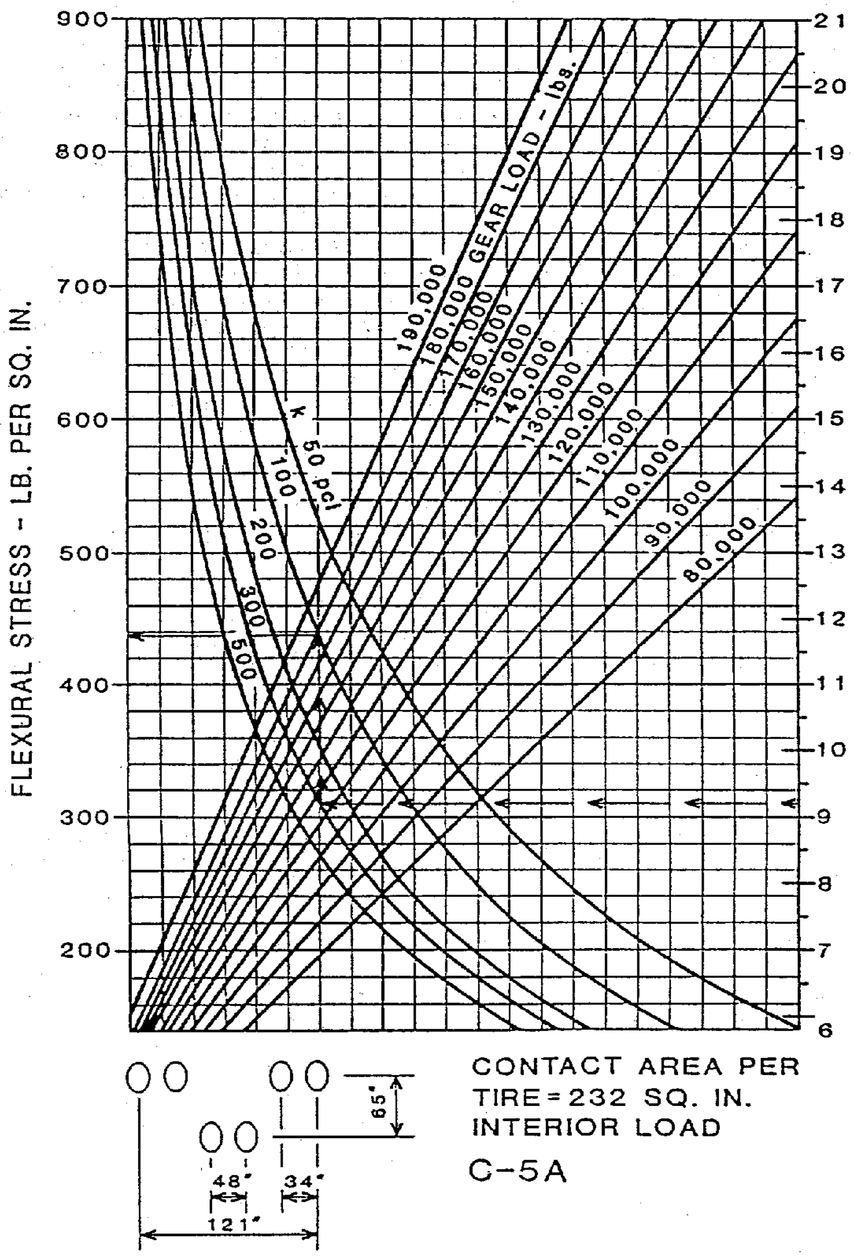
Figure 12-26. Chart for determining flexural stress for C-130 aircraft (Navy)



CONVERSION FACTORS

KILOPASCALS PER MILLIMETER = 0.271 x PCI
KILOGRAMS = 0.453 x POUNDS
MILLIMETERS = 25.4 x INCHES
MEGAPASCALS = 0.006894 x PSI

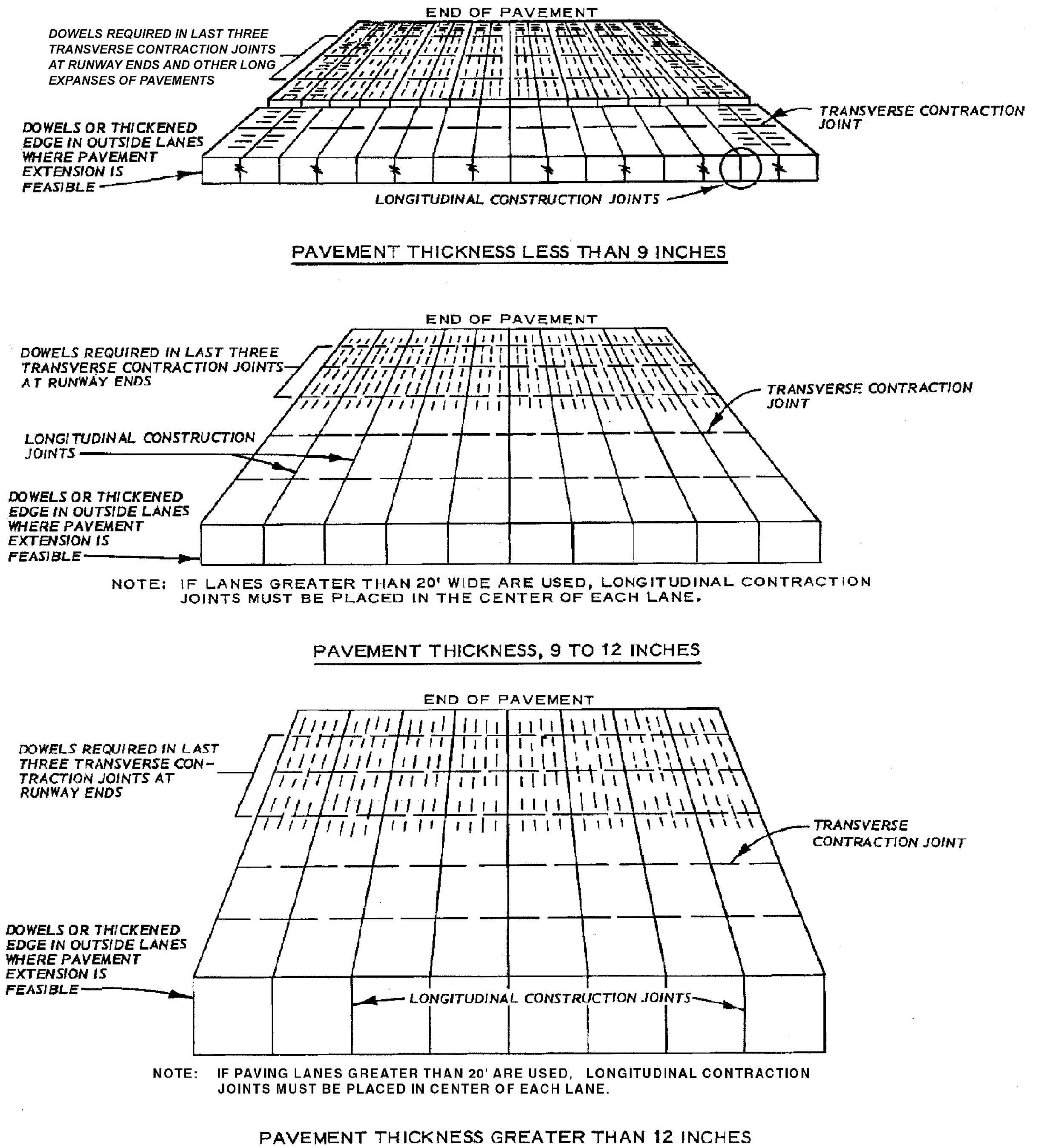
Figure 12-27. Chart for determining flexural stress for C-141 aircraft (Navy)



CONVERSION FACTORS

KILOPASCALS PER MILLIMETER = 0.271 x PCI
KILOGRAMS = 0.453 x POUNDS
MILLIMETERS = 25.4 x INCHES
MEGAPASCALS = 0.006894 x PSI

Figure 12-28. Chart for determining flexural stress for C-5A aircraft (Navy)



CONVERSION FACTORS

MILLIMETERS = 25.4 x INCHES
METERS = 0.3048 x FEET

Figure 12-29. Typical jointing

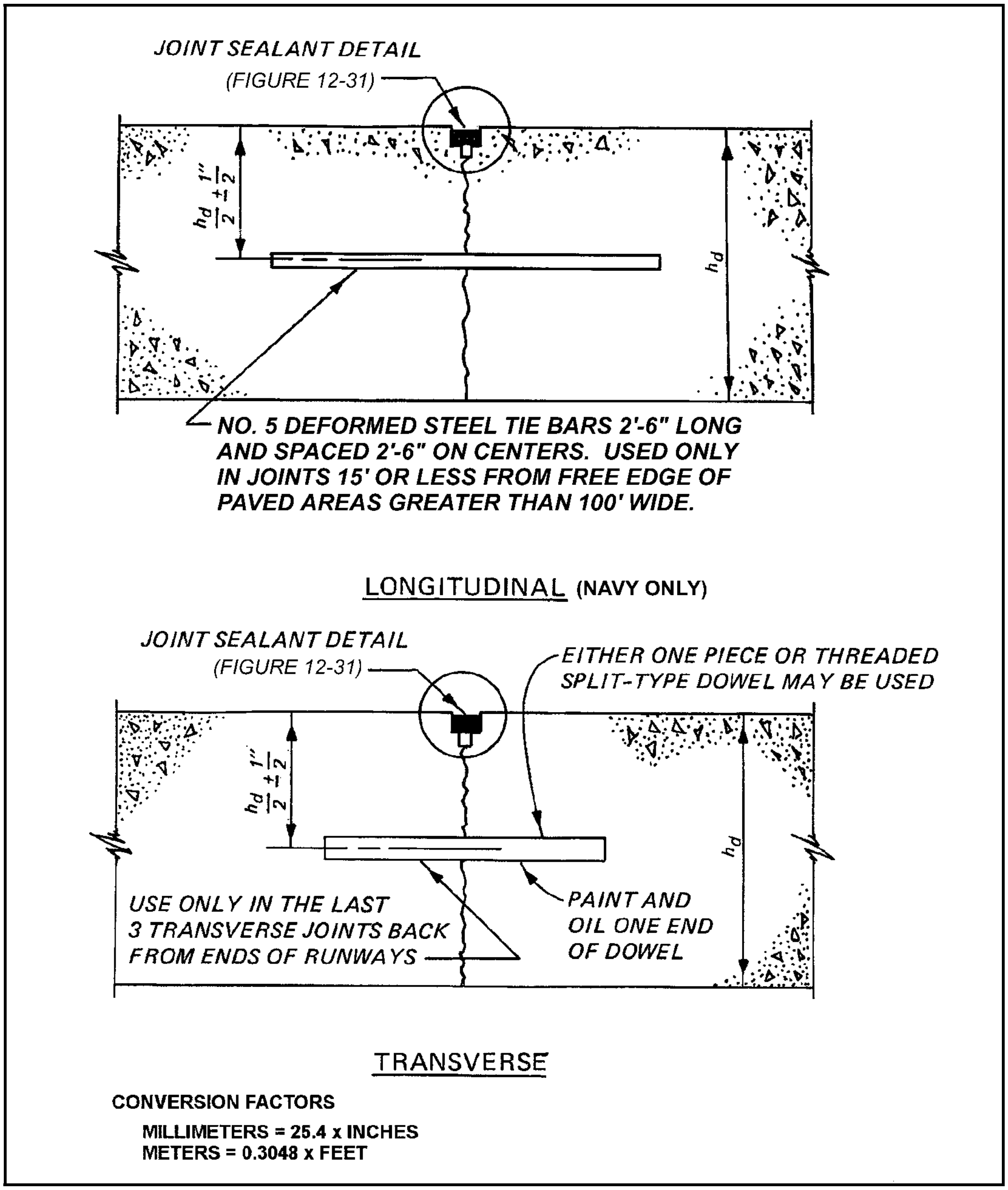
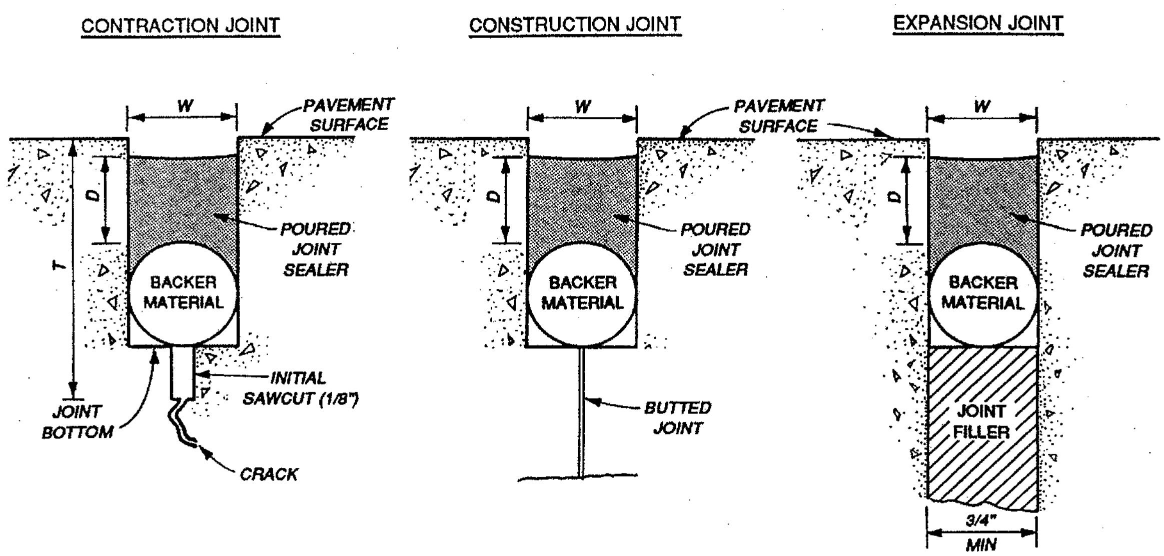


Figure 12-30. Contraction joints for plain concrete pavements



W = WIDTH OF SEALANT RESERVOIR (SEE TABLE)
D = DEPTH OF SEALANT (1.0 TO 1.5 x W) FOR POURED SEALANT; 0.5 W FOR SILICONE SEALANT
T = DEPTH OF INITIAL SAWCUT TYPE JOINT FORMER (CONTRACTION JOINT)

a. 1/4 SLAB THICKNESS ± 1/2" FOR PAVEMENTS LESS THAN 12 INCHES
b. 3 INCHES FOR PAVEMENTS 12-18 INCHES*
c. 1/6 SLAB THICKNESS FOR PAVEMENTS MORE THAN 18 INCHES*
d. DIAMETER OF BACKER MATERIAL = W + 1/8"

TABLE

JOINT SPACING FT	WIDTH, IN.	
	MIN	MAX
20	1/2	5/8
20 (NAVY)	3/8	--

*DESIGNER MAY WANT TO CONSIDER REQUIRING 1/4 SLAB THICKNESS

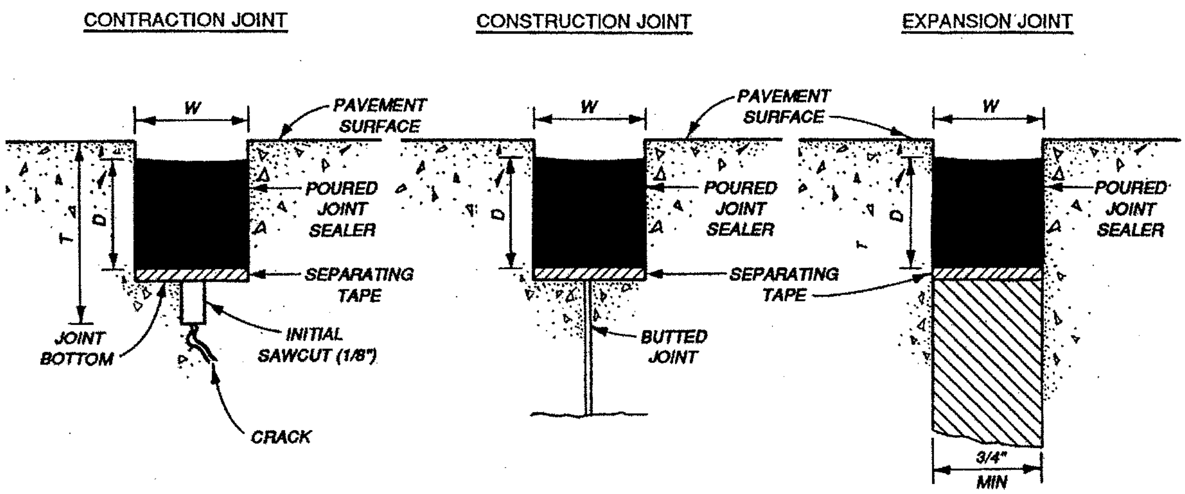
NOTE: TOP OF SEALANT SHALL BE 1/4-IN. TO 1/16 IN. BELOW TOP OF PAVEMENT. IN AREAS TO BE GROOVED, THE JOINT SEAL SHALL BE RECESSED BELOW THE DEPTH OF THE GROOVES.

CONVERSION FACTORS

METERS = 0.3048 X FEET
MILLIMETERS = 25.4 X INCHES

POURED JOINT SEALANT DETAILS (BACKER MATERIAL)

Figure 12-31. Joint sealant details for plain concrete pavements (Sheet 1 of 3)



W = WIDTH OF SEALANT RESERVOIR (SEE TABLE)
D = DEPTH OF SEALANT (1.0 TO 1.5 x W) FOR POURED SEALANT; 0.5 W FOR SILICONE SEALANT
T = DEPTH OF INITIAL SAWCUT TYPE JOINT FORMER (CONTRACTION JOINT)

a. 1/4 SLAB THICKNESS ± 1/2" FOR PAVEMENTS LESS THAN 12 INCHES
b. 3 INCHES FOR PAVEMENTS 12-18 INCHES*
c. 1/6 SLAB THICKNESS FOR PAVEMENTS MORE THAN 18 INCHES*

TABLE

JOINT SPACING FT	WIDTH, IN. MIN	WIDTH, IN. MAX
20	1/2	5/8
20 (NAVY)	3/8	--

*DESIGNER MAY WANT TO CONSIDER REQUIRING 1/4 SLAB THICKNESS

NOTE: TOP OF SEALANT SHALL BE 1/4-IN. TO 1/16 IN. BELOW TOP OF PAVEMENT. IN AREAS TO BE GROOVED, THE JOINT SEAL SHALL BE RECESSED BELOW THE DEPTH OF THE GROOVES.

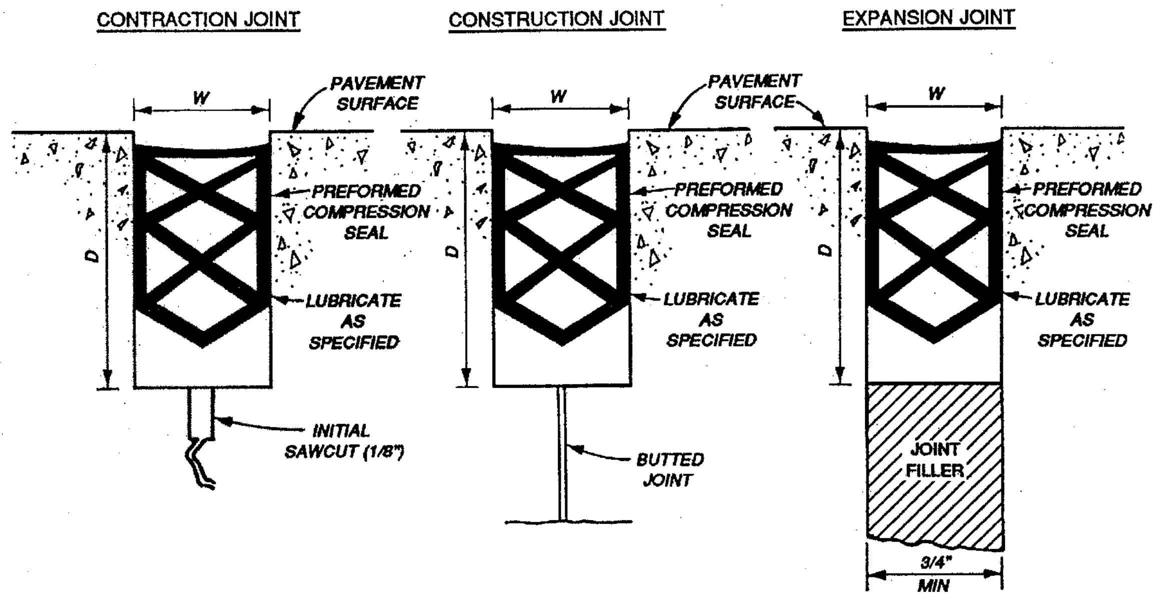
CONVERSION FACTORS

METERS = 0.3048 X FEET
MILLIMETERS = 25.4 X INCHES

POURED JOINT SEALANT DETAILS FOR RIGID PAVEMENTS (SEPARATING TAPE)

Figure 12-31. (Sheet 2 of 3)

PREFORMED COMPRESSION SEAL



NOTE: DEPTH AND WIDTH OF UNCOMPRESSED SEAL SHALL BE AS RECOMMENDED BY MANUFACTURER, EXCEPT THE DEPTH SHALL NOT BE LESS THAN 1.5 INCHES.

TOP OF PREFORMED SEAL SHALL BE 1/8 TO 1/4 INCH BELOW THE PAVEMENT SURFACE. IN AREAS TO BE GROOVED, THE JOINT SEAL SHALL BE RECESSED BELOW THE DEPTH OF THE GROOVES.

COMPRESSION SEALS MUST BE IN COMPRESSION AT ALL TIMES.

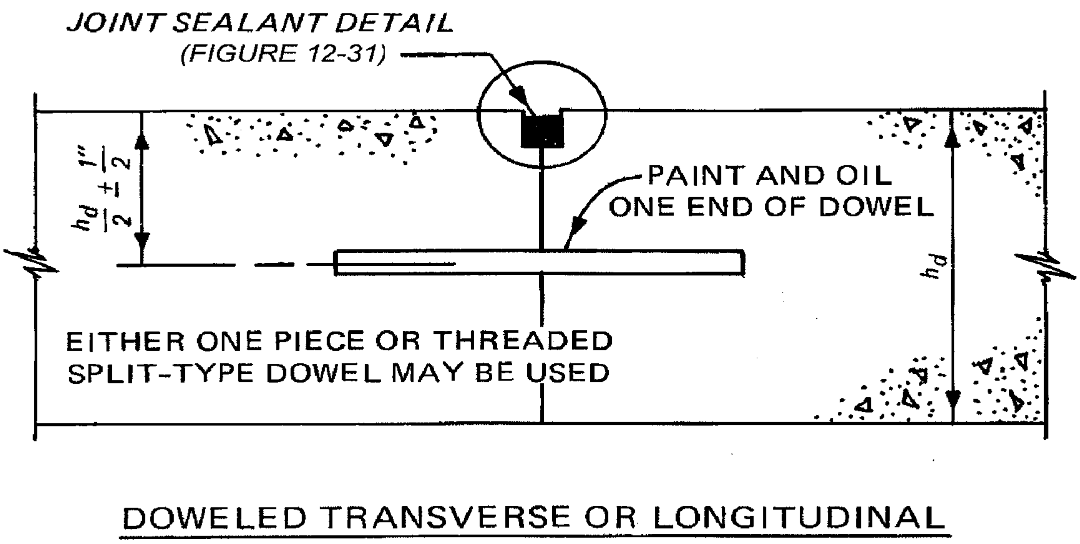
JOINT SPACING FT	WIDTH, IN.	
	MIN	MAX
20	1/2	5/8
20 (NAVY)	3/8	--

CONVERSION FACTORS

METERS = 0.3048 X FEET
MILLIMETERS = 25.4 X INCHES

JOINT SEALANT DETAILS (PREFORMED COMPRESSION SEAL) FOR RIGID PAVEMENT

Figure 12-31. (Sheet 3 of 3)



CONVERSION FACTORS

MILLIMETERS = 25.4 x INCHES
METERS = 0.3048 x FEET

Figure 12-32. Construction joints for plain concrete pavements
(Sheet 1 of 3)

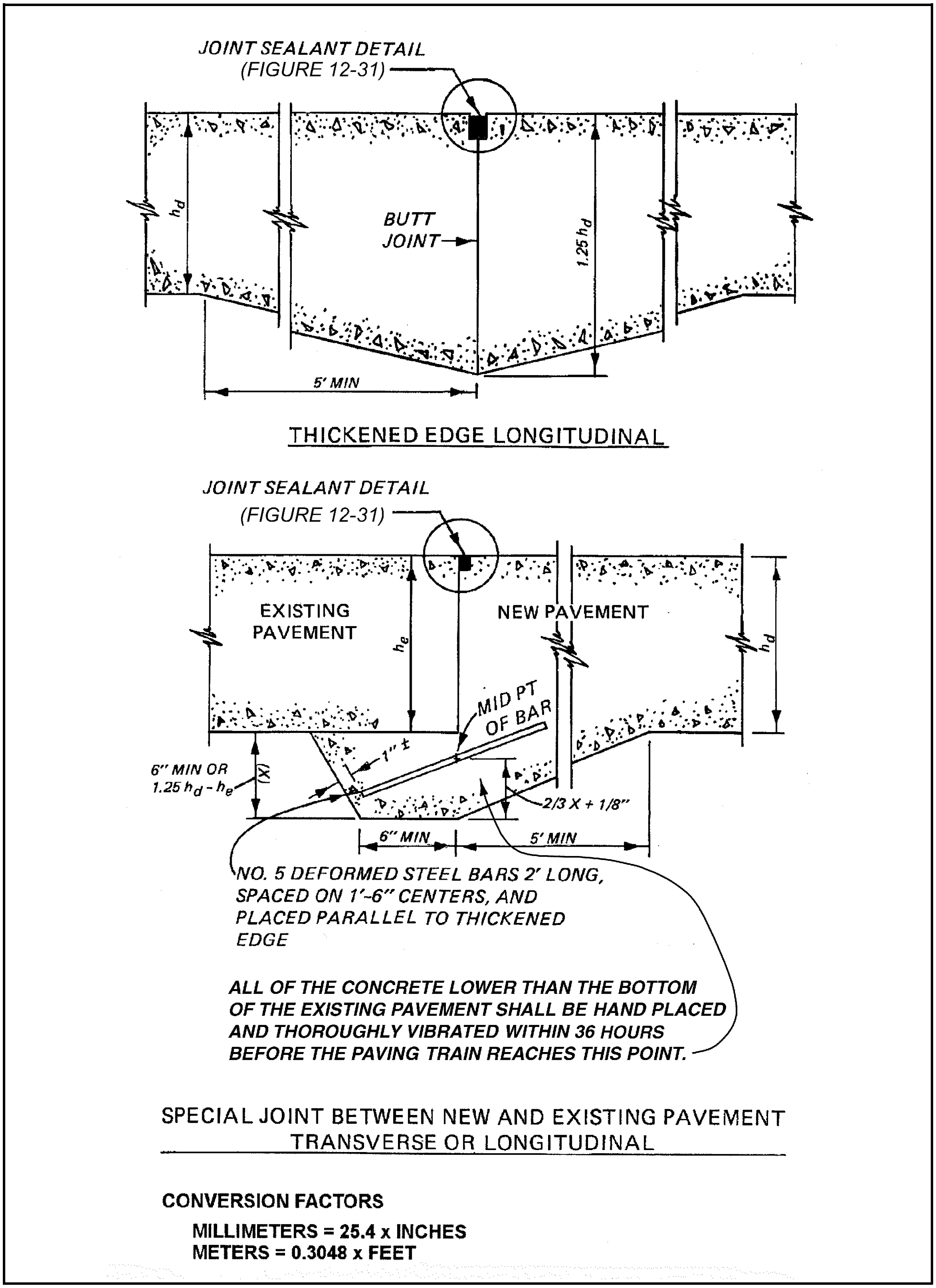
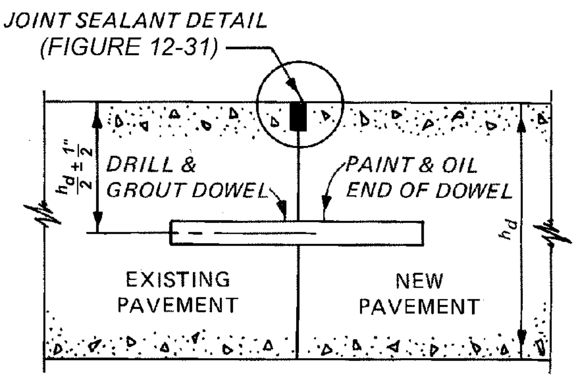
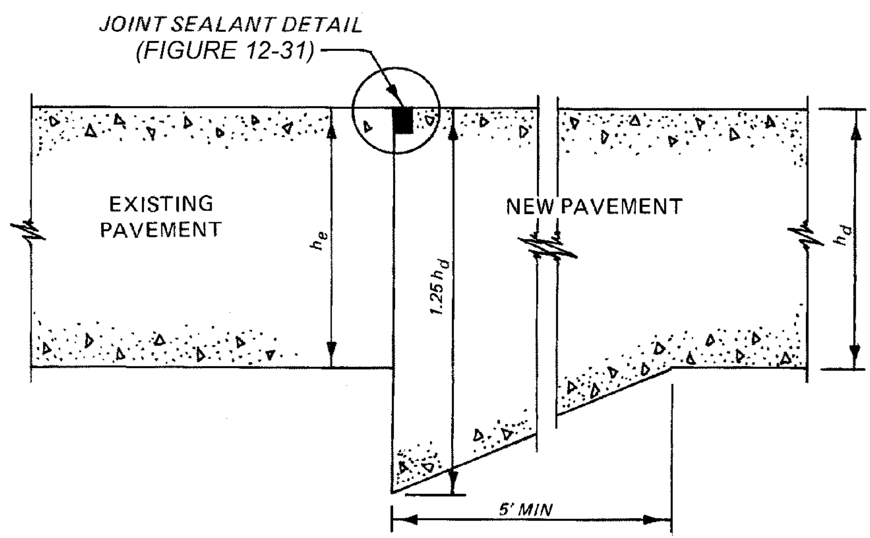


Figure 12-32. (Sheet 2 of 3)



NOTE: EITHER ONE PIECE OR THREADED SPLIT-TYPE DOWEL MAY BE USED

DOWELED JOINT BETWEEN
NEW AND EXISTING PAVEMENT



NOTE: THIS TYPE JOINT SHOULD BE USED ONLY WHEN EXISTING PAVEMENT IS TO BE REPLACED IN A SHORT PERIOD OF TIME, SINCE WITHOUT LOAD TRANSFER IT WILL DETERIORATE QUICKLY.

THICKENED EDGE JOINT BETWEEN
NEW AND EXISTING PAVEMENT

CONVERSION FACTORS

MILLIMETERS = 25.4 x INCHES
METERS = 0.3048 x FEET

Figure 12-32. (Sheet 3 of 3)

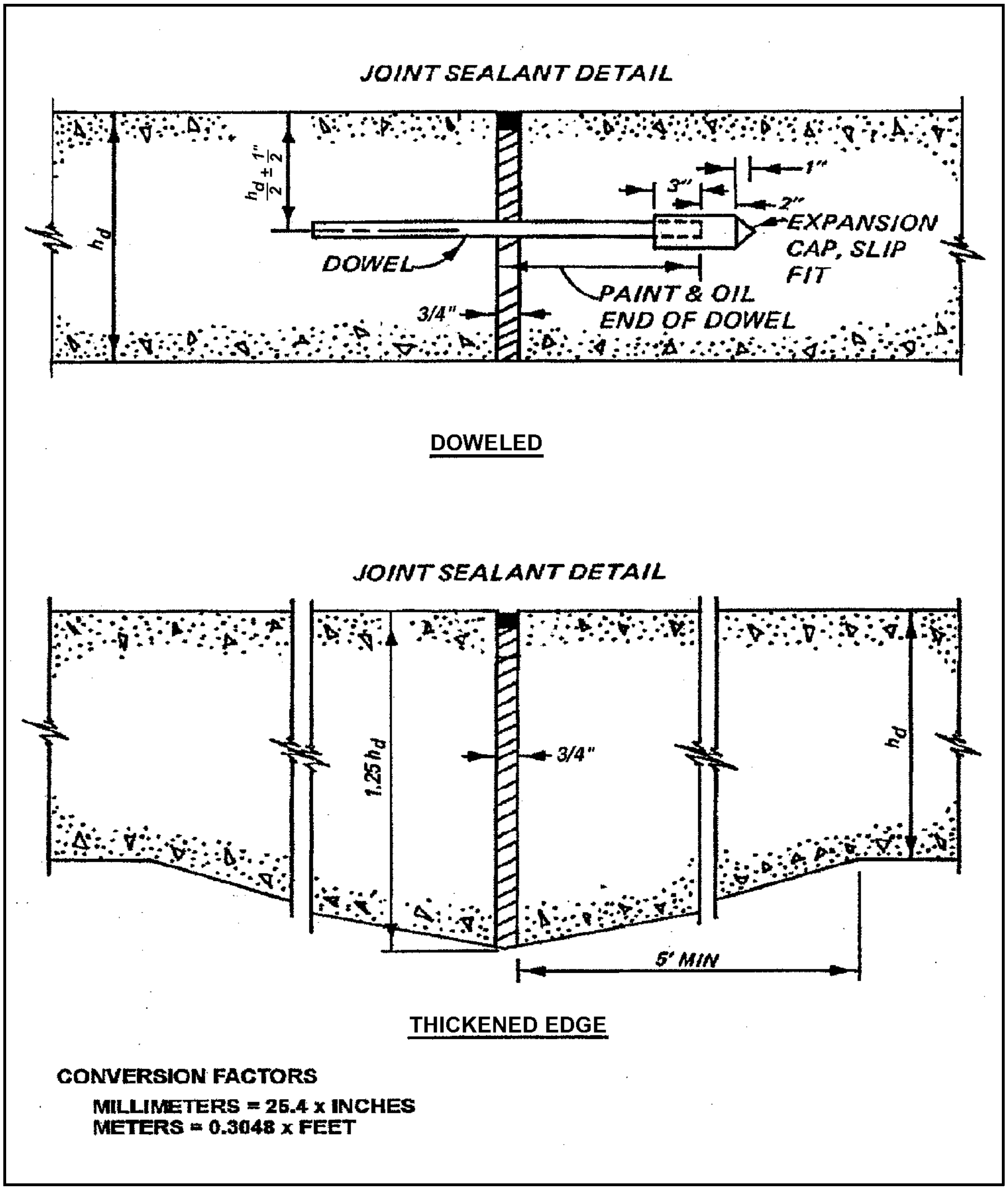
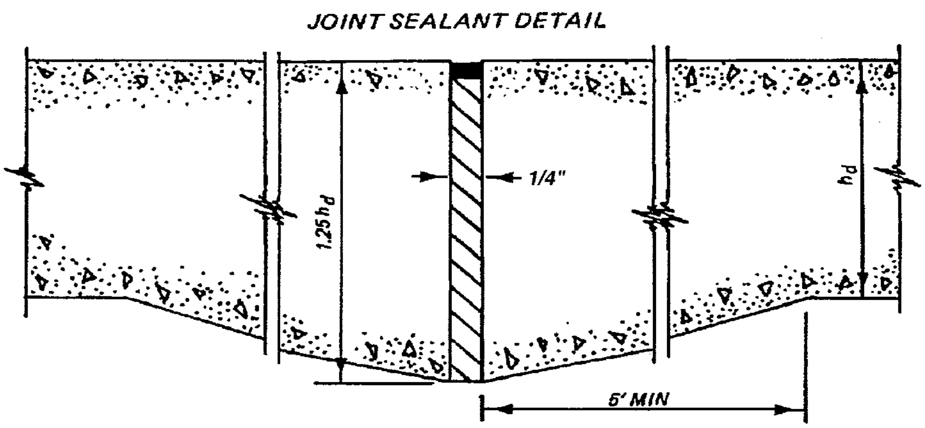


Figure 12-33. Expansion joints for plain concrete pavements

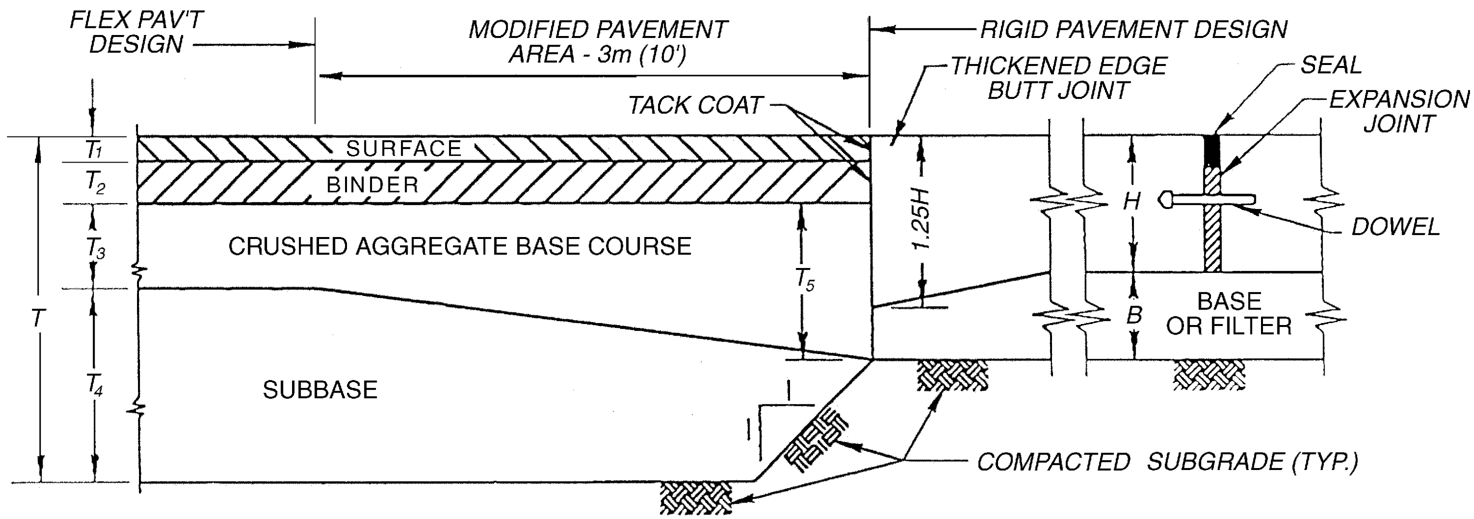


NOTE: THE BOND-BREAKING MEDIUM WILL BE EITHER A HEAVY COATING OF BITUMINOUS MATERIAL NOT LESS THAN 1/4 INCH IN THICKNESS WHEN JOINTS MATCH OR A NORMAL NONEXTRUDING-TYPE EXPANSION JOINT MATERIAL NOT LESS THAN 1/4 INCH IN THICKNESS WHEN JOINTS DO NOT MATCH.

CONVERSION FACTORS

MILLIMETERS = 25.4 x INCHES
METERS = 0.3048 x FEET

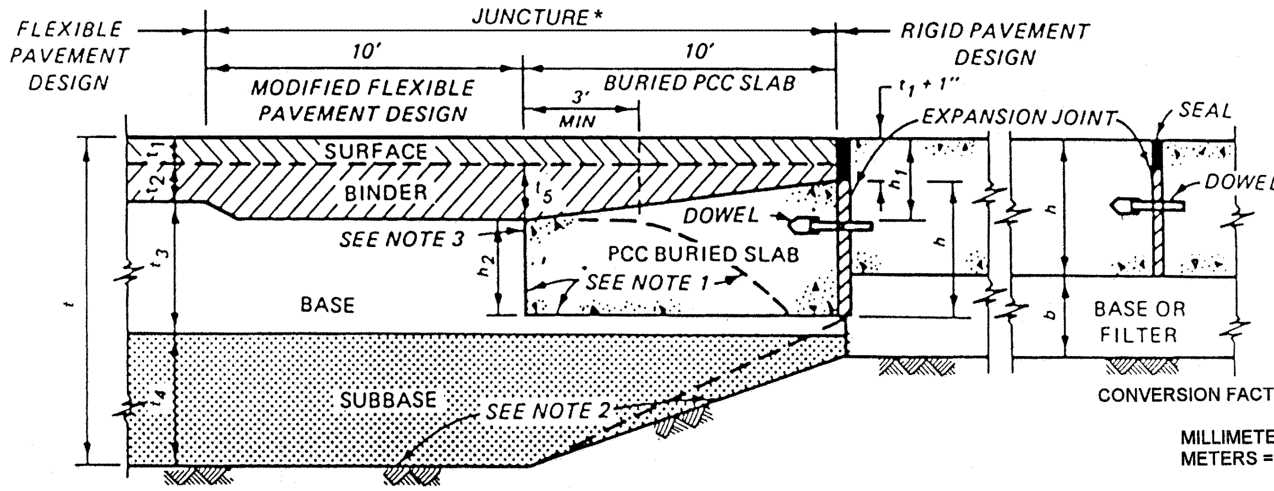
Figure 12-34. Slip joints for plain concrete pavements



SYMBOL	THICKNESS DESIGN
H	DESIGN THICKNESS OF PCC
B	THICKNESS OF BASE OR FILTER
T	DESIGN THICKNESS OF FLEXIBLE PAVEMENT
T_1	DESIGN THICKNESS OF SURFACE COURSE

SYMBOL	THICKNESS DESIGN
T_2	DESIGN THICKNESS OF BINDER COURSE
T_3	DESIGN THICKNESS OF BASE COURSE
T_4	DESIGN THICKNESS OF SUBBASE COURSE
T_5	$(H+B)-(T_1+T_2)$ OR $2(T_3)$, WHICHEVER IS GREATER

Figure 12-35. Rigid-flexible pavement junction (Army or Air Force)



CONVERSION FACTORS

MILLIMETERS = 25.4 x INCHES
METERS = 0.3048 x FEET

NOTES:

1. COMPACTED BASE TO DASHED LINE. CUT OUT TO SOLID LINE NOT DISTURBING THE MATERIALS OUTSIDE LIMITS OF BURIED SLAB.
2. EXCAVATE AND COMPACT SUBGRADE TO DASHED LINE IF A BASE OR FILTER IS NOT USED BENEATH PCC. EXCAVATE AND COMPACT SUBGRADE TO SOLID LINE WHEN BASE OR FILTER COURSE IS USED BENEATH PCC.
3. PLACE PCC BURIED SLAB DIRECTLY AGAINST CUT BACK BASE COURSE. NO FORM WILL BE USED.
4. TOP LIFT OF BINDER COURSE TO BE PLACED AND ROLLED TRANSVERSELY. SURFACE COURSE PLACED AND ROLLED LONGITUDINALLY STOPPING ROLLERS ON RIGID PAVEMENT.
5. FOR HEAVY LOAD DESIGN h_2 NOT LESS THAN 6 IN. FOR LIGHT LOAD DESIGN h_2 NOT LESS THAN 4 IN.
6. JOINT THE BURIED SLAB THE SAME AS THE ADJACENT RIGID PAVEMENT.

SYMBOL	THICKNESS DESIGN
h	DESIGN THICKNESS OF PCC
h_1	$\frac{h + t_1 + 1"}{2}$
h_2	$h - (t_1 + 1")$ BUT NOT LESS THAN 6"
b	THICKNESS OF BASE OR FILTER
t	DESIGN THICKNESS OF FLEXIBLE PAVEMENT
t_1	DESIGN THICKNESS OF SURFACE COURSE
t_2	DESIGN THICKNESS OF BINDER COURSE
t_3	DESIGN THICKNESS OF BASE COURSE
t_4	DESIGN THICKNESS OF SUBBASE COURSE
t_5	$h - h_2$ BUT NOT LESS THAN t_2

* INTENDED FOR CRITICAL TRAFFIC AREAS OR AREAS WHERE SLIGHT DEVIATIONS FROM THE DESIGN GRADE IS OBJECTIONABLE. JUNCTURES SHOULD BE INCORPORATED WHERE PCC JOINS FLEXIBLE PAVEMENT AT ALL TRANSVERSE JUNCTURES IN RUNWAYS AND TAXIWAYS

Figure 12-36. Rigid-flexible pavement junction

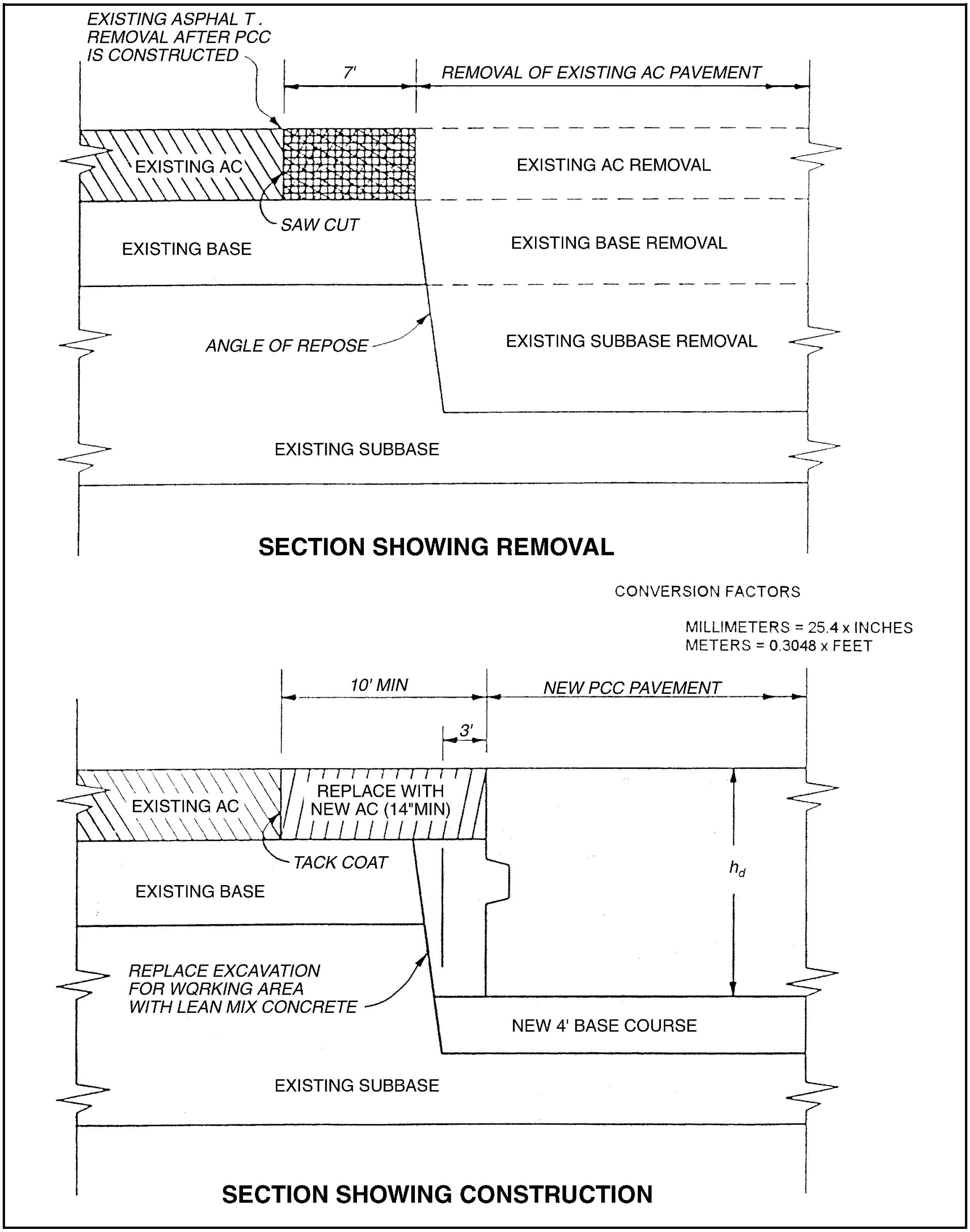


Figure 12-37. PCC to AC joint detail (removal and construction)

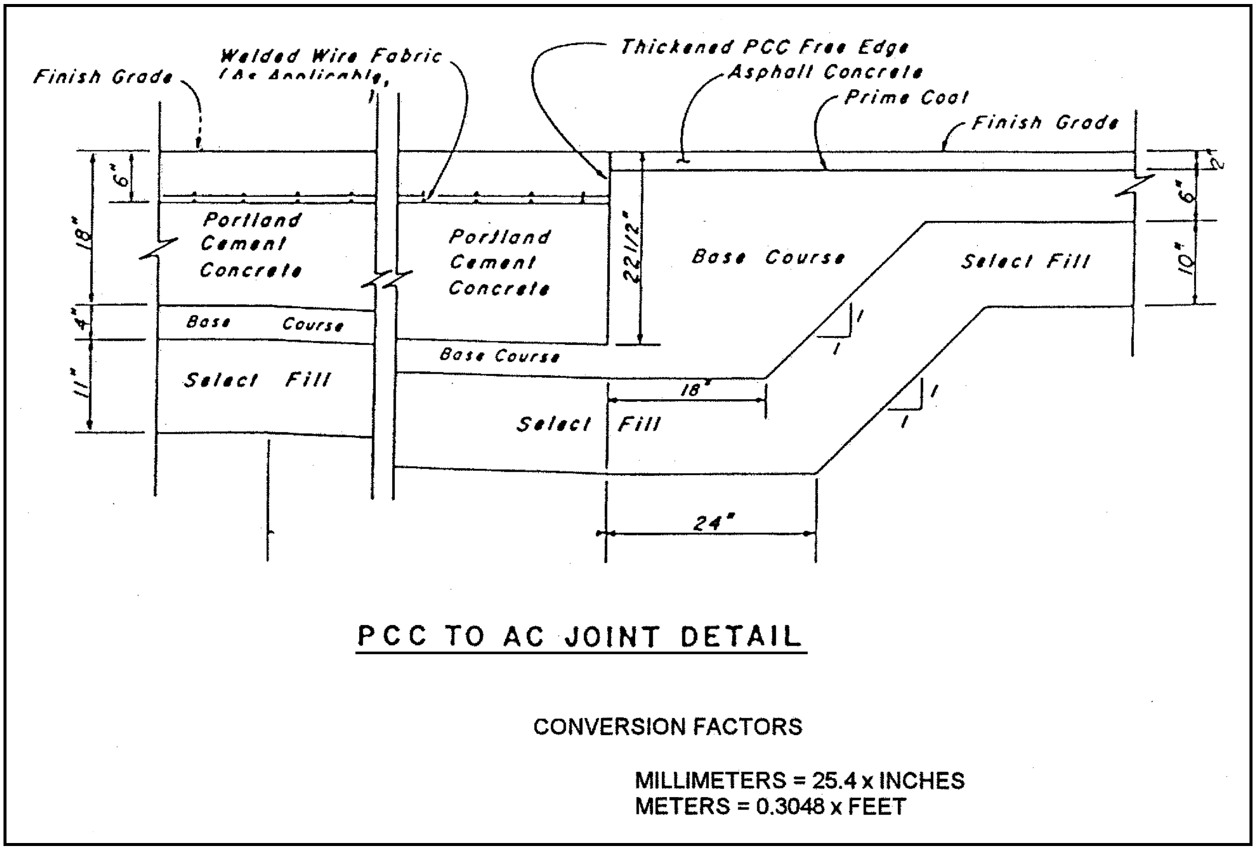


Figure 12-38. PCC to AC joint detail (very little traffic expected)

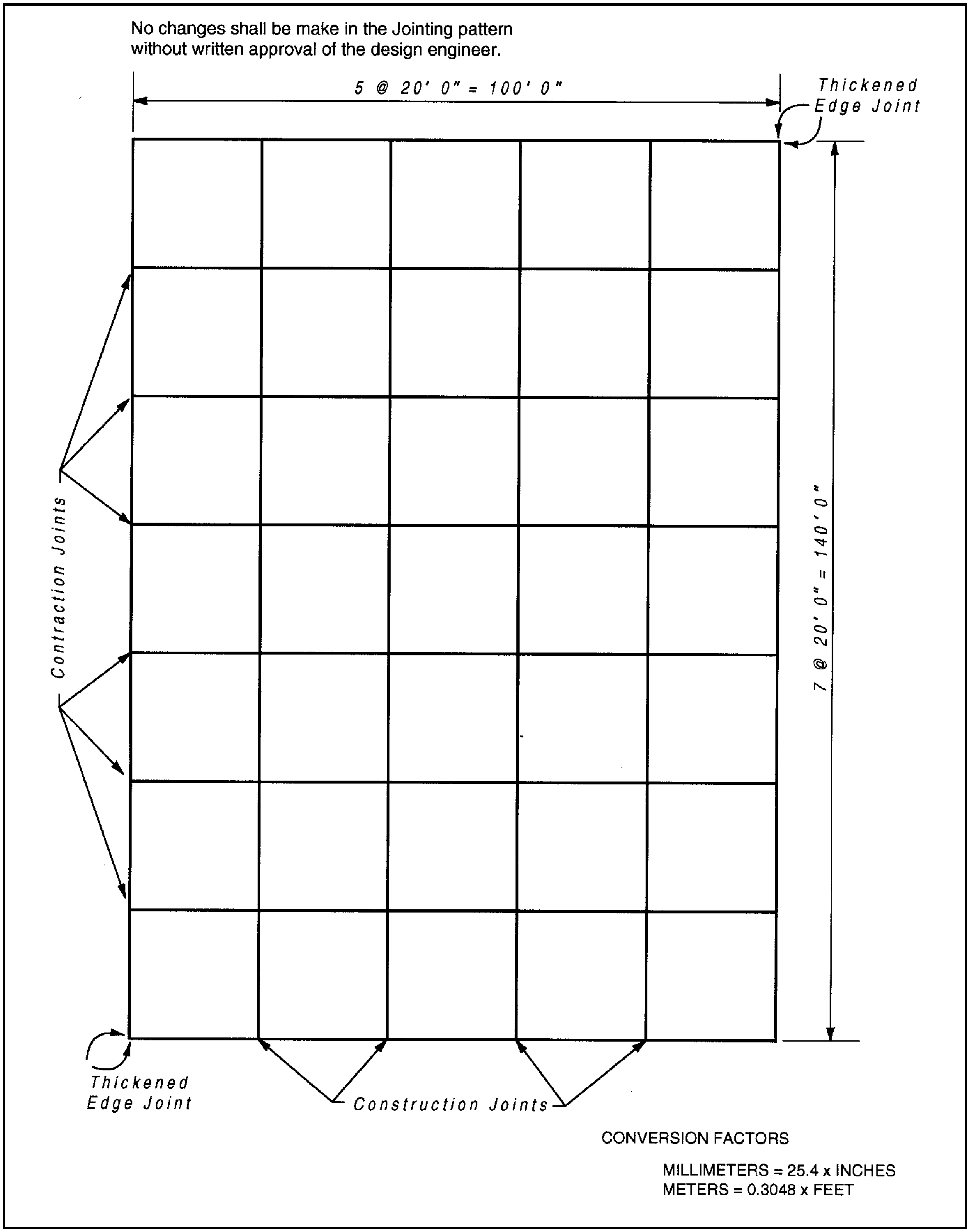


Figure 12-39. Sample jointing pattern (SI units)

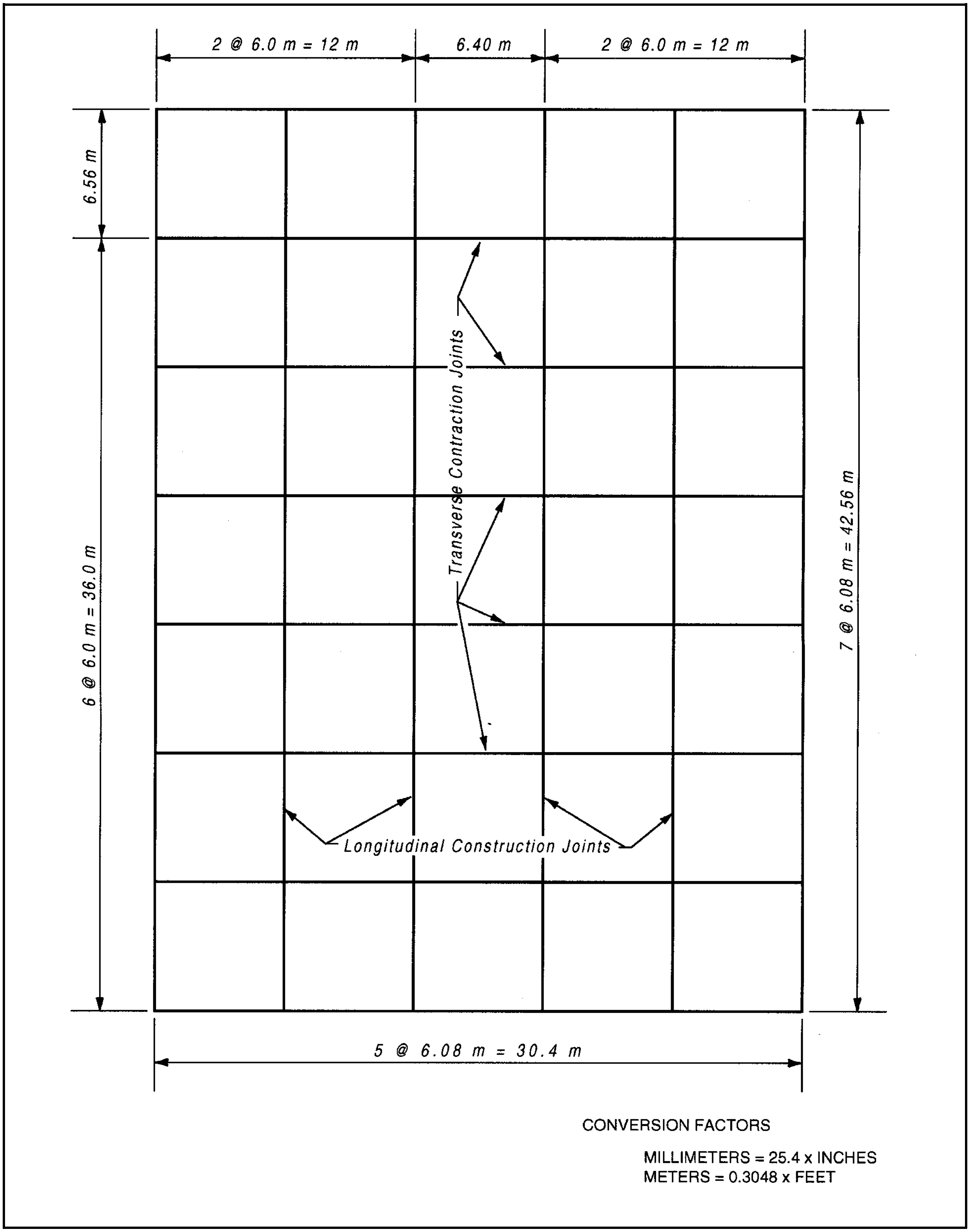


Figure 12-40. Sample jointing pattern (metric units)

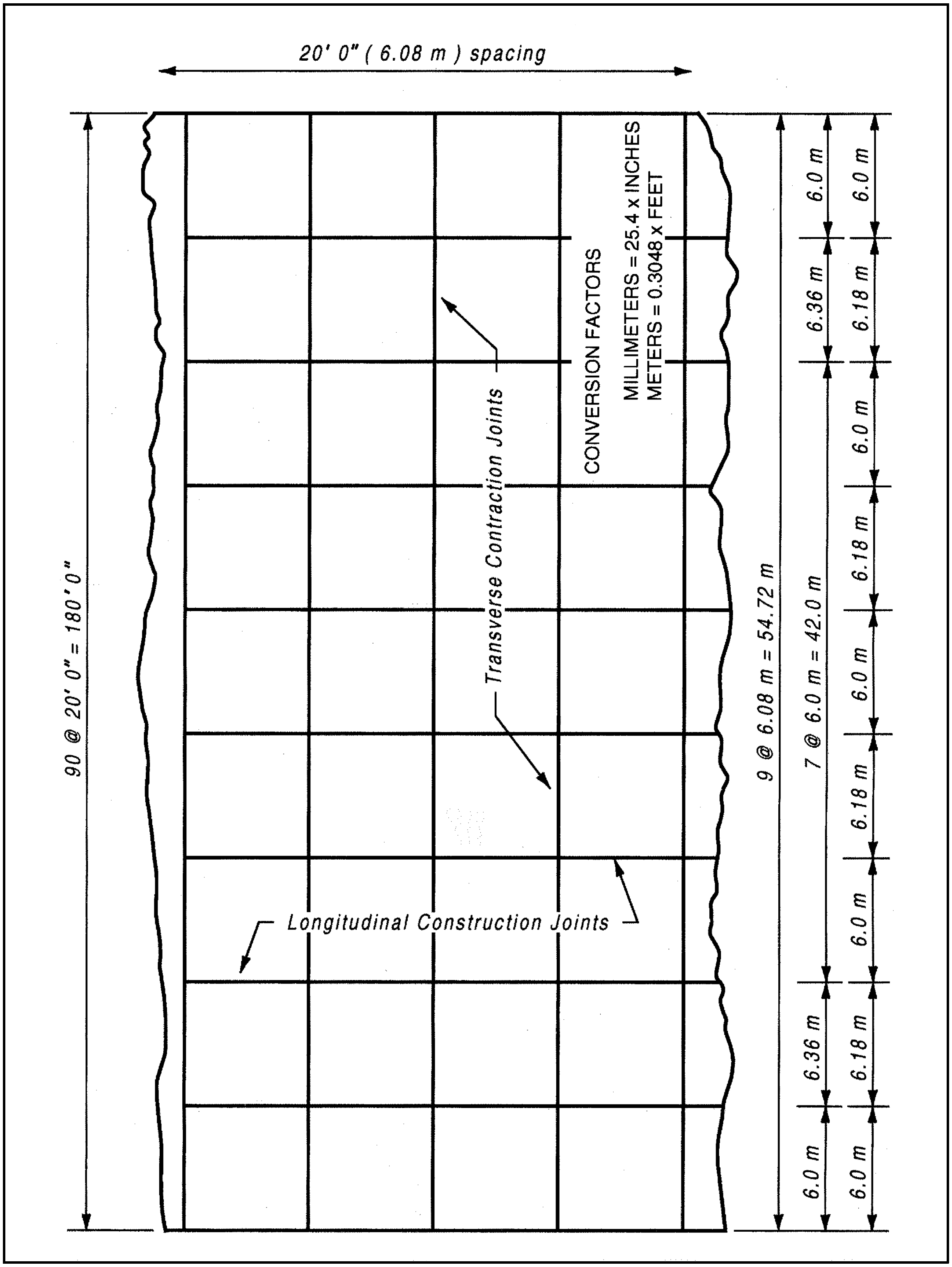


Figure 12-41. Sample jointing pattern for 180-ft.-wide lanes

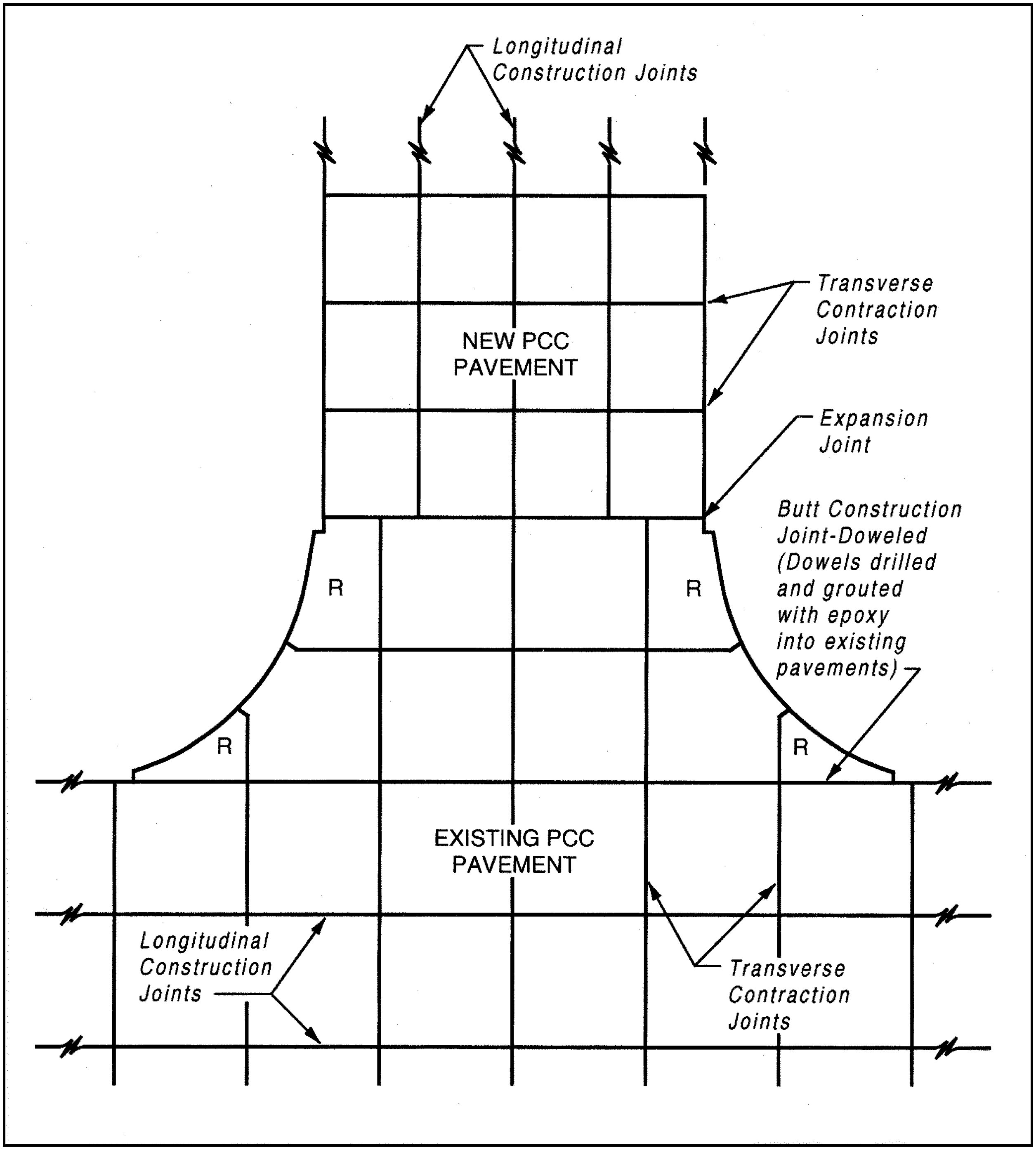


Figure 12-42. Sample jointing pattern at an intersection

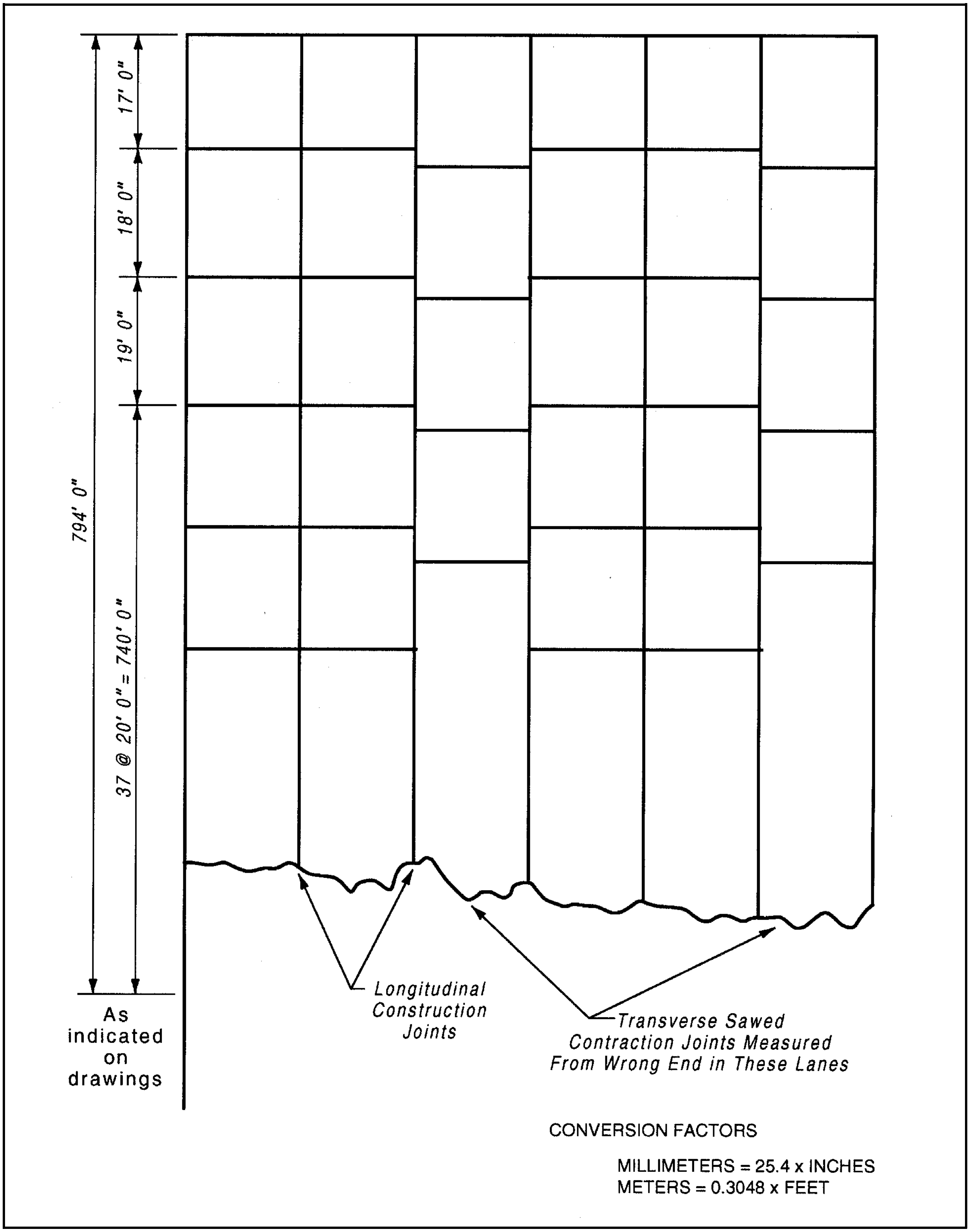


Figure 12-43. Effects of confusion in sawing joints

CHAPTER 13

REINFORCED CONCRETE PAVEMENT DESIGN

1. GENERAL. These designs are applicable to Army and Air Force pavements but will not normally be used for Navy and Marine Corps projects. However, reinforced concrete may be considered for special or unusual design conditions on a case-by-case basis and must be approved by the Naval Facilities Engineering Command. The exception to this is in odd-shaped slabs and mismatched joints where reinforcing is required.

2. BASIS FOR DESIGN - NAVY AND MARINE CORPS. Reinforced concrete pavements employ longer joint spacings than plain concrete pavements. The cracks that develop from shrinkage, warping, curling, and traffic load stresses are held together by reinforcement. Steel reinforcing is used to slow the deterioration of cracks that develop in the concrete slab by holding these cracks tightly together to maintain aggregate interlock. When approved for use, design procedures for Navy and Marine Corps reinforced concrete pavements will be the same as for Army and Air Force reinforced pavements.

a. Thickness. The thickness design for reinforced concrete pavement is similar to plain concrete pavement design, modified by the results of accelerated traffic tests. These tests demonstrate that the required pavement thickness may be less than the required thickness of a plain concrete pavement that provides equal performance. However, as thickness is reduced substantially, premature distress may occur. Therefore, because of inconsistent performance of thin reinforced pavements, for new construction, the thickness shall not be reduced from that determined for plain concrete.

b. Reinforcement. Reinforcing steel is usually required in both the transverse and longitudinal directions. The steel may be deformed bars or welded wire fabric. Typical amounts of reinforcing range from 0.05 to 0.25 percent area.

c. Joints. The maximum slab size for reinforced concrete pavements is a function of the slab thickness, yield strength of the reinforcing steel, and the percent of reinforcement. Slab size is commonly 7.6 meters (25 feet) square. All joints in reinforced concrete pavements, with the exception of keyways and thickened-edge joints, are doweled. Dowels are effective in providing load transfer. Alignment of the dowel bars and adequate consolidation around the dowel basket are critical factors.

3. BASIS FOR DESIGN - ARMY AND AIR FORCE. Steel reinforcement in the concrete provides improved continuity across the cracks that develop because of environmental factors or induced loads. The improved crack continuity results in better performance under traffic and less maintenance than an equal thickness of plain concrete pavement. Thus, for equal performance, the thickness of reinforced concrete pavement can be less than the thickness of plain concrete pavements. The design procedure presented herein yields the thickness of reinforced concrete pavement and the percentage of steel reinforcement required to provide the same performance as a predetermined thickness of plain concrete pavement constructed on the same foundation condition. The procedure has been developed from full-scale accelerated traffic testing. Failure is considered to be severe spalling of the concrete along the cracks that develop during traffic.

4. USES FOR REINFORCED CONCRETE. Reinforced concrete pavement may be used as slabs on grade or as overlay pavements for any traffic area of the airfield. Reinforcement may be used to reduce the required thickness and permit greater spacing between joints. Its selection should be based upon

the economics involved. In certain instances, reinforcement will be required to control cracking that may occur in plain concrete pavements without any reduction in thickness requirements.

5. REDUCED THICKNESS DESIGN - ARMY AND AIR FORCE.

a. General. The greatest use of reinforcement to reduce the required plain concrete pavement thickness will probably be to provide a uniform thickness for the various types of traffic areas as different structural conditions of the base pavement. Since these changes in thickness cannot be made at the surface, reinforcement can be used to reduce the required thickness and thereby avoid the necessity for removal and replacement of pavements or overdesigns. There are other instances in which reinforcement to reduce the pavement thickness may be warranted and must be considered, but the economic feasibility for the use of reinforcement must also be considered. The design procedure consists of determining the percentage of steel required, the thickness of the reinforced concrete pavement, and the maximum allowable length of slabs. In addition, a computer program discussed in Chapter 1 may be used for the design of reinforced concrete pavement.

b. Determination of Required Percent Steel and Required Thickness of Reinforced Concrete Pavement. It is first necessary to determine the required thickness of plain concrete pavement using the design loading and physical properties of the pavement and foundation. When the reinforced concrete pavement is to be placed on stabilized or nonstabilized bases or subgrades, the procedure outline in Chapter 12 will be used to determine the thickness of plain concrete. The thickness of plain concrete is then used to enter Figure 13-1 to determine the required percent steel and the required thickness of reinforced concrete pavement. Since the thickness of reinforced concrete and percent steel are interrelated, it will be necessary to establish a desired value of one and determine the other. The resulting values of reinforced concrete thickness and percent steel will represent a reinforced concrete pavement that will provide the same performance as the required thickness of plain concrete pavement. In all cases, when the required thickness of plain concrete pavement is reduced by the addition of reinforcing steel, the design percentage of steel will be placed in each of two directions (transverse and longitudinal) in the slab. For construction purposes, the required thickness of reinforced concrete must be rounded to the nearest full- and half-inch increment. When the indicated thickness is midway between full- and half-inch, the thickness will be rounded upward.

c. Determination of Maximum Reinforced Concrete Pavement Slab Size. The maximum length or width of the reinforced concrete pavement slabs is dependent largely upon the resistance to movement of the slab on the underlying material and the yield strength of the reinforcing steel. The latter factor can be easily determined, but very little reliable information is available regarding the sliding resistance of concrete on the various foundation materials. For this design procedure, the sliding resistance has been assumed to be constant for a reinforced concrete pavement cast directly on the subgrade, on a stabilized or nonstabilized base course, or on an existing flexible pavement. The maximum allowable width W or length L of reinforced concrete pavement slabs will be determined from the following:

$$W \text{ or } L = 0.2224 \sqrt[3]{h_d (y_s S)^2} \quad \text{for SI Units}$$

$$W \text{ or } L = 0.0777 \sqrt[3]{h_d (y_s S)^2} \quad \text{for English Units} \qquad (13\text{-}1)$$

where

h_d = design thickness of reinforced concrete, millimeters (inches)

y_s = yield strength of reinforcing steel, normally 413.7 MPa (60,000 psi)

S = percent reinforcing steel

The formula above has been expressed on the nomograph (Figure 13-1) for a steel yield strength y_s of 413.7 MPa (60,000 psi), and the maximum length or width can be obtained from the intersection of a straight line drawn between the values of design thickness and percent steel that will be used for the reinforced concrete pavement. The width of reinforced concrete pavement will generally be controlled by the concrete paving equipment and will normally be 7.6-12.1 meters (25-40 feet), unless smaller widths are necessary to meet dimensional requirements.

d. Limitations to Reinforced Concrete Pavement Design Procedure. The design procedure for reinforced concrete pavements presented herein has been developed from a limited amount of investigational and performance data. Consequently, the following limitations are imposed:

(1) No reduction in the required thickness of plain concrete will be allowed for percentages of steel reinforcement less than 0.05.

(2) No further reduction in the required thickness of plain concrete pavement will be allowed over that indicated for 0.5 percent steel reinforcement in Figure 13-1 regardless of the percent steel used.

(3) No single dimension of reinforced concrete pavement slabs will exceed 30.5 meters (100 feet) regardless of the percent steel used or slab thickness.

(4) The minimum thickness of a reinforced concrete pavement or overlay will be 152 millimeters (6 inches).

6. REINFORCEMENT TO CONTROL PAVEMENT CRACKING.

a. General. Reinforcement is mandatory in certain pavement areas to control or minimize the effects of cracking. The reinforcing steel holds cracks tightly closed, thereby preventing spalling at the edges of the cracks and progression of the cracks into adjacent slabs. For each of the following conditions, the slabs or portions of the slabs will be reinforced with 0.05 percent steel in two directions normal to each other unless otherwise specified. No reduction in thickness will be allowed for this steel.

b. Odd-shaped Slabs. It is often necessary in the design of pavement facilities to resort to odd-shaped slabs. Unless reinforced, these odd-shaped slabs often crack and eventually spall along the cracks, producing debris that is objectionable from operational and maintenance viewpoints. In addition, the cracks may migrate across joints into adjacent slabs. In general, a slab is considered to be odd-shaped if the longer dimension exceeds the shorter one by more than 25 percent or if the joint pattern does not result in essentially a square or rectangular slab. Figure 13-2 presents typical examples of odd-shaped slabs requiring reinforcement. Where practicable, the number of odd-shaped slabs can be minimized by using a sawtooth fillet and not reinforcing.

c. Mismatched Joints. Steel reinforcement in the slabs is mandatory to prevent migration of cracks into adjacent pavements for the following two conditions of mismatched joints:

(1) Where joint patterns of abutting pavement facilities do not match, partial reinforcement of slabs may be necessary. In such a condition, the mismatch of joints can cause a crack to form in the adjacent pavement unless there is sufficient width of bond-breaking medium installed in the joint. The determination relative to using reinforcement at mismatched joints in such junctures is based upon the type of joint between the two pavement sections. A partial reinforcement of the slab, as described below, is required when the joint between the abutting pavement is one of the following: (a) doweled construction joint, (b) keyed construction joint, (c) thickened-edge butt joint without a bond-breaking medium, (d) doweled expansion joint, and (e) thickened-edge slip joint with less than 6.4-millimeter (1/4-inch) bond-breaking medium. Reinforcement is not required if the joint between the abutting pavement facilities is either a thickened-edge expansion joint or a thickened-edge slip joint with 6.4 millimeters (1/4 inch) or more of bond-breaking medium, except for a mismatch of joints in the center 23-meter (75-foot) width of runway where reinforcement of the slabs of mismatched joints will be required regardless of the type of joint between the facilities. When reinforcement at mismatched joints is required, the slab in the pavement facility directly opposite the mismatched joint will be reinforced with the minimum 0.05 percent steel. The reinforcing steel will be placed in two rectangular directions for a distance 915 millimeters (3 feet) back from the juncture and for the full width or length of the slab in a direction normal to the mismatched joint. When a new pavement is being constructed abutting an existing pavement, the new slabs opposite mismatched joints will be reinforced in the manner described above. When two abutting facilities are being constructed concurrently, the slabs on both sides of the juncture opposite mismatched joints will be reinforced in the manner described above. For this condition shown in Figure 13-2, the slip joint bond-breaking medium can be specified to be a full 6.4 millimeters (1/4 inch) thick, and the reinforcing may be omitted.

(2) The second condition of mismatched joints where reinforcement is required occurs in the construction of a plain concrete overlay on an existing rigid pavement. Joints in the overlay should coincide with joints in the base pavement. Sometimes this is impracticable due to an unusual jointing pattern in the existing pavement. When necessary to mismatch the joints in the overlay and the existing pavement, the overlay pavement will be reinforced with the minimum 0.05 percent steel. The steel will be placed in two rectangular directions for a distance of at least 915 millimeters (3 feet) on each side of the mismatched joint in the existing pavement. The steel will, however, not be carried through any joint in the overlay except as permitted or required to meet joint requirements. If the joint pattern in the existing pavement is highly irregular or runs at an angle to the desired pattern in the overlay, the entire overlay will be reinforced in both the longitudinal and transverse directions. When a bond-breaker course (see Chapter 17) is placed between the existing pavement and overlay, reinforcement of the overlay over mismatched joints is not required, except for mismatched expansion joints.

d. Reinforcement of Pavements Incorporating Heating Pipes. Plain concrete pavements, such as hangar floors that incorporate radiant heating systems within the concrete, are subject to extreme temperature changes. These temperature changes cause thermal gradients in the concrete that result in stresses of sufficient magnitude to cause surface cracking. To control such cracking, these pavement slabs will be reinforced with the minimum 0.05 percent steel placed in the transverse and longitudinal directions.

e. Reinforcement of Slabs Containing Utility Blockouts. The minimum 0.05 percent steel reinforcement is required in plain concrete pavement slabs containing utility blockouts, such as for hydrant refueling outlets, storm drain inlets, and certain types of flush lighting fixtures. The entire slab or slabs containing the blockouts will be reinforced in two rectangular directions.

7. REINFORCED CONCRETE PAVEMENTS IN FROST AREAS. Normally, plain concrete pavements in frost areas will be designed in accordance with Chapter 22, and reinforcement will be unnecessary. There may, however, be special instances when it will be directed that the pavement thickness be less than required by frost design criteria. Two such instances are: the design of new pavements to the strength of existing pavement when the existing pavement does not meet the frost design requirements, and the design of an inlay section of adequate strength pavement in the center portion of an existing runway when the existing pavement does not meet the frost design requirements. In such instances, the new pavements will be reinforced with a minimum of 0.15 percent steel. The minimum 0.15 percent steel will be placed in each of two directions (transverse and longitudinal) in the slab. The reinforcing steel is required primarily to control cracking that may develop because of differential heaving. The pavement thickness may be reduced, and the maximum slab length, consistent with the percent steel, may be used. Longer slabs will help reduce roughness that may result from frost action. Greater percentages of steel reinforcement may be used when it is desired to reduce the pavement thickness more than is allowable for the required minimum percentage of steel.

8. REINFORCING STEEL.

a. Type or Reinforcing Steel. The reinforcing steel may be either deformed bars or welded wire fabric. Deformed bars should conform to the requirements of ASTM A 615, A 616, or A 617. In general, grade 60 deformed bars should be specified, but other grades may be used if warranted. Fabricated steel bar mats should conform to ASTM A 184. Cold drawn wire for fabric reinforcement should conform to the requirements of ASTM A 82, and welded steel wire fabric to ASTM A 185.

b. Placement of Reinforcing Steel. The reinforcing steel will be placed at a depth of $h_d/4$ + 25 millimeters ($h_d/4$ + 1 inch) from the surface of the reinforced slab. This will place the steel above the neutral axis of the slab and will allow clearance for dowel bars. The wire or bar sizes and spacing should be selected to give, as nearly as possible, the required percentage of steel per foot of pavement width or length. In no case should the percent steel used be less than that required by Figure 13-1. Two layers of wire fabric or bar mat, one placed directly on top of the other, may be used to obtain the required percent of steel; however, this should only be done when it is impracticable to provide the required steel in one layer. If two layers of steel are used, the layers must be fastened together (either wired or clipped) to prevent excessive separation during concrete placement. When the reinforcement is installed and concrete is to be placed through the mat or fabric, the minimum clear spacing between bars or wires will be one and one-half times the maximum size of aggregate. If the strike-off method is used to place the reinforcement (layer of concrete placed and struck off at the desired depth, the reinforcement placed on the plastic concrete, and the remaining concrete placed on top of the reinforcement), the minimum spacing of wires or bars will not be less than the maximum size of aggregate. Maximum bar or wire spacing shall not exceed 305 millimeters (12 inches) nor the slab thickness. Figure 13-3 shows the typical details of slab reinforcement with wire fabric or bar mats. The bar mat or wire fabric will be securely anchored to prevent forward creep of the steel mats during concrete placement and finishing operations. The reinforcement shall be fabricated and placed in such a manner that the spacing between the longitudinal wire or bar and the longitudinal joint, or between the transverse wire or bar and the transverse joint, will not exceed 76 millimeters (3 inches) or one-half of the wire or bar spacing in the fabric or mat (Figure 13-3). The wires or bars will be lapped as follows.

(1) Deformed steel bars will be overlapped for a distance of at least 24 bar diameters, measured from the tip of one bar to the tip of the other bar. The lapped bars will be wired or otherwise securely fastened to prevent separation during concrete placement.

(2) Wire fabric will be overlapped for a distance equal to at least one spacing of the wire in the fabric or 32 wire diameters, whichever is greater. The length of lap is measured from the tip of one wire to the tip of the other wire normal to the lap. The wires in the lap will be wired or otherwise securely fastened to prevent separation during concrete placement.

9. JOINTING.

a. Requirements. Figures 13-4 through 13-6 present details of joints in reinforced concrete pavements. Joint requirements and types will be the same as for plain concrete except for the following:

(1) All joints will be doweled with the exception of thickened-edge-type joints and longitudinal construction joints. One end of the dowel will be painted and oiled to permit movement at the joint.

(2) Thickened-edge-type joints (expansion, butt, or slip) will not be doweled. The edge will be thickened to $1.25h_d$.

(3) When a transverse construction joint is required within a reinforced slab unit, the reinforcing steel will be carried through the joint. In addition, dowels meeting the size and spacing requirements of Table 12-8 or the design thickness h_d will be used in the joint.

b. Joint Sealing. Joint sealing for reinforced concrete pavements will be the same as for plain concrete pavements.

10. EXAMPLES OF REINFORCED CONCRETE PAVEMENT DESIGN.

a. A reinforced concrete pavement is to be used for an Air Force heavy-load airfield. Field and laboratory test programs have yielded design values of 4.8 MPa (700 psi) for the concrete flexural strength R and 54 MN/m^3 (200 pci) for the modulus of soil reaction k for the foundation.

b. Assuming that stabilization will not be used, it is first necessary to determine the required thicknesses of plain concrete pavement. By entering Figure 12-8 with the design values of R and k, the required thicknesses of plain concrete are as shown in column 2 of Table 13-1. At this point, it is necessary to decide whether to preselect the percentage of reinforcing steel and determine the required thickness of reinforced pavements, or to select a thickness of reinforced concrete and determine the percent steel. First, let it be assumed that a S = 0.20 percent will be used and that it is desired to determine the required thickness. Figure 13-1 is entered with S = 0.20 percent and the thickness of plain concrete for each traffic area, and values of reinforced concrete pavement thickness determined as shown in column 3 of Table 13-1. These thicknesses are rounded to the nearest 10-millimeter (½-inch) increment for construction (column 4). After the thicknesses are rounded, it is then necessary to reenter Figure 13-1 to determine the percent steel commensurate with the rounded thickness values (column 5). Next, let it be assumed that types A, B, and C traffic areas are to be constructed to the same thickness of 405 millimeters (16 inches) of reinforced concrete pavement, and type D traffic areas are to be 255 millimeters (10 inches). Figure 13-1 is entered with the thickness of plain concrete and selected values of reinforced concrete thickness to determine the required percent steel (column 7). The maximum length or width of a reinforced concrete pavement slab is a function of the yield strength of the steel, thickness of the slab, and percent steel and can be determined either from Figure 13-1 or by Equation 13-1. Columns 6 and 8 of Table 13-1 present the maximum allowable lengths or widths for the examples using a steel with a yield strength of 413 MPa (60,000 psi).

c. Assume that a 152-millimeter (6-inch) lean concrete base course will be used. The compressive strength of the lean concrete is 20.6 MPa (3,000 psi), and the flexural modulus of elasticity is 13,788 MPa (2×10^6 psi). As with the previous example, the required thicknesses of plain concrete pavement on both the nonstabilized and on the lean concrete base are determined and are shown in columns 2 and 3 of Table 13-2. A value may then be selected for the required thickness of reinforced concrete or the percentage of reinforcing steel and determine the other using Figure 13-1. If a percent steel value of 0.20 is selected, the values of reinforced concrete from Figure 13-1 would be shown in column 4 of Table 13-2. These values rounded for construction are listed in column 5. Then, reenter Figure 13-1 with the rounded values of reinforced concrete to obtain the required percent steel shown in column 6. The allowable slab lengths are determined from Equation 13-1 or Figure 13-1 using a reinforcing steel with a yield strength of 413 MPa (60,000 psi) (column 7). If a reinforced concrete thickness of 380 millimeters (15 inches) is selected for the type A, B, and C traffic areas and a thickness of 255 millimeters (10 inches) is selected for the type D traffic area, then the required percent steel determined from Figure 13-1 would be as shown in column 8. Column 9 presents the allowable lengths or widths of slab for the reinforced concrete pavement.

Table 13-1
Reinforced Concrete Pavement Design Example

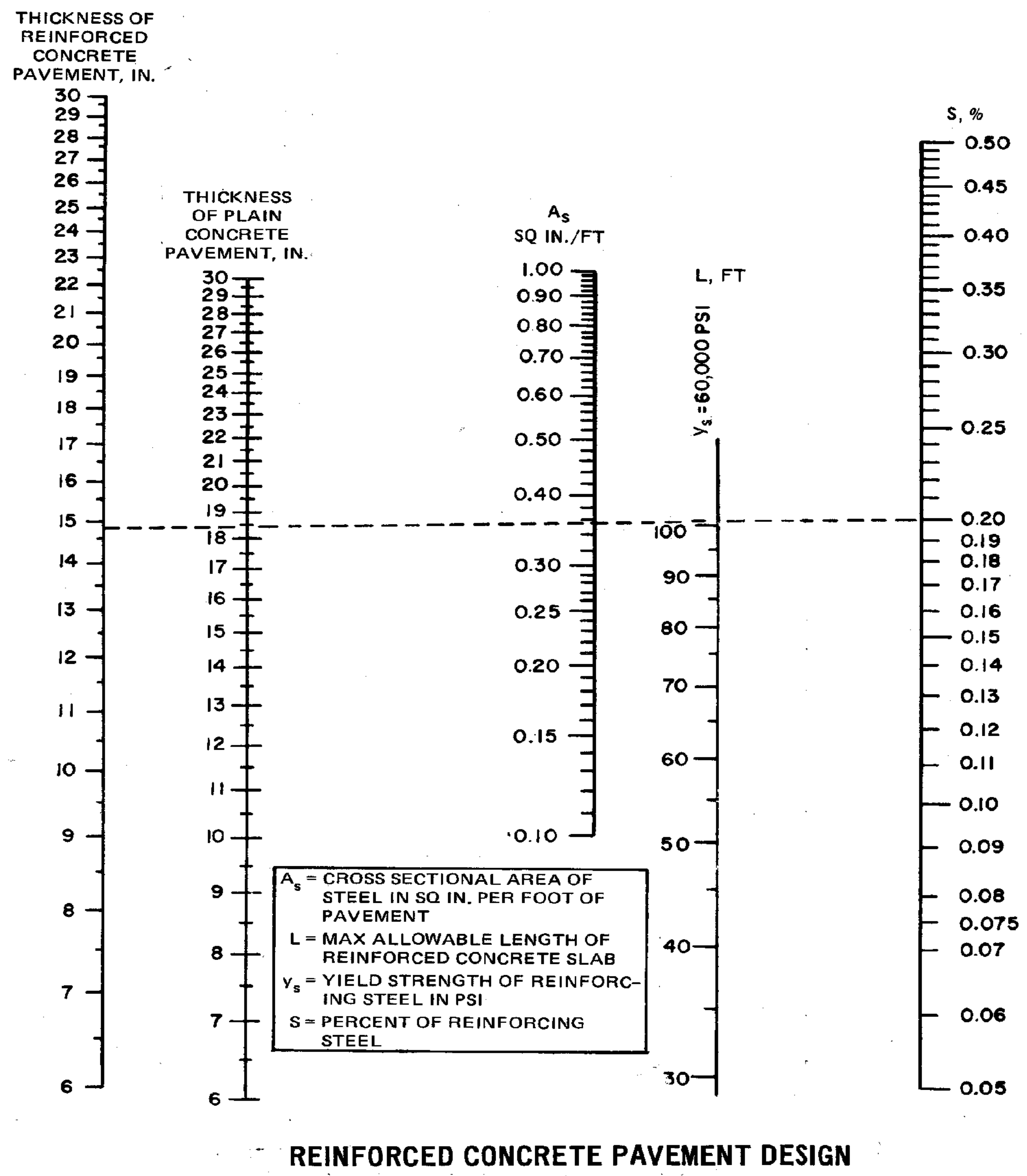
Traffic Area (1)	Thickness of Plain Concrete, in. (2)	Initial Thickness of Reinforced Concrete, in. (3)	Design Thickness of Reinforced Concrete, in. (4)	Percent Steel (5)	Length or Width of Slab, ft (6)	Design Example Preselecting Thickness of Reinforced Concrete	
						Percent Steel (7)	Length or Width of Slab, ft (8)
A	21.7	17.4	17.5	0.190	100[1]	0.356	100[1]
B	21.5	17.3	17.5	0.177	98	0.308	100[1]
C	17.5	14.1	14.5	0.156	85	0.080	56
D	13.5	10.8	11.0	0.178	84	0.309	100[1]

[1] Maximum length or width allowed.
Conversion Factors: Millimeters = 25.4 × inches, Meters = 0.3048 × feet

Table 13-2
Reinforced Concrete Pavement Design Example on a Lean Concrete Base Course

							Design Example Preselecting Thickness of Reinforced Concrete	
Traffic Area (1)	Thickness of Plain Concrete in. (2)	Plain[1] Concrete Overlay Thickness, in. (3)	Initial Reinforced Concrete Overlay Thickness, in. (4)	Design Thickness of Reinforced Concrete, in. (5)	Percent Steel (6)	Length or Width of Slab, ft (7)	Percent Steel (8)	Length or Width of Slab, ft (9)
A	21.7	19.8	16.0	16.0	0.200	100[2]	0.320	100[2]
B	21.5	19.6	15.7	16.0	0.180	100[2]	0.256	100[2]
C	17.5	15.4	12.4	12.5	0.184	95	0.052	42
D	13.5	11.2	9.0	9.0	0.200	85	0.093	53

[1] Thickness of plain concrete overlay determined using Equation 12-1.
[2] Maximum length or width allowed.
Conversion Factors: Millimeters = 25.4 × inches, Meters = 0.3048 × feet



CONVERSION FACTORS

MILLIMETERS = 25.4 x INCHES
METERS = 0.3048 x FEET
SQUARE MILLIMETERS = 645 x SQUARE INCHES

Figure 13-1. Reinforced concrete pavement design

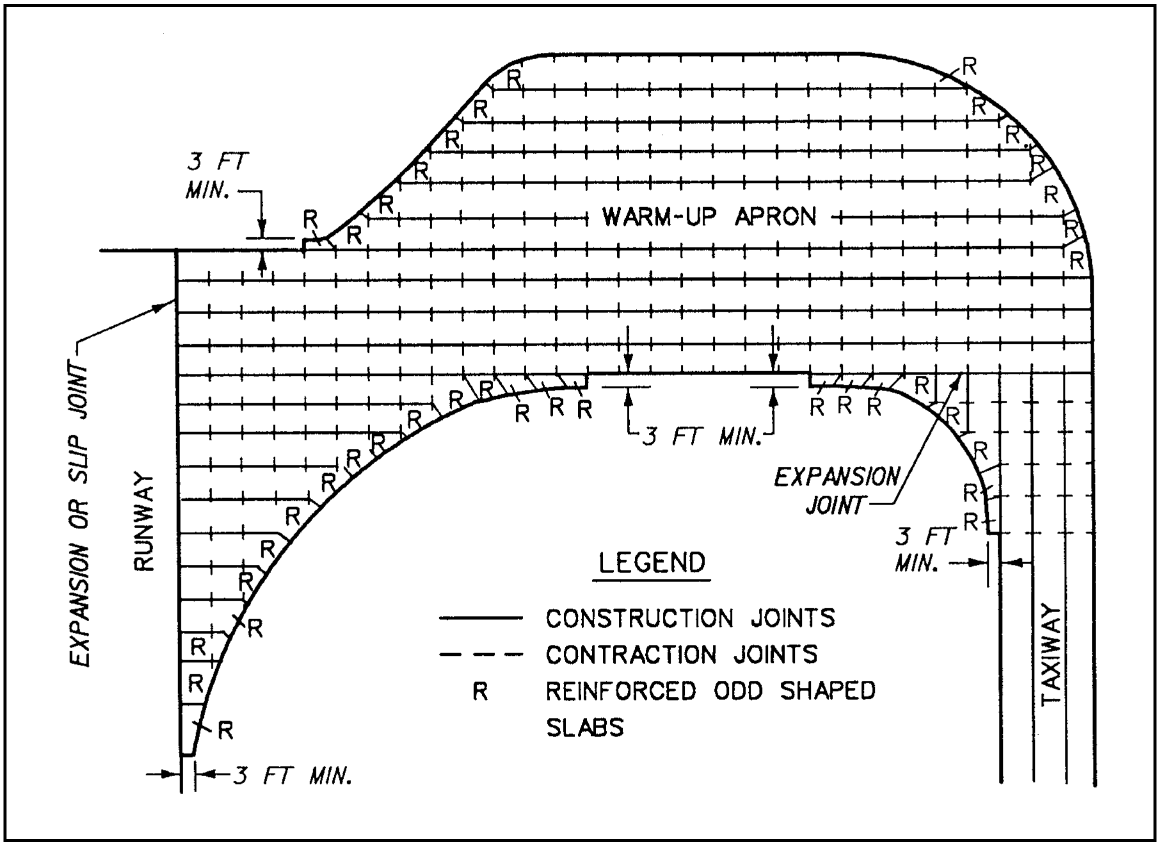


Figure 13-2. Typical layouts showing reinforcement of odd-shaped slabs and mismatched joints (Continued)

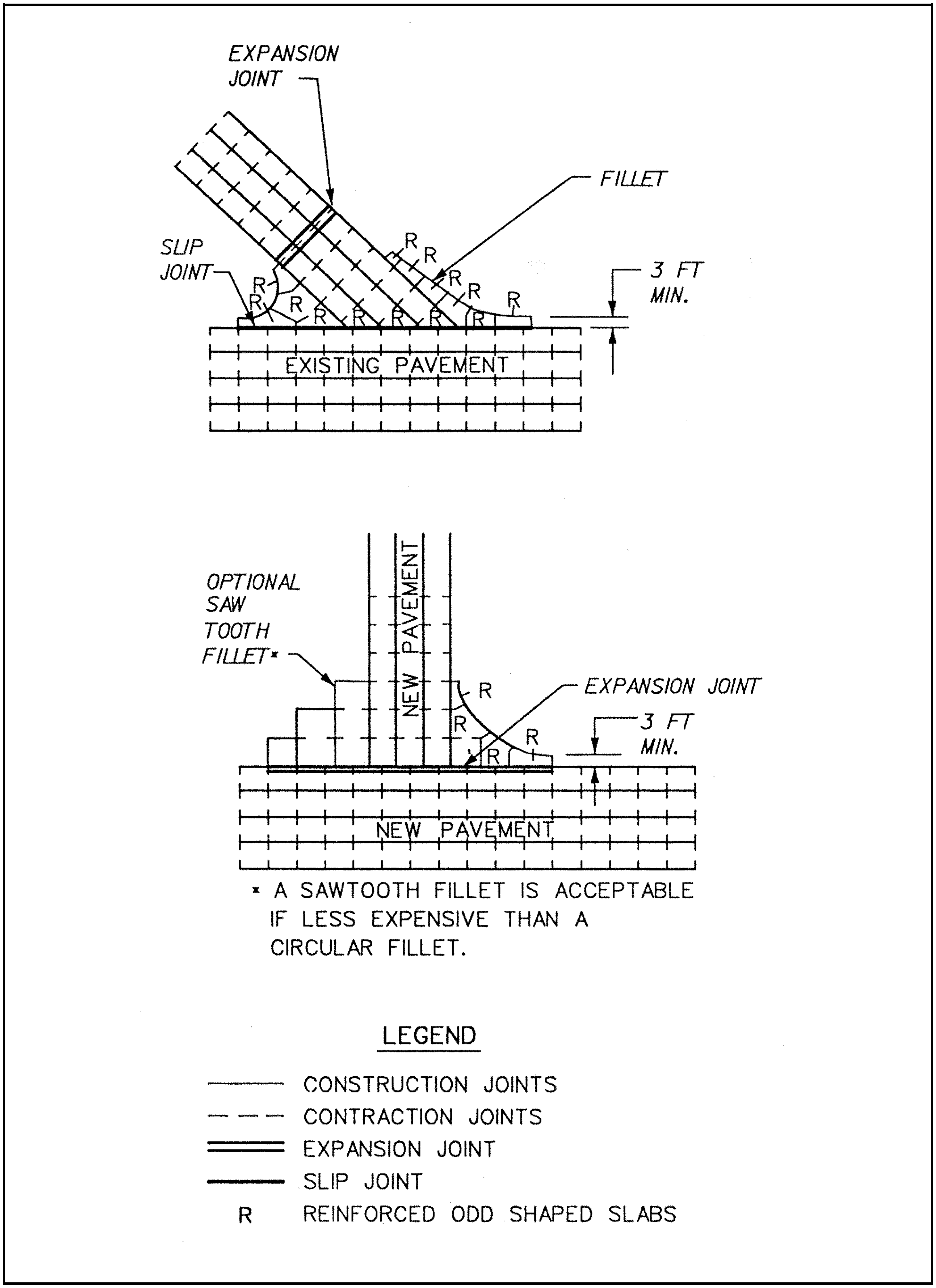
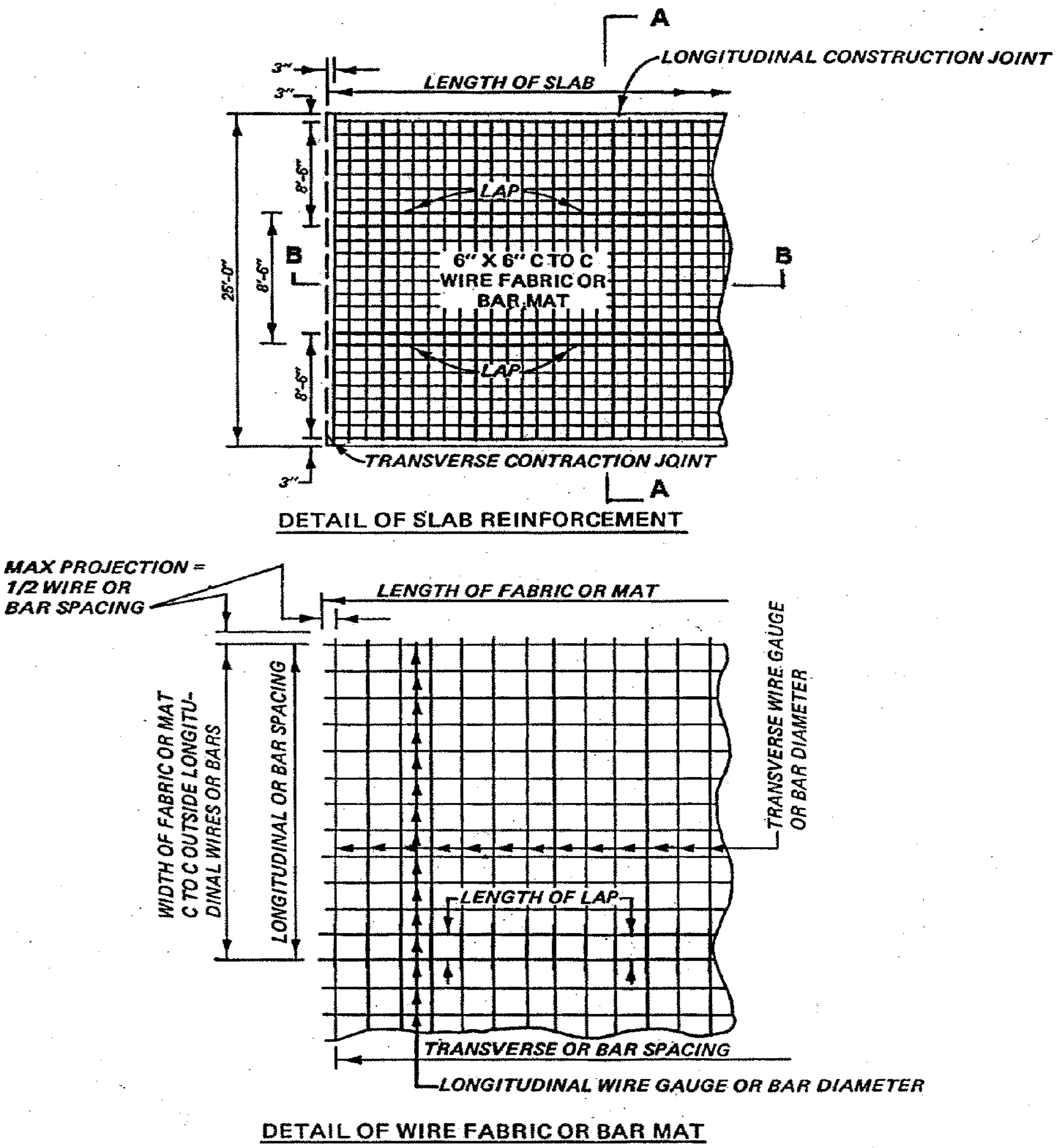


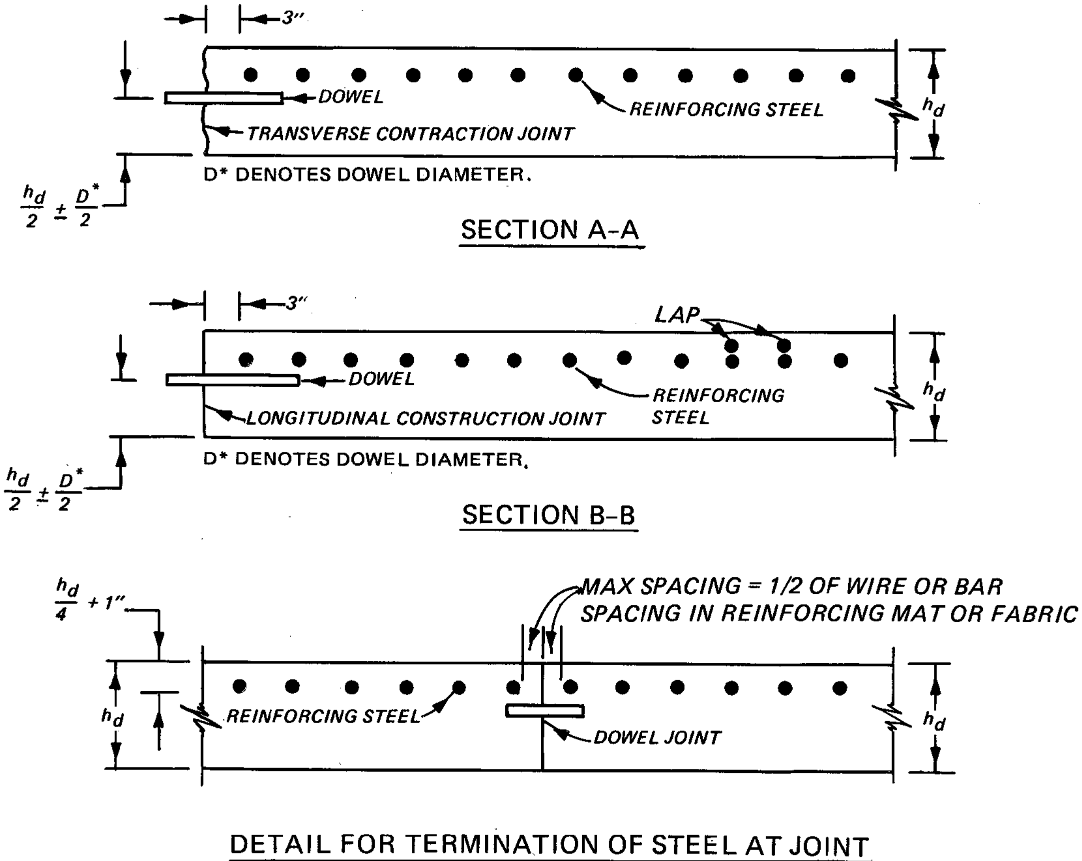
Figure 13-2. (Concluded)



CONVERSION FACTORS

MILLIMETERS = 25.4 x INCHES
METERS = 0.3048 x FEET

Figure 13-3. Reinforcing steel details (Continued)



NOTES:
1. h_d DENOTES REINFORCED CONCRETE PAVEMENT DESIGN THICKNESS
2. REINFORCING STEEL NOT CARRIED THROUGH JOINT
3. ALL JOINTS IN REINFORCED CONCRETE PAVEMENTS DOWELED EXCEPT THICKENED-EDGE AND TRANSVERSE CONSTRUCTION JOINTS

CONVERSION FACTORS

MILLIMETERS = 25.4 x INCHES

Figure 13-3. (Concluded)

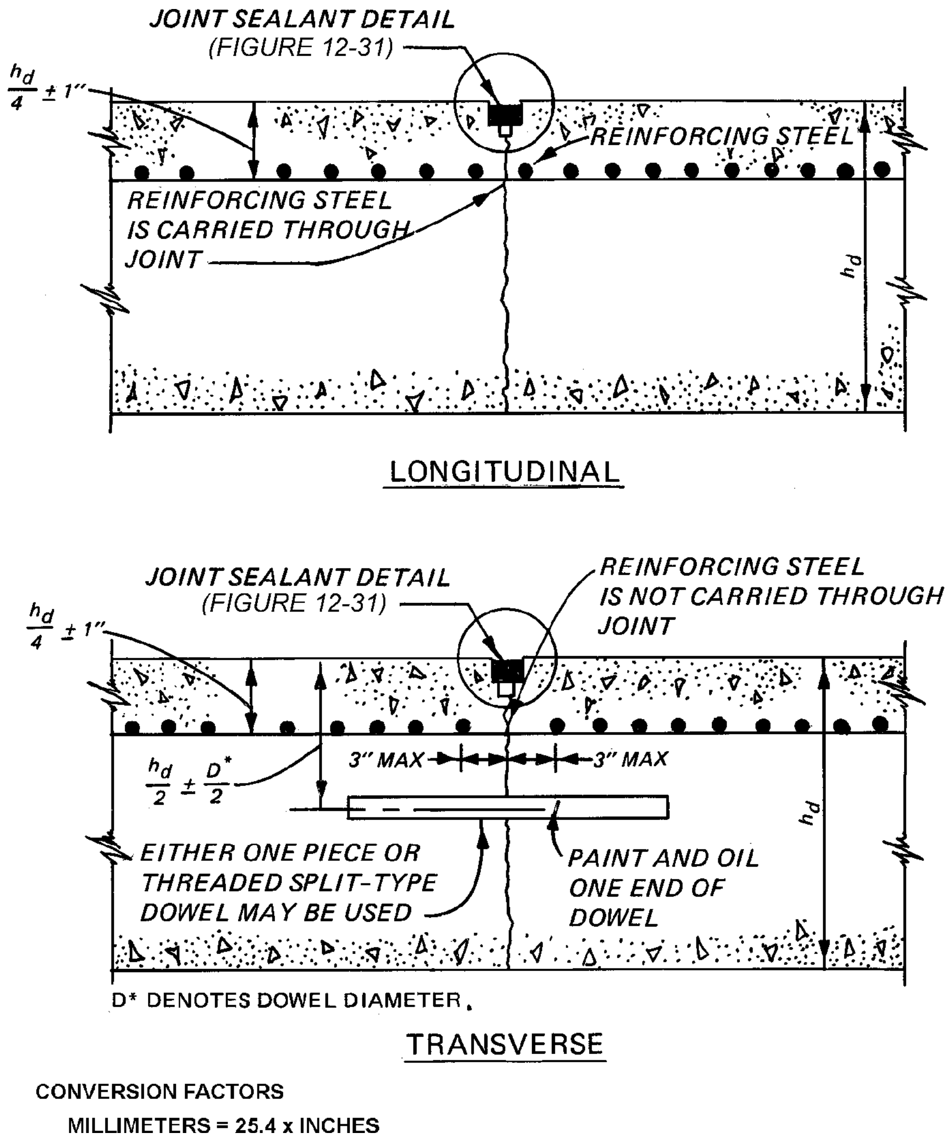
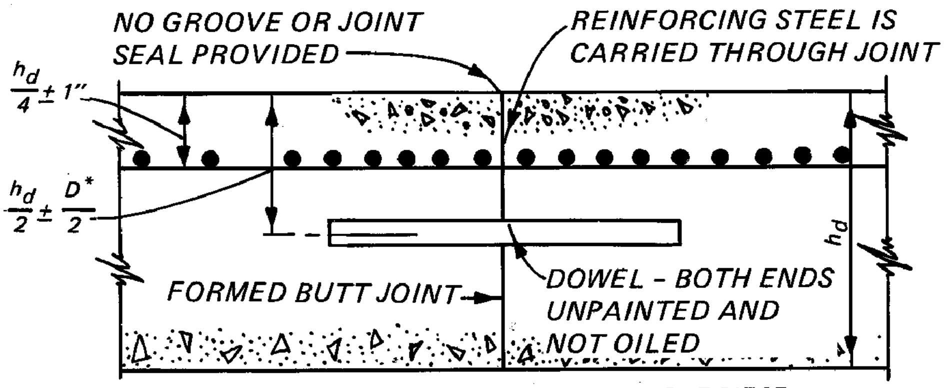


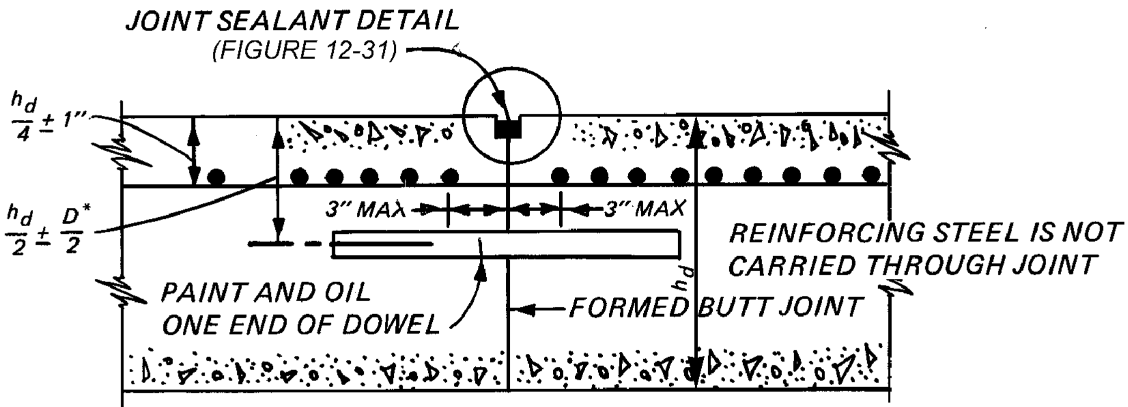
Figure 13-4. Contraction joints for reinforced concrete pavements



D*DENOTES DOWEL DIAMETER.EITHER ONE PIECE
OR THREADED SPLIT-TYPE DOWELS MAY BE USED.

NOTE: THIS DETAIL WILL BE USED ONLY WHEN A TRANSVERSE CONSTRUCTION JOINT IS REQUIRED AT A LOCATION OTHER THAN A REGULARLY SCHEDULED TRANSVERSE CONTRACTION JOINT.

DOWELED TRANSVERSE



D*DENOTES DOWEL DIAMETER.EITHER ONE PIECE OR
THREADED SPLIT-TYPE DOWELS MAY BE USED.

NOTE: THIS DETAIL WILL BE USED WHEN A TRANSVERSE CONSTRUCTION JOINT IS REQUIRED AT A REGULARLY SCHEDULED TRANSVERSE CONTRACTION JOINTS.

DOWELED TRANSVERSE OR LONGITUDINAL

CONVERSION FACTOR

MILLIMETERS = 25.4 x INCHES

Figure 13-5. Construction joints for reinforced concrete pavements
(Sheet 1 of 4)

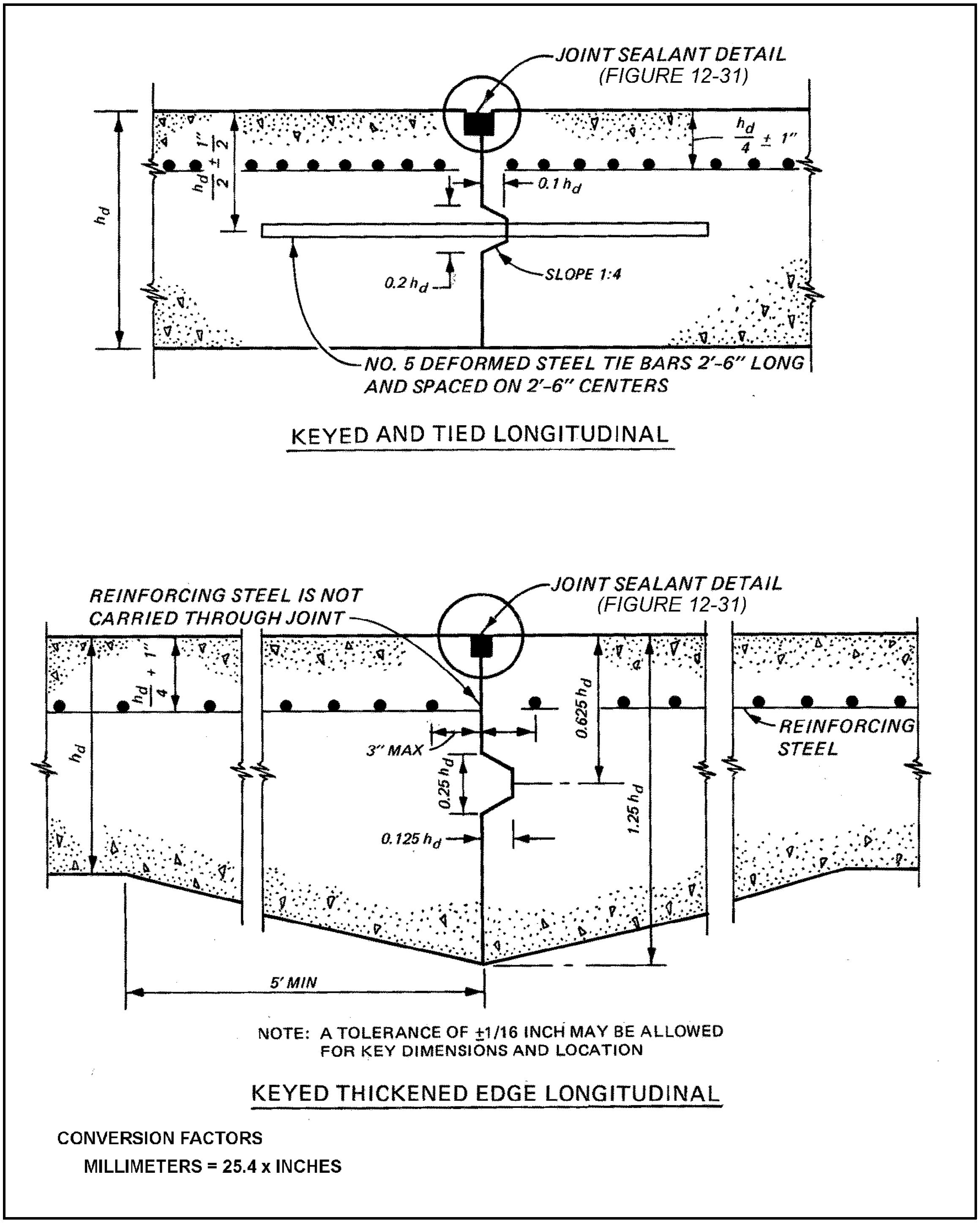
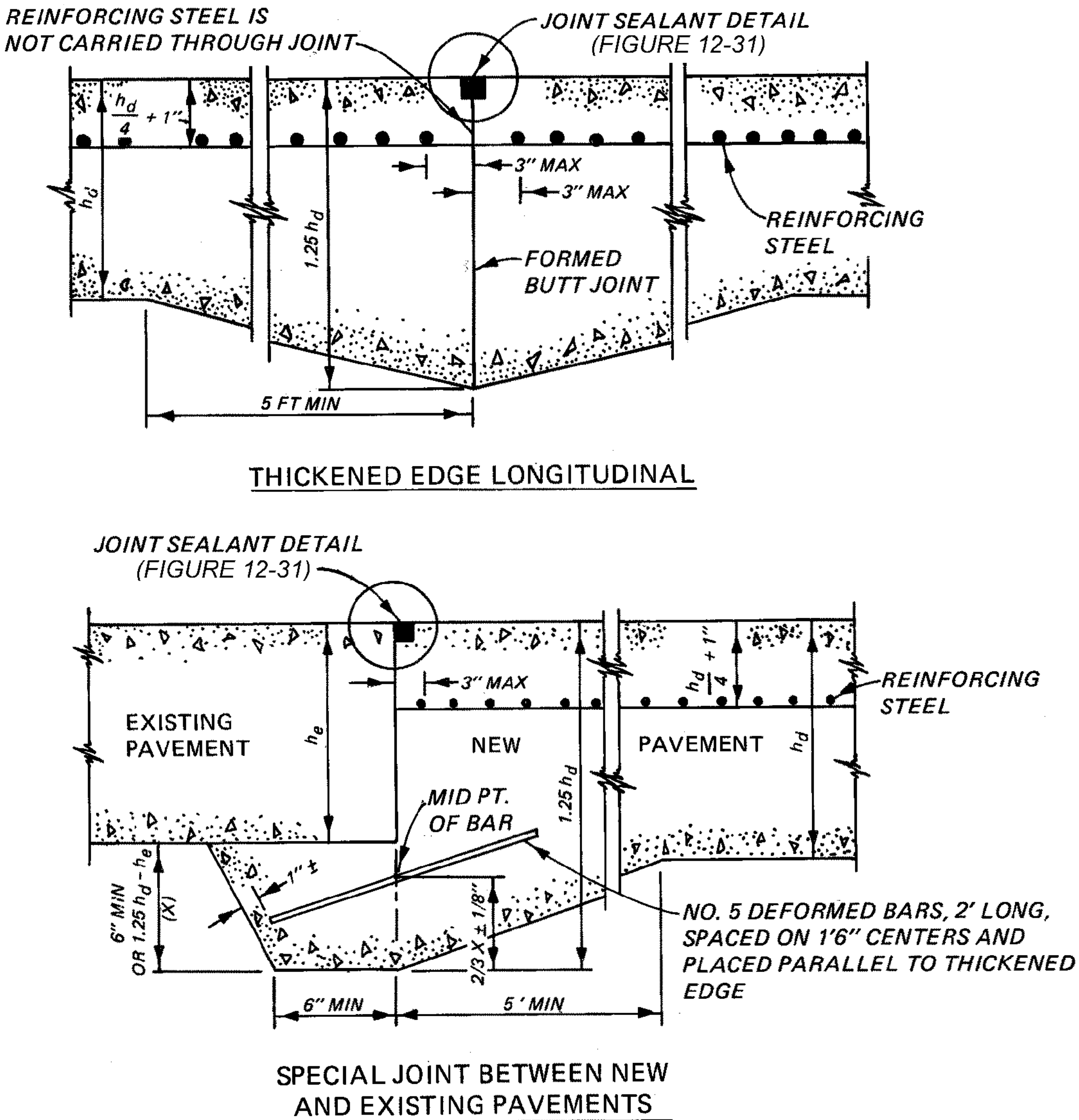


Figure 13-5. (Sheet 2 of 4)



CONVERSION FACTORS

MILLIMETERS = 25.4 x INCHES
METERS = 0.3048 x FEET

Figure 13-5. (Sheet 3 of 4)

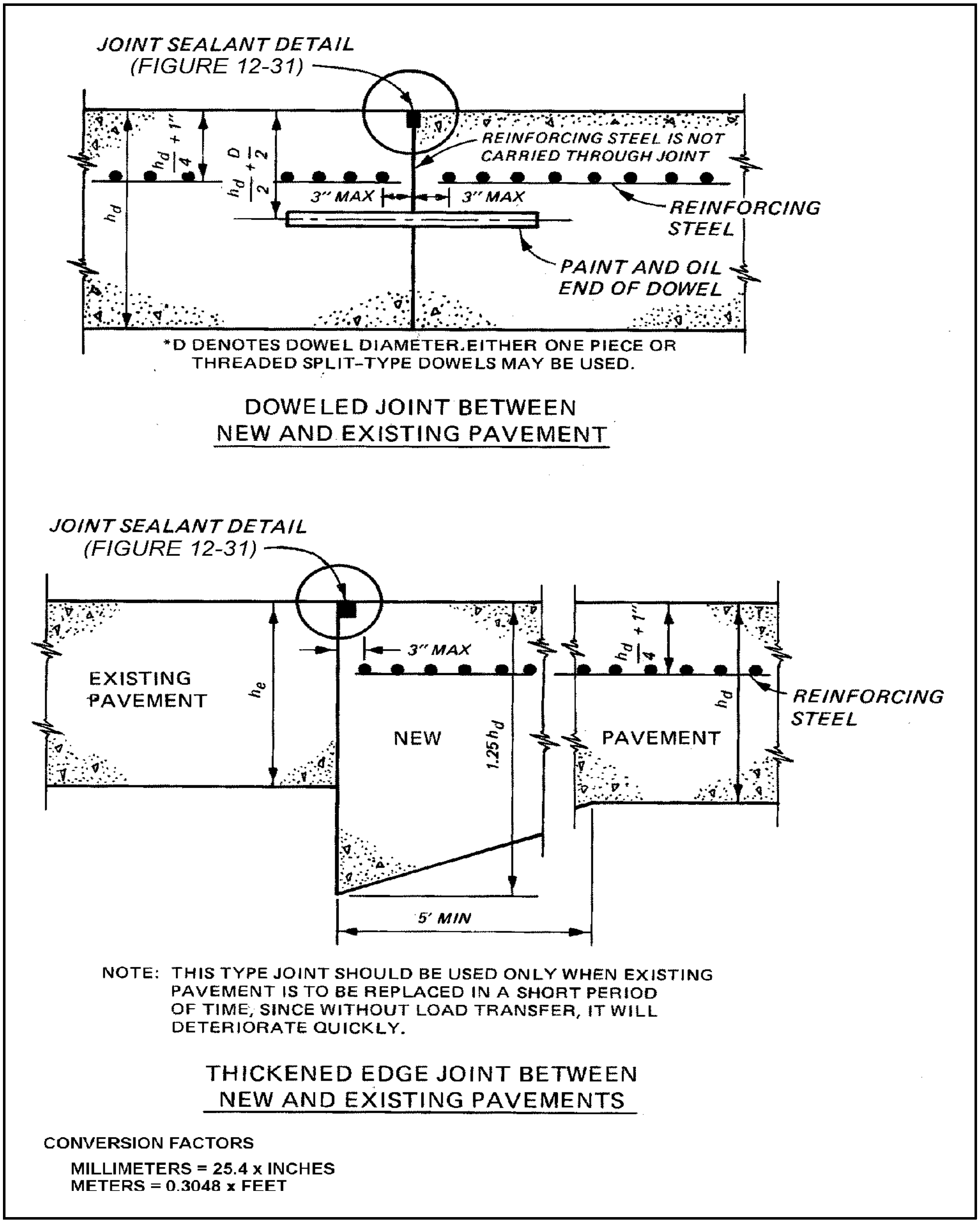


Figure 13-5. (Sheet 4 of 4)

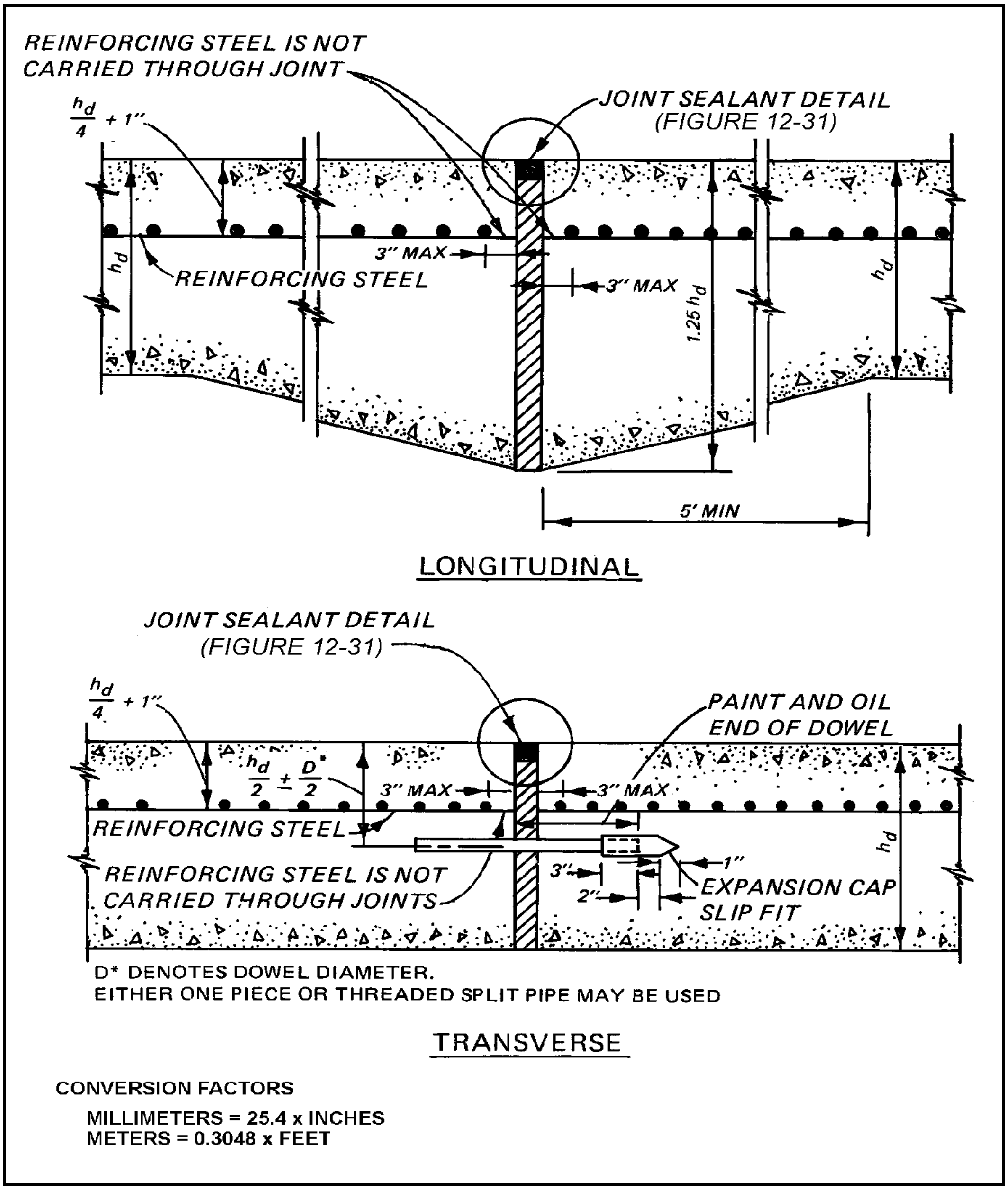


Figure 13-6. Expansion joints for reinforced concrete pavements

CHAPTER 14

FIBROUS CONCRETE PAVEMENT DESIGN

1. BASIS OF DESIGN. The design of fibrous concrete pavement is based upon limiting the ratio of the concrete flexural strength and the maximum tensile stress at the joint, with the load either parallel or normal to the edge of the slab, to a value found to give satisfactory performance in full-scale accelerated test tracks. Because of the increased flexural strength of the fibrous concrete and the bridging of fibers across cracks that develop in the concrete, the thickness can be significantly reduced; however, this results in a more flexible structure, which causes an increase in vertical deflections and potential for densification and/or shear failures in the foundation, pumping of the subgrade material, and joint deterioration. To protect against these latter factors, a limiting vertical deflection criterion has been applied to the thickness developed from the tensile stress criteria.

2. USES FOR FIBROUS CONCRETE. Although several types of fiber have been studied for concrete reinforcement, most of the experience has been with steel fibers, and the design criteria presented herein are limited to steel fibrous concrete. Fibrous concrete is a relatively new material for pavement construction and lacks a long-time performance history. Experience indicates that with time and number of passes logged on a fibrous concrete pavement, the fiber becomes exposed at the wearing surface and becomes an FOD problem. Because of this, its use will require approval of the Headquarters, U.S. Army Corps of Engineers (HQUSACE) (CEMP), HQ Air Force Command, or the Naval Facilities Engineering Command. The major uses to date have been for thin resurfacing or strengthening overlays where grade problems restrict the thickness of overlay that can be used. The use of fibrous concrete pavement should be based upon the economics involved. Fibrous concrete will not be used in Navy pavements.

3. MIX PROPORTIONING CONSIDERATIONS.

a. The design mix proportioning of fibrous concrete will be determined by a laboratory study. Typical mix proportions are shown on Table 14-1. The following are offered as guides and to establish limits where necessary for the use of the design criteria included herein. Additional details may be found in TM 5-822-7/AFM 88-6, Chapter 8.

Table 14-1
Range of Proportions for Normal-Weight Fibrous Concrete[1]

	9.5-mm (3/8-in.) Maximum Sized Aggregate	19-mm (3/4-in.) Maximum Sized Aggregate
Cement kg/m^3 (lb/yd^3)	355-590 (600-1,000)	295-535 (500-900)
Water-cement ratio	0.35-0.45	0.40-0.50
Percent of fine to coarse aggregate	45-60	45-55
Entrained air content (percent)	4-7	4-6
Fiber content (volume percent)		
Deformed steel fiber	0.4-0.9	0.3-0.8
Smooth steel fiber	0.9-1.8	0.8-1.6

[1] From ACI 544.1R-82, used with permission of the American Concrete Institute.

b. The criteria contained herein are based upon fibrous concrete containing 1 to 2 percent by volume 45 to 113 kilograms (100 to 250 pounds) of steel fibers per cubic yard of concrete, and fiber contents within this range are recommended.

c. Most experience to date has been with fibers 25 to 38 millimeters (1 to 1-½ inches) long, and for use of the criteria contained herein, fiber lengths within this range are recommended.

d. For proper mixing, the maximum aspect ratio (length to diameter or equivalent diameter) of the fibers should be about 100.

e. The large surface-area-to-volume ratio of the steel fibers requires an increase in the paste necessary to ensure that the fibers and aggregates are coated. To accomplish this, cement contents of 445 to 535 kg/m^3 (750 to 900 lb/yd^3) of concrete are common. The cement content may be all portland cement or a combination of portland cement and up to 25 percent by volume of fly ash or other pozzolans.

f. Maximum size coarse aggregates should fall between 9.5 and 19 millimeters (3/8 and 3/4 inches). The percent of fine to coarse aggregate has been between 45 and 60 percent on typical projects using fibrous concrete.

4. THICKNESS DETERMINATION. The required thickness of fibrous concrete will be a function of the design concrete flexural strength, the modulus of soil reaction, the thickness and flexural modulus of elasticity of stabilized material if used, the aircraft gross weight, the volume of traffic, the type of traffic area, and the allowable vertical deflection. When stabilized material is not used, the required thickness of fibrous concrete is determined directly from the appropriate chart (Figures 14-1 through 14-9). If the base or subgrade is stabilized and meets the minimum strength requirements of TM 5-822-14/ AFJMAN 32-1019, the stabilized layer will be treated as a low-strength base and the design will be made using Equation 12-1. The resulting thickness must then be checked for allowable deflection. The minimum thickness for fibrous concrete pavements will be 102 millimeters (4 inches).

5. ALLOWABLE DEFLECTION FOR FIBROUS CONCRETE PAVEMENT. The elastic deflection that fibrous concrete pavements experience must be limited to prevent overstressing of the foundation material and thus premature failure of the pavement. Curves are provided (Figures 14-10 through 14-18) for the determination of the vertical elastic deflection that a pavement will experience when loaded and must be checked for all design aircraft. Use of the curves requires three different inputs: slab thickness, subgrade modulus, and gross weight of the design aircraft. The modulus value to use for stabilized layers is determined from Figure 9-1. The slab thickness is that which is determined from Figures 14-1 to 14-19. The computed vertical elastic deflection is then compared with appropriate allowable deflections determined from Figure 14-19 or, in the case of shoulder design, with an allowable deflection value of 0.15 millimeters (0.06 inches). If the computed deflection is less than the allowable deflection, the thickness meets allowable deflection criteria and is acceptable. If the computed deflection is larger than the allowable deflection, the thickness must be increased or a new design initiated with a modified value for either concrete flexural strength or subgrade modulus. The process must be repeated until a thickness based upon the limiting stress criterion will also have a computed deflection equal to or less than the allowable value. Should the vertical deflection criteria indicate the need for a thickness increase greater than that required by the limiting stress criteria, the thickness increase should be limited to that thickness required for plain concrete with a flexural strength of 6.2 MPa (900 psi).

6. JOINTING. The jointing types and designs discussed for plain concrete pavements generally apply to fibrous concrete pavement. For the mix proportioning in Table 14-1, the maximum spacing of

contraction joints will be the same as for plain concrete, except that for thicknesses of 102 to 152 millimeters (4 to 6 inches), the maximum spacing will be 3.8 meters (12.5 feet). Joints in pavements 152 millimeters (6 inches) or greater in thickness will be cut one-third of the depth of the pavement and joints less than 152 millimeters (6 inches) long will be cut one-half the depth of the pavement. Longitudinal construction joints may be either doweled, keyed, keyed and tied, or thickened-edge with a key, in which case the key dimensions will be based upon the thickened-edge thickness. The keyed and tied construction joint will be limited to a width of 30.5 meters (100 feet). For widths greater than 30.5 meters (100 feet), combinations of keyed and tied, doweled, or thickened-edge-type joints may be used. Sealing of joints in fibrous concrete will follow the criteria presented in Chapter 12.

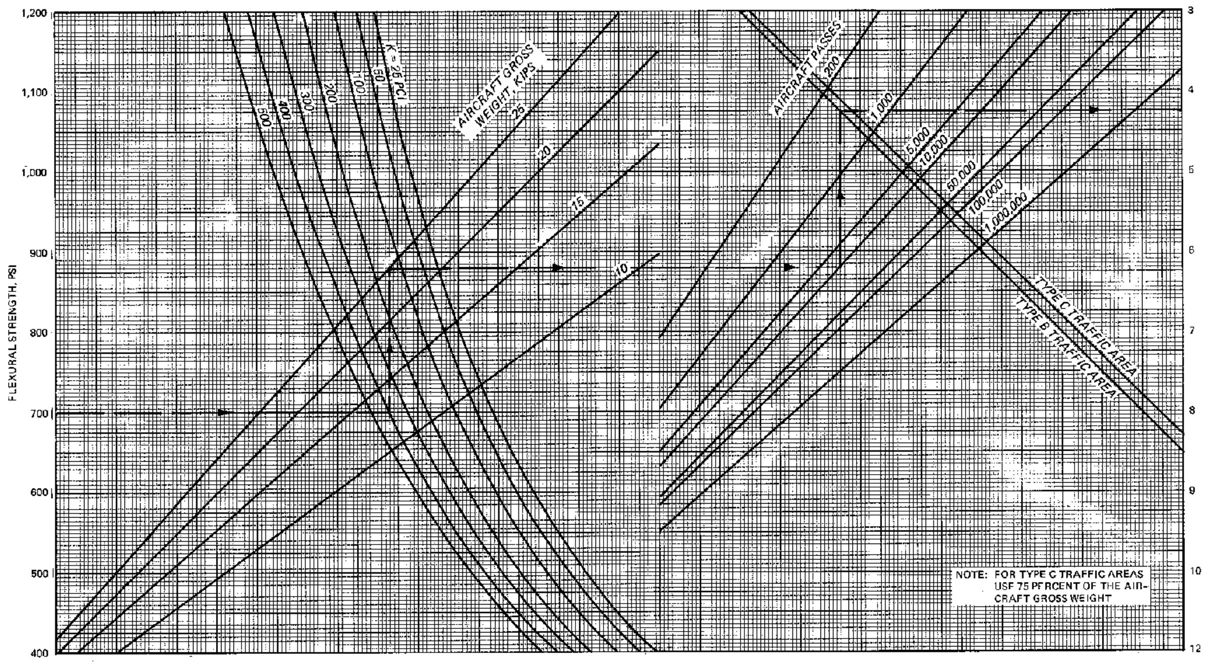
7. EXAMPLE OF FIBROUS CONCRETE PAVEMENT DESIGN.

a. General. An Air Force medium-load airfield is to be designed using fibrous concrete. On-site and laboratory investigations have yielded the following data required for design: (a) subgrade material is a silty sand; (b) modulus of subgrade reaction is 54 kPa/mm (200 pci); (c) an available source of crushed gravel meets the base course requirements; (d) frost does not enter subgrade; and (e) 90-day flexural strength is 6.9 MPa (1,000 psi) with 0.15 percent steel fibers.

b. Example Design—Slab On Grade. Figure 14-5 is entered with the subgrade k, concrete flexural strength, and the pavement thickness determined for the various traffic areas as follows:

Traffic Area	**Thickness mm (in.)**	**Computed Deflection mm (in.)**	**Allowable Deflection mm (in.)**
A	265 (10.5)	0.13 (0.050)	0.13 (0.050)
B	265 (10.5)	0.13 (0.050)	0.14 (0.053)
C	215 (8.5)	0.12 (0.045)	0.14 (0.053)
D	152 (6.0)	0.16 (0.062)	0.29 (0.114)

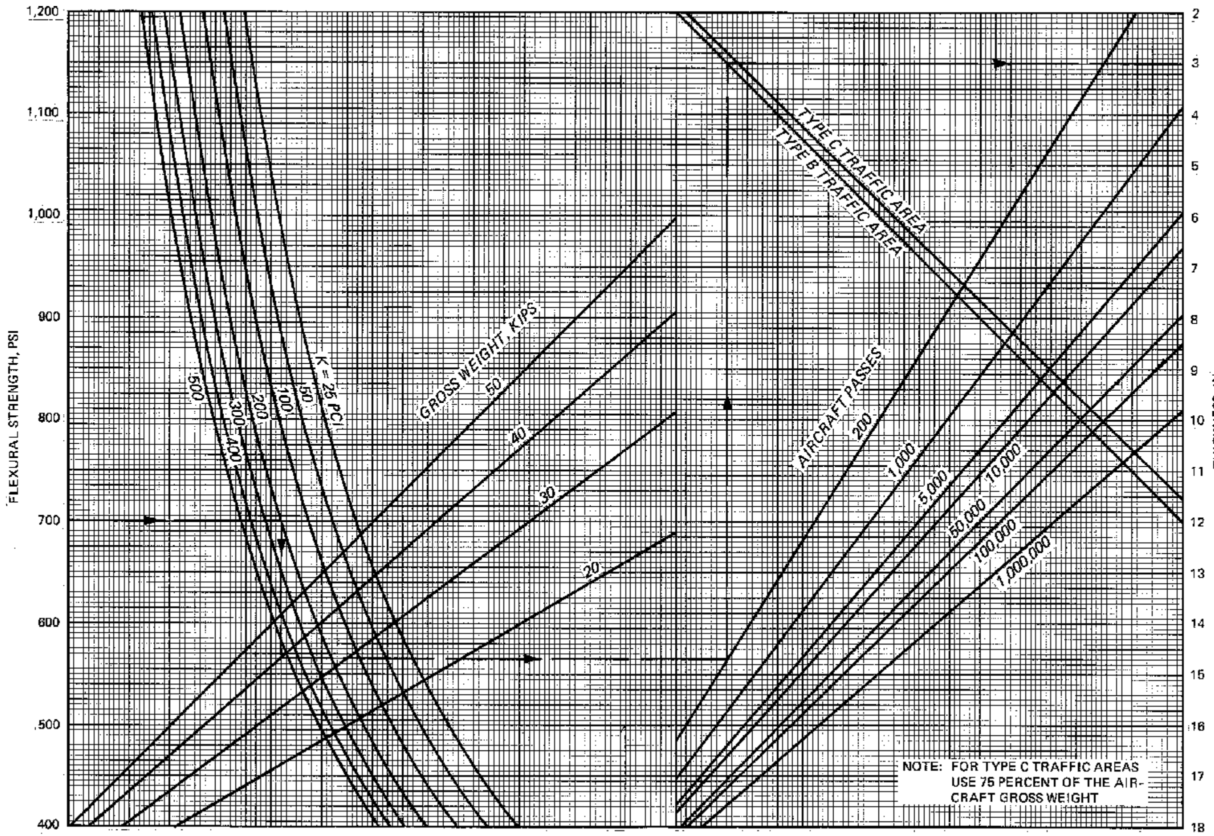
Since the medium-load pavement is designed for the F-15, C-141, and B-52, deflections must be determined for each aircraft. Therefore, by entering Figures 14-13, 14-14, and 14-15 with these thicknesses, the computed deflections for all aircraft may be determined and the controlling value is shown in the tabulation. It should be noted that a comparison of the computed deflections with the allowable deflections from Figure 14-19 reveals that the thicknesses determined by the allowable stress criterion are satisfactory, since the allowable deflections are equal to or greater than the computed deflections for all traffic areas.



CONVERSION FACTORS

MEGAPASCALS = 0.006894 x PSI
KILOPASCALS PER MILLIMETER = 0.271 x PCI
KILOGRAMS = 0.453 x POUNDS
MILLIMETERS = 25.4 x INCHES

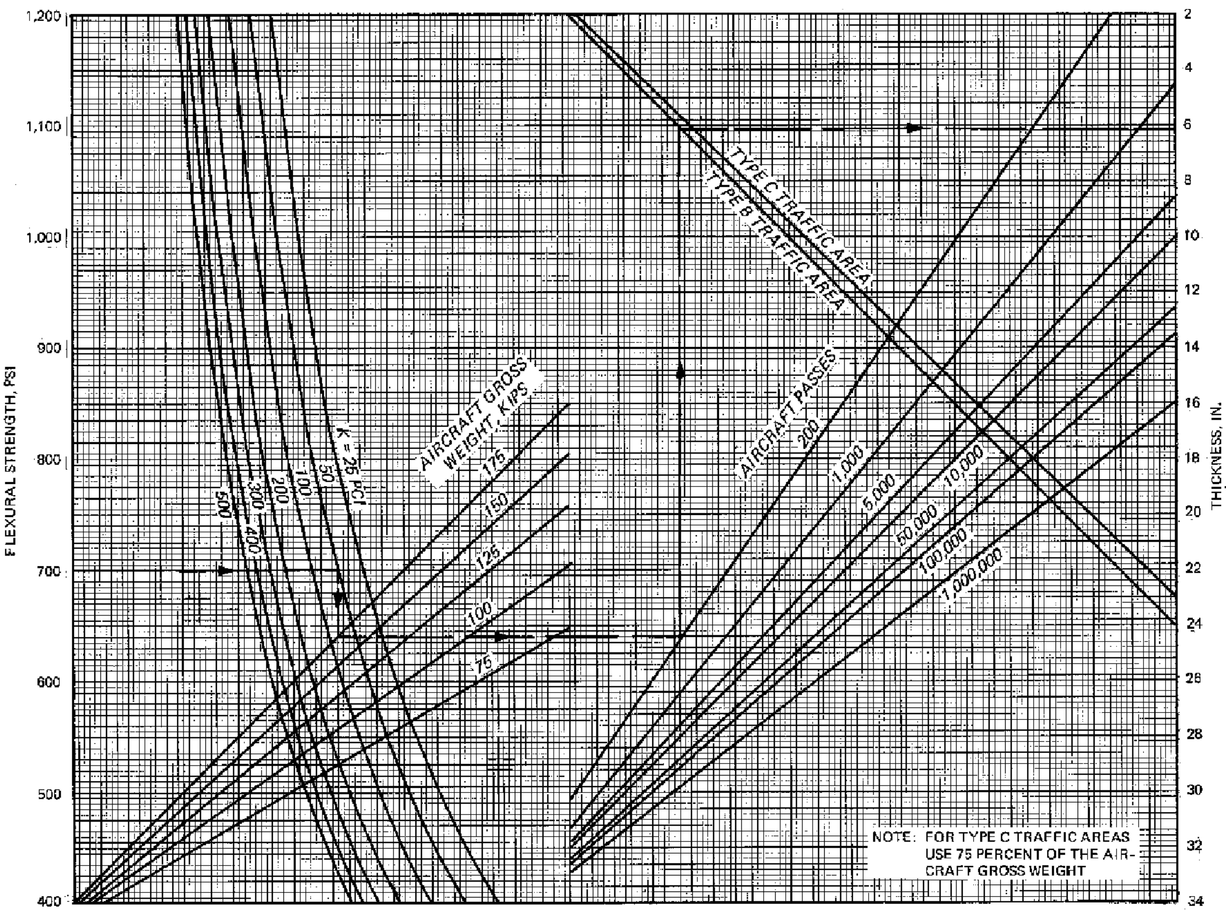
Figure 14-1. Fibrous concrete pavement design curves for UH-60



CONVERSION FACTORS

MEGAPASCALS = 0.006894 x PSI
KILOPASCALS PER MILLIMETER = 0.271 x PCI
KILOGRAMS = 0.453 x POUNDS
MILLIMETERS = 25.4 INCHES

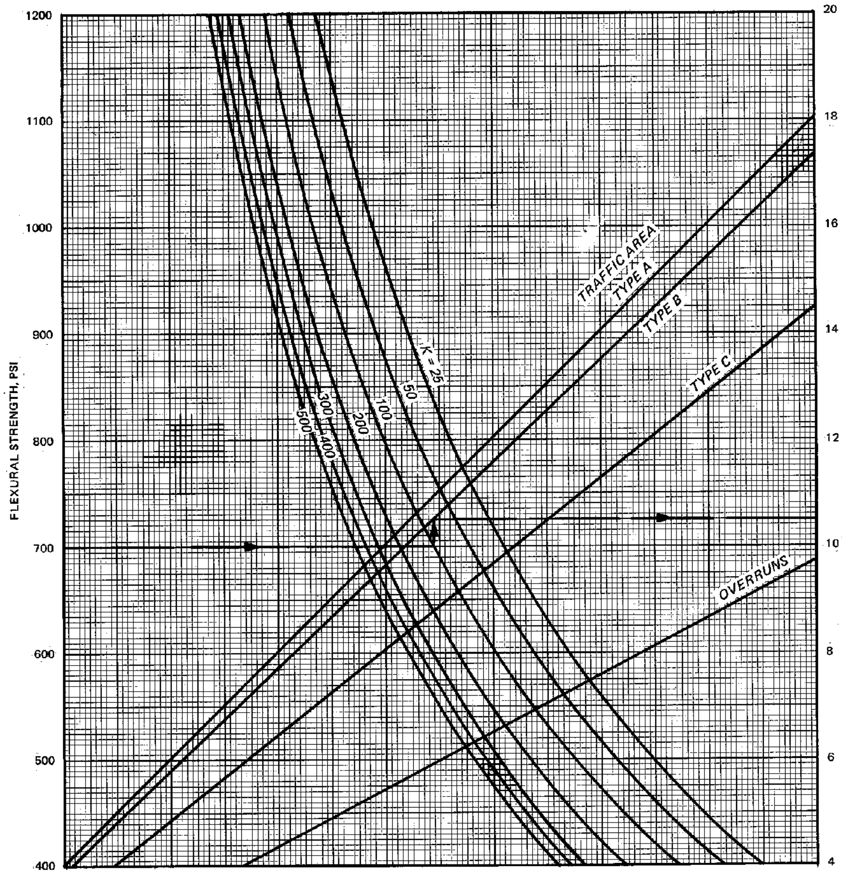
Figure 14-2. Fibrous concrete pavement design curves for CH-47



CONVERSION FACTORS

MEGAPASCALS = 0.006894 x PSI
KILOPASCALS PER MILLIMETER = 0.271 x PCI
KILOGRAMS = 0.453 x POUNDS
MILLIMETERS = 25.4 x INCHES

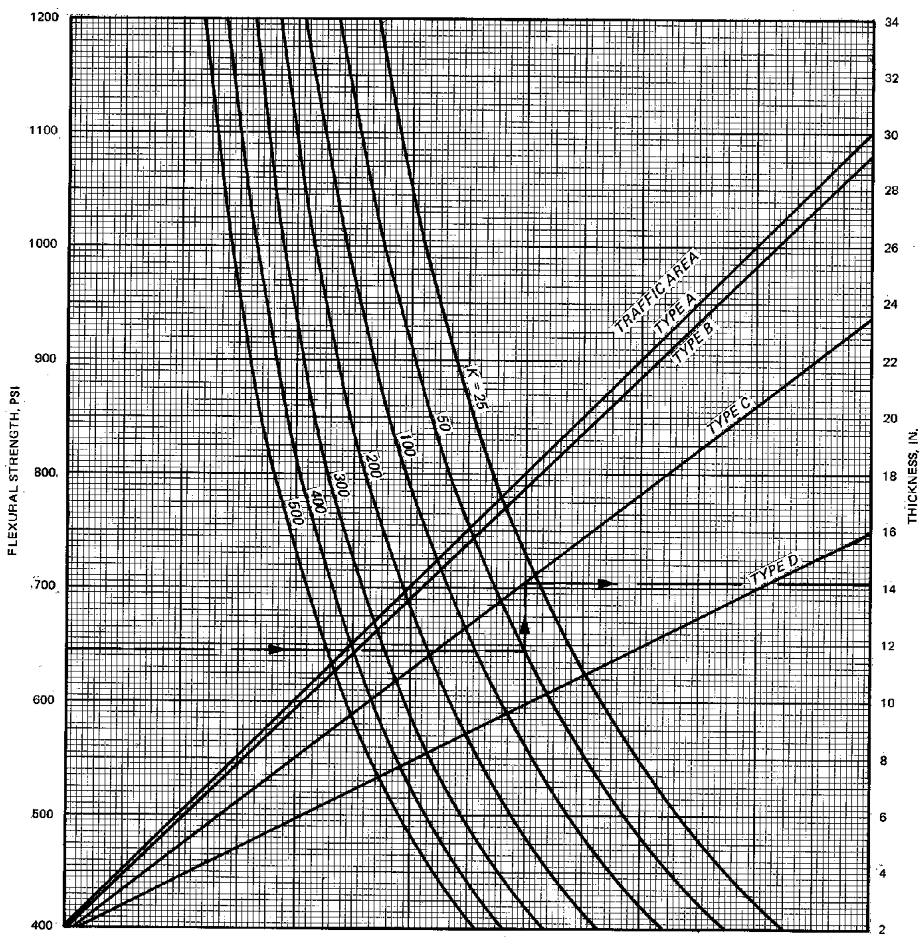
Figure 14-3. Fibrous concrete pavement design curves for C-130



CONVERSION FACTORS

MEGAPASCALS = 0.006894 x PSI
KILOPASCALS PER MILLIMETER = 0.271 x PCI
KILOGRAMS = 0.453 x POUNDS
MILLIMETERS = 25.4 x INCHES

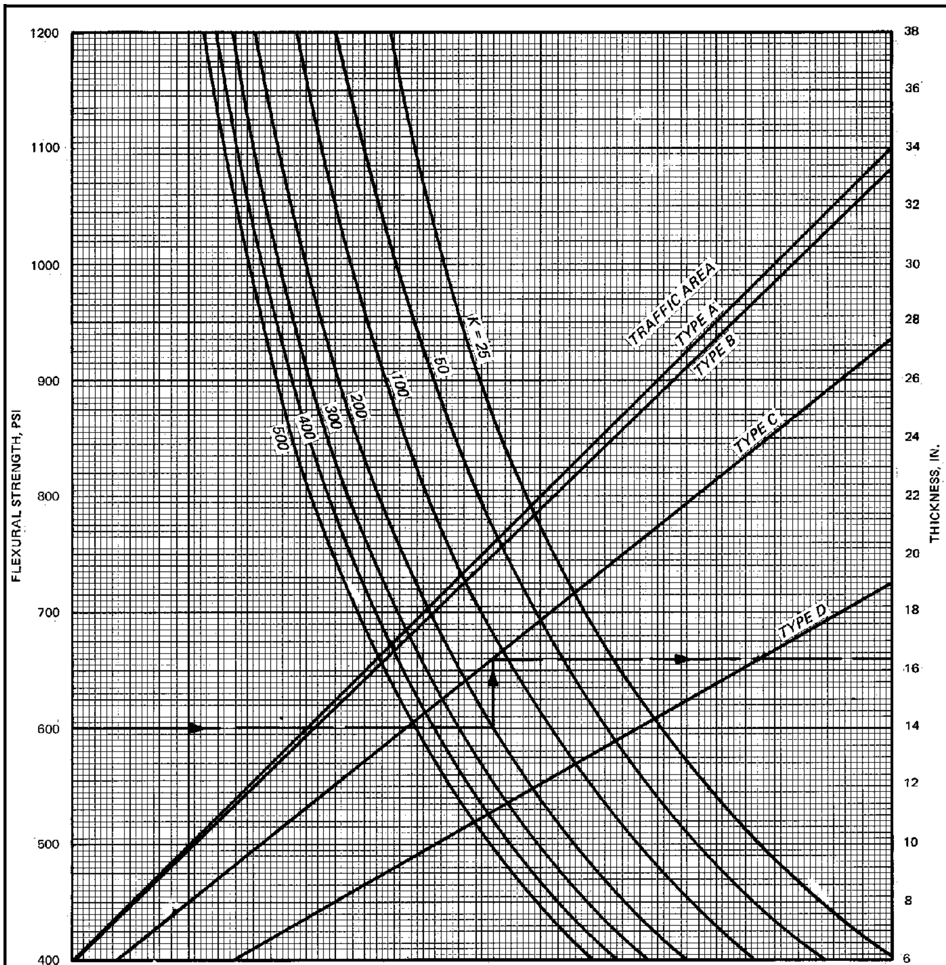
Figure 14-4. Fibrous concrete pavement design curves for Air Force light-load airfields



CONVERSION FACTORS

MEGAPASCALS = 0.006894 x PSI
KILOPASCALS PER MILLIMETER = 0.271 x PCI
KILOGRAMS = 0.453 x POUNDS
MILLIMETERS = 25.4 x INCHES

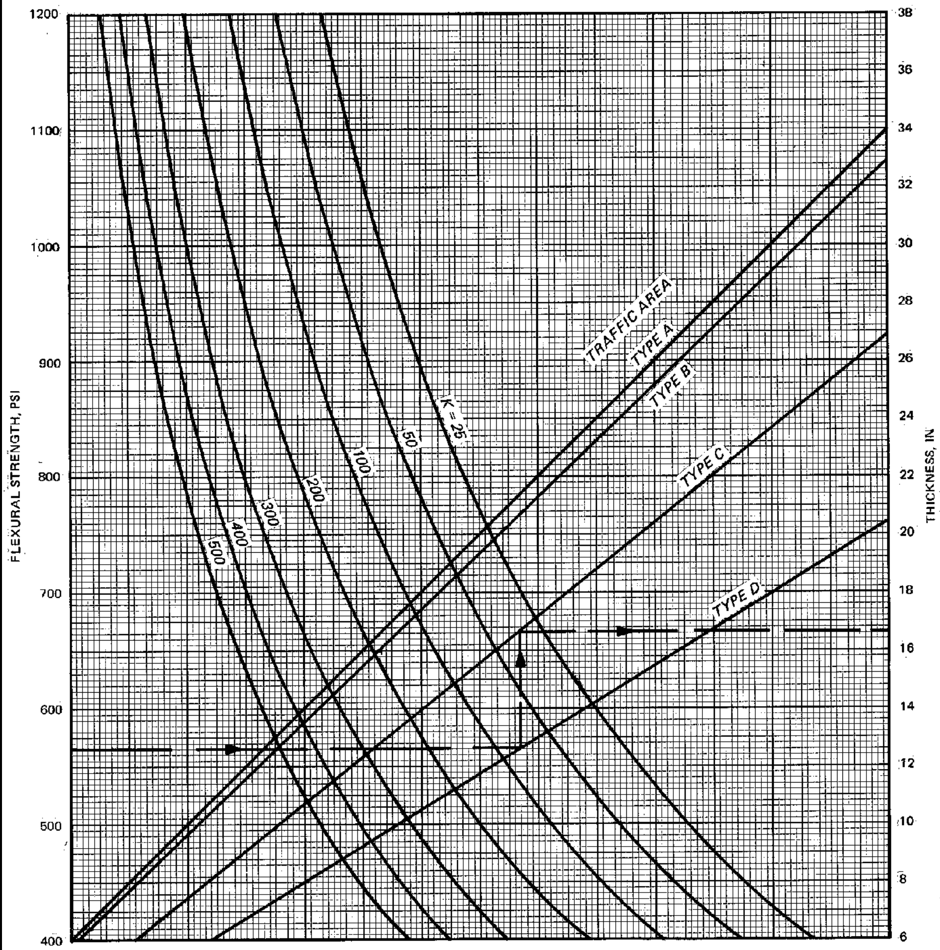
Figure 14-5. Fibrous concrete pavement design curves for Air Force medium-load airfields



CONVERSION FACTORS

MEGAPASCALS = 0.006894 x PSI
KILOPASCALS PER MILLIMETER = 0.271 x PCI
MILLIMETERS = 25.4 x INCHES

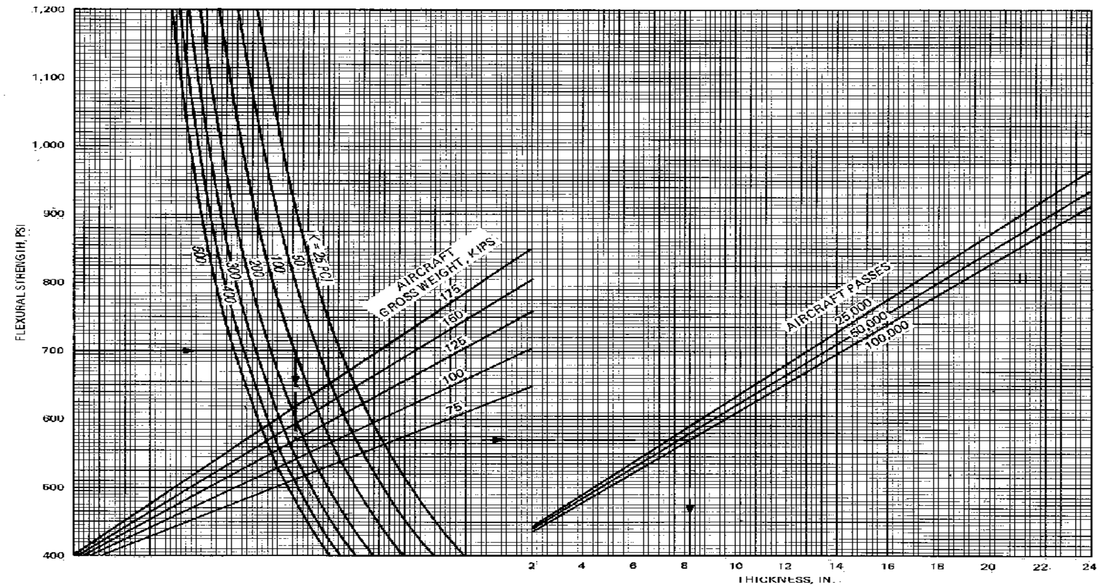
Figure 14-6. Fibrous concrete pavement design curves for Air Force heavy-load airfields



CONVERSION FACTORS

MEGAPASCALS = 0.006894 x PSI
KILOPASCALS PER MILLIMETER = 0.271 x PCI
MILLIMETERS = 25.4 x INCHES

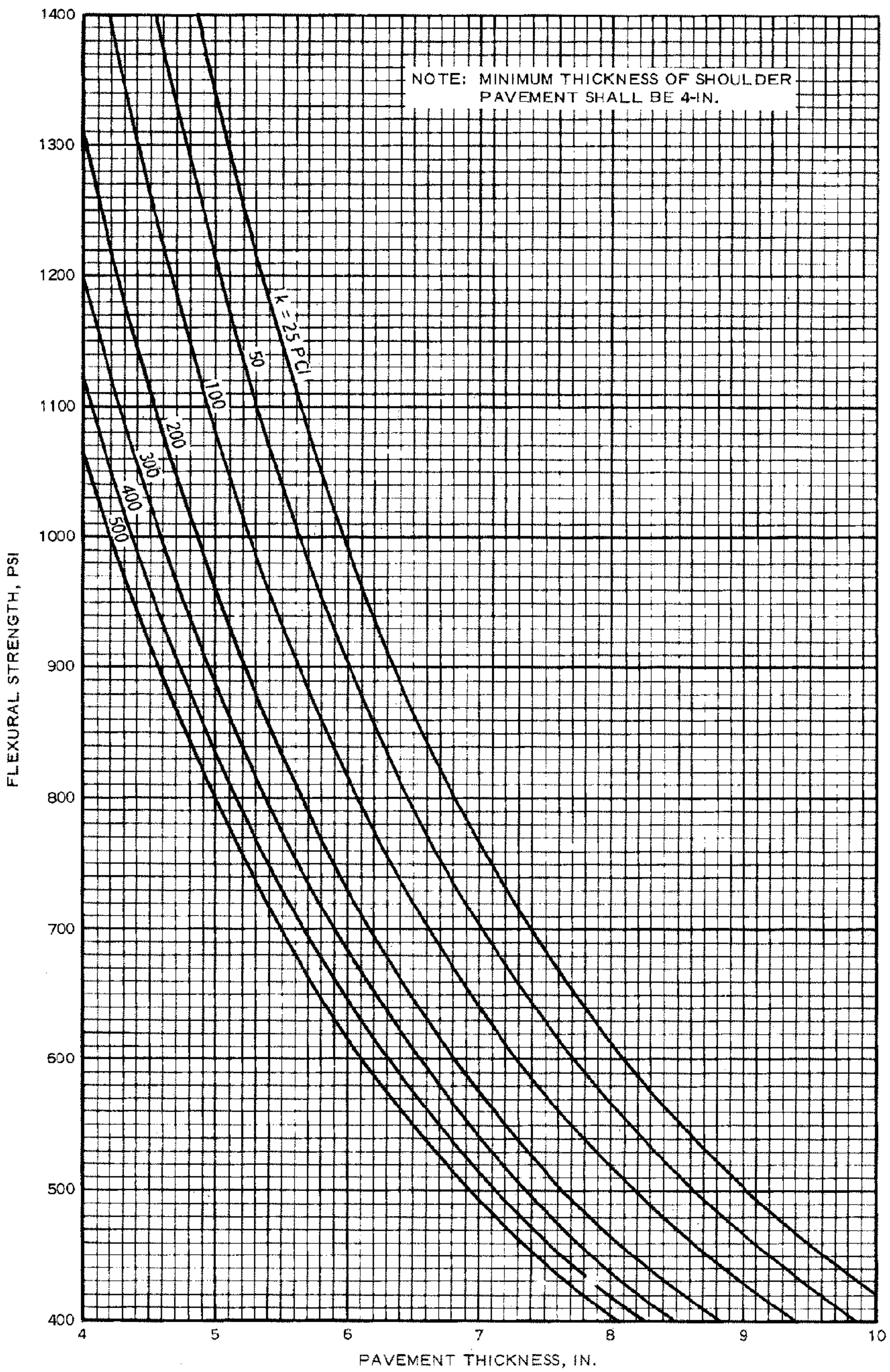
Figure 14-7. Fibrous concrete pavement design curves for Air Force modified heavy-load airfields



CONVERSION FACTORS

MEGAPASCALS = 0.006894 x PSI
KILOPASCALS PER MILLIMETER = 0.271 x PCI
KILOGRAMS = 0.453 x POUNDS
MILLIMETERS = 25.4 x INCHES

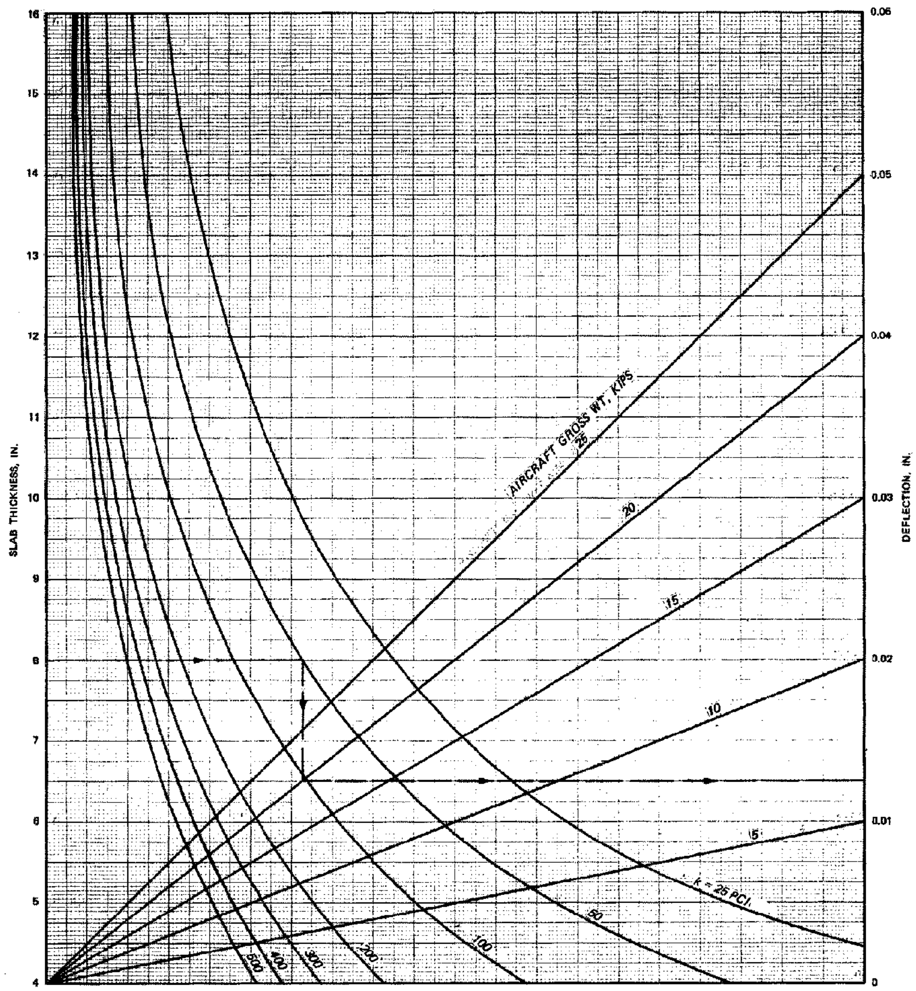
Figure 14-8. Fibrous concrete pavement design curves for Air Force shortfield airfields



CONVERSION FACTORS

MEGAPASCALS = 0.006894 x PSI
KILOPASCALS PER MILLIMETER = 0.271 x PCI
MILLIMETERS = 25.4 x INCHES

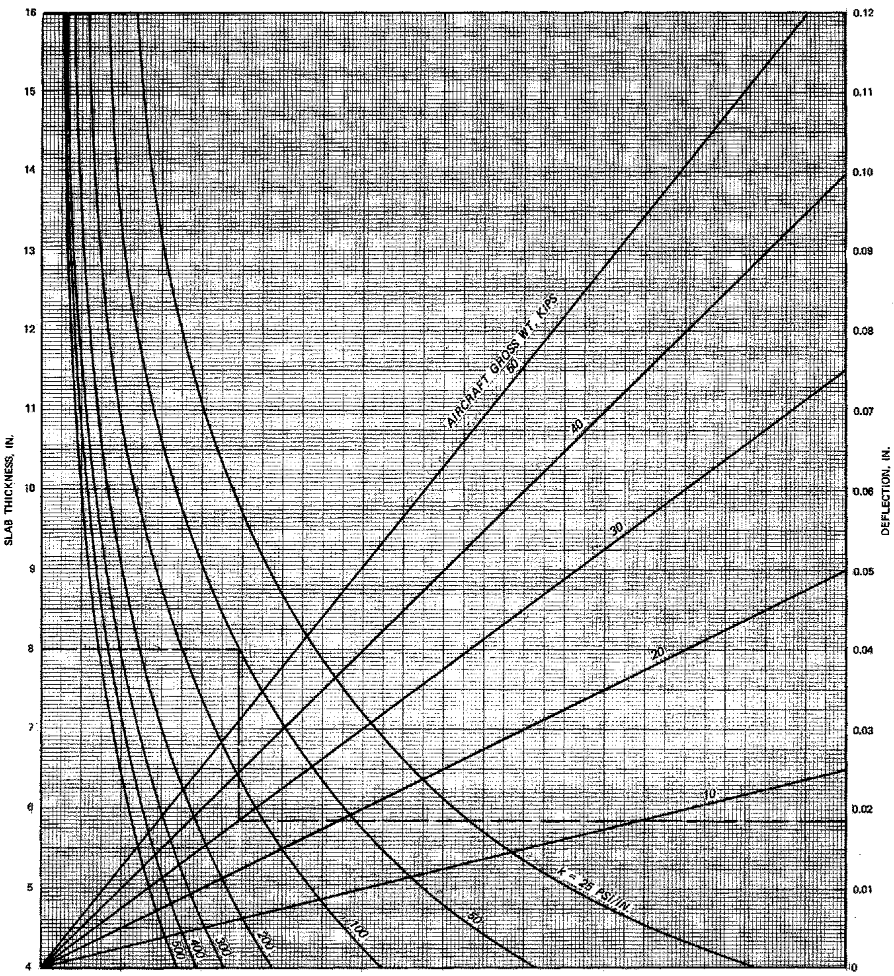
Figure 14-9. Fibrous concrete pavement design curves for shoulders



CONVERSION FACTORS

MEGAPASCALS = 0.006894 x PSI
KILOPASCALS PER MILLIMETER = 0.271 x PCI
MILLIMETERS = 25.4 x INCHES

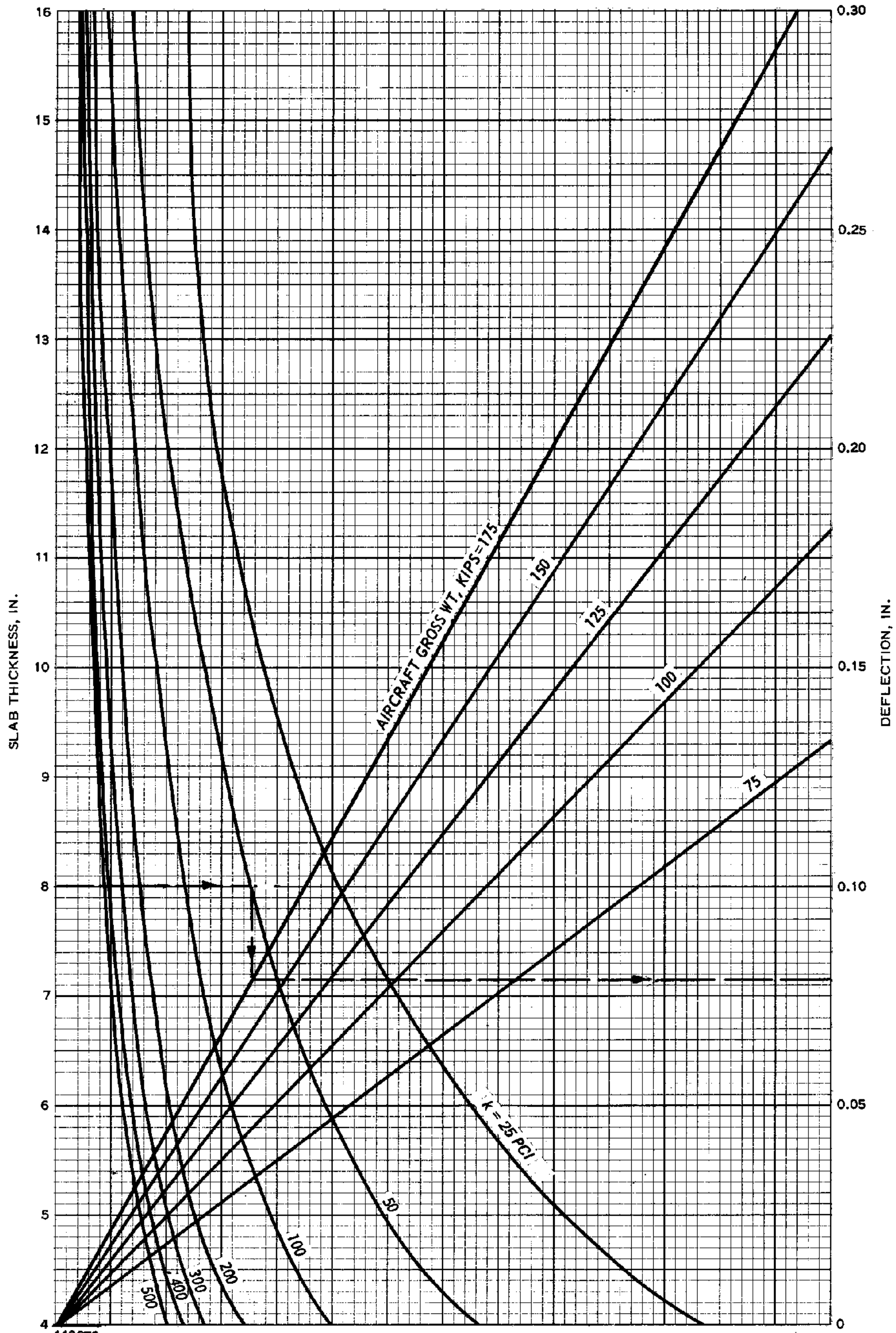
Figure 14-10. Deflection curves for UH-60



CONVERSION FACTORS

MEGAPASCALS = 0.006894 x PSI
KILOPASCALS PER MILLIMETER = 0.271 x PCI
MILLIMETERS = 25.4 x INCHES

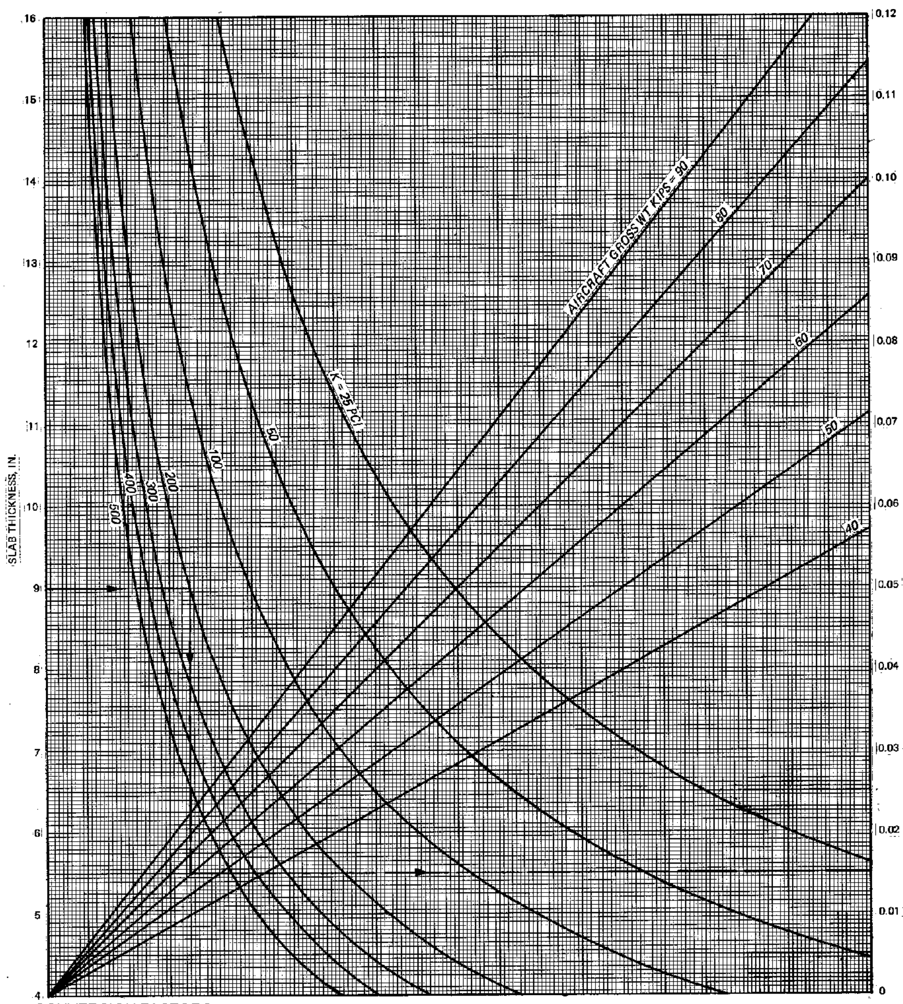
Figure 14-11. Deflection curves for CH-47



CONVERSION FACTORS

MEGAPASCALS = 0.006894 x PSI
KILOPASCALS PER MILLIMETER = 0.271 x PCI
MILLIMETERS = 25.4 x INCHES

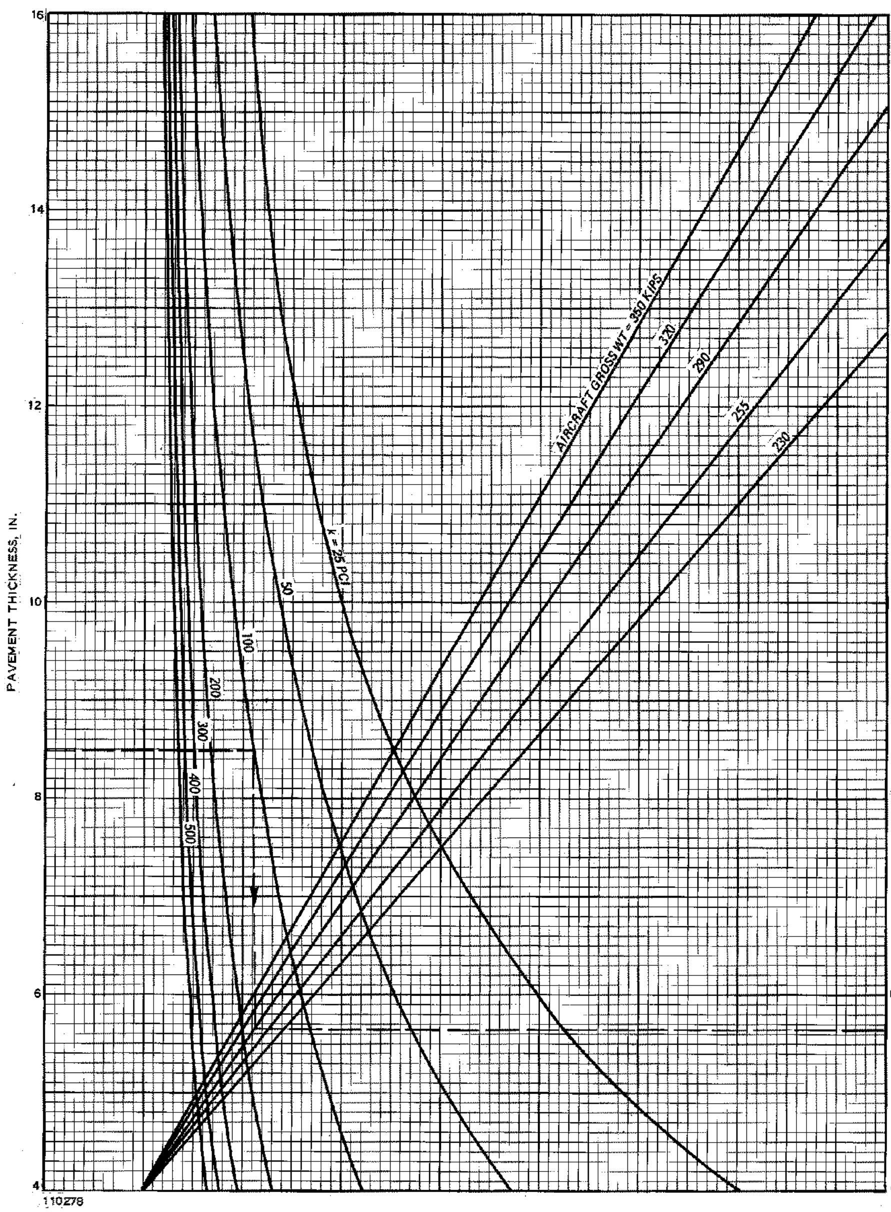
Figure 14-12. Deflection curves for C-130



CONVERSION FACTORS

MEGAPASCALS = 0.006894 x PSI
KILOPASCALS PER MILLIMETER = 0.271 x PCI
MILLIMETERS = 25.4 x INCHES

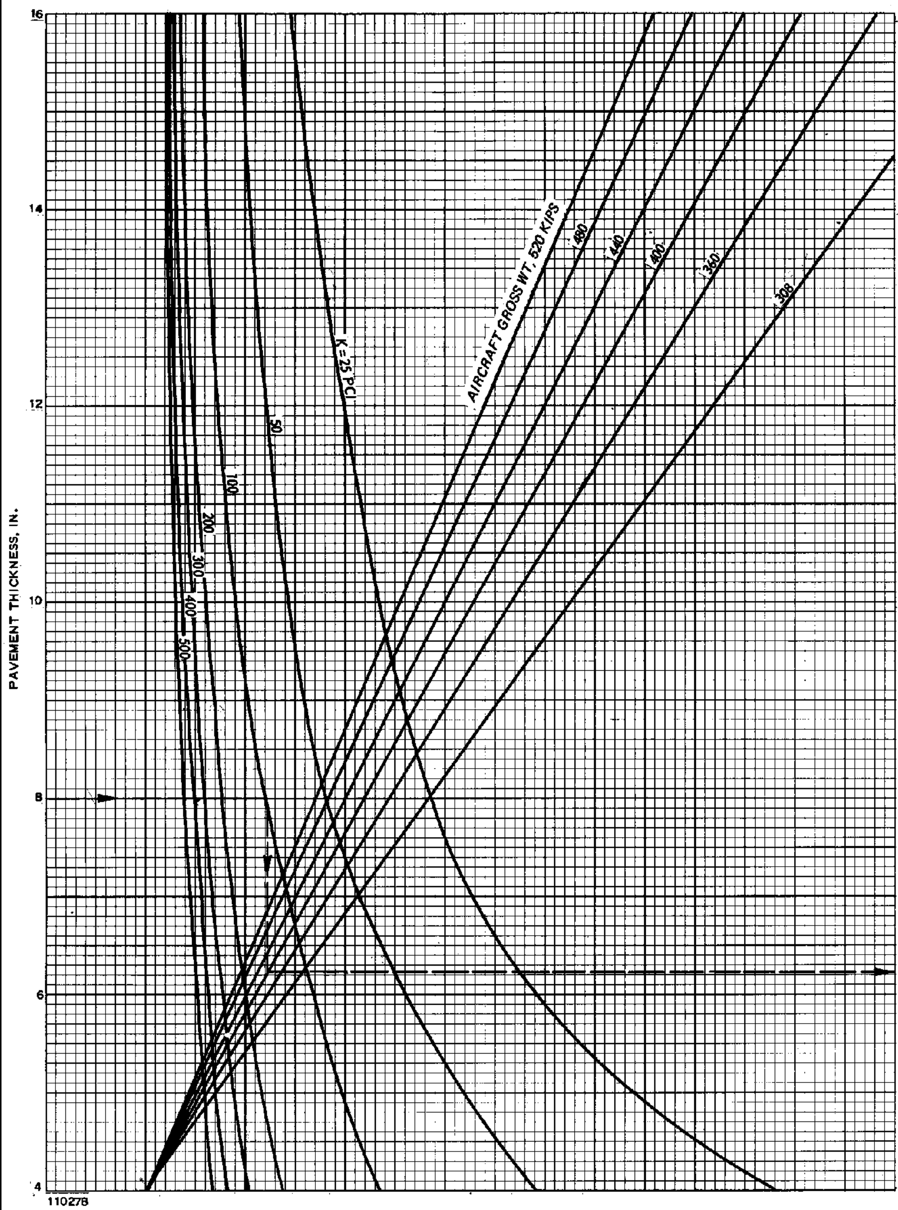
Figure 14-13. Deflection curves for Air Force light-load pavements



CONVERSION FACTORS

MEGAPASCALS = 0.006894 x PSI
KILOPASCALS PER MILLIMETER = 0.271 x PCI
MILLIMETERS = 25.4 x INCHES

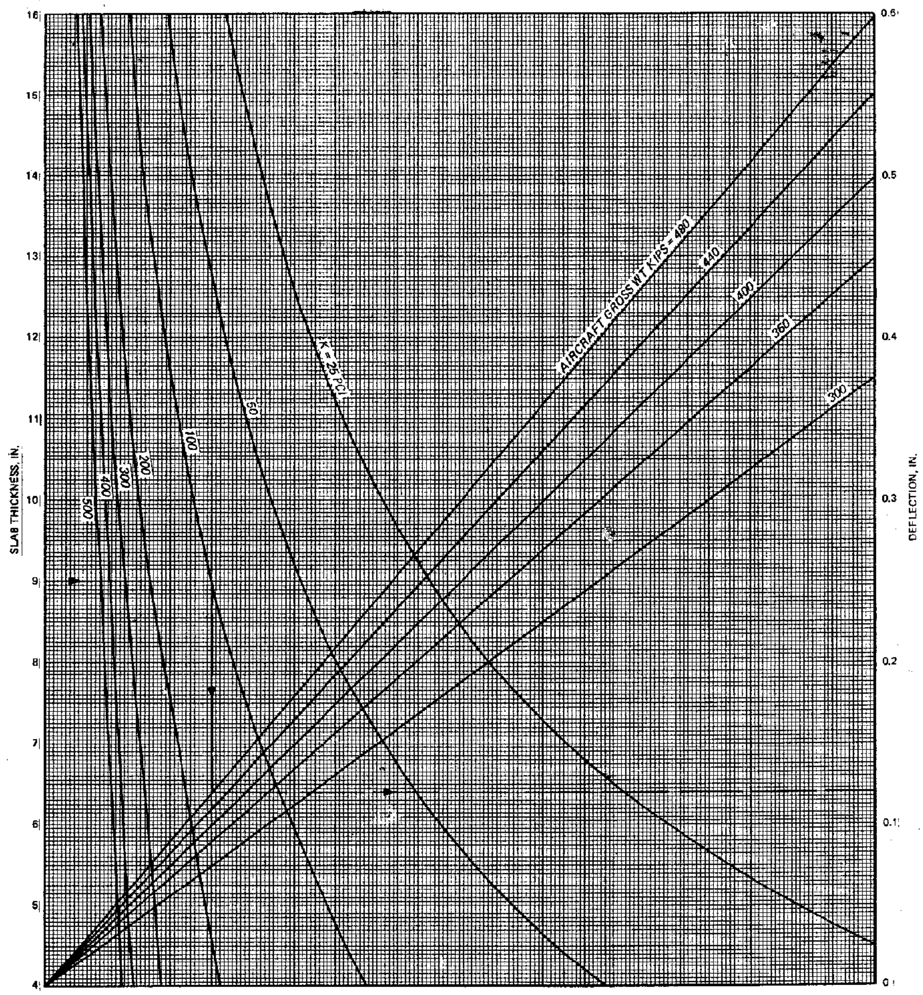
Figure 14-14. Deflection curves for Air Force medium-load pavements



CONVERSION FACTORS

MEGAPASCALS = 0.006894 x PSI
KILOPASCALS PER MILLIMETER = 0.271 x PCI
MILLIMETERS = 25.4 x INCHES

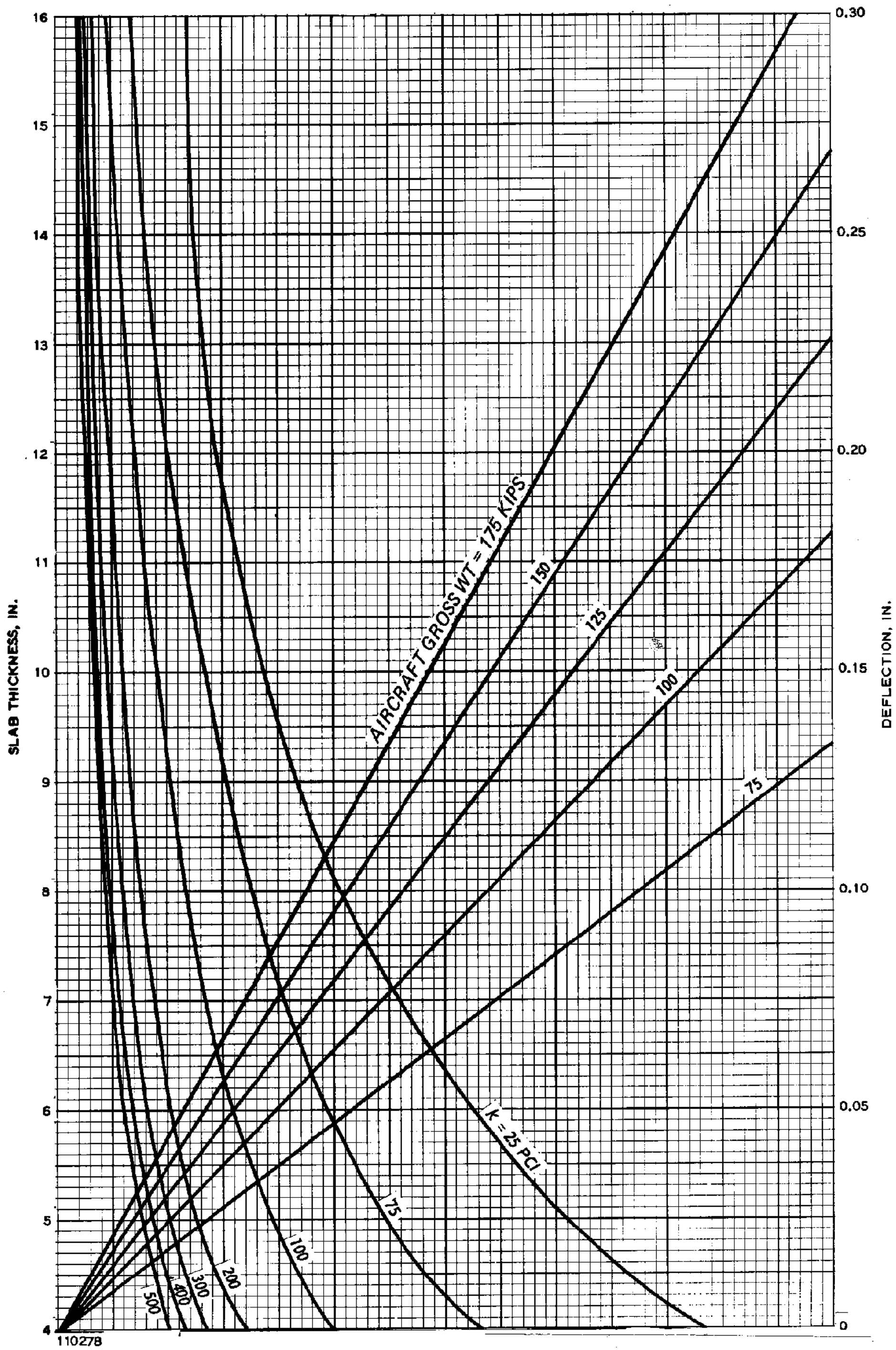
Figure 14-15. Deflection curves for Air Force heavy-load pavements



CONVERSION FACTORS

MEGAPASCALS = 0.006894 x PSI
KILOPASCALS PER MILLIMETER = 0.271 x PCI
MILLIMETERS = 25.4 x INCHES

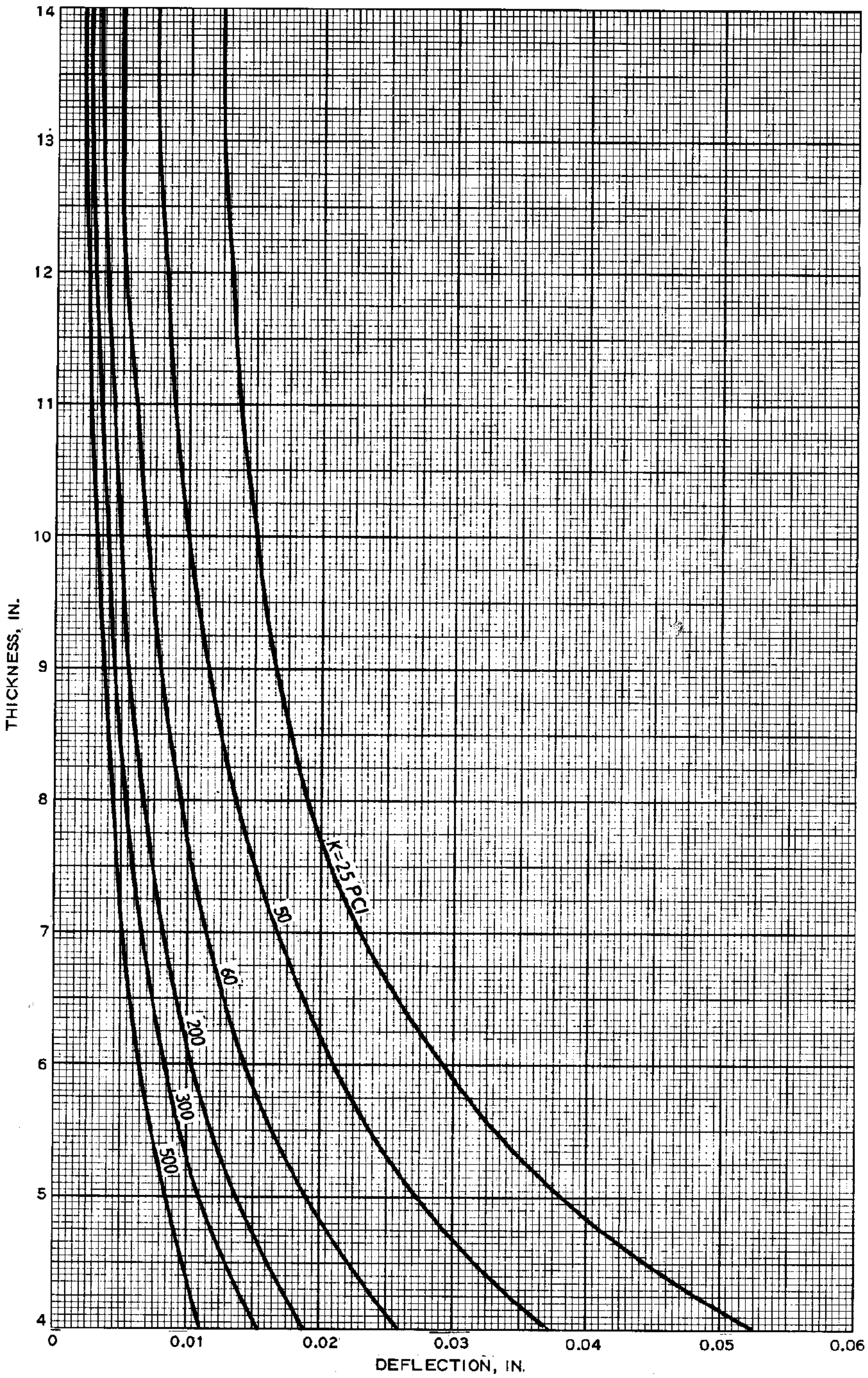
Figure 14-16. Deflection curves for Air Force modified heavy-load pavements



CONVERSION FACTORS

MEGAPASCALS = 0.006894 x PSI
KILOPASCALS PER MILLIMETER = 0.271 x PCI
MILLIMETERS = 25.4 x INCHES

Figure 14-17. Deflection curves for Air Force shortfield pavements



CONVERSION FACTORS

MEGAPASCALS = 0.006894 x PSI
KILOPASCALS PER MILLIMETER = 0.271 x PCI
MILLIMETERS = 25.4 x INCHES

Figure 14-18. Deflection curves for shoulder pavements

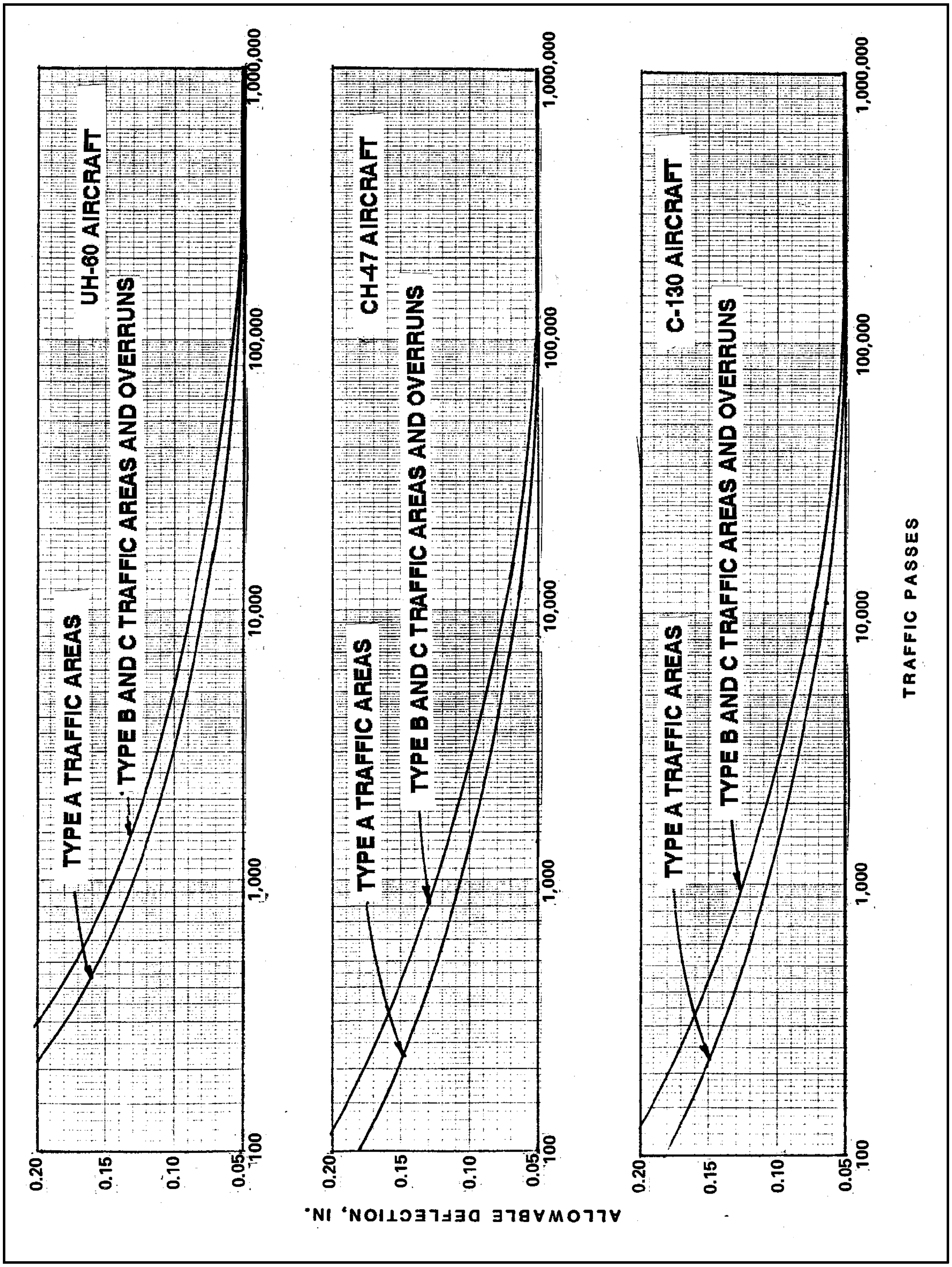


Figure 14-19. Allowable deflection curves for fibrous concrete pavements (Continued)

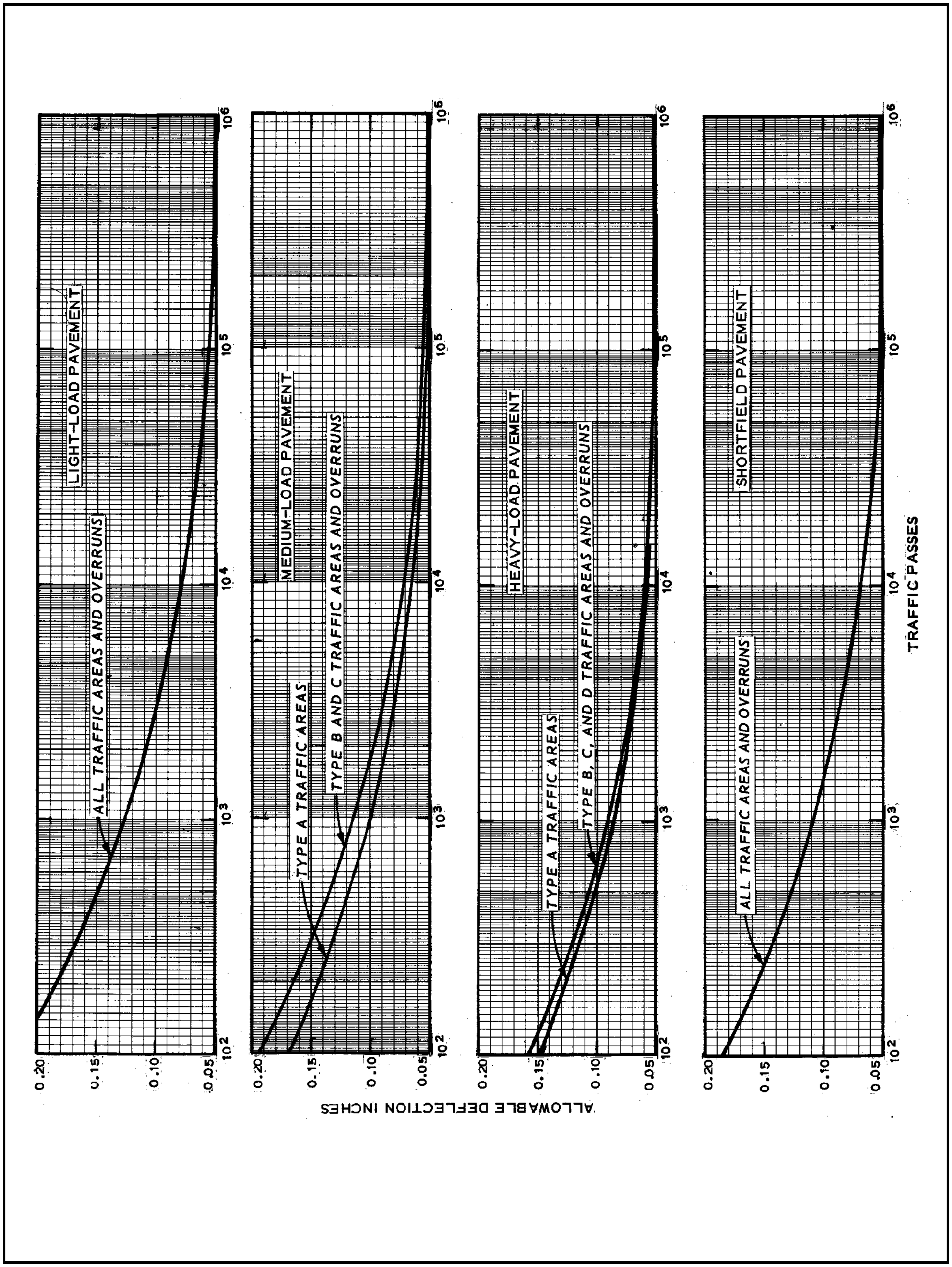


Figure 14-19. (Concluded)

CHAPTER 15

CONTINUOUSLY REINFORCED CONCRETE PAVEMENT DESIGN

1. BASIS OF DESIGN. A continuously reinforced concrete pavement is one in which the reinforcing steel is carried continuously, in both the longitudinal (direction of paving) and transverse (normal to direction of paving) directions, between terminal points. The terminal points may be either the longitudinal construction joints or ends of the pavement, junctures with other pavements or structures, etc. No joints are required between the terminal points; instead, the pavement is permitted to crack. The crack spacing will vary and be dependent upon the percent of reinforcing steel used, interface conditions between the pavement and foundation, and environmental conditions during the early life of the pavement. A transverse crack spacing ranging from 1.5 to 2.5 meters (5 to 8 feet) is desirable; however, experience has shown that even for the most carefully designed system, the crack spacing will vary from as little as 0.6 meters (2 feet) to as much as 3.5 meters (12 feet). The reinforcing steel provides continuity across the nonload-induced cracks, holding them tightly closed and providing good transfer of load. Considerable trouble has been encountered from underdesigned continuously reinforced concrete highway pavements. Consequently, the current trend and the approach adopted here is to make continuously reinforced concrete pavements the same thickness as plain concrete. The steel is assumed to only handle nonload-related stresses and any structural contribution to resisting loads is ignored. When properly designed and constructed, continuously reinforced concrete pavements provide very smooth, low-maintenance pavements. Experience has shown that continuously reinforced concrete pavements perform satisfactorily until the level of cracking reaches the point where punchout of the concrete between the reinforcing steel bars is imminent. The design procedure has been developed primarily from the results of continuously reinforced concrete pavement performance on highways since there has been only limited experience with airfield pavements.

2. USE FOR CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS. Continuously reinforced concrete pavements are applicable for any airfield pavement, but they have received very limited usage for airfield pavement construction. Therefore, long-time performance history is minimal. Because of this, its use will require approval of the Commander, U.S. Army Corps of Engineers (CEMP-ET), the appropriate Air Force Major Command, or the Naval Facilities Engineering Command. The use of continuously reinforced concrete pavement should be based upon the economics involved.

3. FOUNDATION REQUIREMENTS AND EVALUATION. Subgrade compaction and evaluation for a continuously reinforced concrete pavement shall be as described for plain concrete pavements. If economically feasible, the subgrade and/or base course may be modified or stabilized. Stabilized materials must achieve the strength and durability requirements specified in TM 5-822-14/AFJMAN 32-1019.

4. THICKNESS DESIGN. The required thickness of a continuously reinforced concrete pavement is determined using the same procedures as for plain concrete pavement and will be the same thickness as plain concrete pavement. Although continuously reinforced concrete pavement contains steel in addition to being the same thickness as plain concrete pavement, the advantage of using it is that contraction joints are eliminated.

5.R EINFORCING STEEL DESIGN.

a. Longitudinal Direction. The percent of reinforcing steel required in the longitudinal direction for continuously reinforced concrete pavements will be the maximum calculated by the following three equations with the minimum percent steel being 0.43 percent.

$$P_s = (1.3 - 0.2F)\,\frac{f_t}{f_s} \times 100 \qquad (15\text{-}1)$$

$$P_s = \frac{100 f_t}{2(f_s - \Delta T \epsilon_c E_s)} \qquad (15\text{-}2)$$

$$P_s = \frac{f_t}{f_s} \times 100 \qquad (15\text{-}3)$$

where

P_s = percent of reinforcing steel required in the longitudinal direction

F = friction factor; suggested values are 1.0 for unbound fine-grained soils, 1.5 for unbound coarse-grained soils, and 1.8 for stabilized soils

f_t = 7-day tensile strength of the concrete in MPa (psi) determined using the splitting tensile test (Figure 5-1 may be used to convert 7-day flexural strength into tensile strength.)

f_s = working stress in the steel, MPa (psi) (75 percent of yield tensile strength of steel). This produces a safety factor of 1.33.

ΔT = seasonal temperature differential in degrees Celsius (Fahrenheit)

ϵ_c = thermal coefficient of expansion of concrete in millimeters per millimeter per degree Celsius (inches per inch per degree Fahrenheit)

E_s = modulus of elasticity of the reinforcing steel in tension, MPa (psi)

b. Transverse Direction. Transverse reinforcement is required for all continuously reinforced concrete airfield pavements to control any longitudinal cracking that may develop from load repetitions. The percent steel required in the transverse direction will be determined as follows:

$$P_s = \frac{W_s F}{2 f_s} \times 100 \qquad (15\text{-}4)$$

where

W_s = width of slab, m (ft)

c. Type of Reinforcing Steel. The reinforcing steel may be either deformed bars conforming to ASTM A 615 or welded deformed steel wire fabric conforming to ASTM A 497. Generally, longitudinal reinforcement is provided by deformed billet bars with 413-MPa (60,000-psi) minimum yield strength; however, other grades may be used. A grade 40 deformed bar should be used for the transverse reinforcement or for tie bars if bending is anticipated during construction.

d. Placement of Reinforcing Steel. When the slab thickness is 203 millimeters (8 inches) or less, the longitudinal reinforcement should be placed at the middepth of the slab. For thickness in excess of 200 millimeters (8 inches), the longitudinal steel should be placed slightly above the middepth, but a minimum cover of 75 millimeters (3 inches) of concrete shall be maintained in all cases. Transverse reinforcement is normally placed below and used to support the longitudinal steel; however, it may be placed on top of the longitudinal steel if the minimum of 75 millimeters (3 inches) of concrete cover is maintained. Proper lapping of the longitudinal reinforcement is important from the standpoint of load development and is essential for true continuity in the steel. The deformed bars or welded deformed wire fabric shall be lapped in accordance with Chapter 15. It is particularly important to stagger the laps in the reinforcing steel. Generally, not more than one-third to one-half of the longitudinal steel should be spliced in a single transverse plane across a paving lane. The width of this plane should be 610 millimeters (24 inches) if the one-third figure is used, and 1,220 millimeters (48 inches) if the one-half requirement is used. The latter case shall be interpreted to read that not more than one-half of the longitudinal reinforcing members may be spliced in any 1,220-millimeter (48-inch) length of pavement. The stagger of laps with deformed bars may be on a continuous basis rather than the one-third or one-half detail described above.

6.T ERMINAL DESIGN. When appreciable lengths of continuously reinforced concrete pavement are used, the ends experience large movements if unrestrained and will exert large forces if restrained. To protect abutting pavements or structures from damage, the ends of continuously reinforced concrete pavements must be either isolated or restrained. Experience has shown that it is practically impossible to completely restrain or completely isolate the pavement ends, and a combination of these schemes (that is, partial restrain and limited available expansion space) has proven practical. End anchorage and/or expansion joints must be provided when continuously reinforced concrete pavement is not continuous through intersections or when it abuts a structure. Although numerous terminal treatment systems have been attempted, especially on highway pavements, the most successful system appears to be the wide-flange beam joint. Typical drawings of this terminal system are shown in Figure 15-1. For runways, the continuously reinforced concrete pavement should extend to the runway end, where the wide-flange beam joint would be placed as a part of the overrun area.

7.JO INTING. Continuously reinforced concrete pavements will normally use the same type of joints as used for plain concrete pavements except that contraction joints are not normally required. Longitudinal construction joints will be required with the spacing dictated by the paving equipment. The longitudinal construction joints will be butt joints as shown in Figure 12-32. Transverse construction joints, which are required for construction expediency, will be designed to provide slab continuity by continuing the normal longitudinal steel through the joint. The normal reinforcement will be supplemented by additional steel bars, 1.5 meters (5 feet) long (0.75 meters (2.5 feet) on each side of the joint) and the same diameter as the longitudinal reinforcement. The additional steel will be placed between the normal reinforcement and at the same depth in the slab. Thickened-edge slip joints will be used at intersections of pavements where slippage will occur. Otherwise, doweled expansion joints will be used. Expansion joint design will be in accordance with Chapter 12. It will be necessary to provide for expansion at all barriers located in or adjacent to continuously reinforced concrete pavement.

8.JO INT SEALING. The only joints requiring sealing in continuously reinforced concrete pavements will be longitudinal construction joints and expansion joints. Transverse construction joints need not be sealed since they will behave as conventional volume-change cracks that are present elsewhere in the pavement. Joint sealing membranes will be as specified for plain concrete pavements.

9.EXAMPLE OF CONTINUOUSLY REINFORCED CONCRETE PAVEMENT DESIGN. It is required that a pavement be designed as an Air Force medium-load airfield. Types A and B traffic areas are designed for the F-15 at 23,130 kilograms (81,000 pounds), the C-17 at 263,000 kilograms (580,000 pounds), and the B-52 at 181,440 kilograms (400,000 pounds). Types C and D traffic areas and overruns are designed for the F-15 at 27,555 kilograms (60,750 pounds), the C-17 at 197,280 kilograms (435,000 pounds), and the B-52 at 136,080 kilograms (300,000 pounds). Types A, B, and C traffic areas are designed for 100,000 passes of the F-15, 400,000 passes of the C-17, and 400 passes of the B-52. Type D traffic areas and overruns are designed for 1,000 passes of the F-15, 4,000 passes of the C-17, and 4 passes of the B-52. On-site and laboratory investigations have yielded the following data required for design:

- Subgrade = silty sand (SM)
- Modulus of subgrade reaction = 54 kPa/mm (200 lb/in.^{3})
- Flexural strength = 4.83 MPa (700 psi)

The thickness of the continuously reinforced concrete pavement will be the same as required for plain concrete according to the procedures set forth in Chapter 12. The required thicknesses are therefore as follows:

Traffic Area	Calculated Thickness, mm (in.)	Design Thickness, mm (in.)
A	396 (15.6)	405 (16.0)
B	388 (15.3)	394 (15.5)
C	297 (11.7)	305 (12.0)
D and Overruns	238 (9.4)	241 (9.5)

Additional data required for determining the percent longitudinal steel are as follows:

- Tensile strength of concrete (from Figure 15-2) = 3.45 MPa (500 psi)
- Yield strength of steel = 414 MPa (60,000 psi)
- Coefficient of thermal expansion of concrete = 7.2 × 10^{-6} millimeters per millimeter per degree Celsius (4 × 10^{-6}a inches per inch per degree Fahrenheit)
- Modulus of elasticity of steel = 206 × 820 MPa (30 × 10^6 psi)
- Seasonal temperature differential of pavement = 72 degrees Celsius (130 degrees Fahrenheit)

– Friction factor for fine-grained soils = 1.0

The required percentage of longitudinal reinforcement steel is the maximum from Equations 15-1, 15-2, or 15-3.

$$P_s = (1.3 - 0.2F)\,\frac{f_t}{f_s} \times 100$$

$$= (1.3 - 0.2F)\,\frac{3.45}{310} \times 100 = 1.22 \text{ in SI units} \tag{15-5}$$

$$= [1.3 - 0.2(1.0)]\,\frac{500}{45{,}000} \times 100 = 1.22 \text{ in English units}$$

$$P_s = \frac{100f_t}{2(f_s - \Delta T \epsilon_c E_s)}$$

$$= \frac{100(3.45)}{2(310.2 - 72.2 \times .0000072 \times 206820)} = 0.85 \text{ in SI units} \tag{15-6}$$

$$= \frac{100(500)}{2[45{,}000 - 130(4 \times 10^{-6})(30 \times 10^{6})]}$$

$$= 0.850 \text{ in English units}$$

$$P_s = \frac{f_t}{f_s} \times 100$$

$$= \frac{3.45}{310.2} \times 100 = 1.11 \text{ in SI units} \tag{15-7}$$

$$= \frac{500}{45{,}000} \times 100 = 1.11 \text{ in English units}$$

The design percent of longitudinal steel is therefore 1.222. The cross-sectional area of steel A_s required for the Type A traffic area is:

$$A_s = \frac{P_s \times A_p}{100}$$

$$= \frac{1.22 \times 405 \times 1{,}000}{100} = \begin{array}{l}4{,}941 \text{ mm}^2 \text{ per meter} \\ \text{of pavement (SI units)}\end{array} \qquad (15\text{-}8)$$

$$= \frac{1.22 \times 16.0 \times 12}{100}$$

$$= 2.342 \text{ square inches per foot of pavement (English units)}$$

where

A_p = the cross-sectional area of 1 meter (1 foot) of pavement, square millimeters (square inches)

In determining the percent of steel required in the transverse direction, it is assumed that 6-meter (20-foot) paving lanes will be used along with the following equation:

$$P_s = \frac{W_s F}{2 f_s} \times 100 = \frac{20 \times 1.0}{2(45{,}000)} \times 100 = 0.022 \qquad (15\text{-}9)$$

The design percent steel in the transverse direction is therefore 0.022. The cross-sectional area of steel required per 300 millimeters (12 inches) of pavement for the 405-millimeter (16.0-inch) pavement is therefore

$$A_s = \frac{P_s \times A_p}{100} = \frac{0.022 \times 405 \times 300}{100} = 26.7 \text{ mm}^2 \text{ } (0.0414 \text{ in.}^2) \qquad (15\text{-}10)$$

The percent steel for other traffic areas would be computed in the same manner.

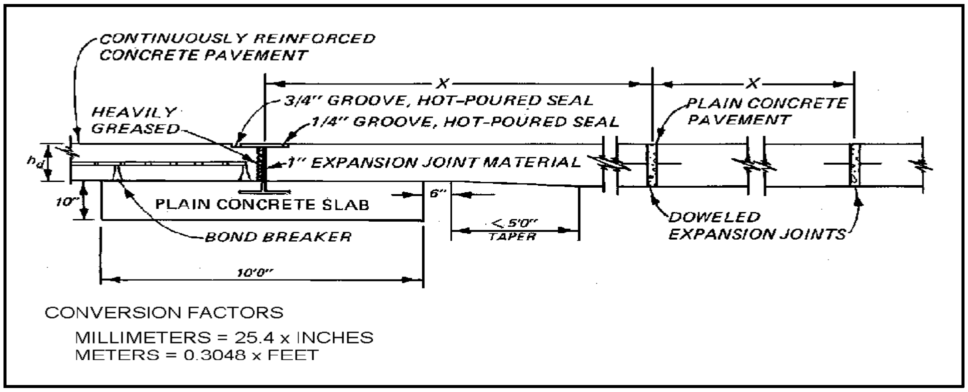


Figure 15-1. Details of a wide-flange beam joint

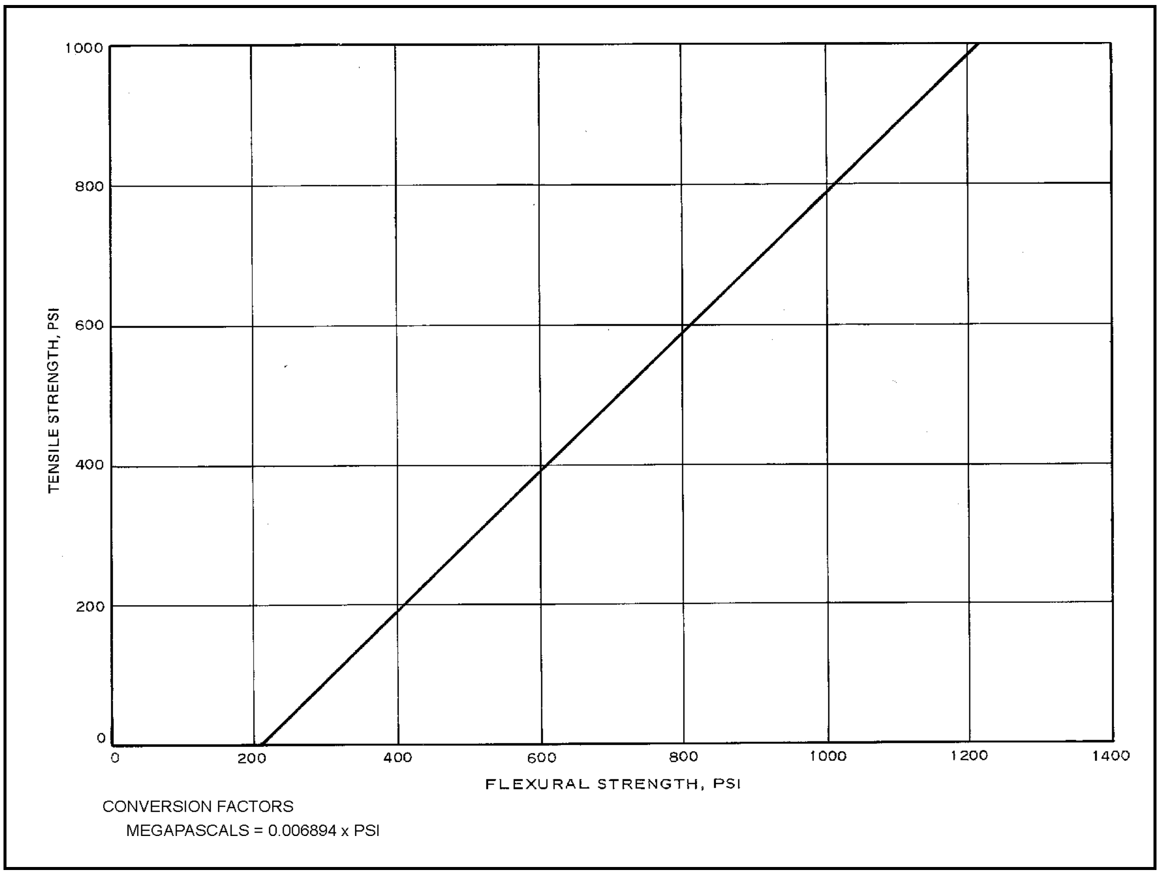


Figure 15-2. Relationship between flexural strength and tensile strength of concrete

CHAPTER 16

PRESTRESSED CONCRETE PAVEMENT DESIGN

1. BASIS OF DESIGN. A prestressed concrete pavement is one in which a significant compressive stress has been induced in both the longitudinal and transverse directions prior to the application of a live load. The induced compressive stress offsets the damaging effects of tensile stresses resulting from applied live loads and permits the formation of momentary, or partial, plastic hinges under passage of wheel loads that change the failure mode from tensile cracking at the bottom of the pavement to tensile cracking in the upper surface of the pavement due to negative moments. These two factors permit the prestressed concrete pavement to carry substantially greater loadings than equal thickness of plain concrete or reinforced concrete pavement and still provide a functionally adequate pavement.

2. UNITS. The design equations and criteria in this chapter are controlled by English units. Therefore, the equations have not been converted to SI units.

3. USES FOR PRESTRESSED CONCRETE PAVEMENT. Although prestressed concrete pavements have been used in Europe, a long-time performance history of prestressed concrete pavements in the United States is not extensive. Therefore, its use will require the approval of HQUSACE (CEMP), the approval Air Force Major Command, or Naval Facilities Engineering Command. Several test or demonstration sections in the United States have shown good performance, but problems have been experienced with joints between long prestressed sections where large movements are experienced. For this reason, complex joints and extreme care are required during construction. The selection of prestressed concrete pavements should be based upon the economics involved.

4. FOUNDATION REQUIREMENTS.

a. Subgrade and base. In general, the subgrade for a prestressed concrete pavement will be treated and evaluated in the same manner as for other types of rigid pavements. The reduced thickness of prestressed concrete pavement will result in a more flexible system and higher vertical stresses in the foundation than for plain concrete pavements. For this reason, the quality and strength of the foundation becomes more important. The foundation should be strengthened through the use of a high-quality (stabilized or nonstabilized) base course and/or stabilized or modified subgrade to provide a minimum modulus of soil reaction or composite modulus of soil reaction of 54 kPa/mm (200 pcl). In addition, because the amount of design prestress is a function of the foundation restraint, the surface of the foundation should be finished as smooth and as free of undulations, holes, etc., as possible.

b. Friction-Reduction Layer. A friction-reducing layer shall be used between the prestressed concrete pavement and the foundation. A satisfactory friction-reducing layer may consist of two polyethylene sheets over a thin 6- to 13-millimeter (1/4- to 1/2-inch) uniform size sand layer. The sand layer is used primarily to smooth out the surface irregularities of the foundation. Other types of friction-reducing material may be considered.

5. METHOD OF PRESTRESSING. Pavements may be prestressed using pretensioning or posttensioning. The method most commonly used for pavements is posttensioning, in which tendons are installed before concrete placement and stressed after concrete placement. The tendons either are placed in conduits or are plastic-encased to prevent bonding with the concrete. The tendons are threaded through bearing plates cast into the face of the concrete at the ends or sides of the concrete slabs. After the concrete has gained sufficient strength, the tendons are stressed, using the bearing

plates and concrete slab as a reaction, to the required total stress level and locked. The total stress level in the tendons is the sum of the stress needed to provide the design prestress level in the concrete plus the stress necessary to offset the various losses that will occur. To help reduce cracking in the concrete during the cure period, a preliminary level of prestress is normally applied at a very early age, and the final level of prestress applied after several days of curing. Both longitudinal and lateral prestressing is needed to obtain the desired structural capacity in the pavement.

6. DESIGN PROCEDURE.

a. General. In the design of prestressed pavements, both thickness and level of prestress will be unknowns; therefore, their determination, in both the longitudinal and transverse directions, becomes an iterative process (that is, one is selected and other computed). A normal practice is to compute the thickness requirements for a range of prestress levels, after which the final selection is made based upon an economic analysis. A maximum value of design prestress of 400 psi is recommended; and based upon experience, a design prestress level falling between 100 and 400 psi has been most economical. The minimum thickness of prestress concrete pavement will be 150 millimeters (6 in.).

b. Design Equation. The design prestress for a given thickness of pavement will be determined as follows:

$$d_s = \frac{6PNB}{wh_p^2} - R + r_s + t_s \qquad (16\text{-}1)$$

where

d_s = design prestress required in concrete, psi

P = aircraft gear load, pounds

N = load-repetition factor

B = load-moment factor

w = ratio of multiple-wheel gear load to single-wheel gear load

h_p = design thickness of prestressed concrete pavement, inches

R = design flexural strength of concrete, psi

r_s = foundation restraint stress, psi

t_s = temperature warping stress, psi

Since both d_s and h_p will be unknown, it is necessary to select values of h_p and compute d_s. For guidance, experience has shown that d_s levels between 100 and 400 psi are generally economical, and at these levels h_p will be about one-third of the required thickness of plain concrete pavement. The design gear load P will depend upon the aircraft for which the pavement is being designed. The load-repetition factor N is a function of the type of design aircraft and the traffic area type. The design aircraft pass level is divided by the aircraft pass per coverage factor to determine the design number of stress repetitions, which are in turn used in Figure 16-1 to obtain N. The load-moment factor B and ratio of multiple-wheel load to single-wheel load w are determined from Figures 16-2 and 16-3, respectively, by entering with a value of A/ℓ^2 (note that for the light-load and Class I airfields, w is 1.0 for all values of A/ℓ^2). A is the contact area in square inches of a tire in the main gear of the design aircraft, and ℓ is computed by

$$\ell = \left[\frac{E h_p^3}{12(1 - \mu^2) k} \right]^{1/4} \tag{16-2}$$

where

ℓ = radius of relative stiffness, inches

E = the modulus of elasticity of concrete (a value of 4,000,000 psi is normally used)

h_p = design thickness of prestressed concrete pavement, inches

μ = Poisson's ratio

k = modulus of subgrade reaction, pci

c. Foundation Restraint Stress. The subgrade restraint stress r_s is a function of the coefficient of sliding friction between the pavement and underlying foundation and the length or width of the prestressed concrete slab and is determined by

$$r_s = \frac{C_f L \rho}{2(144)} \quad or \quad r_s = \frac{C_f W \rho}{2(144)} \tag{16-3}$$

where

r_s = foundation restraint stress, psi

C_f = coefficient of sliding friction

L = length of prestressed concrete slab, feet

W = width of prestressed concrete slab, feet

ρ = density of concrete, lb/ft^3

Experience has shown that for a prestressed concrete pavement constructed with sand and polyethylene sheet bond-breaking medium on the surface of the prepared foundation, a value of C_f of 0.60 is representative. This value can be reduced, with a subsequent reduction in the design prestress level, through the selection of materials with lower coefficients of friction and through careful preparation of the foundation layer.

d. Temperature Warping Stress. The temperature warping stress results from the development of a temperature gradient through the prestressed concrete pavement thickness and can be determined by:

$$t_s = \frac{ET\epsilon_c}{2(1 - v)} \tag{16-4}$$

where

t_s = temperature warping stress, psi

T = difference in temperature in degrees Fahrenheit between the top and bottom of the prestressed concrete pavement

ϵ_c = coefficient of thermal expansion, inches/inch

Values of T should be determined by a test on a pavement in the vicinity of the proposed prestressed concrete pavement; however, without other data, a value of 1 to 3 degrees per inch of pavement has been found to be fairly representative of the maximum temperature gradient.

7. PRESTRESSING TENDON DESIGN.

a. General. The size and spacing of prestressing tendons required will be a function of the required prestress level and the various losses that will occur in the steel tendons during and following construction.

b. Size and Spacing on Tendons. The tendon stress losses occur as a result of elastic shortening and creep of the concrete, concrete shrinkage, tendon relaxation, and slippage in the anchorage system. The determination of these tendon losses is complex because of the many variables, some of which are unknown without extensive field testing. From the experience gained in the few test and demonstration sections and actual pavement sections, the tendon losses can be approximated as 20 percent of the tendon stress needed to achieve the design prestress level in the concrete. With this approximation, the total area of tendon steel required to accomplish the prestress level in the concrete after allowance for tendon losses can be determined by

$$A_s = \frac{1.2d_sA_c}{0.7f_\mu} \tag{16-5}$$

where

A_c = cross-sectional area of concrete being prestressed, square inches

f_μ = ultimate strength of the tendon steel, psi

The equation above is applicable to the determination of A_s based upon a recommended maximum anchorage stress equal to seven-tenths of the ultimate strength of the tendon steel. If the steel is anchored at a stress other than seven-tenths of the ultimate strength, the equation above must be modified accordingly. With the total required A_s determined, the number and size of prestressing tendons can be selected. Spacings of two to four times the prestressed concrete pavement thickness are recommended for the longitudinal tendons, and spacings of three to six times the prestressed concrete pavement thickness are recommended for the transverse tendons.

c. Prestressing Steel Tendons. The tendons used for prestressed concrete pavement will consist of either high-strength wires, strands, or bars.

(1) Wires will conform to the requirements of ASTM A 421.

(2) Seven-wire strands will conform to the requirements of ASTM A 416.

(3) High-strength bars will conform to the requirements of section 405(f) of ACI 318.

d. Prestressing Conduits. Conduits used for enclosing the steel tendons should be either rigid or flexible metal tubing. However, the tendons may be plastic-encased.

(1) Metal conduits must be strong enough to resist damage in transit or during handling. The metal may be bright or galvanized.

(2) When tendons are plastic-encased, the tendons should be permanently protected from rust or corrosion.

e. Placement of Tendons and Conduits. The transverse conduits will be placed on metal chairs at the desired depth and used to support the longitudinal conduits or tendons. Conduits and tendons will be tied firmly in place to maintain proper alignment during placement of the concrete. A preliminary stress applied to the tendons may help maintain the alignment. The inside diameter of metal conduits will be at least 6 millimeters (0.25 inch) larger than the diameter of the stressing tendons. The minimum cover of the conduits will be 75 millimeters (3 inches) at the pavement surface and 50 millimeters (2 inches) at the bottom of the pavement.

f. Tendon Stressing. The prestressed tendons must be stressed to provide a stress in the concrete equal to 1.2 times the design prestress d_s plus sufficient stress to overcome the frictional resistance between the tendon and conduit. After concrete placement and prior to beginning the prestressing operation, any preliminary tension in the tendons must be released. If the tendons are conduit-encased, they should be pulled back and forth several times to reduce and to measure the tendon stress due to friction. This need not be done for plastic-encased tendons. The measured tendon-friction stress must be added to the tendon stress required to produce $1.2d_s$ in the concrete. If the tendons were sized as described in b above, the required tendon stress will be the selected anchorage stress ($0.7f_{\mu}$ or other value if used to size the tendon), plus the stress required to overcome friction. After the maximum tendon stress is reached, it will be held for several minutes and then released to the selected anchorage stress. The longitudinal tendon stressing will be applied in three stages with the amount of prestress at each successive stage being 25, 50, and 100 percent of the anchorage stress. The prestressing will be applied as soon as possible to prevent or minimize the occurrence of contraction cracking in the concrete.

g. Grouting. When the stressing tendons are placed in conduits, the space between the tendons and conduits will be grouted after the final prestressing load is reached. The grout will be made from either cement and water or cement, fine sand, and water. Admixtures to obtain high early strength or to increase workability may be used if they will have no injurious effects on the stressing tendons or conduits. Grouting vents will be provided at each end of the conduits and along the conduits at intervals not to exceed 45 meters (150 feet). A grouting pumping will be used to inject the grout. The grouting will commence at an end vent and continue until grout is forced out of the first interior vent along the conduit. The end vent will then be sealed, and grout will be injected through the first interior vent until it is extruded from the second interior vent. This procedure will be continued until the entire length of conduit has been grouted.

8. JOINTING.

a. Joint Spacing. Experience has shown that from a practical standpoint, the maximum length of prestressed concrete slabs should be 150 meters (500 feet), although lengths of 180 and 215 meters (600 and 700 feet) have been constructed. The width of the slab will vary depending upon the capability of the construction equipment but will generally be a minimum of 7.6 meters (25 feet).

b. Joint Types.

(1) Longitudinal joint. Runway and taxiway pavements will be prestressed for their full width, and the longitudinal joints will be the butt type with the prestressed tendons carried through the joint. The transverse prestressing operation will be carried out after all paving lanes have been completed. For areas wider than 150 meters (500 feet) (such as aprons), the pavement must be constructed in widths not to exceed 150 meters (500 feet); therefore, longitudinal fill-in lanes will be required to permit access for applying the transverse prestressing.

(2) Transverse joint. Because of the length of prestressed slabs and the low subgrade restraint, large movements will occur at the transverse joints. The transverse joint must be designed to accommodate these movements that are a function of the temperature change, slab length, and moisture conditions. The anticipated movements can be determined by

$$\Delta_{LT} = 12L\epsilon_c\Delta T \tag{16-6}$$

and

$$\Delta_{LM} = 12L\epsilon_M \tag{16-7}$$

where

Δ_{LT} = change in length of slab due to temperature change ΔT, inches

L = slab length, feet

ΔT = change in temperature in degrees (either daily or seasonally)

Δ_{LM} = maximum change in length of slab due to seasonable moisture change

ϵ_M = coefficient of moisture expansion of concrete (assumed to be 1×10^{-4} inch per inch seasonally)

The transverse joint must be capable of withstanding the sum of the temperature and moisture change in length. Figure 16-4 shows typical sections of two general methods of construction of the transverse joints. Type A consists of having the transition slab rest directly on the subbase. The transition slab will be constructed to the thickness requirements of either plain or reinforced concrete pavements and connected to the prestressed slabs with dowel bars to provide load transfer through the joint. The size and spacing of the dowel bars will be determined from Chapter 12 based upon the plain or reinforced concrete thickness requirements. Type B consists of a grade slab underlying the ends of the prestressed concrete pavement and transition slab. The transition slab will be reinforced concrete of the same thickness as the prestressed concrete pavement. The grade slab will also be reinforced concrete. The thickness of the grade slab and the percent of reinforcing steel in both the transition slab and grade slab will be determined in accordance with overlay design procedures if the transition slab is a reinforced concrete overlay of the reinforced grade slab.

c. Joint Seals. Longitudinal joints in prestressed concrete pavements, except where longitudinal transition lanes will be required to permit prestressing operations of wide paved areas, need not be sealed since they will be held tightly closed by the prestressing. However, if these joints are sealed, materials meeting the requirements for plain concrete pavements should be used. When longitudinal transition lanes are required, the longitudinal joint should be treated in the same manner as a transverse joint. Several types of sealants have been used for the transverse joints, but no standardized seals have been established. Poured-in-place materials have not been satisfactory to accommodate the large movements that occur. Preformed and mechanical seals, such as shown in Figure 16-5 are recommended. The final selection of a sealant will be a matter of engineering judgment that must be approved by HQUSACE (CEMP-ET), the appropriate Air Force Major Command, or the Naval Facilities Engineering Command.

9. EXAMPLES OF PRESTRESSED CONCRETE PAVEMENT DESIGN.

a. General. A 75-foot-wide by 10,000-foot-long taxiway pavement is to be designed for 100,000 passes of the C-141 aircraft at 320,000 pounds gross weight using prestressed concrete. Laboratory and field test programs have yielded the following pertinent physical property data for the foundation and concrete: modulus of soil reaction, k = 200 pci; 90-day flexural strength of concrete, R = 700 psi; density of concrete = 150 lb/ft^3; modulus of elasticity in flexure of concrete, E = 4×10^6 psi; Poisson's ratio of concrete, v = 0.15; and coefficient of thermal expansion of concrete, $\epsilon_c = 4 \times 10^{-6}$ inch per inch per degree Fahrenheit.

b. Determination of Design Prestress Level. Prestress loads will be determined for preselected thicknesses h_p of 6, 7, and 8 inches. Following the procedures described in paragraph 5, the load-repetition factor N is 2.46 (Figure 16-1) and the load-moment factor B is 0.0523, 0.0544, and 0.0565 for thicknesses of 6, 7, and 8 inches, respectively. The ratio of multiple-wheel gear load to single-wheel gear load, w is 2.22, 2.23, and 2.335 for thickness of 6, 7, and 8 inches, respectively. A polyethylene sheet bond-breaking medium will be used between the foundation and prestressed slab, and the coefficient of sliding friction C_f will be 0.60. A slab length L of 400 feet will be used; therefore, the subgrade restraint stress in the longitudinal direction will be

$$r_s = \frac{C_f L \gamma}{2(144)} = \frac{0.60 \times 400 \times 150}{2(144)} = 125 \text{ psi} \tag{16-8}$$

In the transverse direction, the subgrade restraint stress will be

$$r_s = \frac{C_f W \gamma}{2(144)} = \frac{0.60 \times 75 \times 150}{2(144)} = 23.4 \text{ psi} \tag{16-9}$$

The maximum difference in temperature between the top and bottom of the prestressed concrete pavement is estimated to be about 6, 7, and 8 degrees for the 6-, 7-, and 8-inch pavements, respectively, with resulting temperature warping stresses of 46, 65, and 75 psi, respectively. The design prestressing required in the concrete is then determined by the following equation:

$$d_s = \frac{6PNB}{wh_p^2} - R + r_s + t_s \tag{16-10}$$

For h_p values of 6, 7, and 8 inches, the design prestress d_s in the longitudinal direction will be 853, 492, and 253 psi, respectively, and in the transverse direction the values of d_s will be 761, 391, and 151 psi, respectively. Plotting these values, as shown in Figure 16-6, permits the selection of various thicknesses and prestressing levels that will support the design loading condition. Experience has shown that d_s levels between 100 and 400 psi are most practicable; therefore, from Figure 16-6, a 7.5-inch pavement with longitudinal prestress of 360 psi and transverse prestress of 250 psi would provide a satisfactory pavement. With a slab length of 400 feet, 25 slabs and thus 24 joints will be required for the 10,000-foot-long taxiway. In actual design, several combinations of k, h_p, slab length, etc., should be considered, and the final selection should be based on an economic study considering all aspects of material and construction costs.

c. Prestressed Tendon Design. Plastic-encased stranded wire having an ultimate strength f_μ of 240,000 psi is selected for the prestressed tendons. The stranded wire tendon will be finally anchored at a stress not to exceed $0.7f_\mu$ or 168,000 psi. The required area of steel in the longitudinal and transverse directions to achieve the design prestressing level in the concrete and allowing for the various tendon stress losses will be

Longitudinal Direction

$$A_s = \frac{1.2 \times 360 \times 7.5 \times 75 \times 12}{0.7 \times 240{,}000} = 17.4 \text{ square inches} \tag{16-11}$$

Transverse Direction

$$A_s = \frac{1.2 \times 250 \times 7.5 \times 400 \times 12}{0.7 \times 240{,}000} = 64.3 \text{ square inches} \tag{16-12}$$

Several combinations of wire diameter and spacing will yield the required cross-sectional area of steel for the stressing tendons. For example, if in the longitudinal direction, a spacing of four times the prestressed concrete pavement thickness (30 inches) is selected, then 30 tendons will be required, each having a cross-sectional area of 0.58 square inch and diameter of 0.86 inch. Therefore, a 7/8-inch-diameter tendon could be selected. Selection of a tendon that is greater or less than that required may require the final anchor stress to be revised. If, in the transverse direction, a spacing of five times the prestressed concrete pavement thickness (37.5 inches) is selected, then 128 tendons would be needed and the required cross-sectional area of the tendons would be 0.50 square inch. Therefore, a 13/16-inch-diameter tendon would provide the required prestressing.

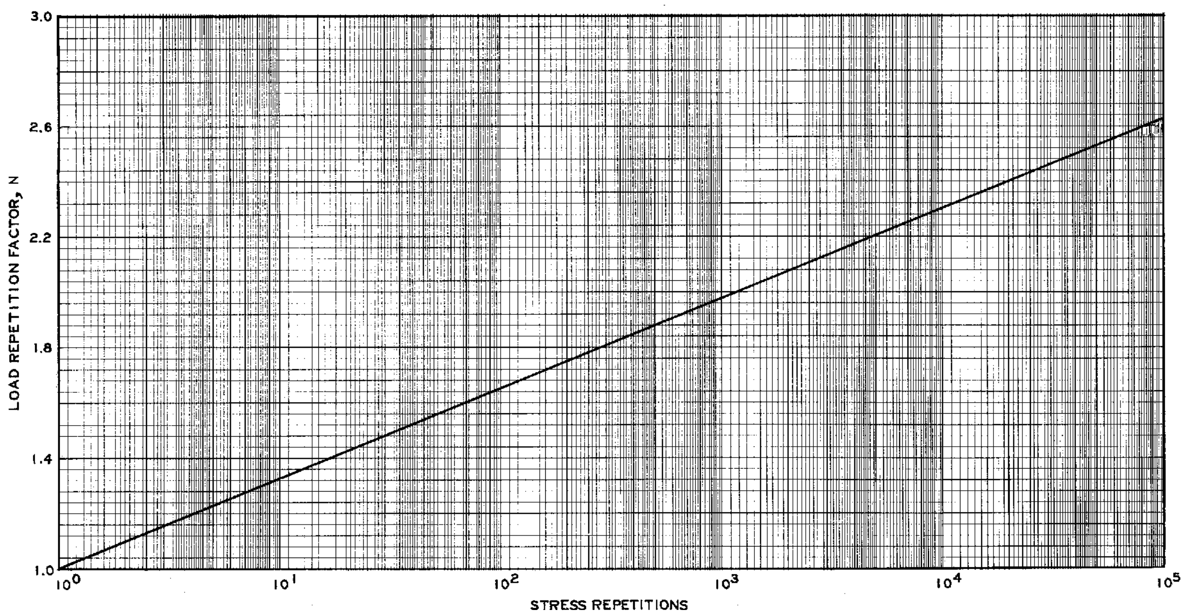


Figure 16-1. Stress repetitions versus load repetition factor

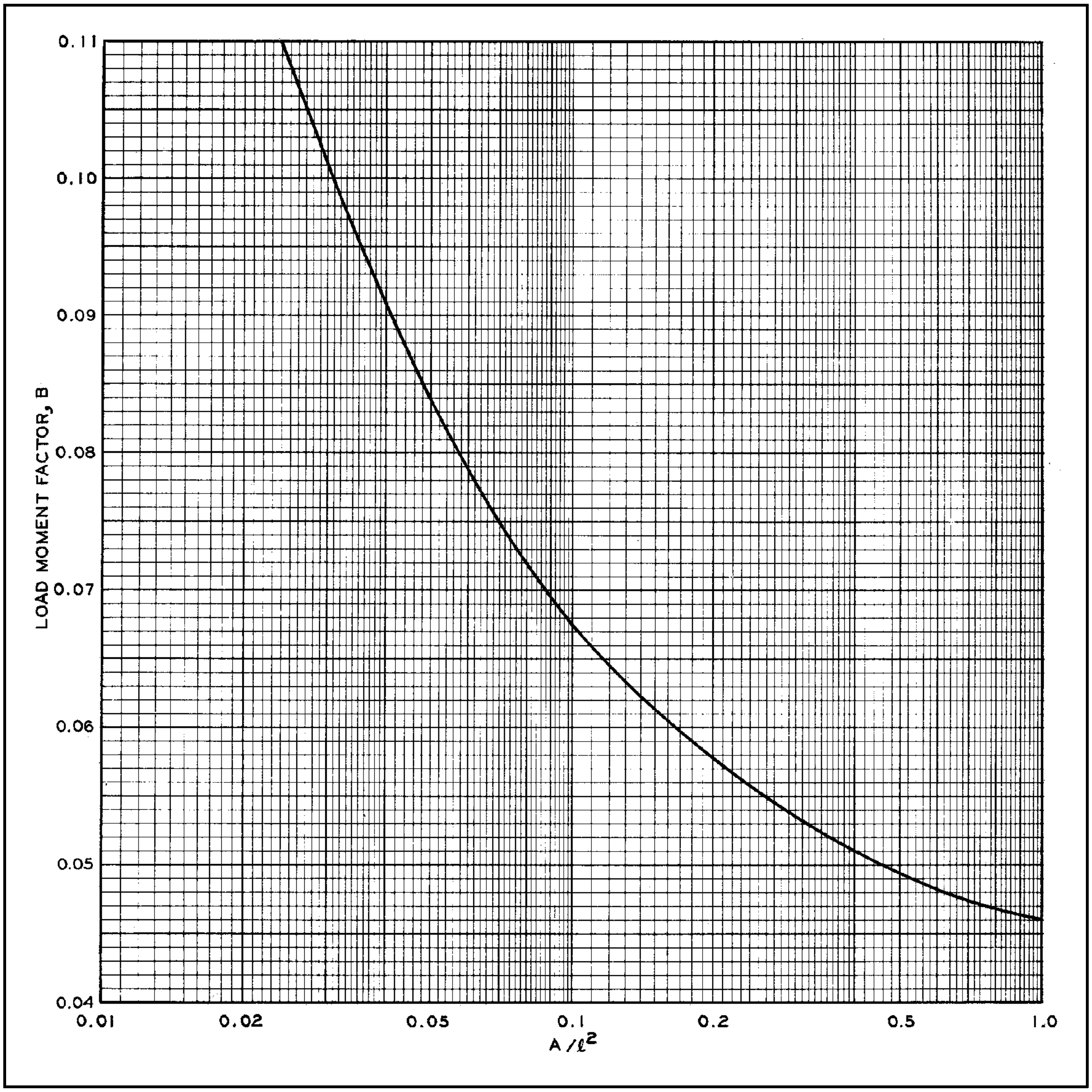


Figure 16-2. A/ℓ^2 versus load-moment factor

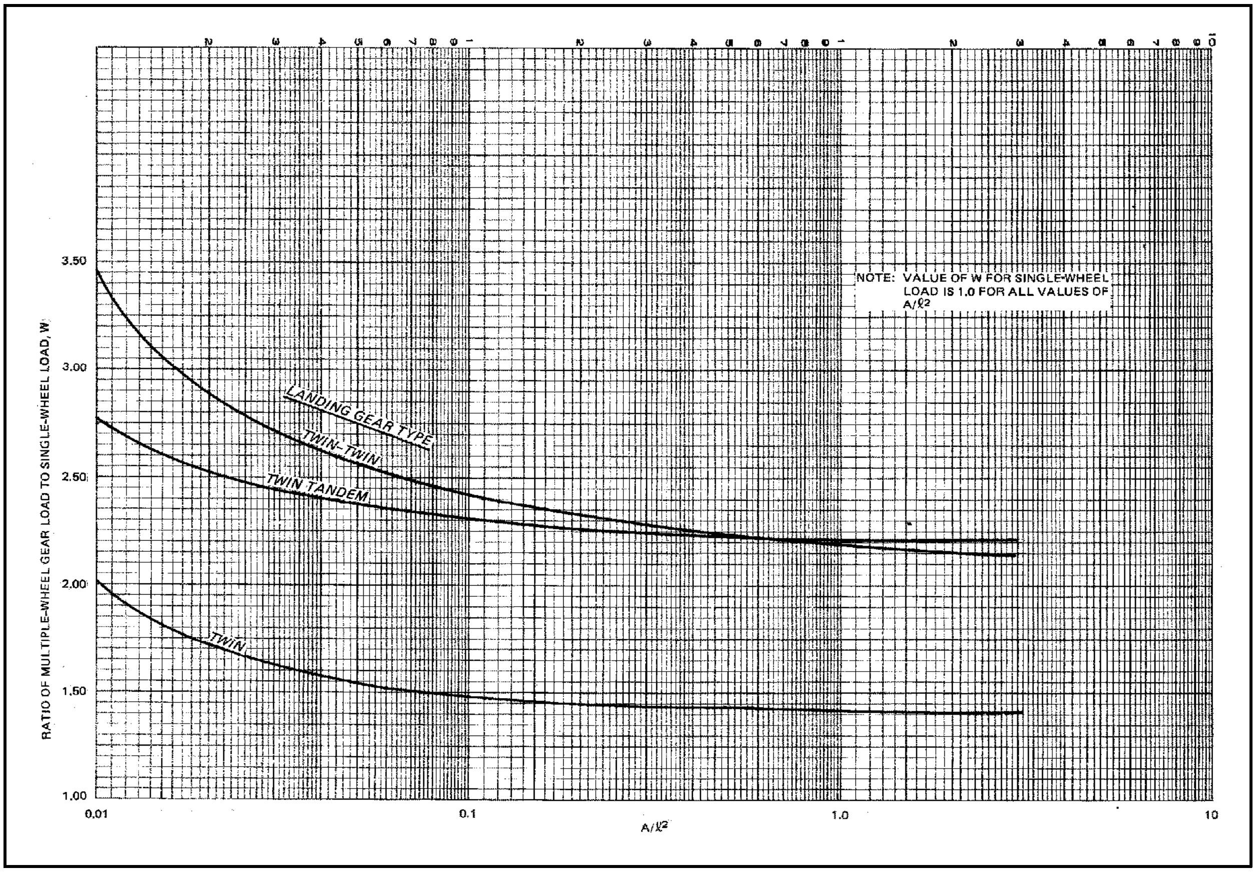


Figure 16-3. Ratio of multiple wheel gear to single-wheel gear load versus A/ℓ^2

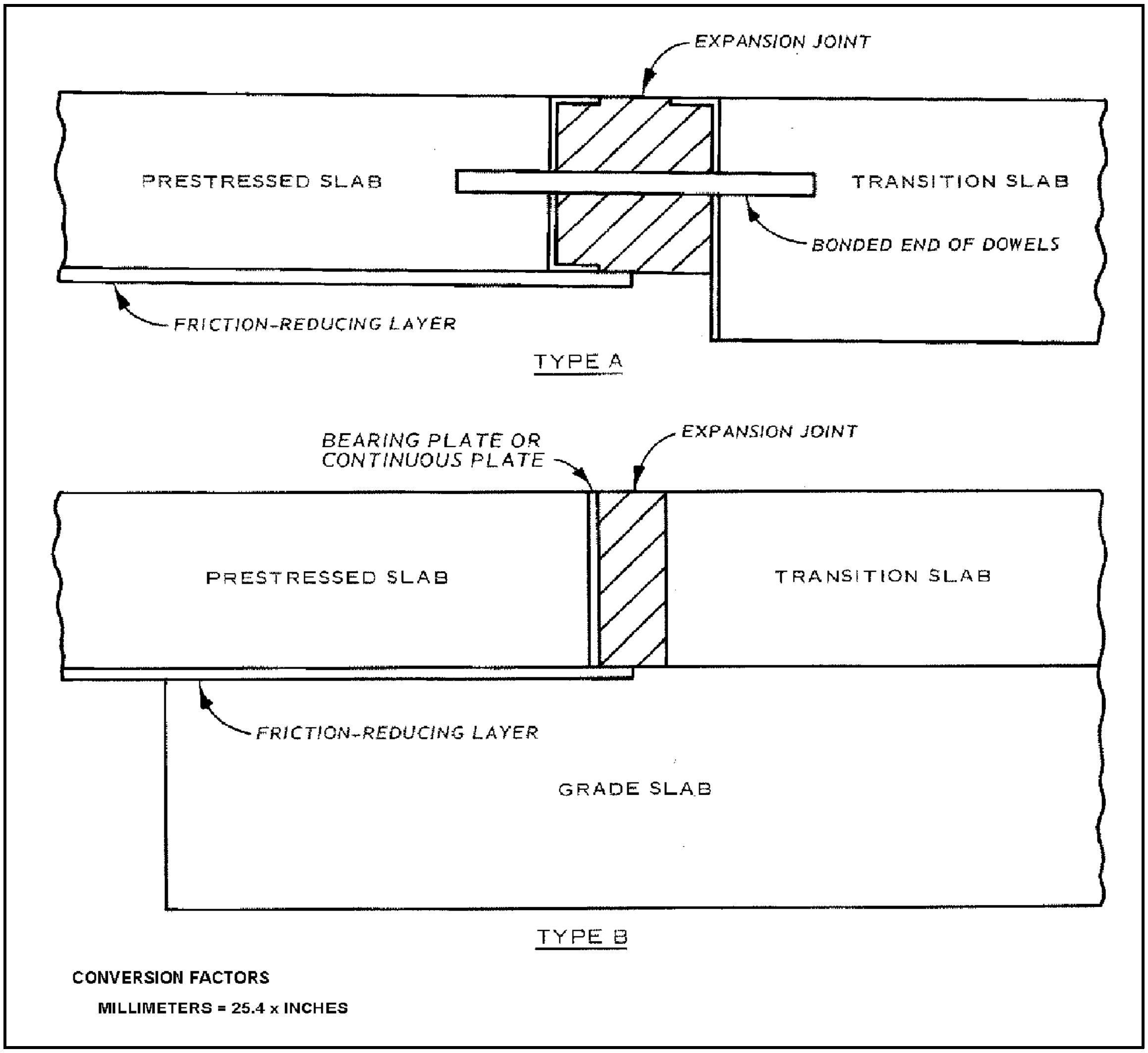


Figure 16-4. Typical section of transverse joints

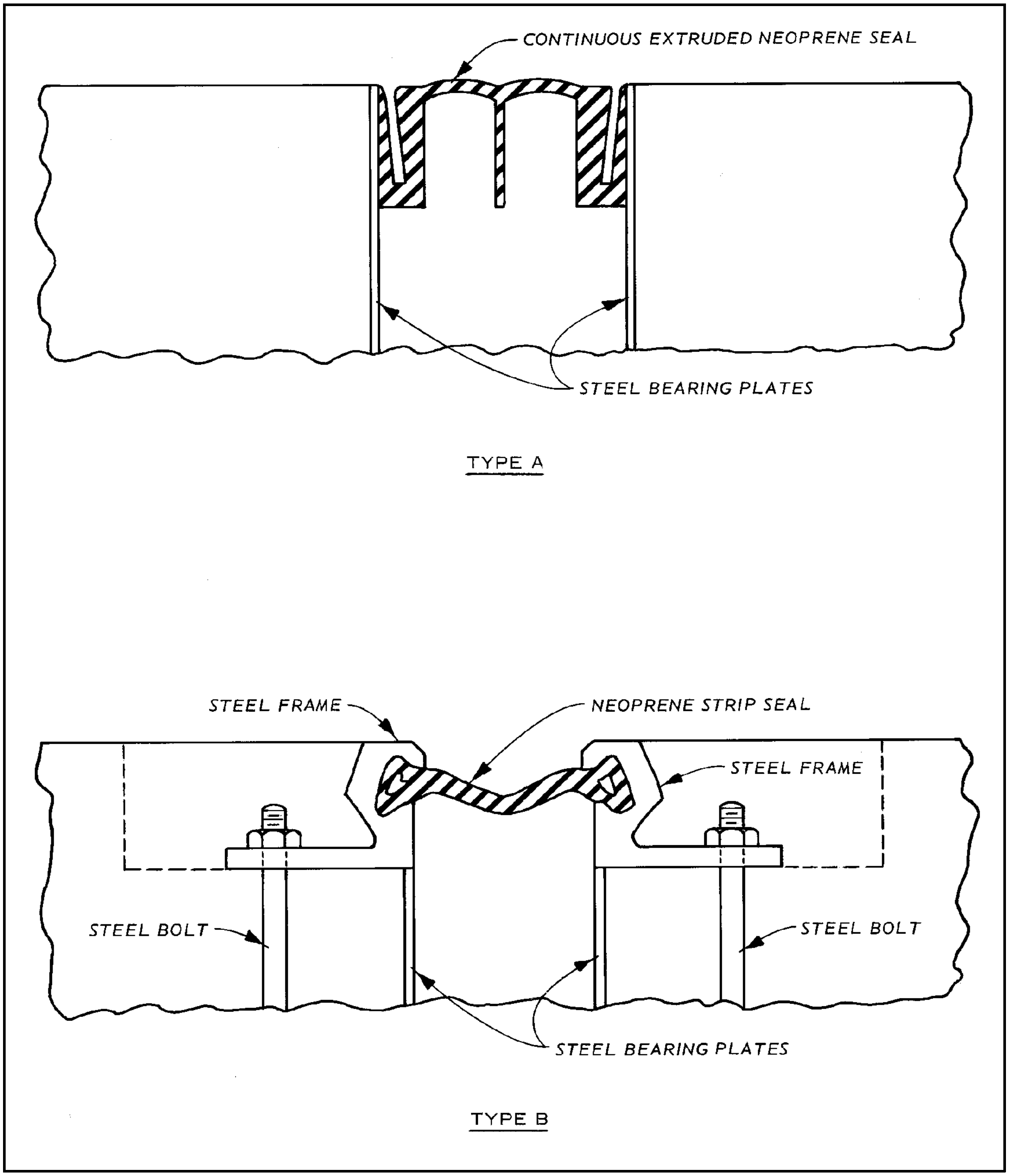


Figure 16-5. Typical transverse joint seals (Sheet 1 of 3)

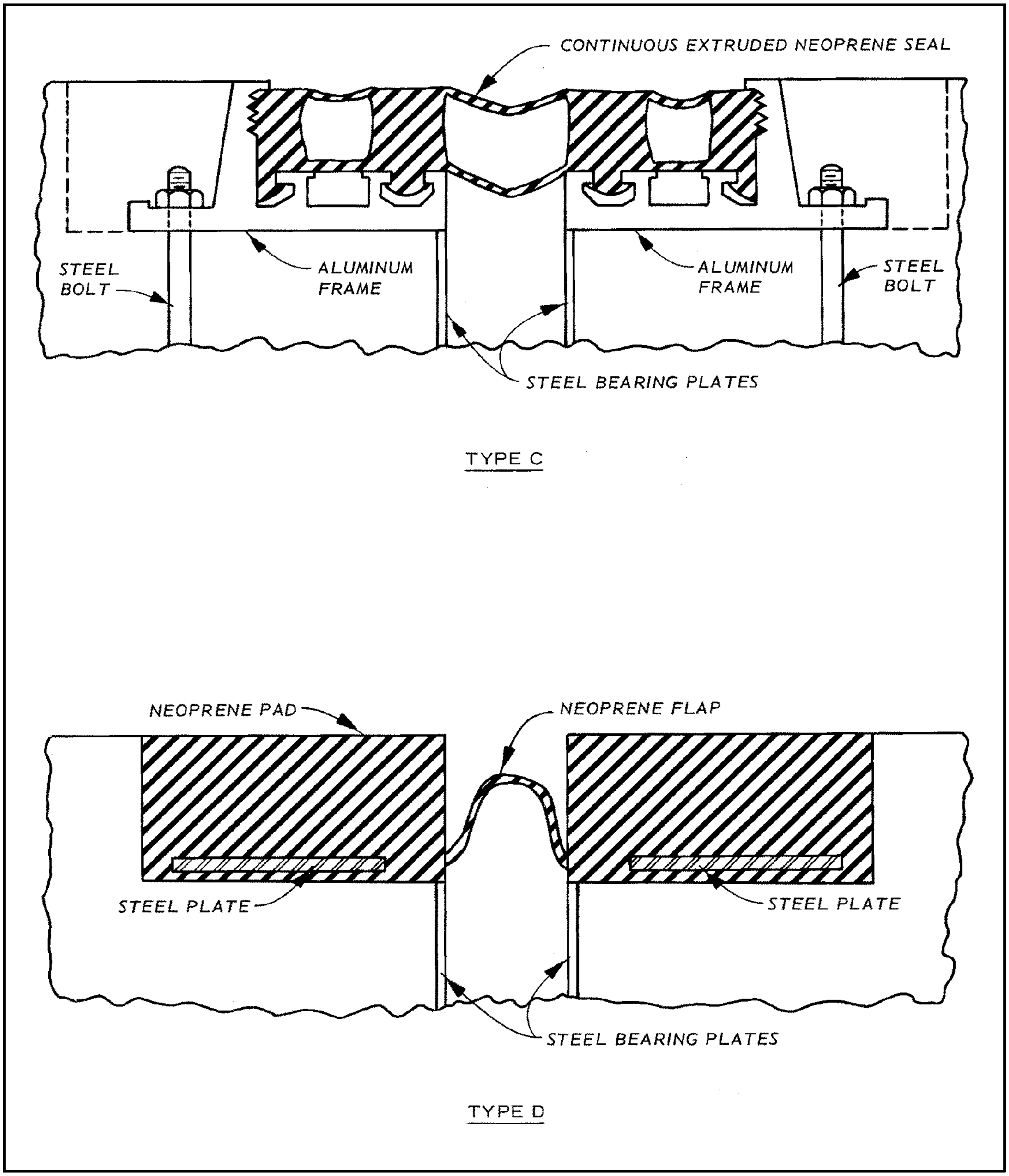
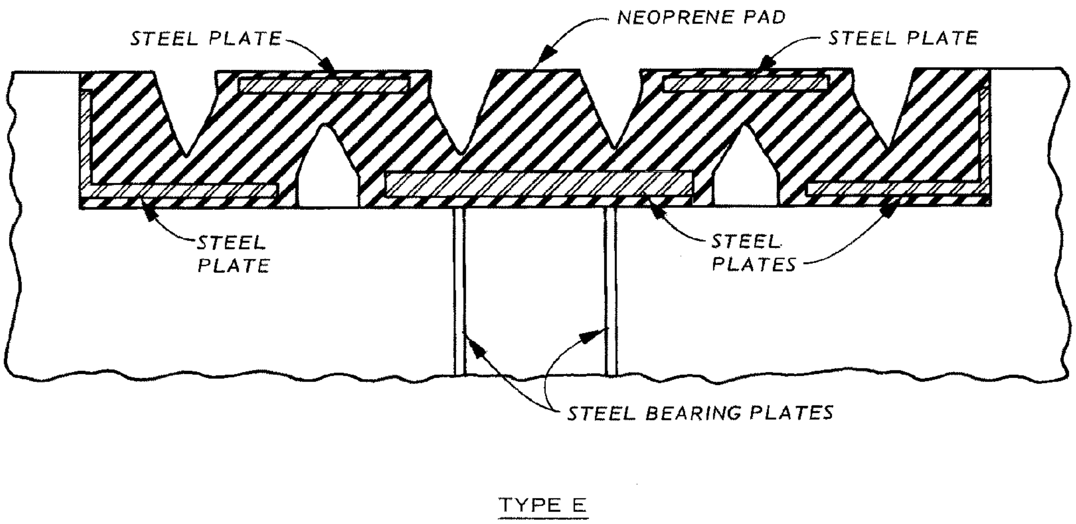


Figure 16-5. (Sheet 2 of 3)



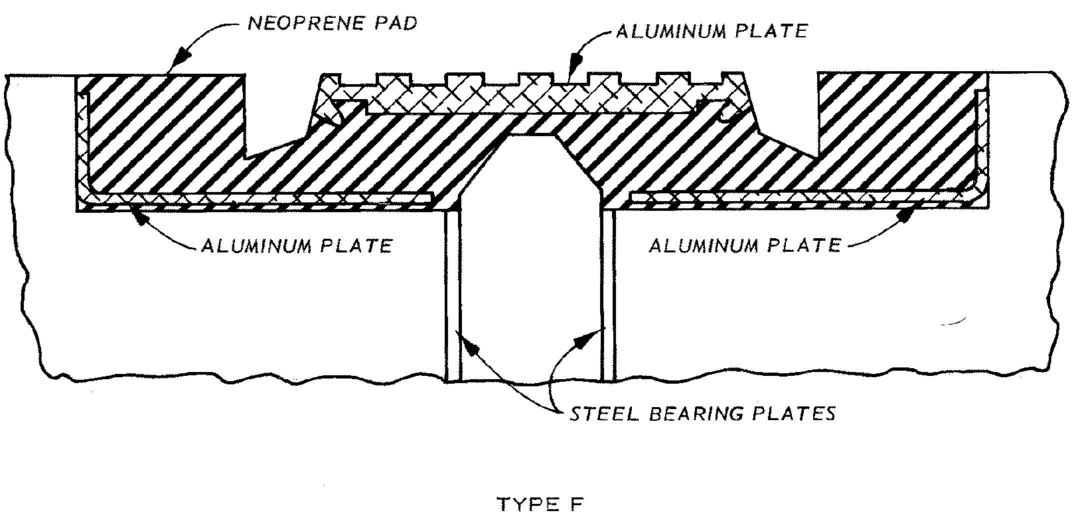


Figure 16-5. (Sheet 3 of 3)

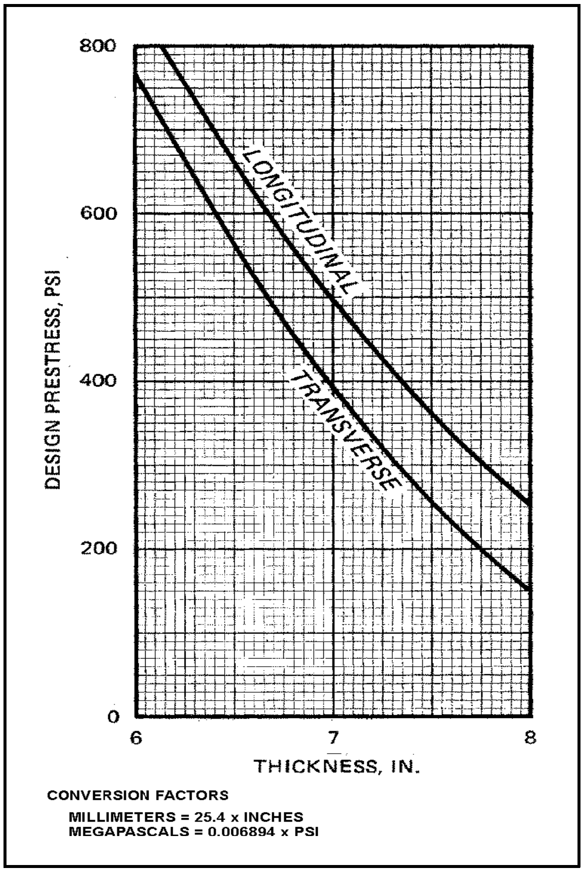


Figure 16-6. Thickness versus design prestress

CHAPTER 17

OVERLAY PAVEMENT DESIGN

1. GENERAL. Overlay pavements are designed to increase the load-carrying capacity (strength) of the existing pavement. The basis for design is to provide a layer or layers of material on the existing pavement that will result in a layered system which will yield the predicted performance of a new rigid pavement if constructed on the same foundation as the existing pavement. Two general types of overlay pavement are considered: rigid and nonrigid. Procedures are presented for the design of plain concrete, reinforced concrete, continuously reinforced concrete, fibrous concrete, prestressed concrete, and nonrigid overlays. Nonrigid overlays include both flexible (nonstabilized base and bituminous concrete wearing course) and all-bituminous concrete for strengthening existing plain concrete, reinforced concrete, and flexible pavements. Continuously reinforced, fibrous, and prestressed concrete overlays will not be permitted unless it is technically and economically justified and approved by HQUSACE (CEMP), Air Force Major Command, or Naval Facilities Engineering Command. Overlays will be used when the nonstabilized aggregate base course can be positively drained. When the overlay includes a nonstabilized aggregate base course layer, the unbound base course must be positively drained.

2. CONVENTIONAL OVERLAY DESIGN EQUATION BACKGROUND AND LIMITATIONS. The overlay design equations for rigid and flexible overlays of rigid pavements presented in this chapter are based on full-scale accelerated traffic tests conducted in the 1950's modified with experience and performance observations in succeeding years. The equations were developed to support a program of strengthening Air Force airfield pavements to accommodate the introduction of the large B-47 and B-52 aircraft into the inventory. Because of theoretical limitations of the time, the overlay equations are empirical. They have the advantage of simplicity for use, but their empirical basis means that they are valid only for conditions consistent with their original development. To use these equations effectively, one must be aware of their limitations and their proper application as discussed in this chapter. For more complex situations, a more comprehensive overlay analysis as presented in the layered elastic design chapter may be necessary.

a. The overlay equations for rigid and flexible overlays of rigid pavements recognize four basic conditions:

(1) Fully bonded overlay where the rigid overlay and rigid base pavement are fully bonded and behave monolithically. Because of problems with providing load transfer, these overlays are generally limited to correcting surface deficiencies of a structurally adequate pavement in good condition other than the surface problems.

(2) Partially bonded overlay where no particular attempt is made to achieve or prevent bond between the rigid overlay and the base pavement. This equation is a best fit to empirical data and therefore can give either conservative or nonconservative thicknesses. Partially bonded overlays are particularly well suited for structurally upgrading an essentially sound pavement to accommodate larger loads as might happen when a mission change brings new heavier aircraft to a base.

(3) Unbonded overlay where a thin separation layer asphalt concrete or other material is interposed between the rigid overlay and the base pavement to avoid direct bonding between the

two. This equation gives generally conservative results. Unbonded overlays are best suited for restoring a deteriorated pavement to structural and functional capacity.

(4) Flexible overlay where an asphaltic concrete is placed directly on a rigid base pavement to restore surface and structural quality. For very thick overlays, a combination of granular base and asphalt concrete surface can be used provided the granular base is positively drained so that no water can be trapped in the overlay. When compared to more powerful layered elastic based overlay analysis, the flexible overlay equation tends to be somewhat unconservative for thin overlay thicknesses and conservative for relatively thick overlay designs. Because of reflective cracking problems, flexible overlays are probably best suited as an interim rehabilitation technique that postpones more comprehensive restoration of a deteriorated pavement.

b. Because of concerns over FOD damage to jet aircraft engines, the empirical rigid and flexible overlay equations were developed for entirely different failure conditions in the accelerated traffic field tests upon which they were based. The rigid overlay sections were considered failed when initial structural cracks appeared, since such cracking was considered the precursor of spalling and potential FOD problems. Failure for the flexible overlays was taken to be when the underlying slab was shattered into 35 or more pieces and the subgrade was on the verge of failing. Because these equations represent two vastly different pavement conditions at the end of the pavement design life, it is not appropriate to try to make comparative cost comparisons between flexible overlays and rigid overlays designed using these equations. Also, this extreme terminal design condition for the flexible overlay equation is empirical and can give anomalous results such as negative numbers. This simply means the design case is outside the valid conditions, and the minimum thickness flexible overlay of 100 millimeters (4 inches) should be used.

3. SITE INVESTIGATIONS. Explorations and tests of the existing pavement will be made to determine the structural condition of the existing pavement prior to overlay, assess the required physical properties of the existing pavement and foundation materials, and locate and analyze all existing areas of defective pavement and subgrade that will require special treatment. The determination of the structural condition and required physical properties of the existing pavement will depend upon the type of overlay used as described in subsequent paragraphs. An investigation will be conducted to determine whether there are voids under the existing rigid pavement. This investigation is especially important if there has been, or is, any evidence of pumping or bleeding of water at cracks, joints, or edges of the existing rigid pavement. Nondestructive pavement test equipment has application for this type of investigation. If voids are found under the existing rigid pavements, fill the voids with grout before the overlay is placed. The results of the investigation, especially the nondestructive tests, may show rather large variations in the strength of the existing pavement and may lead to a requirement for more extensive testing to determine the cause of the variation. It will then be necessary to determine the feasibility and economics of using a variable thickness overlay, basing the design on the lower-strength pavement section, or removing and replacing the low-strength pavement areas.

4. PREPARATION OF EXISTING PAVEMENT.

a. General. The preparation of the existing pavement prior to overlay will vary, depending upon whether the overlay is rigid or nonrigid.

b. Rigid Overlay. Overlay thickness criteria are presented for three conditions of bond between the rigid overlay and existing rigid pavement: fully bonded, partially bonded, and nonbonded. The fully bonded condition is obtained when the concrete is cast directly on concrete and special efforts are made to obtain bond. The partially bonded condition is obtained when the concrete is cast directly on concrete with no special efforts to achieve or destroy bond. The nonbonded condition is obtained when the bond is prevented by an intervening layer of material. When a fully bonded or partially bonded rigid overlay is to be used, the existing rigid pavement will be cleaned of all foreign matter (such as oil and paint), spalled concrete, extruded joint seal, bituminous patches, or anything else that would act as a bond-breaker between the overlay and existing rigid pavement.

(1) In addition, fully bonded overlays use careful surface preparation to ensure the overlay and underlying base slab are fully bonded and behave monolithically. To reliably achieve this full bond, the base slab is cold milled or shotblasted to remove all deteriorated or defective concrete and all surface contamination. This roughened surface must be thoroughly cleaned by sandblasting followed by airblasting, waterblasting, or both. Achieving and maintaining the surface cleanliness concrete placement is critical for achieving good bond. A portland-cement grout is then pneumatically applied immediately ahead of the concrete placement to help achieve a high degree of bond between the new and old concrete. This grout must not dry prior to placement of the concrete so usually it is only applied about 3 to 4 m ahead of the concrete placement. If the grout dries out prior to the concrete placement, the grout should be removed by sandblasting or other similarly reliable method and reapplied prior to continuing concrete placement. Older requirements for acid etching the base concrete surface are unnecessary and are not environmentally sound. Portland-cement grouts have proven adequate, and more expensive epoxy or polymer grouts are not normally needed. Some bonded overlays have reportedly been successfully placed with no bonding grout, but the military has no experience with such at present. For military airfield work where debonding poses such a serious FOD hazard, the intense surface preparation, surface cleaning, and use of a portland-cement grout are considered to be the minimum allowable effort for fully bonded overlays.

Past tests and studies have failed to identify adequate methods of providing satisfactory load transfer in fully bonded overlays. Consequently, fully bonded overlays will only be used on military airfields to correct surface deficiencies, and they are not suitable for structural upgrades unless the pavement is redesigned assuming no load transfer exists. The minimum thickness for a fully bonded overlay is 50 millimeters (2 inches), and most military airfield bonded overlays have been 75 to 125 millimeters (3 to 5 inches) thick. Typical past uses have included correction of surface smoothness or skid resistance problems, providing a sound operational surface over underlying pavements that are scaling, posing an FOD hazard from popouts or spalling and raveling, or to cover pavement surfaces that pose an FOD hazard from D-cracking, excess surface grout, or alkali-aggregate reaction deterioration.

All joints and cracks in the base pavement will reflect through a fully bonded overlay. Therefore, the overlay joints must match the base slab joints. Cracked slabs in the pavement to be overlaid should be removed and replaced, or the bonded overlay slab above the cracked slab should be reinforced.

(2) When a nonbonded rigid overlay is being used, the existing rigid pavement will be cleaned of all loose particles and covered with a leveling or bond-breaking course of bituminous concrete, sand-asphalt, heavy building paper, polyethylene, or other similar stable material. The bond-breaking medium generally should not exceed a thickness of about 25 millimeters (1 inch), except in the case of leveling courses where greater thicknesses may be necessary. When a rigid overlay is being applied to an existing flexible pavement, the surface of the existing pavement will be cleaned of loose materials and any potholing or unevenness, exceeding about 25 millimeters

(1 inch), will be repaired by cold planing, localized patching, or the application of a leveling course using bituminous concrete, sand-asphalt, or a similar material.

c. Nonrigid Overlay. When a flexible overlay is used, no special treatment of the surface of the existing pavement will be required other than the removal of loose material. When an all-bituminous concrete overlay is used, the surface of the existing pavement will be cleaned of all foreign matter. Spalled concrete, fat spots in bituminous patches, and extruded soft or spongy joint seal material on rigid pavements will be removed. Joints or cracks less than 25 millimeters (1 inch) wide in an existing rigid pavement will be filled with joint sealant. Joints or cracks that are 25 millimeters (1 inch) or greater in width will be cleaned and filled with an acceptable bituminous mixture (such as sand-asphalt) which is compatible with the overlay. Leveling courses of bituminous concrete will be used to bring the existing pavement to the proper grade when required. Prior to placing the all-bituminous concrete overlay, a tack coat will be applied to the surface of the existing pavement.

5. CONDITION OF EXISTING CONCRETE PAVEMENT.

a. General. The support that the existing rigid pavement will provide to an overlay is a function of its structural condition just prior to the overlay. In the overlay design equations, the structural condition of the existing concrete pavement is assessed by a condition factor, C. The value of C should be selected based upon a condition survey (ASTM D 5340) of the existing rigid pavement. Interpolation of C values between those shown below may be used if it is considered necessary to more accurately define the existing structural condition. As an alternative, Figure 17-1 may be used to select the C value for plain concrete or nonrigid overlays. This figure relates a structural condition index (SCI) and C. The SCI is that part of the pavement condition index (PCI) related to structural distress types as deduct values. To determine SCI values, a condition survey is conducted according to ASTM D 5340. However, rather than calculating the PCI, an SCI is calculated by subtracting the deduct values for corner breaks, longitudinal, transverse and diagonal cracking, shattered slabs, spalling along joints, and spalling corners from 100.

b. Rigid Overlay. The following values of C are assigned for the following conditions of plain and reinforced concrete pavements.

(1) Condition of existing plain concrete pavement:

C = 1.00 - Pavements in the trafficked areas are in good condition with little or no structural cracking because of load

C = 0.75 - Pavements in the trafficked areas exhibit initial cracking because of load but no progressive cracking or faulting of joints or cracks

C = 0.35 - Pavements in the trafficked areas exhibit progressive cracking because of load accompanied by spalling, raveling, or faulting of cracks and joints

(2) Condition of existing reinforced concrete pavement.

C = 1.00 - Pavements in the trafficked areas are in good condition with little or no short-spaced transverse (305- to 610-millimeter (1- to 2-foot)) cracks, no longitudinal cracking, and little spalling or raveling along cracks

C = 0.75 - Pavements in the trafficked areas exhibit short-spaced transverse cracking but little or no interconnecting longitudinal cracking because of load and only moderate spalling or raveling along cracks

C = 0.35 - Pavements in the trafficked areas exhibit severe short-spaced transverse cracking and interconnecting longitudinal cracking because of load, severe spalling along cracks, and initial punchout-type failures

c. Nonrigid Overlay. The following values of C are assigned for the following conditions of plain and reinforced concrete pavement.

(1) Condition of existing plain concrete pavements.

C = 1.00 - Pavements in the trafficked areas are in good condition with some cracking because of load but little or no progressive-type cracking

C = 0.75 - Pavements in the trafficked areas exhibit progressive cracking because of load and spalling, raveling, and minor faulting at joints and cracks

C = 0.50 - Pavements in the trafficked areas exhibit multiple cracking along with raveling, spalling, and faulting at joints and cracks

(2) Condition of existing reinforced concrete pavement.

C = 1.00 - Pavements in the trafficked areas are in good condition but exhibit some closely spaced load-induced transverse cracking, initial interconnecting longitudinal cracks, and moderate spalling or raveling of joints and cracks

C = 0.75 - Pavements in trafficked areas exhibit numerous closely spaced load-induced transverse and longitudinal cracks, rather severe spalling or raveling or initial evidence of punchout failures

6. RIGID OVERLAY OF EXISTING RIGID PAVEMENT.

a. General. There are three basic equations for the design of rigid overlays which depend upon the degree of bond that develops between the overlay and existing pavement: fully bonded, partially bonded, and nonbonded. The fully bonded overlay equation is used when special care is taken to provide bond between the overlay and the existing pavement. The partially bonded equation will be used when the rigid overlay is to be placed directly on the existing pavement and no special care is taken to provide bond. A bond-breaking medium and the nonbonded equation will be used when (a) a plain concrete overlay is used to overlay an existing reinforced concrete pavement, (b) when a continuously reinforced or prestressed concrete overlay is used to overlay an existing plain concrete or reinforced concrete pavement, (c) when a plain concrete overlay is being used to overlay an existing plain concrete pavement that has a condition factor $C \leq 0.35$, and

(d) when matching joints in a plain concrete overlay with those in the existing plain concrete pavement cause undue construction difficulties or result in odd-shaped slabs.

b. Plain Concrete Overlay.

(1) Thickness Determination. The required thickness h_o of plain concrete overlay will be determined from the following applicable equations:

Fully bonded

$$h_o = h_d - h_E \tag{17-1}$$

Partially bonded

$$h_o = \sqrt[1.4]{h_d^{1.4} - C\left(\frac{h_d}{h_e} \times h_E\right)^{1.4}} \tag{17-2}$$

Nonbonded

$$h_o = \sqrt{h_d^2 - C\left(\frac{h_d}{h_e} \times h_E\right)^2} \tag{17-3}$$

where

h_E = existing plain concrete pavement thickness

h_d and h_e = design thicknesses of rigid pavement determined using the design flexural strength of the overlay and measured flexural strength of the existing rigid pavement, respectively; the modulus of soil reaction k of the existing rigid pavement foundation; and the design loading, traffic area, and pass level needed for overlay design.

Use of fully bonded overlay is limited to existing pavements having a condition index of 1.0, and to overlay thickness of 50 to 120 millimeters (2.0 to 5.0 inches). The fully bonded overlay is used only to correct a surface problem such as scaling rather than as a structural upgrade. The factor h_E represents the thickness of the existing plain concrete pavement or the equivalent thickness of plain concrete pavement having the same load-carrying capacity as the existing pavement. If the existing pavement is reinforced concrete, h_E is determined from Figure 13-1 using the percent reinforcing steel S and design thickness h_e. The minimum thickness of plain concrete overlay will be 50 millimeters (2 inches) for a fully bonded overlay and 150 millimeters (6 inches) for a partially bonded or nonbonded overlay. The required thickness of overlay must be rounded to the nearest full- or half-inch increment. When the indicated thickness falls midway between a full and half-inch, the thickness will be rounded upward.

(2) Jointing. For all partially bonded and fully bonded plain concrete overlays, joints will be provided in the overlay to coincide with all joints in the existing rigid pavement. It is not necessary for joints in the overlay to be of the same type as joints in the existing pavement. When it is

impractical to match the joints in the overlay to joints in the existing rigid pavement, either a bond-breaking medium will be used and the overlay designed as a nonbonded overlay, or the overlay will be reinforced over the mismatched joints. Should the mismatch of joints become severe, a reinforced concrete overlay design should be considered as an economic alternative to the use of nonbonded plain concrete overlay. For nonbonded plain concrete overlays, the design and spacing of transverse contraction joints will be in accordance with requirements for plain concrete pavements on grade. For both partially bonded and nonbonded plain concrete overlays, the longitudinal construction joints will be doweled using the dowel size and spacing given in Table 12-8. Any contraction joint in the overlay that coincides with an expansion joint in the existing rigid pavement within the prescribed limits of a type A traffic area will be doweled. Dowels and load-transfer devices will not be used in fully bonded overlays. Joint sealing for plain concrete overlays will conform to the requirements for plain concrete pavements on grade.

(3) Example of Plain Concrete Overlay Design. An existing plain concrete pavement will be strengthened to serve as a type A traffic area for an Air Force medium-load pavement using a plain concrete overlay. The pertinent physical properties of the existing rigid pavement are: h_E = 200 millimeters (8 inches), R = 4.83 MPa (700 psi), and k = 27 MN/m^3 (100 pci). The design (90-day) flexural strength of the concrete for the overlay is 5.17 MPa (750 psi).

(a) The existing pavement is showing some initial cracking due to load so that the condition factor C is 0.75. The condition of the existing pavement is such that there is no reason to use a leveling course or other bond-breaking medium. The required thickness h_o of the plain concrete overlay is then determined using the partially bonded overlay equation (Equation 17-2). The design thickness h_d of plain concrete pavement, using the design flexural strength of 5.17 MPa (750 psi) for the overlay concrete and k = 27 MN/m^3 (100 pci) for the existing foundation, from Figure 12-7 (medium-load design curve) and type A traffic area, is 457 millimeters (18.0 inches). The design thickness h_e of plain concrete pavement, using the 4.82 MPa (700 psi) flexural strength of the existing pavement, a k value of 27 MN/m^3 (100 pci), and Figure 12-7 is 488 millimeters (19.2 inches). Since the existing rigid pavement is plain concrete, h_E = 200 millimeters (8 inches). Substituting these values in Equation 17-2,

$$h_o = \sqrt[1.4]{457^{1.4} - 0.75\left(\frac{457}{488} \times 200\right)^{1.4}}$$

$$= 384 \text{ mm (SI units)}$$

$$h_o = \sqrt[1.4]{18.0^{1.4} - 0.75\left(\frac{18.0}{19.2} \times 8\right)^{1.4}}$$

$$= 15.1 \text{ inches (use 15.0 inches) (English units)}$$

(b) The existing rigid pavement is 200 millimeters (8 inches) of reinforced concrete with 0.15 percent of reinforcing steel S and a condition factor C of 0.75. All properties of the existing pavement and proposed plain concrete overlay are the same as above. Since the existing pavement is reinforced concrete, it will be necessary to use a bond-breaking medium and determine the required thickness of plain concrete overlay using the nonbonded overlay equation

(Equation 17-3). The design thickness h_d of plain concrete is 457 millimeters (18.0 inches), and the design thickness h_e is 488 millimeters (19.2 inches). The value of h_E, the thickness of plain concrete pavement equivalent to the existing thickness of reinforced concrete pavement, determined from Figure 13-1 using the existing thickness of reinforced concrete pavement of 200 millimeters (8 inches) and S = 0.15 percent, is 241 millimeters (9.5 inches). Substituting these values in the equation above,

$$h_o = \sqrt{457^2 - 0.75\left(\frac{457}{488} \times 241\right)^2}$$

$$= 413 \text{ millimeters (SI units)}$$

$$h_o = \sqrt{18.0^2 - 0.75\left(\frac{18.0}{19.2} \times 9.5\right)^2}$$

$$= 16.3 \text{ inches (use 16.5 inches) (English units)}$$

c. Reinforced Concrete Overlay. A reinforced concrete overlay may be used to strengthen either an existing plain concrete or reinforced concrete pavement. Generally, the overlay will be designed as a partially bonded overlay. The nonbonded overlay design will be used only when a leveling course is required over the existing pavement. The reinforcement steel for reinforced concrete overlays will be designed and placed in accordance with reinforced concrete slabs on grade.

(1) Thickness determination. The required thickness of reinforced concrete overlay will be determined using Figure 13-1 after the thickness of plain concrete overlay has been determined using the appropriate overlay equation. Then, using the value for the thickness of plain concrete overlay, either the thickness of reinforced concrete overlay can be selected and the required percent steel determined, or the percent steel can be selected and the thickness of reinforced concrete overlay determined from Figure 13-1. The minimum thickness of reinforced concrete overlay will be 152 millimeters (6 inches).

(2) Jointing. Whenever possible, the longitudinal construction joints in the overlay should match the longitudinal joints in the existing pavement. All longitudinal joints will be of the butt-doweled type with dowel size and spacing designated in accordance with Chapter 12 using the thickness of reinforced concrete overlay. It is not necessary for transverse joints in the overlay to match joints in the existing pavement; however, when practical, the joints should be matched. The maximum spacing of transverse contraction joints will be determined in accordance with Figure 13-1, but it will not exceed 30 meters (100 feet) regardless of the thickness of the pavement or the percent steel used. Joint sealing for reinforced concrete pavements will conform to the requirements for plain concrete pavements.

(3) Example of reinforced concrete overlay design. An existing rigid pavement will be strengthened to serve as a type B traffic area for a heavy-load pavement using a reinforced concrete overlay. The pertinent physical properties of the existing plain concrete pavement are: h_E = 250 millimeters (10 inches), R = 4.48 MPa (650 psi), and k = 54 MN/m^3 (200 pci). The design (90-day) flexural strength of the overlay is 5.17 MPa (750 psi).

(a) The existing rigid pavement is plain concrete with a structural condition C of 0.35; however, there is no significant faulting of the slabs and a leveling course is not needed. The required thickness of plain concrete overlay is determined using the partially bonded overlay equation (Equation 17-2). The required thickness h_d of plain concrete pavement for the overlay design flexural strength of 5.17 MPa (750 psi) and the k value of 54 MN/m^3 (200 pci) for the foundation under the existing pavement determined from Figure 12-8 (heavy-load design curve) type B traffic area is 521 millimeters (20.5 inches). The design thickness h_e of plain concrete pavement for the flexural strength of 4.48 MPa (650 psi) of the existing pavement and the k value of 54 MN/m^3 (200 pci) from Figure 12-8 is 574 millimeters (22.6 inches). Since the existing pavement is plain concrete, the equivalent thickness h_E is equal to the 250-millimeter (10-inch) thickness of the existing slab. Substituting these values in Equation 17-2,

$$h_o = \sqrt[1.4]{521^{1.4} - 0.35\left(\frac{521}{574} \times 250\right)^{1.4}}$$

$$= 478 \text{ millimeters (SI units)}$$

$$h_o = \sqrt[1.4]{20.5^{1.4} - 0.35\left(\frac{20.5}{22.6} \times 10\right)^{1.4}}$$

$$= 18.8 \text{ inches (English units) (Use 19.0 inches)}$$

This is the thickness of the plain concrete overlay required to strengthen the existing plain concrete pavement for the design loading condition. The thickness of reinforced concrete overlay is then dependent upon the percent of reinforcing steel S that will be used. Let it be assumed that because of grade problems, the overlay thickness must be limited to 380 millimeters (15 inches). Then, the value of S required, determined from Figure 13-1 using the plain concrete overlay thickness of 478 millimeters (19.0 inches) and the reinforced concrete overlay thickness of 380 millimeters (15 inches), is 0.25 percent. It is also noted from Figure 13-1 that a maximum joint spacing of 30 meters (100 feet) may be used with a reinforcing steel having a yield strength y_s of 413 MPa (60,000 psi).

(b) The existing pavement in the example above consists of 250 millimeters (10 inches) of reinforced concrete with 0.10 percent of reinforcing steel and all other properties and design requirements remain the same. The thickness of plain concrete pavement h_E equivalent to the 250 millimeters (10 inches) of existing reinforced concrete pavement, determined from Figure 13-1 using the existing thickness of 250 millimeters (10 inches) and S = 0.10, is 287 millimeters (11.3 inches). Substituting these values in the partially bonded overlay equation yields a required overlay thickness h_o of plain concrete equal to:

$$h_o = \sqrt[1.4]{521^{1.4} - 0.35\left(\frac{521}{574} \times 287\right)^{1.4}}$$

$$= 470 \text{ millimeters (SI units)}$$

$$h_o = \sqrt[1.4]{20.5^{1.4} - 0.35\left(\frac{20.5}{22.6} \times 11.0\right)^{1.4}}$$

$$= 18.5 \text{ inches (English units)}$$

From Figure 13-1, the thickness of reinforced concrete overlay using the thickness of plain concrete of 470 millimeters (18.5 inches) and a percent steel of 0.20 is 380 millimeters (15 inches).

d. Continuously Reinforced Concrete Overlay. A continuously reinforced concrete overlay may be used to strengthen either an existing plain concrete or reinforced concrete pavement. For both conditions, a bond-breaking medium is required between the overlay and the existing pavement. The required thickness of a continuously reinforced concrete pavement is determined in the same manner and will be equal in thickness to a plain concrete overlay. Jointing and sealing of joints in a continuously reinforced concrete pavement will be the same as for continuously reinforced concrete pavements on grade.

e. Fibrous Concrete Overlay. A fibrous concrete overlay may be used to strengthen either an existing plain or reinforced concrete pavement. The mix proportioning of the fibrous concrete overlay will follow the considerations presented for fibrous concrete pavements on grade.

(1) Thickness determination. The required thickness of fibrous concrete overlay will be determined using the partially bonded or nonbonded overlay equations. Normally, the partially bonded equation will be used, but in cases of extremely faulted or uneven existing pavement surfaces, a leveling course may be required and the design of the overlay will be made using the nonbonded overlay equation. If the existing rigid pavement is plain concrete, then the equivalent thickness is equal to the existing slab thickness. If the existing rigid pavement is reinforced concrete, however, then the equivalent thickness must be determined from Figure 13-1 using the thickness of the existing slab and the percent of reinforcing steel. The minimum thickness of fibrous concrete overlay will be 100 millimeters (4 inches).

(2) Jointing. In general, the joint types, spacing, and designs discussed for plain concrete pavements apply to fibrous concrete overlays, except that for thicknesses from 100 millimeters (4 inches) to 150 millimeters (6 inches), the maximum spacing will be 3.8 meters (12.5 feet). Joints in the fibrous overlay should coincide with joints in the existing rigid pavement. Longitudinal construction joints will be the butt-doweled type, and dowels will be required in transverse contraction joints exceeding 15-meter (50-foot) spacings. For pavement thickness less than 150 millimeters (6 inches), it will be necessary to obtain guidance on joint construction from HQUSACE (CEMP-ET), the appropriate Air Force Major Command, or the Naval Facilities Engineering Command. Sealing of joints in fibrous overlays will be in accordance with sealing of joints in fibrous concrete pavements on grade.

(3) Example of fibrous concrete overlay design. An existing rigid pavement will be strengthened to serve as a type B traffic area for an Air Force light-load pavement using a fibrous concrete overlay. The pertinent physical properties of the existing rigid pavement are: existing thickness is 150 millimeters (6 inches), R = 4.8 MPa (700 psi), and k = 27 MN/m^3 (100 pci). The design (90-day) flexural strength of the fibrous concrete overlay is 6.2 MPa (900 psi). The existing rigid pavement is plain concrete with a structural condition, C, of 1.0. A leveling course will not be required; therefore, the required thickness of fibrous concrete overlay will be determined using the

partially bonded overlay equation (Equation 17-2). Use of this equation requires that h_d be the thickness of fibrous concrete from the appropriate fibrous concrete design curve. The design thickness of fibrous concrete pavement is determined from Figure 14-4 to be 228 millimeters (9 inches) using the design flexural strength of the fibrous concrete overlay (6.2 MPa (900 psi)) and k value of (27 MN/m^3 (100 pci)) for the existing rigid pavement foundation. The design thickness of plain concrete, using the flexural strength of the existing pavement (4.8 MPa (700 psi)) and k of 27 MN/m^3 (100 pci) for the existing foundation strength, is 310 millimeters (12.2 inches). Since the existing rigid pavement is plain concrete, h_E = 150 millimeters (6 inches); substituting these values in the partially bonded overlay equation yields a required thickness of fibrous concrete overlay of:

$$h_o = \sqrt[1.4]{228^{1.4} - 1.0\left(\frac{228}{310} \times 150\right)^{1.4}}$$

$$= 165 \text{ millimeters (SI units)}$$

$$h_o = \sqrt[1.4]{8.99^{1.4} - 1.0\left(\frac{9.00}{12.2} \times 6\right)^{1.4}}$$

$$= 6.5 \text{ inches (English units)}$$

7. PRESTRESSED CONCRETE OVERLAY OF RIGID PAVEMENT. A prestressed concrete overlay may be used above any rigid pavement. The procedure for designing the prestressed concrete overlay is to consider the base pavement to have a k value of 135 MN/m^3 (500 pci) and design the overlay as a prestressed concrete pavement on grade.

8. RIGID OVERLAY OF EXISTING FLEXIBLE OR COMPOSITE PAVEMENT. Any type of rigid overlay may be used to strengthen an existing flexible or composite pavement. The existing pavement is considered to be a composite pavement when it is composed of a rigid base pavement that has been strengthened with 100 millimeters (4 inches) or more of nonrigid (flexible or all-bituminous) overlay. If the nonrigid overlay is less than 100 millimeters (4 inches), the rigid overlay is designed using the nonbonded overlay equation. The design of the rigid overlay will follow the procedures outlined in Chapters 12 through 16 of this document. The strength afforded by the existing pavement will be characterized by the modulus of soil reaction k determined using the plate bearing test, or Figure 8-1. The following modifications or limitations apply: (a) The plate bearing test will be performed when the pavement temperature equals or exceeds the maximum ambient temperature for the hottest period of the year, and (b) in no case will a k value greater than 135 MN/m^3 (500 pci) be used for design. When Figure 8-1 is used to estimate the k value at the surface of the existing flexible pavement, the bituminous concrete portion will be assumed to be unbound base material since its performance will be similar to a base course.

9. NONRIGID OVERLAY OF EXISTING RIGID PAVEMENT.

a. General. Two types of nonrigid overlay, all-bituminous concrete overlay, and flexible overlay, may be used with certain reservations to strengthen an existing rigid pavement.

b. All-Bituminous Overlay. The all-bituminous overlay will be composed of hot-mix bituminous concrete meeting the requirements of TM 5-822-8/AFM 88-6, Chapter 9. A tack coat is required between the existing rigid pavement and the overlay. The all-bituminous overlay is the preferred nonrigid type overlay to lessen the danger of entrapped moisture in the overlay.

c. Flexible Overlay. The flexible overlay will be composed of hot-mix bituminous concrete and high-quality crushed aggregate base with a CBR of 100, provided positive drainage of the base course is achieved. The bituminous concrete will meet the requirements of TM 5-822-8/AFM 88-6, Chapter 9 and the minimum thickness requirements of Chapter 8. If the design thickness of nonrigid overlay is less than that required by the minimum thickness of bituminous concrete and base course, the overlay will be designed as an all-bituminous overlay.

d. Thickness Determination. Regardless of the type of nonrigid overlay, the required thickness t_o will be determined by

$$t_o = 3.0(Fh_d - Ch_E) \qquad (17\text{-}4)$$

where

h_d = design thickness of plain concrete pavement using the flexural strength R of the concrete in the existing rigid pavement and the modulus of soil reaction k of the existing pavement.

The factor h_E represents the thickness of plain concrete pavement equivalent in load-carrying ability to the thickness of existing rigid pavement. If the existing rigid pavement is plain concrete, then the equivalent thickness equals the existing thickness; however, if the existing rigid pavement is reinforced concrete, the equivalent thickness must be determined from Figure 13-1. F is a factor, determined from Figure 17-2, that projects the cracking expected to occur in the base pavement during the design life of the overlay. Use of Figure 17-2 requires converting passes to coverages using values shown in Table 17-1. C is a coefficient based upon the structural condition of the existing rigid pavement. The minimum thickness of overlay used for strengthening purposes will be 50 millimeters (2 inches) for Air Force type D traffic areas and all overruns, 75 millimeters (3 inches) for Army Class I, II, and III pavements, 75 millimeters (3 inches) for Air Force types B and C traffic areas on light-load pavements, 75 millimeters (3 inches) for Navy and Marine Corps secondary pavements designed for fighter aircraft, and 100 millimeters (4 inches) for all other Army, Air Force, Navy and Marine Corps pavements. In certain instances, the nonrigid overlay design equation will indicate thickness requirements less (sometimes negative values) than the minimum values. In such cases the minimum thickness requirement will be used. When strengthening existing rigid pavements that exhibit flexural strength less than 3.5 MPa (500 psi) or that are constructed on foundations with k values exceeding 54 MN/m^3 (200 pci), it may be found that the flexible pavement design procedure in Chapter 10 or 11 may indicate a lesser required overlay thickness than the overlay design formula. For these conditions, the overlay thickness will be determined by both methods, and the lesser thickness used for design. For the flexible pavement design procedure, the existing rigid pavement will be considered to be either an equivalent thickness of high-quality crushed aggregate base with a CBR = 100 or an equivalent thickness of all-bituminous concrete (equivalency factor of 1.15 for base and 2.3 for subbase), and the total pavement thickness determined based upon the subgrade CBR. Any existing base or subbase layers will be considered as corresponding layers in the flexible pavement. The thickness of required overlay will then be the difference between the required flexible pavement thickness and the combined thicknesses of existing rigid pavement and any base or subbase layers above the subgrade.

e. Reflective Cracking. If a flexible overlay is placed over a rigid pavement, the underlying joints will reflect through the overlay, and these cracks will progressively deteriorate by raveling. This reflective cracking is primarily caused by seasonal and diurnal environmental changes occurring in the overlaid rigid pavement, and reflective cracking will often appear during the first winter after the placement of the overlay. At present there is no completely reliable method of preventing reflective cracking. Consequently, in many cases, the designer should probably consider a flexible overlay as a maintenance tool to upgrade the serviceability and to a more limited extent, the structural capacity of a rigid pavement for a relatively limited time while more comprehensive rehabilitation is postponed to the future. Some methods of ameliorating the adverse effects of reflective cracking include:

(1) Overlay Thickness: The thicker the overlay, the longer the cracking will be postponed and the slower it will deteriorate. Hence, abiding by minimum flexible overlay thicknesses is an important issue.

(2) Saw and Seal: Since there is no way to reliably avoid reflective cracking, another approach is to saw the flexible overlay directly above the rigid pavement joints and seal this with an appropriate sealer. These sealed cuts are then more easily and effectively maintained than the reflective cracks would be. The Air Force has found this to be an effective approach, and it is generally their preferred approach to dealing with flexible overlays over rigid pavements.

(3) Geotextiles: Geotextiles have shown a limited ability to slow the development and severity of reflective cracking in warm climates. Field trials found that in Area I of Figure 17-3, geotextiles were usually helpful, in Area II they gave mixed results, and in Area III, they were ineffective in dealing with reflective cracking. The minumum overlay thickness is 100 millimeters (4 inches).

(4) Crack & Seat and Rubblizing: An alternative approach is to break the existing rigid pavement slabs into smaller individual segments (crack and seat) or to pulverize them into shattered small fragments (essentially rubblize to aggregate) before overlaying . Concetually, the shattered slabs or rubblized concrete fragments are then too small to develop movements to generate reflective cracks. This technique has proven successful on highways, but experience on thicker pavements such as found on airfields is very limited at present.

(5) Bond Breakers: Open graded materials, aggregate bases as part of the flexible overlay, and specially designed stress/strain absorbing membranes have all been tried to provide a layer capable of absorbing the movement of the underlying rigid pavement without transmitting it to the asphalt concrete overlay surface. These have given mixed results, and some systems are proprietary.

(6) Reinforcing: Besides geotextiles, other proprietary reinforcing systems using steel wire and fiberglass grids to combat reflective cracking are available. These have not been evaluated by the military.

Military experience has found thicker overlays and in some warm climates geotextiles may help mitigate but not prevent reflective cracking in flexible overlays. Sawing and sealing above the rigid pavement joints has also been found to be a pragmatic way of minimizing the problems with

Table 17-1
Pass per Coverage Ratios

Aircraft Type	Pass per Coverage Ratios for Traffic Areas: Traffic Area A	Traffic Areas B, C, D, and Overruns
B-1	3.41	5.65
B-52	1.58	2.15
B-727	3.32	5.87
C-5A	1.66	2.11
C-9	3.73	6.89
C-12	7.07	13.89
C-17	1.37	1.90
C-130	4.40	8.54
C-141	3.49	6.23
CH-46E	8.01	15.22
CH-47	4.38	7.64
CH-53E	5.23	9.53
CH-54	4.31	8.51
DC-10-10	3.64	5.80
DC-10-30	3.77	5.59
E-4	3.62	5.12
F-4C	8.77	17.37
F-14	7.78	15.34
F-15 C&D	9.30	15.34
F-15E	8.10	13.36
F/A-18	9.57	17.04
F-111	5.63	9.77
KC-135	3.48	6.14
L-1011	3.58	5.44
ORBITER	3.60	6.49
OV-1	10.36	17.28
P-3	3.58	6.68
UH-60	11.94	19.49

reflective cracking. The other techniques discussed above have given mixed results or have not been independently evaluated by the military.

f. Example of Nonrigid Overlay Design. An existing rigid pavement will be strengthened to support 75,000 operations of the C-130 aircraft using a nonrigid overlay. It is a type B traffic area. The existing rigid pavement is 229 millimeters (9 inches) of plain concrete on a 152-millimeter (6-inch) crushed aggregate base and has the following properties: R = 4.8 MPa (700 psi), k of subgrade = 41 MN/m^3 (150 pci), and C = 0.75. The k value on top of the base course is determined to be 54 MN/m^3 (200 pci) from Figure 8-1 using the subgrade k of 41 MN/m^3 (150 pci) and 152 millimeters (6 inches) of base course. The required thickness of nonrigid overlay is determined by

$$t_o = 3.0\ (Fh_d - Ch_E) \tag{17-5}$$

To determine F, convert passes of the C-130 into coverages using the pass per coverages ratio of 8.54 from Table 17-1. The 75,000 passes convert to 1,171 coverages. Therefore, for a k of 54 MN/m^3 (200 pci) and 1,171 coverages, the F factor from Figure 19-2 is 0.78. Values of h_d, determined from Figure 12-5 with the design gross aircraft weight of 79,380 kilograms (155 kips), flexural strength of 4.8 MPa (700 psi), and k value of 54 MN/m^3 (200 pci) is 256 millimeters (10 inches). Since the existing pavement is concrete, then the equivalent thickness h_E is equal to the existing thickness of 229 millimeters (9.0 inches). Therefore, the required overlay thickness t_o is:

$$(3)(0.78 \times 256 - 0.75 \times 229) = 84 \text{ mm (SI units)}$$

$$(3)(0.78 \times 10 - 0.75 \times 9) = 3.15 \text{ in. (English units)}$$

Use the minimum thickness of 102 millimeters (4 inches).

10. NONRIGID OVERLAY ON FLEXIBLE PAVEMENT. After a determination has been made that strengthening of a flexible pavement is required, design the overlay thickness as follows:

a. Determine the total thickness of the section, and the thickness of the base and surface courses from the criteria in Chapter 12 or 13 for the design aircraft. Compare the new design requirements with the existing section to determine the thickness of overlay required.

b. Where the in-place density of the existing material is less than required, the overlay thickness should be increased or the low-density material recompacted. In some instances this is possible by using heavy rollers on the surface to compact the underlying layers. However, if the moisture content of these layers, particularly if cohesive, is above optimum, their shear strength may be decreased by heavy rolling. Heavy rolling, also, will frequently damage the surface layer if brittle. The decision to excavate and recompact low density layers or to increase the overlay thickness should be examined very carefully in each case. Factors to be considered in this examination are depth of water table, subgrade soil properties, and the performance of the existing pavement.

c. Overlaid asphalt courses must meet the quality requirements for their position in the strengthened pavement.

d. As an example of the overlay design procedure, it is assumed that an existing pavement (type B traffic area) is to be upgraded to an Air Force medium-load pavement. The existing pavement consists of 75 millimeters (3 inches) of AC, 150 millimeters (6 inches) of base (100 CBR), and 533 millimeters (21 inches) of subbase (50 CBR). The subgrade is a lean clay with a CBR of 6, and has a density of 95 percent in the top 150 millimeters (6 inches) and 90 percent below 150 millimeters (6 inches). From Figure 10-18, the total thickness of new pavement required is 1,143 millimeters (45 inches) and the thickness of base and surface required over the 50 CBR subbase is 178 millimeters (7 inches). However, from Table 8-5, the minimum surface and aggregate base course required for medium load and traffic area B is 25 millimeters (10 inches). From Table 6-2, it is noted that the in-place subgrade density is adequate. Based on above information, the following analysis is made:

(1) New design criteria requires a 1,143-millimeter (45-inch) pavement section above the subgrade and, from Table 8-5, 254 millimeters (10 inches) above the subbase.

(2) Existing pavement section is 758 millimeters (30 inches) with 225 millimeters (9 inches) above the subbase.

(3) In this example, the existing thickness would require an additional inch of pavement to meet the minimum thickness asphalt and the thickness required above the subbase. A 1-inch overlay however is not sufficient to protect the subgrade which requires 1,143 millimeters (45 inches) (or equivalent) of pavement above it. Any thickness of asphalt exceeding the minimum of 100 millimeters (4 inches) can be converted to an equivalent thickness of subbase. This excessive thickness of asphalt is equal to the thickness of overlay plus any existing thickness of asphalt minus the minimum thickness. The required thickness of overlay (t_o) is then determined as follows:

$$t_m + (t_o + t_e - t_m)E_f + t_b + t_{Sb} = T_p \qquad (17\text{-}6)$$

where

t_m = minimum thickness of asphalt

t_o = thickness of overlay

t_e = thickness of existing asphalt

E_f = equivalency factor for converting asphalt to an equivalent thickness of subbase

t_{Sb} = thickness of existing base course

t_b = thickness of existing subbase

T_p = total thickness of pavement required above the subgrade

For this example, the equation is

$$4 + (t_o + 3 - 4)2.3 + 6 + 21 = 45 \text{ (English units)}$$

The thickness of overlay to use would then be 178 millimeters (7 inches).

11. OVERLAYS IN FROST REGIONS. Whenever the subgrade is subject to frost action, the design will meet the requirements for frost action stated in Chapter 22. The design will conform to frost requirements for rigid pavements. If subgrade conditions will produce detrimental nonuniform frost heaving, overlay pavement design will not be considered unless the combined thickness of overlay and existing pavement is sufficient to prevent substantial freezing of the subgrade.

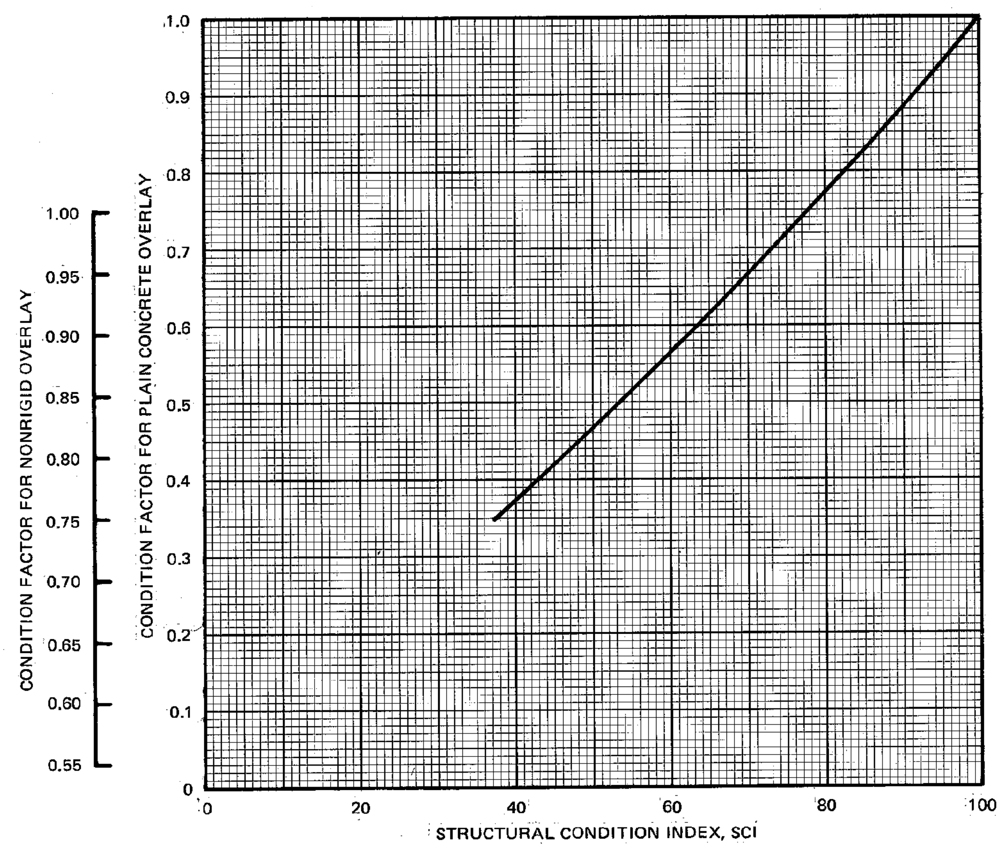


Figure 17-1. Structural condition index versus condition factor

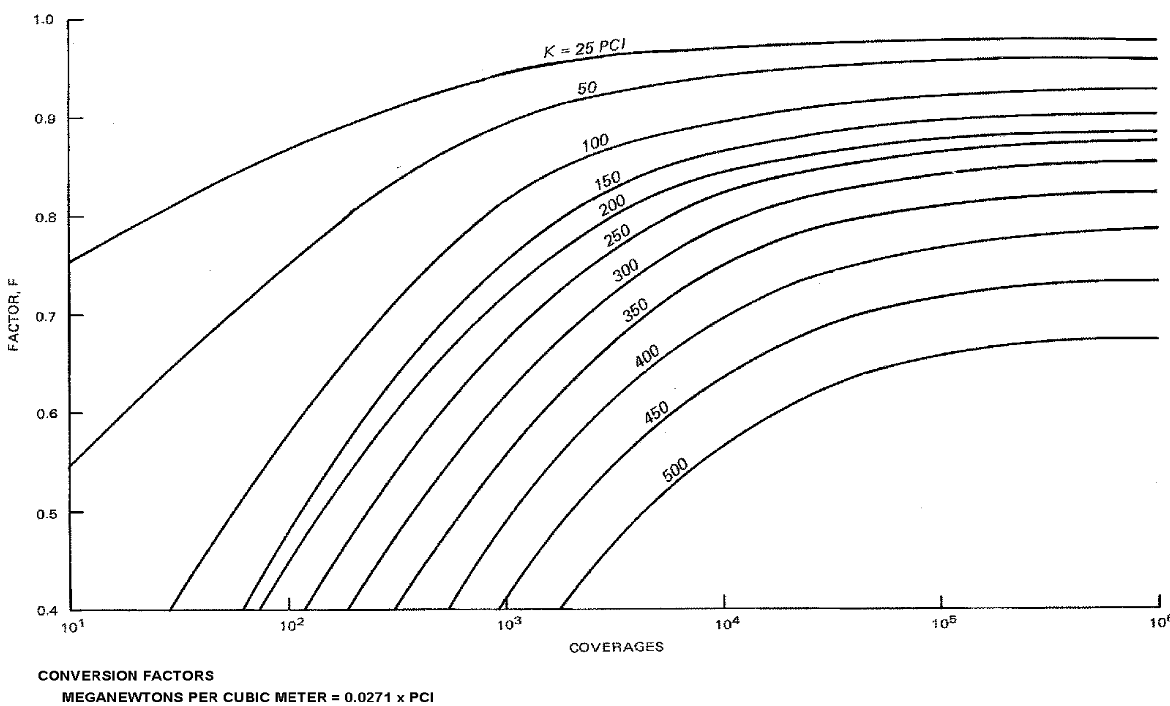


Figure 17-2. Factor for projecting cracking in a flexible pavement

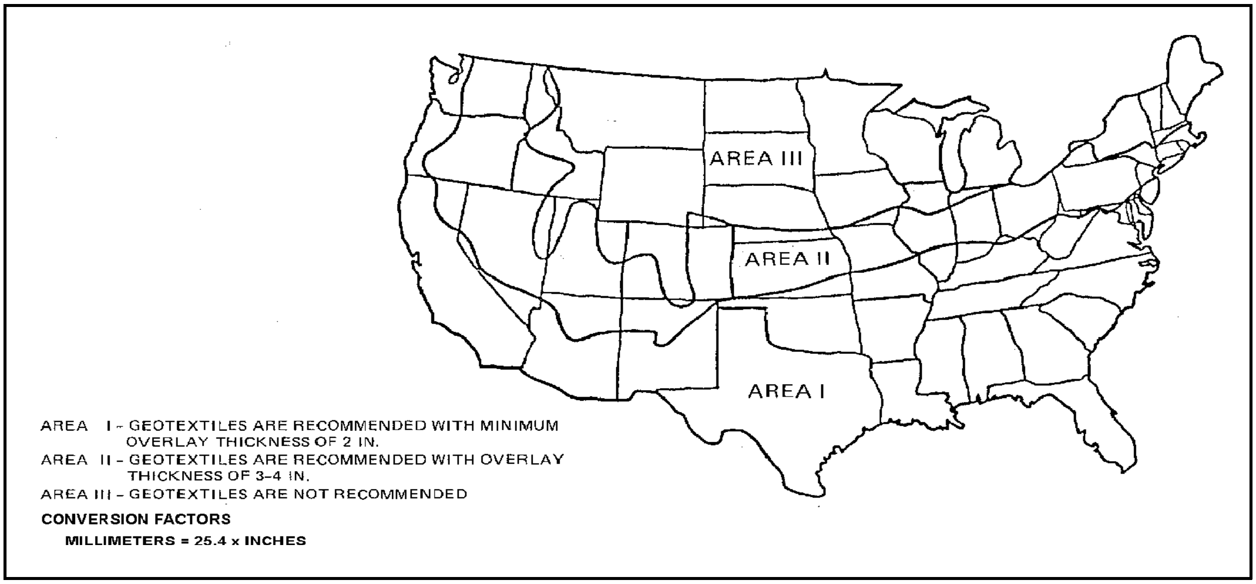


Figure 17-3. Location guide for the use of geotextiles in retarding reflective cracking

CHAPTER 18

RIGID PAVEMENT INLAY DESIGN

1. GENERAL. Many existing airfield pavement facilities have developed severe distress because the design life or the load-carrying capacity of the facilities has been exceeded. The distress normally occurs first in the center lanes of the runways and taxiways because of the concentration of traffic. A method commonly used to rehabilitate these distressed facilities is to construct an adequately designed rigid pavement inlay section in the center of the facility. These inlays are generally 15 meters (50 feet) wide for taxiways and 23 meters (75 feet) wide for runways; however, the widths will be influenced by the lateral traffic distribution and, in existing rigid pavements, by the joint configuration. The inlay pavement may consist of plain concrete or reinforced concrete. The thickness design of the rigid inlay will be the same as outlined in Chapters 12 through 16 or 19, except for the special requirements presented herein.

2. RIGID INLAYS IN EXISTING FLEXIBLE PAVEMENT.

a. Figure 18-1 shows a section of a typical rigid pavement inlay in an existing flexible pavement.

b. Removal of the existing flexible pavement will be held to the absolute minimum. The depth of the excavation will not exceed the design thickness of rigid inlay pavement. The width of excavation of the existing pavement will not exceed the required width of the inlay section plus the minimum necessary, approximately 1 meter (3 feet), for forming or slipforming the edges of the concrete pavement (Figure 18-1).

c. Subdrains and drainage layers will be considered only when they are essential to the construction of the inlay section or necessary for proper drainage. When required, the subdrains will be placed outside of the edge of the rigid inlay and at least 100 millimeters (4 inches) below the bottom of the inlay pavement to permit construction of the stabilized layer required in the following paragraph.

d. Unless the material in the bottom of the excavation is granular and free-draining or the airfield is located in a arid climate, the bottom full width of the excavation will be scarified to a minimum depth of 150 millimeters (6 inches), and recompacted to the density requirements for the top 150 millimeters (6 inches) of base course or subgrade as specified previously. This type of overlay may trap water, and satisfactory drainage must be provided. Reference should be made to TM 5-822-14/AFJMAN 32-1019 for selection of stabilizing agent and minimum strength requirements.

e. The modulus of soil reaction k used for the design of the rigid pavement inlay will be determined on the surface of the material at the bottom of the excavation prior to stabilization. If stabilization is used and if the strength of the stabilized material does not meet the requirements in TM 5-822-14/AFJMAN 32-1019 for pavement thickness reduction, no structural credit will be given to the stabilized material in the design of the rigid pavement inlay. If the strength of the stabilized layer meets the minimum strength requirement for pavement thickness reduction in TM 5-822-14/AFJMAN 32-1019, the rigid pavement inlay will be designed in accordance with applicable sections of Chapters 12 through 16 pertaining to the use of stabilized soil layers.

f. If the existing pavement is not composed of nonfrost-susceptible materials sufficient to eliminate substantial frost penetration into an underlying frost-susceptible material, an appropriate reduction in the k value will be made in accordance with Chapter 20.

g. After the construction of the rigid pavement inlay, the working areas used for forming or slipforming the sides of the concrete will be backfilled to within 100 millimeters (4 inches) of the pavement surface with either lean-mix concrete or normal paving concrete.

h. The existing bituminous concrete will be sawed parallel to and at a distance of 3 meters (10 feet) from each edge of the inlay. The bituminous concrete surface and binder courses and, if necessary, the base course will be removed to provide a depth of 100 millimeters (4 inches). The exposed surface of the base course will be recompacted, and a 3-meter (10-foot) wide paving lane of bituminous concrete, 100 millimeters (4 inches) thick, will be used to fill the gap (Figure 18-1). The bituminous concrete mix will be designed in accordance with Chapter 9.

I. In cases where the 3-meter (10-foot) width of new bituminous concrete at either side of the inlay section does not permit a reasonably smooth transition from the inlay to the existing pavement, additional leveling work outside of the 3-meter (10-foot) lane will be accomplished by removal and replacement, planer operation, or both.

3. RIGID INLAYS IN EXISTING RIGID PAVEMENT.

a. Figure 18-2 shows a section of a typical rigid pavement inlay in an existing rigid pavement.

b. The existing rigid pavement will be removed to the nearest longitudinal joints that will provide the design width of the rigid pavement inlay. Care will be exercised in the removal of the existing rigid pavement to preserve the load-transfer device (key, keyway, or dowel) in the longitudinal joint at the edge of the new inlay pavement. If the existing load-transfer devices can be kept intact, they will be used to provide load transfer between the rigid pavement inlay and the existing pavement except that a male key will be removed. If the load-transfer devices are damaged or destroyed, a thickened-edge joint shall be used to protect against edge loading of the existing pavement or the face shall be sawed vertically and dowels installed. In addition to the removal of the existing pavement, the existing base and/or subgrade will be removed to the depth required for the design thickness of the rigid pavement inlay.

c. The criteria for subdrains, stabilization, soil strength and frost also pertain to rigid pavement inlays in existing rigid pavements.

d. The design of the rigid pavement inlay, including joint types and spacing, will be in accordance with the chapter pertaining to the type of rigid pavement selected.

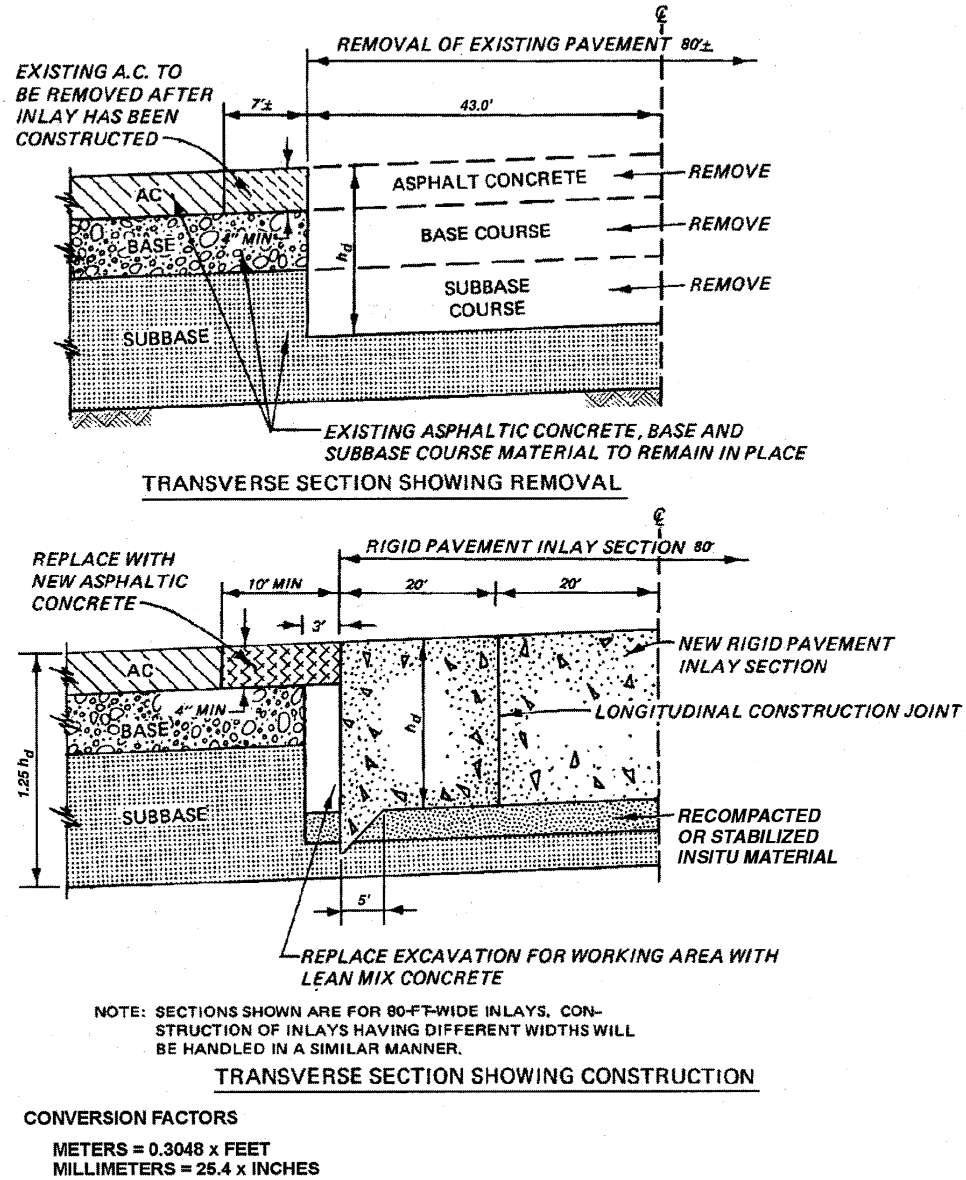


Figure 18-1. Typical rigid pavement inlay in existing flexible pavement

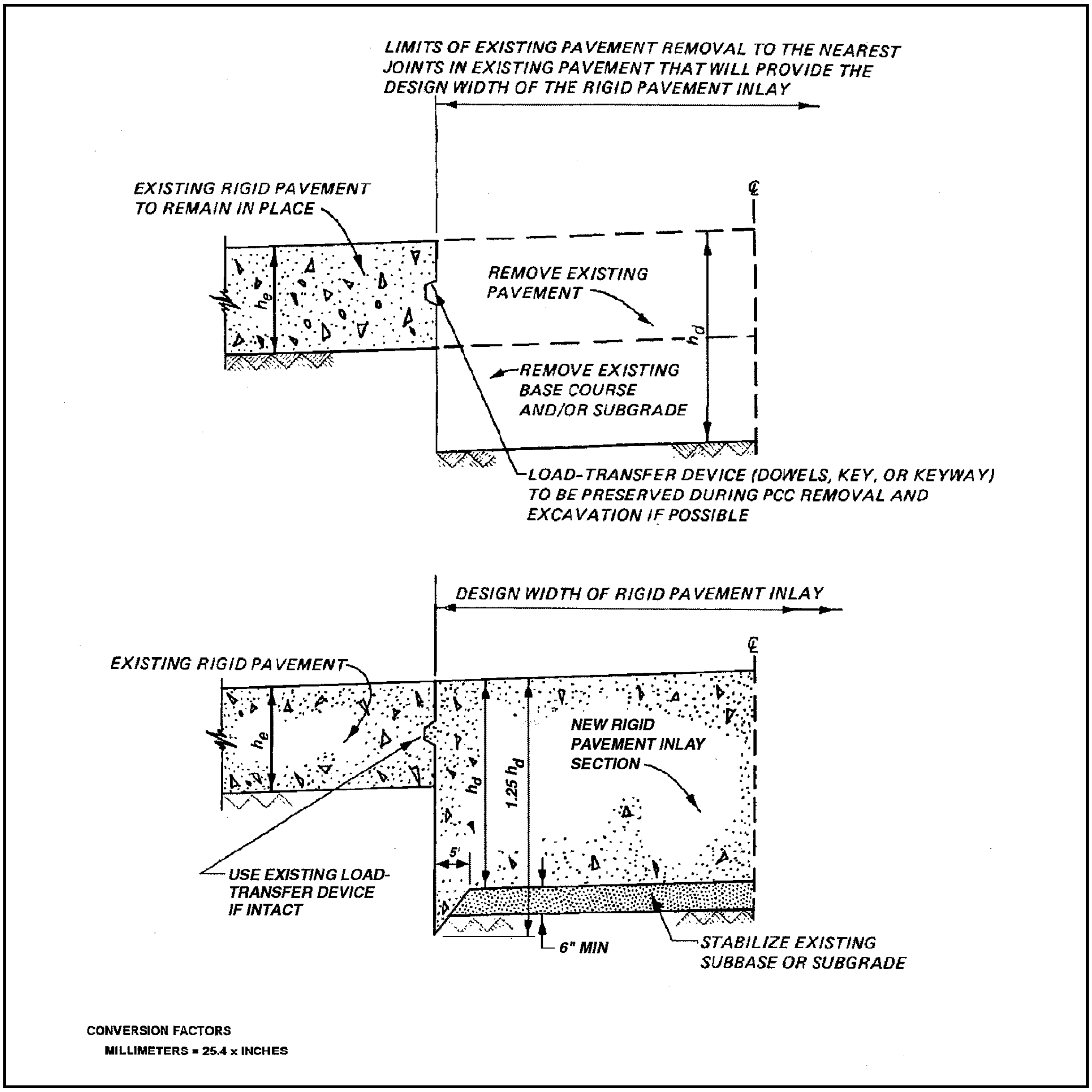


Figure 18-2. Typical rigid pavement inlay in existing rigid pavement

CHAPTER 19

LAYER ELASTIC DESIGN OF RIGID PAVEMENTS

1.RIGID PAVEMENT DESIGN PRINCIPLES. The basic design principle for this design procedure is to limit the tensile stresses in the Portland Cement Concrete (PCC) to levels that are sufficiently below the flexural strength of the concrete such that failure occurs only after the pavement has sustained a number of load repetitions. The tensile stress is modeled by the use of Burmister's solution for elastic multilayered continua and calculated using the JULEA computer program. The computed tensile stress divided by the concrete strength is the design parameter and is referred to as the design factor. This parameter has been related to pavement performance through a study of test section data. To account for mixed traffic, i.e., traffic producing stresses of varying magnitudes, the cumulative damage concept based on Miner's hypothesis is employed. This procedure may be used as an option to the empirical procedure for the design of new Navy pavements. The design procedure is illustrated in Figure 19-1 and summarized as follows:

a. Select three or four concrete slab thicknesses and compute the maximum tensile stresses in the slabs under the design aircraft load.

b. Based on the computed stresses, determine the allowable coverages N_i ($N_i = C_o$ for initial cracking criteria or $N_i = C_f$ for complete failure criteria) using Equations 19-1, 19-2, and 19-3 for each thickness design.

c. Compute the damage for each design which is equal to the ratio of the design coverage n_i to the allowable coverage N_i, where i varies from 1 to the number of aircraft.

d. Select the proper slab thickness at a damage value of 1.0 from the relationship between damage and slab thicknesses.

e. The selection of an unbound granular base or a stabilized base under the concrete slab is a matter of engineering judgment depending on many factors such as cost, material availability, frost penetration requirement, and subgrade swell potential. Subgrade soil may be stabilized to gain strength or modified to increase its workability and reduce swell potential.

2.R IGID PAVEMENT RESPONSE MODEL. The pavement is assumed to be a multilayered continuum with each layer being elastic, isotropic, and homogeneous. Each layer is to extend to infinity in the horizontal direction and to have, except for the bottom layer, a finite thickness. The applied loads to the pavement are considered as static circular and uniform over the contact area. The program chosen for the analysis is JULEA computer code. This program was chosen because it provided accurate computations and provisions for different degrees of bond between interfaces. Investigations into modeling rigid pavements with this code have resulted in the performance criteria being developed with the assumptions that the interface between the PCC slab and the supporting subgrade is considered smooth with no bond; i.e., there is no frictional resistance at the interface and all other interfaces are considered to be completely bonded. At a depth of 6 meters (20 feet), a very stiff bottom layer is used to mitigate the assumption that the bottom layer extends to infinity. Figure 21-1 presents a diagram for the design of pavements using the layered elastic analysis.

3.DESI GN PROCEDURE. Design of rigid pavements using the elastic layered procedure is initiated by assuming a pavement section. The assumptions are the number of layers, type of materials, and layer thicknesses. For each material in the assumed section, the modulus of elasticity (E) and Poisson's ratio (μ) are determined. The design flexural strength (R) of the concrete is also determined. The aircraft parameters are defined beginning with the first aircraft (AC_1) in the list of aircraft. The parameters required for the response model are tire contact area, tire loading, number of tires, and tire spacing. Traffic volume is expressed in terms of coverages. The elastic parameters for the materials, the layer thicknesses, and the aircraft parameters for the first aircraft are input into the response model (JULEA computer code) to calculate the tensile stress (σ_1) in the concrete resulting from loading the first aircraft. The computed stress is used along with the concrete design strength to compute a design factor for the first aircraft (DF_1). The design factor is input into the performance model to determine the allowable traffic (N_1) in terms of coverages for the first aircraft on the assumed pavement section. The damage caused by the first aircraft is computed by dividing the applied traffic by the allowable traffic, i.e., n_1/N_1 . The damage caused by the first aircraft is then added to the damage caused by subsequent aircraft. After computing the damage for the first aircraft, the procedure is repeated for other aircraft. After completing the damage computations for all aircraft, the computed cumulative damage is compared with unity. If the assumed section gives a computed cumulative damage substantially different from unity, then a new section is assumed and the procedure repeated for all aircraft. After computing the damage for two sections, a plot of log damage as a function of pavement thickness can be used to estimate the required thickness and used as the assumed section for the next iteration. By updating the plot, the thickness yielding a cumulative damage approximately equal to unity can quickly be established.

4.MAT ERIAL CHARACTERIZATION.

a. Portland-Cement Concrete (PCC).

(1) General. The effects of repeated load on PCC modulus of elasticity are not considered because of the complexity of the relationship between modulus of elasticity and repeated loads and the apparently small magnitude of change caused by traffic. There may be some decrease in modulus because of repeated loads or exposure, but conversely, there should be some increase because of the effects of long-term hydration. The net result is that the computation of the modulus of elasticity from the stress-strain relationship obtained from the initial loading of a PCC specimen is considered adequate for characterizing the material for the life of a pavement.

(a) Poisson's ratio for PCC normally receives very little attention. The range of statically determined Poisson's ratio is only about 0.11 to 0.21, and the average of dynamically determined values was about 0.24. Added factors are the difficulty of measurement and relatively small influence that varying Poisson's ratio within a reasonable range has on the computed response. No procedures are recommended for determining Poisson's ratio for PCC. It is recommended that a value of 0.15 be used for all PCC.

(b) The magnitude of stress that can be sustained by PCC before cracking is a function of the number of repetitions of the stress. This stress magnitude decreases as the number of stress repetitions increases. The number of stress repetitions of a given magnitude that a material can sustain is dependent on numerous factors, such as age, mix proportions, type of aggregate, rate of loading, range of loading, etc. The most important, however, is the static strength of the material. The stress in the slabs is due primarily to bending, and a flexural test is considered the most appropriate for characterizing PCC.

(2) Modulus of elasticity and flexural strength. The modulus of elasticity E_f and flexural strength R of PCC will be determined from static flexural tests of beams having a cross-sectional area

of 152 by 152 millimeters (6 by 6 inches) with a length long enough to permit testing over a span of 457 millimeters (18 inches). The recommended procedures are widely accepted and extensively used for determining the properties of PCC. The test procedure for determining flexural strength and modulus of elasticity will be determined in accordance with ASTM C 78 and CRD-C 21, respectively. When aggregate larger than the 51-millimeter (2-inch) nominal size is used in the concrete, the mix will be wet-screened over a 51-millimeter (2-inch) square mesh sieve before it is used for casting the beam specimen.

(3) Mix proportioning and control. Proportioning of the concrete mix and control of the concrete for pavement construction will be in accordance with TM 5-822-7/AFM 88-6, Chapter 8. Normally, a design flexural strength at 90-days will be used for pavement thickness determination. Should it be necessary to use the pavements at an earlier age, consideration should be given to the use of a design flexural strength at the earlier age or to the use of high early-strength cement, whichever is more economical.

b. Bound Bases (Subbases).

(1) General. Chemically stabilized materials (portland cement, lime, fly ash, etc.) and bituminous-stabilized materials need to be discussed separately, even though the conclusions regarding inclusion of effects of repeated loading are the same. Due to the viscous and temperature-dependent behavior of the bituminous binder, bituminous-stabilized materials are affected by temperature and rate of loading to a much greater extent than any other component in a pavement structure.

(2) Requirements. Bituminous base materials are designed in accordance with TM 5-822-8/ AFM 88-6, Chapter 9. The design for frost consideration will be in accordance with Chapter 20, herein. Chemically stabilized materials should meet requirements set forth in TM 5-822-14/AFM 32-1019. Among these are requirements for durability and the requirement that strength increase with age. These requirements are intended to ensure that the materials continue to function with age and that no adverse chemical reactions occur. However, in terms of ensuring that the material functions as a bound material (sustains flexural loading), it is required that the material attain an unconfined compressive strength of 1.7 MPa (250 psi) at 28 days. This requirement should be used in lieu of strength requirements in the above references. Chemically treated soils in which no substantial increase in strength is considered are modified soils and should be characterized using the methods presented herein for unbound base, subbase, and subgrade materials. Chemically treated soils having unconfined compressive strengths greater than 1.7 MPa (250 psi) should be tested in accordance with the methods specified for stabilized materials. Pavement designs that result in a nonstabilized (pervious) layer sandwiched between a stabilized or modified soil (impervious) layer and the pavement present the danger of entrapped water with subsequent instability in the nonstabilized layer. These designs will not be used unless the nonstabilized layer is positively drained, and its use on Air Force bases will require the approval of the appropriate Air Force Major Command.

(3) Modulus and Poisson's ratio. The modulus of elasticity E_f of bound base material will be determined from cyclic flexural tests of beams. The recommended test procedures have not been standardized but are described in Appendix J. There are differences in the procedures for chemically stabilized materials and those stabilized with bituminous binders. These differences are necessary because of the sensitivity of bituminous-stabilized bases to rates of loading and temperature.

(a) A simply supported unconfined beam loaded at the third point with essentially point loads will be used for bound bases (subbases). For chemically stabilized bound bases, the ultimate load is first determined. Loads of 0.4, 0.6, and 0.8 times the ultimate load are applied repetitively, and the modulus is computed from the load-deflection curves. The modulus used should be the average obtained for the three loadings. For bituminous-stabilized materials, the definition of an ultimate load will be dependent on the rate of application of load and the temperature. Several loads should be selected that will result in stresses in the outer fibers of the beam, which are less than the values shown in Table 19-1. One test should be conducted at about 0.34 MPa (50 psi).

Table 19-1
Recommended Maximum Stress Levels to Test Bituminous-Stabilized Materials

Temperature Range, °C(°F)	Maximum Stress Level in Extreme Fibers, MPa (psi)
4.4-15.5 (40-60)	3.1 (450)
15.5-27 (60-80)	2.1 (300)
27-38 (80-100)	1.4 (200)

(b) An indirect method of obtaining an estimated modulus value for bituminous concrete is presented in detail in Appendix C. The use of this method requires that the ring-and-ball softening point and the penetration of the bitumen as well as the volume concentration of the aggregate and percent air voids of the compacted mixture be determined.

(c) No procedures are provided for determining Poisson's ratio of bound base material. It is recommended that the values in Table 19-2 be used.

Table 19-2
Poisson's Ratio Values for Bound Base Material

Material	Poisson's Ratio
Bituminous-stabilized	0.5 for E < 3,447 MPa (500,000 psi)
	0.3 for E > 3,447 MPa (500,000 psi)
Chemically stabilized	0.2

c. Unbound (Granular) Bases (Subbases).

(1) General. Unbound granular materials are extremely difficult to characterize. The state of stress, particularly the confining stress, is the dominating factor in determining load-deformation properties. Repeated loadings also affect the modulus of granular materials. The general pattern noted was that repeated loadings increased the stiffness provided shear failure was not progressing. This implies that the modulus of elasticity is increased.

(2) Material requirement. A complete investigation will be made to determine the source, quantity, and characteristics of available materials. A study should be made to determine the most economical thickness of material for a base course that will meet requirements. The base course may consist of natural materials or processed materials, well-graded and high-stability, as referred to in Chapter 8. All base courses to be placed beneath airfield rigid pavements will conform to the following requirements:

(a) Well-graded course to fine.

(b) Not more than 85 percent passing the 2-millimeter (No. 10) sieve.

(c) Not more than 15 percent passing the 0.075-millimeter (No. 200) sieve.

(d) PI not more than 8 percent.

However, when it is necessary that the base course provide drainage, the requirements set forth in TM 5-820-2/AFM 88-5, Chapter 2, will be followed. When frost penetration is a factor, the requirements set forth in Chapter 20, herein, will be followed.

(3) Compaction requirements. High densities are essential to keep future consolidation to a minimum; however, thin base courses placed on yielding subgrades are difficult to compact to high densities. Therefore, the design density in the base course materials should be as required in Chapters 7 and 8.

(4) Modulus and Poisson's ratio. The modulus values of unbound granular bases (subbases) will be determined from cyclic triaxial tests on prepared samples. The recommended test procedure is outlined in Appendix O. The outputs from the test procedure are measures of modulus of elasticity and Poisson's ratio. Triaxial compression tests should be conducted at confining pressures of 13.8, 34.5, 41.4, and 68.9 KPa (2, 5, 6, and 10 psi). Axial stresses should be applied that result in ratios with confining stresses (σ_1/σ_3) of 13.8, 20.7, 27.6, and 34.5 KPa (2, 3, 4, and 5 psi). Plots of resilient modulus versus first stress invariant ($\sigma_1 + \sigma_2 + \sigma_3$ or $\sigma_x + \sigma_y + \sigma_z$) should be prepared and an average relationship established. From this relationship, a value of resilient modulus at a first-stress invariant of 68.9 KPa (10 psi) should be selected. No well-defined relationships exist for Poisson's ratio. However, plots of Poisson's ratio versus ratio of axial to confining stress (σ_1/σ_3) may be made and representative values selected. The modulus value of granular material may also be estimated from the relationship in a chart in which the modulus is a function of the underlying layer and the layer thickness. The chart and the procedure for use of the chart are given in Appendix I. However, it is recommended that the chart be used in conjunction with test results to determine a representative modulus rather than as the sole method. A Poisson's ratio of 0.3 will be used unless there is a reason to believe that it is significantly different for the material in question.

d. Subgrade Soils.

(1) General. Subgrades may be divided into the general classes of cohesive and cohesionless soils. Repeated loadings affect both cohesive and cohesionless soils. Cohesionless sands, gravels, or sand-gravel combinations will respond much like granular bases or subbase. Cohesive soils are more sensitive to repeated loadings. The resilient modulus of cohesive subgrades generally increases with load repetitions provided the level of stress is lower than that required to initiate shear failure. However, the number of stress repetitions required before a stable condition is reached may be greater than for bound bases, granular bases, or cohesionless subgrades.

(2) Exploration. In all instances, field and laboratory tests will be conducted to determine the classification, moisture-density relations, expansion characteristics, and strength of the subgrade. If stabilization of the subgrade is to be considered, other tests as required by TM 5-822-14/AFM 32-1019, will be made, as well as chemical analysis and clay mineralogy determination. When a subgrade soil that has a chemical stabilizing agent added but does not meet the 1.72-MPa (250-psi) compressive strength requirement, the soil should be characterized with procedures for subgrades and be considered simply as part of the subgrade. The engineer is cautioned that although the elastic layered method requires only the modulus of elasticity and Poisson's ratio of the subgrade, such factors as groundwater, surface water infiltration, soil capillarity, topography, drainage, rainfall, and frost conditions may affect the future support rendered by the prepared subgrade or base course. Experience has shown that the subgrade will reach near saturation, even in semiarid and arid regions, after a pavement has been constructed. If conditions exist that will cause the subgrade soil to be affected adversely by frost action, the subgrade will be treated in accordance with the requirements in Chapter 20. Subgrades and base courses are grouped into three types with respect to behavior during saturation: low plastic soils exhibiting little or no swell, swelling soils, and cohesionless sands and gravels. Special cases of subgrade soil are discussed in Chapter 6.

(3) Modulus and Poisson's ratio. The modulus of elasticity and Poisson's ratio of subgrade soils will be determined from repetitive triaxial tests on undisturbed samples when possible or on samples prepared as close as possible to field conditions when fill is involved. The samples considered should represent the worst anticipated condition in the field. The recommended test procedures are outlined in Appendix K. The procedures are similar to those used for granular base (subbase) materials. There are differences in details of the test procedures and presentation of results for cohesive and cohesionless materials. These differences are necessary because of the sensitivity of cohesive soils to moisture and the differences in the behavior as a function of the state of stress.

(a) For characterizing cohesive materials, the triaxial tests should be conducted at a range of stress conditions. Tests should be conducted at confining stresses of 13.8, 27.6, and 41.4 KPa (2, 4, and 6 psi), and at axial stresses applied that will result in a range of deviator stress from about 13.8 to 110 KPa (2 to 16 psi). From the composite curve, the resilient modulus used to represent the material should be selected at a deviator stress of 34.5 KPa (5 psi). No well-defined relationships exist for Poisson's ratio, but similar plots may be made and a representative value selected.

(b) For cohesionless soils, the confining stress in the triaxial tests should approximate conditions in the subgrade. The minor principal stress in the subgrade is a measure of the confinement. For cohesionless subgrade soils, it is considered appropriate to select properties at minimum values of the first stress invariant and confining stress, since the general trends are applicable for cohesionless subgrade soils, i.e., as the confining stress and the first stress invariant decreases, the resilient modulus decreases.

(c) Basically, the same stresses should be used in the triaxial tests for characterizing cohesionless material as are used for granular bases. Confining pressures of 13.8, 27.6, 41.4, and 68.9 KPa (2, 4, 6, and 10 psi) and axial stresses that result in principal stress ratios (σ_1/σ_3) of 2, 3, 4, and 5 should be applied. From the average relationship of resilient modulus versus first stress invariant, a representative modulus value should be selected at a first stress invariant of 68.9 KPa (10 psi). A representative value of Poisson's ratio should be selected from a composite plot of Poisson's ratio versus principal stress ratio. If test results prove unreliable or are not available, the values of 0.4 for cohesive and 0.3 for cohesionless materials may be used.

(4) Modulus of soil reaction. In Westergaard-type solutions, the modulus of soil reaction k characterizes the foundation support under a rigid pavement. Consequently, the modulus of soil reaction k has been used extensively to define the supporting value of all unbound subgrade and base-course materials and all soils that have been additive-modified (TM 5-822-14/AFM 32-1019). The k value has been determined by the field plate bearing test as described in CRD-C 655. When elastic-layered procedures are used for pavements in which only information on modulus of soil reaction k is available, a correlation between the modulus of elasticity E and modulus of soil reaction k may be employed. Figure 19-2 shows such a correlation for subgrade soils. Figure 19-2 should be used with caution as the correlation was developed based on very limited data.

5.DESI GN CRITERIA.

a. The limiting stress (fatigue) criteria form the backbone of the design of rigid airfield pavements. The criteria provide for a prediction of pavement deterioration in terms of a structural condition index (SCI). The SCI is derived from a pavement condition index (PCI) as presented in ASTM D 5340. The SCI is defined as

$$\text{SCI} = \text{PCI} - \text{All nonload-related deducts}$$

The SCI prediction is based on a relationship between design factor and stress repetitions for initial cracking (SCI = 100) and for complete failure (SCI = 0). It is assumed to be linearly related to the logarithm of coverages between initial cracking and complete failure, which results in the relationship illustrated in Figure 19-3.

b. The thickness of the PCC is so selected that the maximum tensile stress at the bottom of the slab does not exceed the allowable value. The criteria are presented as a relationship between design factor, the SCI, and the logarithm (to the base ten) of coverages by the equations:

$$DF = 0.5234 + 0.3920 \log_{10} (C_o) \tag{19-1}$$

and

$$DF = 0.2967 + 0.3881 \log_{10} (C_f) \tag{19-2}$$

and the design factor is defined as

$$DF = R/\sigma \tag{19-3}$$

where

DF = design factor computed with elastic-layered method

R = concrete slab flexural strength, MPa (psi)

σ = maximum computed tensile stress with elastic-layered model such as JULEA computer program, MPa (psi)

C_o = coverage level at which the SCI begins to decrease from 100

C_f = coverage level at which the SCI becomes 0

SCI = the structural condition index desired at the end of the pavement design life

c. When aircraft passes are given, then the pass-per-coverage ratio for the particular design aircraft will be used to convert passes to coverages. The engineer is cautioned that Equations 19-1 and 19-2 were formulated based on accelerated traffic tests with volumes less than 10,000 coverages. The use of the relationship to design for traffic volume greater than 10,000 coverages, which will frequently be the case for current traffic volumes, will require extrapolation of the linear relationship. The pass-per-coverage ratios for some aircraft are shown in Table 17-1.

6.F ROST CONSIDERATION. Two methods have been developed for determining the thickness design of a pavement in frost areas. One method is to limit subgrade frost penetration and the other is to design the pavement for reduced subgrade strength. The first method is directed specifically to the control of pavement distortion caused by frost heave. It requires a sufficient thickness of pavement, base, and subbase to limit the penetration of frost into the frost-susceptible subgrade to an acceptable amount. Complete frost penetration prevention is nearly always uneconomical and unnecessary except in regions with a low design freezing index or where the pavement is designed for heavy-load aircraft. When the rigid airfield pavement is designed by the reduced subgrade strength method, a minimum thickness of 102 millimeters (4 inches) of granular unbound base will be used. A mechanistic procedure for seasonal frost is being developed. Until it is available, the method in Chapter 20 should be used.

7.ALT ERNATE OVERLAY DESIGN PROCEDURE. A methodology for the design of rigid overlays of rigid pavements has been developed that predicts pavement structural deterioration from load induced stresses. The performance of the pavement is expressed in terms of an SCI which relates the type, degree, and severity of pavement cracking and spalling on a scale from 0 to 100. The design methodology for rigid overlays uses the layered-elastic analytical model and the analysis of fatigue cracking in the base slab to predict rigid overlay deterioration in terms of an SCI. Because the methodology predicts performance, an accurate characterization of the materials, structural pavement condition, and fatigue are required. The steps for designing rigid overlays of rigid pavements are illustrated in Figure 19-1 and are implemented in the LEDRRO group of programs.

a. Material Properties. Each layer of the pavement must be described by a modulus of elasticity and a Poisson's ratio.

(1) The modulus value for the concrete can be determined in the laboratory or conservatively estimated as 27,576 MPa (4,000,000 psi).

(2) Modulus values for subgrade soils are often estimated from correlations with existing tests.

(3) Flexural strength of concrete overlays should be determined as part of the mixture proportioning studies. The flexural strength of the base slab may be determined from historical data, flexural beams cut from the base pavement, or approximate correlations between flexural strength and tests run on cores taken from the base pavement.

(4) The interface condition between layers also needs to be determined. The condition of the base slab at the time of the overlay determines the bonding condition used for the overlay. In general, the interface between concrete and other materials is considered to be frictionless. A frictionless interface may be attained by providing a bond breaker course between the overlay and the base pavement. If special effort is taken to prepare the surface for complete bonding, then the interface is considered to be fully bonded.

b. Base Slab Pavement Fatigue and Structural Condition. Traffic applied on the base slab before the overlay is placed consumes some of its fatigue life. If it has begun to deteriorate from traffic, an SCI can be determined from a pavement condition survey. The ratio between the effective modulus of elasticity (E_e) and the initial undamaged modulus of elasticity (E_i) is determined by the relationship:

$$R_E = \frac{E_e}{E_i} = 0.02 + 0.0064 * SCI + (0.00584 * SCI)^2 \quad (19\text{-}4)$$

This equation is used to account for the deterioration of the base pavement with the application of traffic. If the SCI of the base pavement is equal to 100, the amount of past traffic must be determined to estimate the remaining fatigue life of the base slab.

c. Selection of Trial Thickness. The rigid overlay design procedure is an iterative process. A trial overlay thickness is assumed, and its condition assessed in terms of the overlay life predicted for the design SCI. If the predicted life is unacceptably low, then a thicker overlay thickness is assumed. If the initial trial overlay thickness predicts a pavement life that is too high, then a thinner overlay is tried.

d. Base Slab Performance. The base pavement performance curve is determined by calculating the damage rate at the time of initial cracking (DR_o) and the damage rate at the time of complete failure (DR_f). Equations 19-1, 19-2, and 19-3 in conjunction with the following equations are used to compute the damage rates.

$$DR_o = \sum_{i=1}^{nac} \frac{(C_r)_i}{C_o} \quad \text{and} \quad DR_f = \sum_{i=1}^{nac} \frac{(C_r)_i}{C_f} \quad (19\text{-}5)$$

$$t_o = \frac{B_o}{DR_o} \quad \text{and} \quad t_f = \frac{B_f}{DR_f} \quad (19\text{-}6)$$

where

C_r = design traffic rate, coverages per year

C_o = allowable coverage level at the time of initial cracking (SCI begins to decrease from 100)

C_f = allowable coverage level at the time of complete failure (SCI = 0)

nac = number of aircraft

t_o, t_f = time to initial cracking and time to complete failure, respectively

B_o, B_f = remaining life of base pavement to initial cracking and complete failure, respectively. The remaining life may be estimated from PCI surveys or by computing the damage caused by applied traffic before overlay. ($B_o = 1 - \sum C_i/C_o$ and $B_f = 1 - \sum C_i/C_f$)
C_i = applied past traffic, coverages

e. Time Periods. The base pavement performance curve (with the overlay in place) is divided into time periods so that the variation of the base slab support with time can be determined. The first time period is up to the base slab t_o. The last time period is the time past the t_f. If some traffic has been applied before overlay, the fatigue life consumed must be subtracted from t_o and t_f because this damage has already occurred. To calculate the stresses in the overlay, Equation 19-4 is used to determine the varying base slab support for each of the time periods. If the base slab has begun to deteriorate before the overlay is placed (SCI is less than 100), the base SCI value at the time of the overlay determines the initial support condition. If the time to initial cracking computed exceeds t_o, the time to initial cracking can be set to t_o. Doing so is equivalent to assuming that the base pavement will start to deteriorate with the first coverage of traffic on the overlay. Figure 19-4 illustrates the performance curve for the base slab subdivided into five time periods.

f. Overlay Performance Curve. Once the base pavement performance curve is established, the damage is computed and accumulated for each time period. The damage for a time period is computed as:

$$(d_o)_j = \Delta T_j * \sum_{i=1}^{nac} \frac{C_{ij}}{(C_o)_j} \quad and \quad (d_f)_j = \Delta T_j * \sum_{i=1}^{nac} \frac{C_{ij}}{(C_f)_j} \tag{19-7}$$

where

$(d_o)_j$ = damage to initial cracking for time period j

$(d_f)_j$ = damage to complete failure for time period j

$(C_o)_j$ and $(C_f)_j$ = a function of the changing modulus of elasticity of the base slab in each time period whereas $j\Delta T_j$ is the magnitude of the time interval in years.

By plotting the cumulative damage versus time in years, the time to initial cracking and complete failure for the overlay can be established. These times correspond to the times when the cumulative damage reaches a value of one. From these time values, a plot of SCI versus logarithm of time (performance curve) then indicates how long the trial thickness will last for the selected design aircraft, traffic rate, and design SCI at the end of the composite overlay pavement design life. Figure 19-5 illustrates the composite overlay performance. If the life of the overlay for the trial overlay thickness is not adequate, a new overlay thickness is assumed and the process is repeated. If several overlay thicknesses are assumed, then a plot of thickness versus logarithm of time, like the one shown in Figure 19-6, can be generated for the selected design SCI, and the design overlay thickness can be chosen.

8.REI NFORCED CONCRETE. Limited full-scale accelerated traffic test data are available for the design of reinforced concrete pavements. The test tracks contained reinforced test sections of varying thickness and percentages of reinforcement. Comparisons were made between the performance of plain and reinforced pavements. The improvements in performance were related to the amount of steel in the concrete slabs. The basis for the comparison was the thickness of unreinforced pavement. The established criteria for the design of reinforced pavements is shown in Figure 19-7. Assuming that the proposed elastic layer design procedure can result in adequate thicknesses of unreinforced pavement, application of the criterion illustrated in Figure 19-7 will result in adequate thicknesses of reinforced pavements.

9.DESI GN EXAMPLES. Design examples are given illustrating various layer elastic design procedures. The first example illustrates the procedure for selecting a concrete thickness for an airfield designed for a single aircraft. This design example considers the cases of unreinforced concrete slabs. The second example is for an airfield subject to mixed traffic. Overlay designs are given in the last example. The designed concrete pavements are for a type A or primary traffic area. The steps in designing a rigid pavement using the elastic layered method are to establish input data, compute critical stresses, and complete final design.

a. Input Data Required for the Design.

(1) Modulus values and Poisson's ratios of the PCC, bonded and nonbonded granular materials, and subgrade soil. For the purpose of this design example, the following values are assumed in the computation.

E_{PCC} and μ_{PCC} = 27,580 MPa (4,000,000 psi) and 0.2, respectively

E_{bound} and μ_{bound} = 1,034 MPa (150,000 psi) and 0.2, respectively (stabilized base)

$E_{unbound}$ and $\mu_{unbound}$ = 207 MPa (30,000 psi) and 0.3, respectively (granular base)

$E_{subgrade}$ and $\mu_{subgrade}$ = 42 MPa (6,000 psi) and 0.4, respectively

(2) Flexural strength of the PCC. A value of 4.48 MPa (650 psi) is assumed.

(3) Aircraft parameters. The characteristics of the design aircraft and other traffic data required in design are wheel load, number and spacing of wheels in an assembly, tire contact pressure, design life, design traffic, design coverage level, and pass-to-coverage ratio for the particular aircraft.

(4) Limiting stress criteria. Equation 19-1 and 19-2 are used to determine the allowable coverages based on the computed critical stresses induced by the design aircraft.

b. Computation of Critical Stresses. The critical tensile stress in the trial concrete section is computed using the JULEA elastic layered model based on the design aircraft loading and the material properties of each component layer. The interface conditions between layers are such that frictional constraints do not exist between the PCC slab and the base layer and that frictional constraint is developed between the base layer and subgrade soil. Several concrete trial sections are needed for each design. A nearly optimum concrete slab thickness should first be selected, and concrete thicknesses less and greater than the optimum value are then selected. Computations should also be made for different thickness of base-course materials.

c. Final Design. The accumulated damage for each trial concrete section is computed based on the design and the allowable coverages. The final concrete slab thickness is selected as that thickness having an accumulated damage of 1.

10.DESI GN EXAMPLE 1, SINGLE AIRCRAFT.

a. Plain Concrete. This design example is for an airfield taxiway supporting the C-130 aircraft. The design loading for the C-130 on the taxiway is 70,300 kilograms (155,000 pounds). The design is for the C-130 aircraft having a single tandem gear with a tire spacing of 1.5 meters (60 inches) c-c, a tire load of 15,820 kilograms (34,875 pounds), a tire contact area of 0.258 m^2 (400 $in.^2$), a design traffic of 200,000 passes and a pass to coverage ratio of 4.40. For this example an SCI of 80 is desired at the end of the design life.

(1) Computations of critical stresses and damages. Several trial concrete slab thicknesses, i.e., 330, 356, 380, and 405 millimeters (13, 14, 15, and 16 inches) and two thicknesses of granular base and stabilized base, i.e., 15 and 457 millimeters (6 and 18 inches), were selected for design. The maximum tensile stresses in each concrete slab were computed using the elastic layered model JULEA. Equations 19-1, 19-2, and 19-3 were then used to calculate the allowable coverages based on the calculated stresses and the 4.48-MPa (650-psi) flexural strength of the PCC. The amount of damage is the ratio of the design passes to the allowable passes. The computed values, together with other pertinent pavement information, are presented in Tables 19-3 and 19-4 for different base materials. As an illustration, the determination of values shown in the first line of Table 19-3 is explained. For a pavement with 330-millimeter (13-inch) PCC and a 15-millimeter (6-inch) base, the maximum stress under the C-130 aircraft using the computer program JULEA is 2.36 MPa (343 psi). Since an SCI = 80 is desired at the end of the design life, the allowable pass level should be determined from the linear variation between initial cracking (C_o) and complete failure (C_f) (Figure 19-3). From Equation 19-1, the log C_o = 3.50, and from Equation 19-2, the log C_f = 4.12. Interpolating for an SCI = 80, a coverage level of 4,248 is obtained. The allowable pass level is computed as 4,248 * 4.40 = 18,691. The damage is calculated as the ratio of 200,000 and 18,691, i.e., 200,000/18,691 = 10.7.

(2) Selection of Concrete Thickness. The results between PCC thickness and damage presented in Table 19-3 for granular bases and in Table 19-4 for stabilized bases are plotted in Figure 19-8. The required PCC thicknesses are determined at a damage of 1. The required concrete thicknesses are 373 millimeters (14.7 inches) and 378 millimeters (14.9 inches) for granular bases of 457 millimeters (18 inches) and 152 millimeters (6 inches), respectively, and are 358 millimeters (14.1 inches) and 373 millimeters (14.7 inches) for stabilized bases of 457 millimeters (18 inches) and 152 millimeters (6 inches), respectively (thicknesses will be rounded to the nearest 10 millimeters (½ inches) for construction). Figure 19-8 shows that in the case of granular base, the increase of the base thickness from 152 to 457 millimeters (6 to 18 inches) reduces the PCC only 5 millimeters (2/10 inch). In the case of the stabilized base, the increase of the base thickness from 152 to 457 millimeters (6 to 18 inches) can reduce 13 millimeters (½ inch) of PCC. However, an economical comparison should be made between the 13-millimeter (½-inch) reduction in PCC and the 305-millimeter (12-inch) additional stabilized base to determine the final design.

b. Reinforced Concrete. For reinforced concrete pavements, the increase in effective slab thickness due to the presence of the steel in the pavement can be determined from the relationship shown in Figure 19-7. For example, if 0.10 percent reinforcing steel is used for the particular concrete thickness of 381 millimeters (15.0 inches), which was computed in the previous example (see Figure 19-8 for the case of a 152-millimeter (6-inch) base), the relationship shown in Figure 19-7 indicates that the slab thickness can be reduced to 381 millimeters × 0.9 = 343 millimeters (15 inches × 0.9 = 13.5 inches).

c. Frost Action. When frost action needs to be considered in the design, it should first be determined if the subgrade soil is frost susceptible. A description of frost susceptible soils is given in Chapter 20. The depth of frost penetration in the region shall be determined to check if the frost action is deep enough to weaken the subgrade soil. When this is the case, the reduced subgrade strength method shall be used for design. The procedures to determine the PCC thickness using the elastic layered model are then applied in the same manner as in the first part of this example; the only input parameter change is the (reduced) subgrade elastic modulus. To check for a lesser thickness requirement with limited frost penetration procedures, the criteria in Chapter 20 should be used.

11. DESIGN EXAMPLE 2, MIXED AIRCRAFT TRAFFIC. This design example is for type A traffic areas. The airfield has traffic of 12,500 passes of C-141 (156,500 kilograms (345,000 pounds)), 100 passes of B-52 (181,450 kilograms (400,000 pounds)), and 25,000 passes of F-15 (30,850 kilograms (68,000 pounds)), and 12,500 passes of C-17 (1,179,400 kilograms (260,000 pounds)). The characteristics of the design aircraft are presented in Table 19-5. A 250-millimeter (10-inch) thick stabilized base layer is used in this example. An SCI = 80 is desired at the end of the design life.

a. Computations of Critical Stresses and Damage. A number of trial concrete slab thicknesses were selected for design. The maximum tensile stress in each concrete slab under each aircraft loading was computed using the elastic layered model. Equations 19-1, 19-2, and 19-3 were used to calculate the allowable coverages based on the calculated stresses and the flexural strength of 4.48 MPa (650 psi) for the PCC following the same procedure outlined in example 1. The amount of damage is the ratio of the design or applied passes to the allowable passes. The computed damage for different PCC

Table 19-3
Computation of Cumulative Damage for Selected Pavement Sections, Granular Bases, and C-130 Aircraft

PCC Thickness, in. (1)	Base Thickness, in. (2)	Maximum Stress, psi (3)	Design Passes (4)	Allowable Passes[1] (5)	Damage (6) = (4)/(5)
13	6	343	200,000	18,691	10.7
14	6	309	200,000	64,299	3.11
15	6	280	200,000	232,481	0.86
16	6	255	200,000	894,250	0.22
13	18	336	200,000	23,888	8.37
14	18	303	200,000	80,842	2.47
15	18	275	200,000	290,452	0.69
16	18	251	200,000	1,111,962	0.18

[1] Allowable passes are computed using equations 19-1, 19-2, and 19-3 based on the computed maximum stress shown in column (3), on a selected value of R, and the pass-to-coverage ratio for the C-130 aircraft.
Conversion Factors: Millimeters = 25.4 × inches, Megapascals = 0.006894 × psi

Table 19-4
Computation of Cumulative Damage for Selected Pavement Sections, Stabilized Bases, and C-130 Aircraft

PCC Thickness, in. (1)	Base Thickness, in. (2)	Maximum Stress, psi (3)	Design Passes (4)	Allowable Passes[1] (5)	Damage (6) = (4)/(5)
13	6	338	200,000	22,008	9.09
14	6	305	200,000	75,689	2.64
15	6	276	200,000	276,198	0.72
16	6	252	200,000	1,073,564	0.19
13	18	313	200,000	54,498	3.67
14	18	285	200,000	179,847	1.11
15	18	261	200,000	635,265	0.31
16	18	239	200,000	2,403,285	0.08

[1] Allowable passes are computed using equations 19-1, 19-2, and 19-3 based on the computed maximum stress shown in column (3), on a selected value of R, and the pass-to-coverage ratio for the C-130 aircraft.
Conversion Factors: Millimeters = 25.4 × inches, Megapascals = 0.006894 × psi

Table 19-5
Characteristics of Design Aircraft

Aircraft	Pass-to-Coverage Ratio	Gear Type	Wheel Spacing, m (in.)	Wheel Load, kg (lb)	Tire Contact Area, sq m (sq in.)
C-141	3.50	Twin-Tandem	0.83×1.22 (32.5×48)	17,605 (38,812)	0.134 (208)
B-52	1.58	Twin-Twin Bicycle	0.94×1.57×0.94 (37×62×37)	23,590 (52,000)	0.172 (267)
F-15	9.34	Single	N/A	13,880 (30,600)	0.06 (87)
C-17	1.37	Triple-Tandem	(43 x 43) x 97	19,700 (43,300)	0.242 (314)

thicknesses under each of the four different aircraft are presented in Table 19-6. The total damage induced by the mixed traffic for different PCC thicknesses are tabulated in Table 19-7. The total damage is the sum of the damage caused by all the design aircraft.

b. Selection of Concrete Thickness. The results between the PCC thickness and damage presented in Table 19-7 are plotted in Figure 19-9, and the required slab thickness corresponding to a damage of 1 is determined as 470 millimeters (18.5 inches). Results in Table 19-7 indicate that for

Table 19-6
Computation of Cumulative Damage for Mixed Traffic, 10-inch Stabilized Base Courses

Aircraft (1)	P/C Ratio (2)	PCC Thickness (in.) (3)	Maximum Tensile Stress, psi (4)	Design Passes (5)	Design Coverages (6)	Allowable Coverages C_o (SCI = 100) (7)	Allowable Coverages C_f (SCI = 0) (8)	Allowable Coverages (SCI = 80) (9)	Damage (10) = (6)/(9)
C-141	3.49	16	358.1	12500	3582	1974	8175	2622	1.37
		18	311.3	12500	3582	9803	41268	13068	0.27
		20	272.7	12500	3582	55633	238314	74422	0.05
		22	240.8	12500	3582	355513	1551544	477351	0.00
		24	217.0	12500	3582	2023491	8986671	2726470	0.00
B-52	1.58	16	480.2	100	63	131	529	173	0.37
		18	417.0	100	63	438	1786	580	0.11
		20	365.3	100	63	1599	6612	2124	0.03
		22	322.4	100	63	6427	26939	8560	0.01
		24	286.7	100	63	28081	119466	37513	0.00
F-15	9.30	16	175.5	25000	2688	1.30E+08	6.01E+10	1.76E+08	0.00
		18	143.0	25000	2688	1.82E+10	8.86E+10	2.50E+10	0.00
		20	118.6	25000	2688	4.43E+12	2.28E+13	6.14E+12	0.00
		22	99.9	25000	2688	1.83E+15	1.00E+16	2.57E+15	0.00
		24	85.2	25000	2688	1.34E+18	7.82E+18	1.91E+18	0.00
C-17	1.37	16	363.0	12500	9124	1709	7069	2270	4.02
		18	321.1	12500	9124	6742	28275	8980	1.02
		20	287.5	12500	9124	27060	115076	36145	0.25
		22	259.7	12500	9124	112128	483711	150206	0.06
		24	235.6	12500	9124	504476	2209407	677870	0.01

Note: Allowable passes are computed using equations 19-1, 19-2, and 19-3 based on the computed maximum stress shown in column 3 based on a selected value of k and the pass-to-coverage ratio for the specific aircraft.
Conversion Factors: Millimeters = 25.4 × inches, Megapascals = 0.006894 × psi

Table 19-7
Relationship Between Cumulative Damage and PCC Thickness for Mixed Traffic

PCC Thickness mm (in.)	Damage				
	C-141	B-52	F-15	C-17	Cumulative
406 (16)	1.37	0.37	0.00	4.02	5.76
457 (18)	0.27	0.11	0.00	1.02	1.40
508 (20)	0.05	0.03	0.00	0.25	0.33
558 (22)	0.00	0.01	0.00	0.06	0.07
610 (24)	0.00	0.00	0.00	0.01	0.01

this mix of traffic, most pavement damage is caused by the 12,500 passes of the C-17 aircraft. Although the B-52 is a very heavy bomber aircraft, the 100 passes used for design at a reduced load cause minor damage to the pavement. Because the F-15 aircraft is very light, its 25,000 passes cause practically no damage to the pavement.

12.D ESIGN EXAMPLE 3, OVERLAY DESIGN. The overlay design example presented is for the airfield pavement illustrated in design example 1. The airfield had a 380-millimeter (15-inch) PCC originally designed for the C-130 aircraft. After several years of service, the airfield is to be upgraded to the mixed traffic presented in example 2. Based on the results of subgrade evaluation and following the design procedures in design example 2, the required PCC thickness without a base layer is computed as 470 millimeters (18.5 inches). The existing pavement is in good condition structurally, and the C factor for Equations 17-2 and 17-3 is equal to 0.75. Also, the flexural strength of the concrete in the existing slab is very close to that of the overlay (therefore, $h_d = h_c$), and the required overlay thicknesses h_o can be computed from Equations 17-2 and 17-3 as follows:

a. Computation for Nonbonded Concrete:

$$h_o = \sqrt{470^2 - 0.75(380)^2} = 335 \text{ millimeters}$$

$$h_o = \sqrt{18.5^2 - 0.75(15)^2} = 13.2 \text{ inches}$$

b. Computation for Partially Bonded Concrete:

$$h_o = \sqrt[1.4]{470^{1.4} - 0.75(380)^{1.4}} = 262 \text{ millimeters in SI units}$$

$$h_o = \sqrt[1.4]{18.5^{1.4} - 0.75(15)^{1.4}} = 10.3 \text{ in English units}$$

13.DESI GN EXAMPLE 4, ALTERNATE OVERLAY DESIGN PROCEDURE. This example is based on predicting structural deterioration from load-induced stresses. A concrete overlay must be designed to support the traffic mix from example 2. The pavement consisted of a 381-millimeter (15-inch) PCC pavement originally designed for the C-130 aircraft. It was considered that the concrete flexural strength of the overlay will be approximately equal to that of the base slab which is 4.48 MPa (650 psi). Only minor cracking of the base slab was observed; therefore, a SCI of 100 was assumed. It was also estimated from pavement condition surveys that 90 percent of the pavement life to reach initial cracking has been consumed. A bond breaker layer will be placed between the base slab and the overlay (unbonded case). The overlay will be designed for a 20-year operating life and an SCI = 80 at the end of its life.

a. Establish Base Slab Performance Curve. The first step in designing concrete overlays using the alternate methodology is to determine the performance of the base slab under the new traffic when the overlay is placed. For this example, overlay trial thicknesses of 305, 356, and 406 mm (12, 14, and 16 in.) are used. For each trial overlay, the tensile stress caused by each aircraft is computed at the bottom of the base slab. From these computed stresses the coverages to initial cracking and complete failure are computed. Table 19-8 presents in detail the necessary data and equations to perform the calculations. Column 1 of Table 19-8 contains the overlay trial thicknesses, column 2 contains the design aircraft, and column 3 contains design traffic data for each aircraft. Since the design is for a 20-year life, the traffic rate for the B-52 would be 100 passes (from example 2) divided by 20 years, or 5 passes per year. Column 4 contains the factor to convert passes to coverages. Column 5 contains the calculated tensile stresses at the bottom of the base slab using the elastic layer computer program JULEA. The coverages for initial cracking and complete failure of the base slab were computed using Equations 19-1 and 19-2. The damage rate (DR_o) is then computed and accumulated in column 7. The sum of the damage rates is used to calculate the time for initial cracking (T_o) in column 8. Similar calculations are performed in columns 9, 10, and 11 to calculate the damage rate for complete failure (DR_f) and the time for complete failure (T_f) of the base slab. These two time values establish the base slab rate of deterioration between the SCI=100 and an SCI=0. Figure 19-10 shows the base slab performance curve for the 356-millimeter (14-inch) overlay. Similar plots are generated for the 305- and the 406-millimeter (12- and the 16-inch) overlay trials. Finally, the time from the placement of the overlay (m_o) to initial cracking of the base slab is computed in column 12. Since 90 percent of the base slab life has been consumed, the remaining life is then 10 percent (B_o = 0.10). For the 356-millimeter (14-inch) overlay, m_o = 0.10/0.0158 = 6.33 years.

b. Subdivide Base Slab Performance Curve. The next step is to subdivide the base slab performance curve for a trial overlay thickness into time intervals. For the 356-millimeter (14-inch) overlay (Figure 19-10), the curve is divided into six intervals. The first interval will be from the time when the overlay is placed (m_o) to initial cracking of the base slab (T_o). This first interval then corresponds to 6.33 years. Between T_o and T_f, the performance curve is then divided into time intervals to account for the deterioration of the base slab with time (the base slab modulus of elasticity decreases). The slope between T_o and T_f represents the rate of deterioration of the base slab when the SCI decreases from 100. To illustrate this, the time between T_o and T_f in Figure 19-10 is divided in four equal time intervals (on a logarithm scale) and the magnitude of each time interval recorded. The last time period corresponds to the time T_f and beyond (SCI=0). Table 19-9 summarizes this procedure and Figure 19-11 illustrates the actual base slab performance curve when the 356-millimeter (14-inch) overlay is in place. The magnitude of these time intervals will be used in the calculation of the cumulative damage in the overlay within a time interval.

Table 19-8
Data for Overlay Design, Example 4 (Base Slab Calculations)

Overlay Thickness (in.) (1)	Design Aircraft (2)	Traffic Rate (Passes/Year) (3)	P/C (4)	Tensile Stress (psi) (5)	C_o (Coverages) (6)	DR_o (Damage/Year) (7)	T_o (Years) (8)	C_f (Coverages) (9)	DR_f (Damage/Year) (10)	T_f (Years) (11)	m_o (Years) (12)
12.00	B-52	5	11.88	423.00	384.42	0.0011		1,566.41	0.0003		
	C-141	625	3.87	324.00	6,061.55	0.0266		25,393.50	0.0064		
	F-15	1,250	356.03	131.00	2.10E+11	0.0000		1.05E+12	0.0000		
	C-17	625	1.44	318.00	7,570.87	0.0573		31,787.40	0.0137		
					Sum DR_o =	0.0851	11.76	Sum DR_f =	0.0203	49.30	1.18
14.00	B-52	5	11.88	365.00	1,613.28	0.0003		6,669.16	0.0001		
	C-141	625	3.87	283.00	33,421.82	0.0048		142,435.96	0.0011		
	F-15	1,250	356.03	110.00	5.48E+13	0.0000		2.89E+14	0.0000		
	C-17	625	1.44	279.00	40,553.98	0.0107		173,167.81	0.0025		
					Sum DR_o =	0.0158	63.31	Sum DR_f =	0.0037	270.03	6.33
16.00	B-52	5	11.88	312.00	9,537.22	0.0000		40,136.42	0.0000		
	C-141	625	3.87	244.00	288,766.63	0.0006		1,257,614.71	0.0001		
	F-15	1,250	356.03	92.00	4.88E+16	0.0000		2.76E+17	0.0000		
	C-17	625	1.44	243.00	307,973.30	0.0014		1,342,130.33	0.0003		
					Sum DR_o =	0.0020	496.64	Sum DR_f =	0.0005	2,163.14	49.68

DEFINITIONS:

Traffic Rate = Number of design aircraft passes per year.
P/C = Pass to Coverage Ratio at offset where the maximum damage occurs.
C_o = Coverage level at which the SCI begins to decrease from 100 (initial cracking).
C_f = Coverage level at which the SCI becomes 0 (complete failure).
DR_o = Damage rate to initial cracking.
DR_f = Damage rate to complete failure.
T_o = Time in years to initial cracking.
T_f = Time in years to completed failure.
m_o = Time from the placement of overlay to initial cracking of the base slab.

B_o = Remaining life of base slab.
(5) = Computed tensile stress at the bottom of the base slab.
(6) = Coverages to initial cracking (C_o) calculated using stress in (5).
(7) = (3)/(6)/(4).
(8) = 1.0/(7) = 1.0/Sum DR_o.
(9) = Coverage to complete failure (C_f) calculated using stress in (5).
(10) = (3)/(9)/(4).
(11) = 1.0/(10) = 1.0/Sum DR_f.
(12) = Bo/(7) = Bo/Sum DR_o.
Conversion Factors:
Millimeters = 25.4 × inches
Megapascals = 0.006894 × psi

Table 19-9
Time Intervals for the 356-millimeter (14-inch) Overlay

Time Interval Number	Time at the Beginning of Each Interval, years	Time Between Intervals, years
1	0.000	
2	6.33	6.33
3	34.00	27.67
4	73.77	39.77
5	130.92	57.15
6	213.05	82.13

c. Compute the Cumulative Damage in the Overlay. Once the base slab performance curve is established, the damage in the trial overlay can be assessed. The procedure basically consists of computing the tensile stresses at the bottom of the overlay, calculating the number of coverages to initial cracking and complete failure, and calculating and cumulating the damage in the overlay for each time period. This process is demonstrated in Table 19-10. Columns 1 and 2 contain the interval number and the magnitude of the interval in years, respectively. Column 3 contains the average SCI's within each interval that is used to compute the reduced modulus of elasticity (Equation 19-4). Columns 4, 5, and 6 contain the design aircraft, traffic rate, and pass-to-coverage ratio. Column 7 contains the computed tensile stresses at the bottom of the overlay. These stresses are computed with the elastic layer computer program JULEA assuming the interface between the overlay and the slab is unbonded since a bond-breaker layer is used. Column 8 contains the number of coverages to initial cracking (Co) of the overlay for each aircraft. The damage (Do) is computed in column 9 and accumulated in column 10 (DAMo). In a similar fashion the damage to complete failure (DAMf) is calculated and accumulated in columns 11, 12, and 13. This process is repeated for each time interval as is shown in the table.

d. Determine Required Overlay Thickness. The cumulative damage for initial cracking (DAMo) and complete failure (DAMf) of the trial overlay for each time interval can now be plotted. Figure 19-12 shows the plot for the 356-millimeter (14-inch) overlay. From this plot, the years to initial cracking and complete failure of the overlay can be obtained by reading the years at which the DAMo and DAMf curves cross a cumulative damage of 1.0. For the 356-millimeter (14-inch) overlay shown in Figure 19-12, these values correspond approximately to 26 years to initial overlay cracking and 50 years to complete failure of the overlay. Similar curves can be generated for the 406-millimeter (16-inch) and 457-millimeter (18-inch) overlay trials. Figure 19-13 summarizes the analysis performed on the 305-, 356-, and 406-millimeter (12-, 14-, and 16-inch) overlay trials. The values obtained from Figure 19-12 are used to generate the composite overlay performance curve. From Figure 19.13, for the case of the 356-millimeter (14-inch) overlay, the overlay performs at an SCI of 100 for 4.0 years before it starts to deteriorate. It then deteriorates linearly with the logarithm of time until it reaches a complete failure condition (SCI=0.0) after 50 years. Finally from Figure 19-13, the life of each overlay trial can be obtained for the design overlay SCI of 80. These values are 4.2 years, 29.6 years, and 81.7 years for the 305-, 356-, 406-millimeter (12-, 14-, and 16-inch) overlays, respectively. To obtain the required thickness for the design life of 20 years, a plot of the overlay thicknesses versus the life of each overlay is generated as illustrated in Figure 19-14. From this figure, a 426-millimeter (16.8-inch) overlay would be required for a design life of 20 years and a SCI of 80.

Table 19-10
Computation of the Cumulative Damage for the 14-inch Overlay

Time Interval Number (1)	Time Interval Years (2)	Average SCI (3)	Design Aircraft P/C (4)	Traffic Rate (Passes/Year) (5)	P/C (6)	Tensile Stress (psi) (7)	C_o (8)	D_o (9)	DAM_o (10)	C_f (11)	D_f (12)	DAM_f (13)
1	6.33	100	B-52	5	11.88	389.00	846.10	0.0011		3,475.13	0.0003	
			C-141	625	3.87	286.00	29,011.46	0.0130		123,464.34	0.0030	
			F-15	1,250	356.03	137.00	58.64E+09	1.3956E-10		2.89E+11	2.8342E-11	
			C-17	625	1.44	292.00	22,051.45	0.0459		93,586.25	0.0108	
							Sum D_o =	0.0600	0.1630	Sum D_f =	0.0141	0.0384
2	27.67	87.5	B-52	5	11.88	416.00	447.47	0.0260		1,826.13	0.0064	
			C-141	625	3.87	306.00	12,123.56	0.3686		51,143.94	0.0874	
			F-15	1,250	356.03	147.00	8.81E+09	1.1032E-08		4.25E+10	2.2834E-09	
			C-17	625	1.44	311.00	9,919.98	1.2107		41,763.72	0.2876	
							Sum D_o =	1.6054	1.7684	Sum D_f =	0.3813	0.4198
3	39.77	62.5	B-52	5	11.88	479.00	133.82	0.1251		539.53	0.0310	
			C-141	625	3.87	352.00	2,374.03	2.7053		9,852.24	0.6519	
			F-15	1,250	356.03	171.00	2.30E+08	6.0714E-07		1.07E+09	1.3036E-07	
			C-17	625	1.44	354.00	2,232.92	7.7298		9,260.91	1.8638	
							Sum D_o =	2.8303	4.5987	Sum D_f =	2.5466	2.9664

DEFINITIONS:

D_o = Damage within a time interval when analyzing for initial cracking.
D_f = Damage within a time interval when analyzing for complete failure.
DAM_o = Cumulative damage up to a time interval when analyzing for initial cracking.
DAM_f = Cumulative damage up to a time interval when analyzing for complete failure.
(7) = Computed tensile stress at the bottom of the overlay layer.
(8) = Coverages to initial cracking (C_o) calculated using stress in (6).
(9) = (2)*(((5)/(8)/(6).
(10) = Cumulative D_o up to that interval.
(11) = Coverages to complete failure (C_f) calculated using stress in (6).
(12) = (2)*(((5)/(11)/(6).
(13) = Cumulative D_f up to that interval.
Conversion Factors:
Millimeters = 25.4 × inches
Megapascals = 0.006894 × psi

(Continued)

Table 19-10 (Concluded)

Time Interval Number (1)	Time Interval Years (2)	Average SCI (3)	Design Aircraft P/C (4)	Traffic Rate (Passes/Year) (5)	P/C (6)	Tensile Stress (psi) (7)	C_o (8)	D_o (9)	DAM_o (10)	C_f (11)	D_f (12)	DAM_f (13)
4	57.14	37.5	B-52	5	11.88	553.00	46.06	0.5223		183.71	0.1309	
			C-141	625	3.87	406.00	560.97	16.4527		2,294.53	4.0224	
			F-15	1,250	356.03	200.00	9.03E+09	2.2224E-05		4.07E+07	4.9294E-06	
			C-17	625	1.44	405.00	574.15	43.2018		2,348.98	10.5596	
							Sum D_o =	16.9750	21.5737	Sum D_f =	14.7130	17.6794
5	82.13	0.0	B-52	5	11.88	639.00	18.18	1.9007		71.86	0.4810	
			C-141	625	3.87	468.00	161.39	82.1834		651.92	20.3456	
			F-15	1,250	356.03	234.00	563,590.57	0.0005		2.47E+06	0.0001	
			C-17	625	1.44	464.00	173.15	205.8681		699.92	50.9293	
							Sum D_o =	84.0847	105.6584	Sum D_f =	71.7559	89.4353

DEFINITIONS:

D_o = Damage within a time interval when analyzing for initial cracking.
D_f = Damage within a time interval when analyzing for complete failure.
DAM_o = Cumulative damage up to a time interval when analyzing for initial cracking.
DAM_f = Cumulative damage up to a time interval when analyzing for complete failure.
(7) = Computed tensile stress at the bottom of the overlay layer.
(8) = Coverages to initial cracking (C_o) calculated using stress in (6).
(9) = (2)*(((5)/(8)/(6).
(10) = Cumulative D_o up to that interval.
(11) = Coverages to complete failure (C_f) calculated using stress in (6).
(12) = (2)*(((5)/(11)/(6).
(13) = Cumulative D_f up to that interval.
Conversion Factors:
Millimeters = 25.4 × inches
Megapascals = 0.006894 × psi

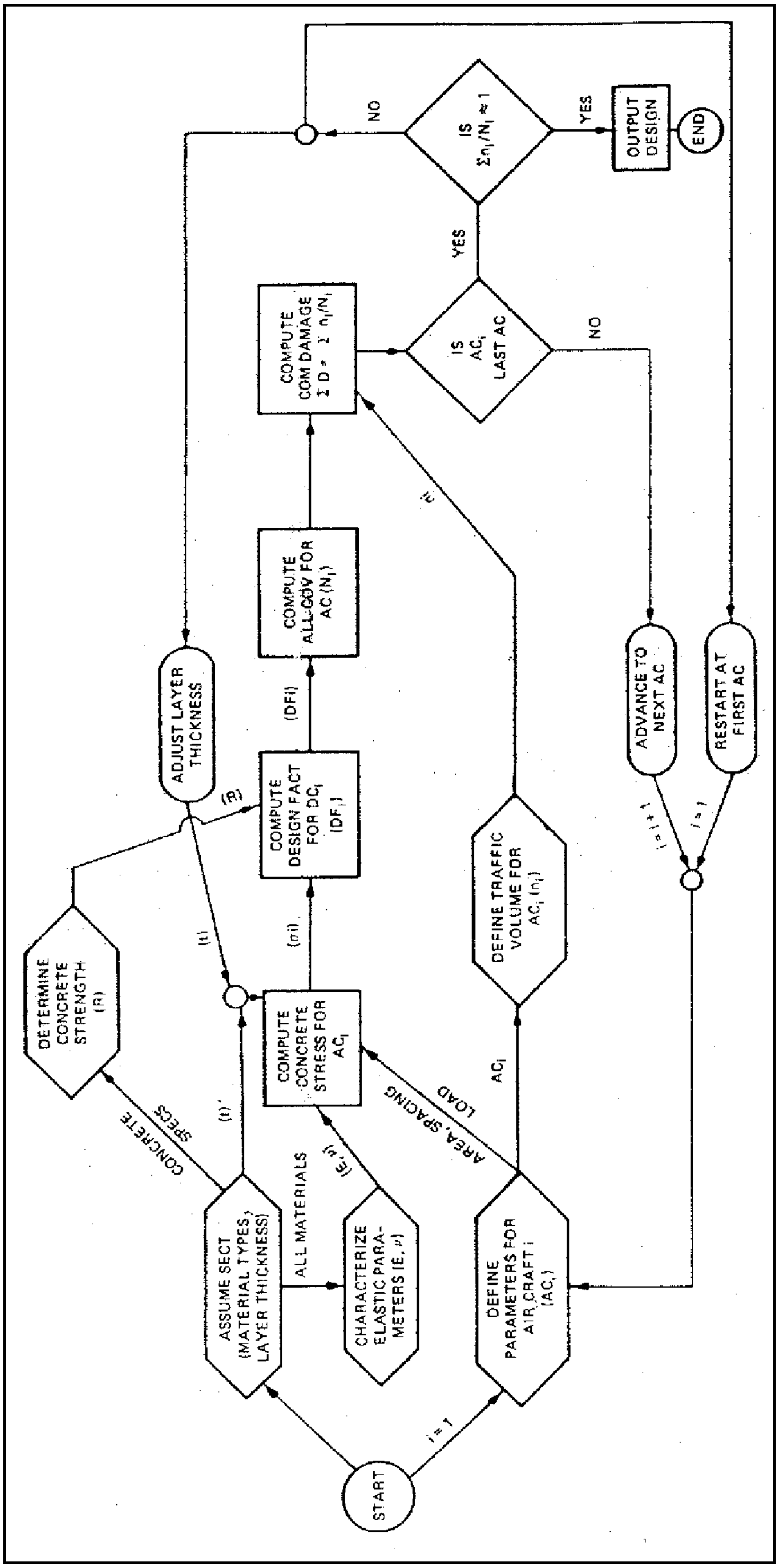


Figure 19-1. Diagram for design of airfield rigid pavements by layered elastic theory

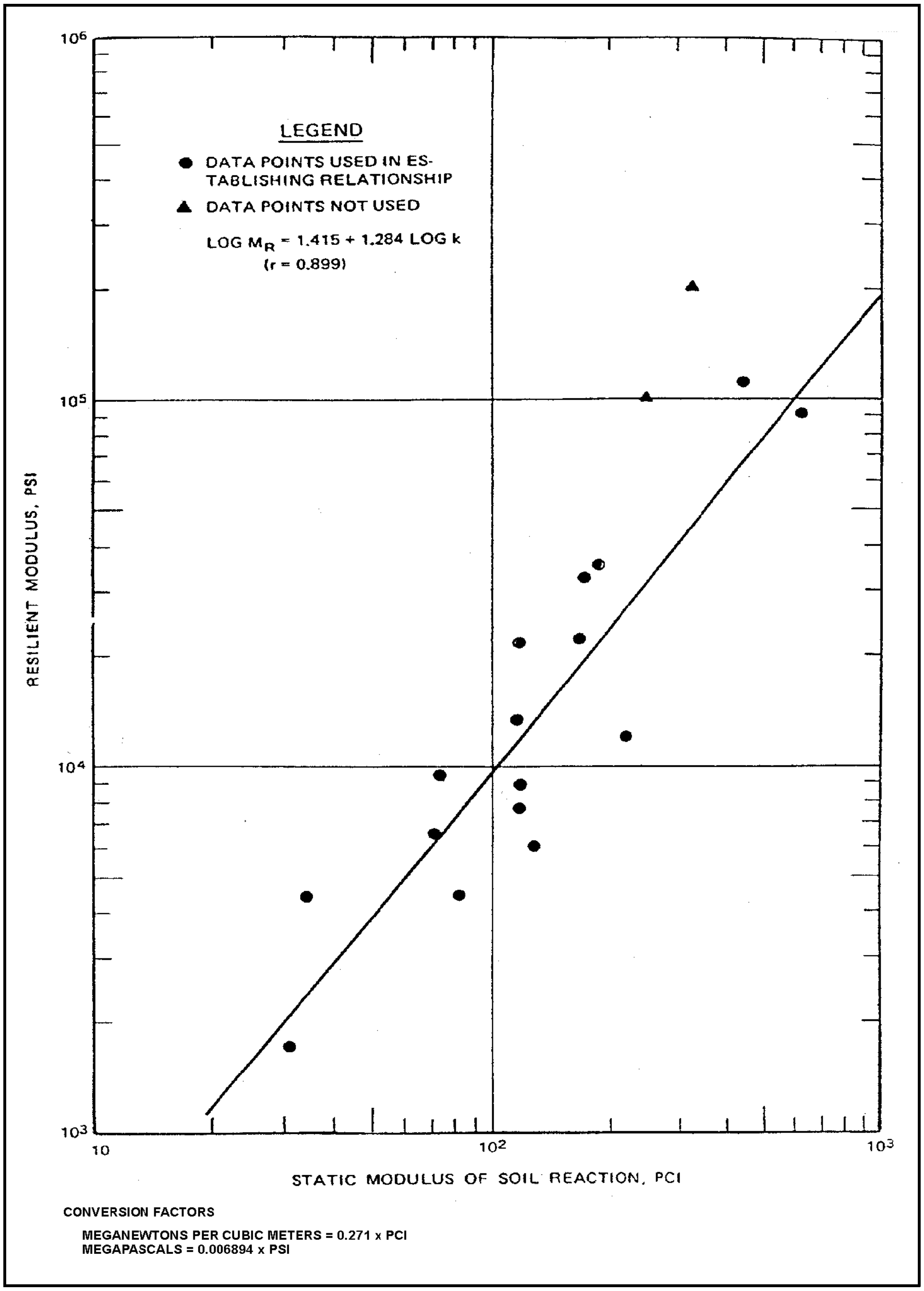


Figure 19-2. Correlation between resilient modulus of elasticity and static modulus of soil reaction

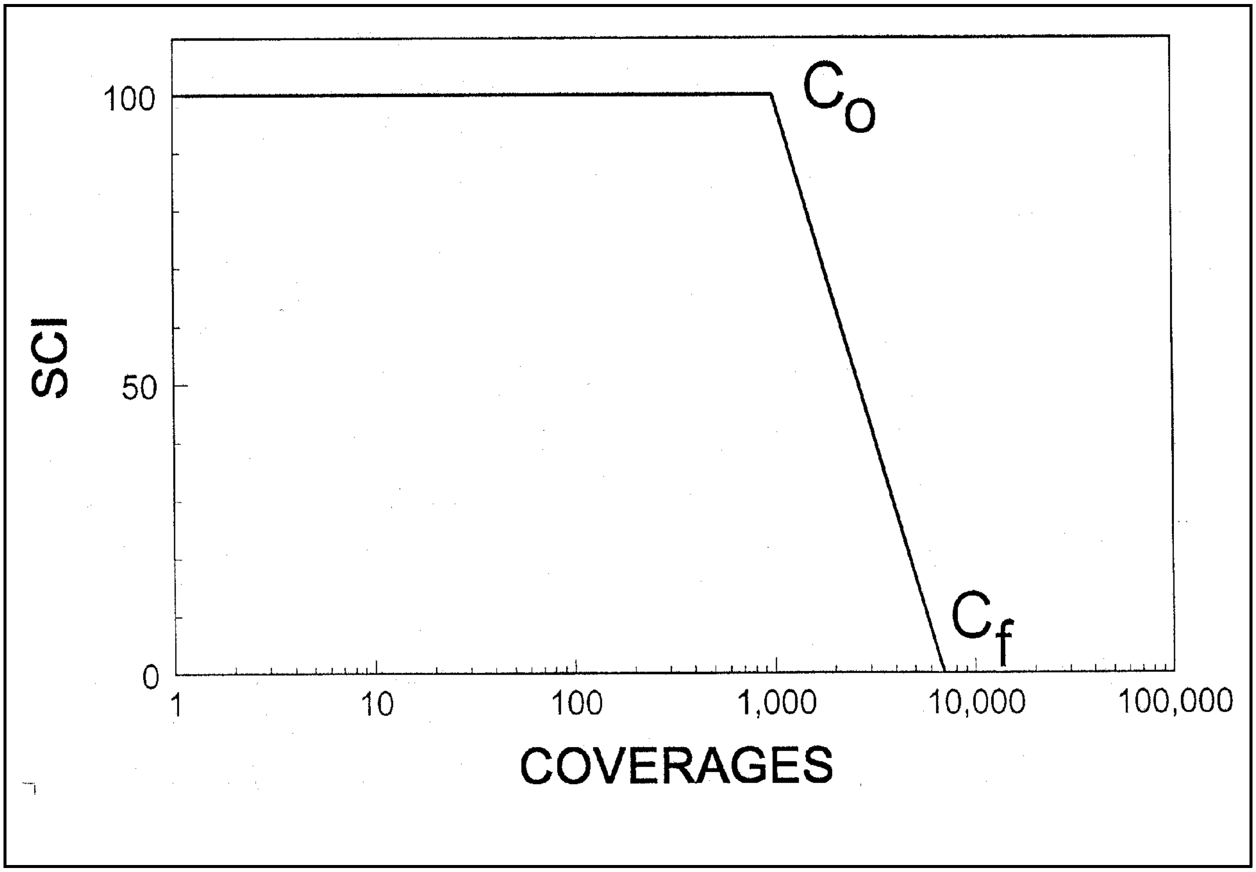


Figure 19-3. Relationship between SCI and coverages at initial cracking and complete failure

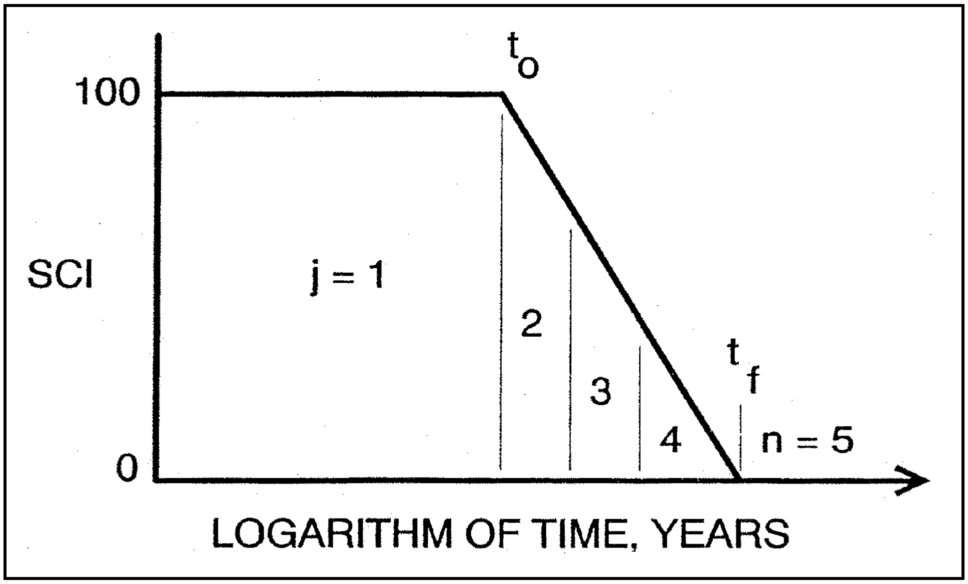


Figure 19-4. Base slab performance curve (SCI versus logarithm of time) subdivided into five time periods

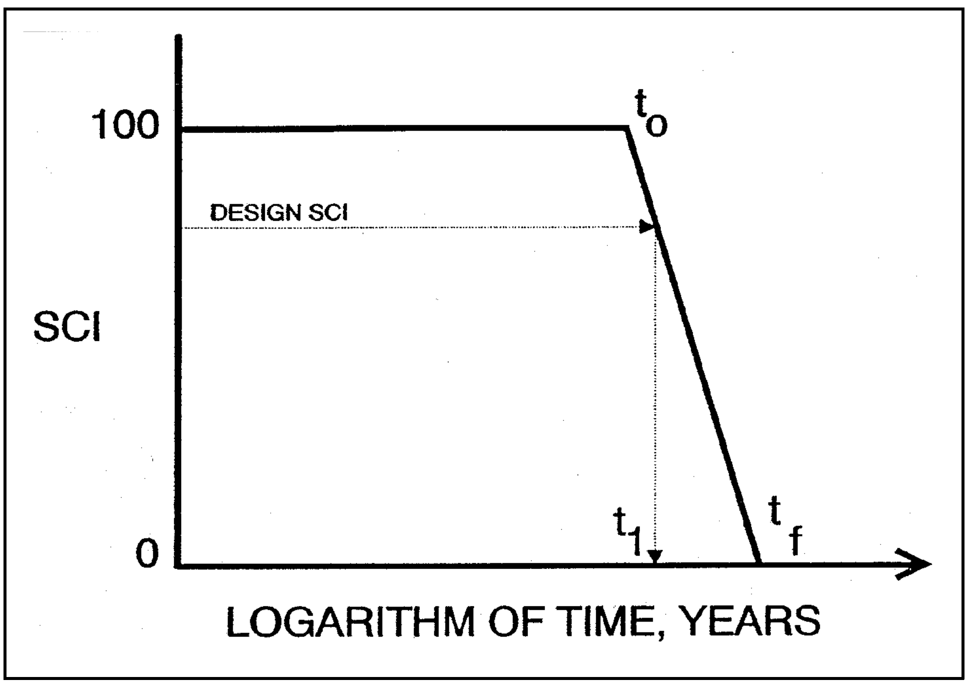


Figure 19-5. Composite overlay performance curve

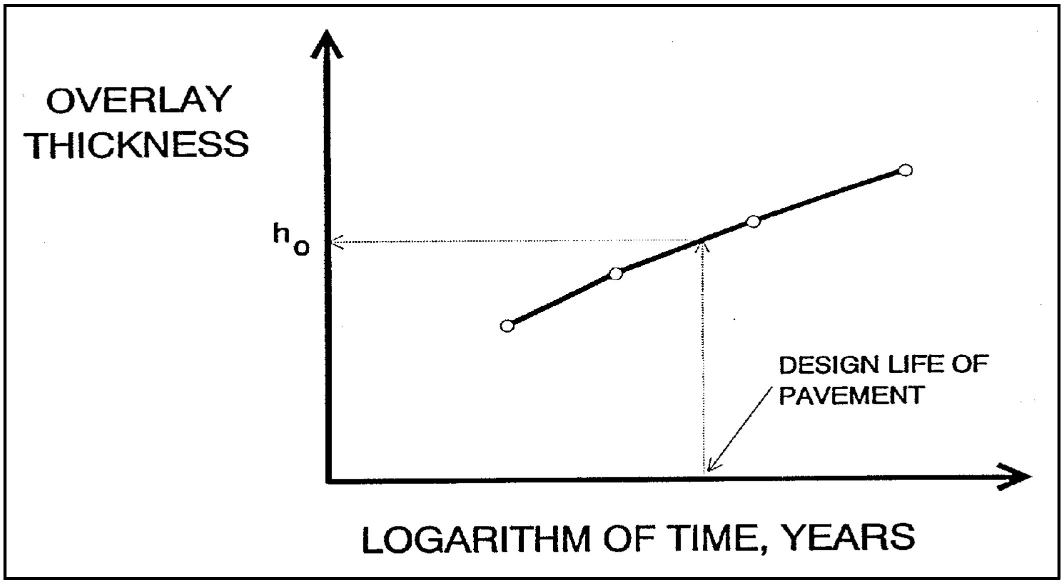


Figure 19-6. Overlay thickness versus logarithm of time

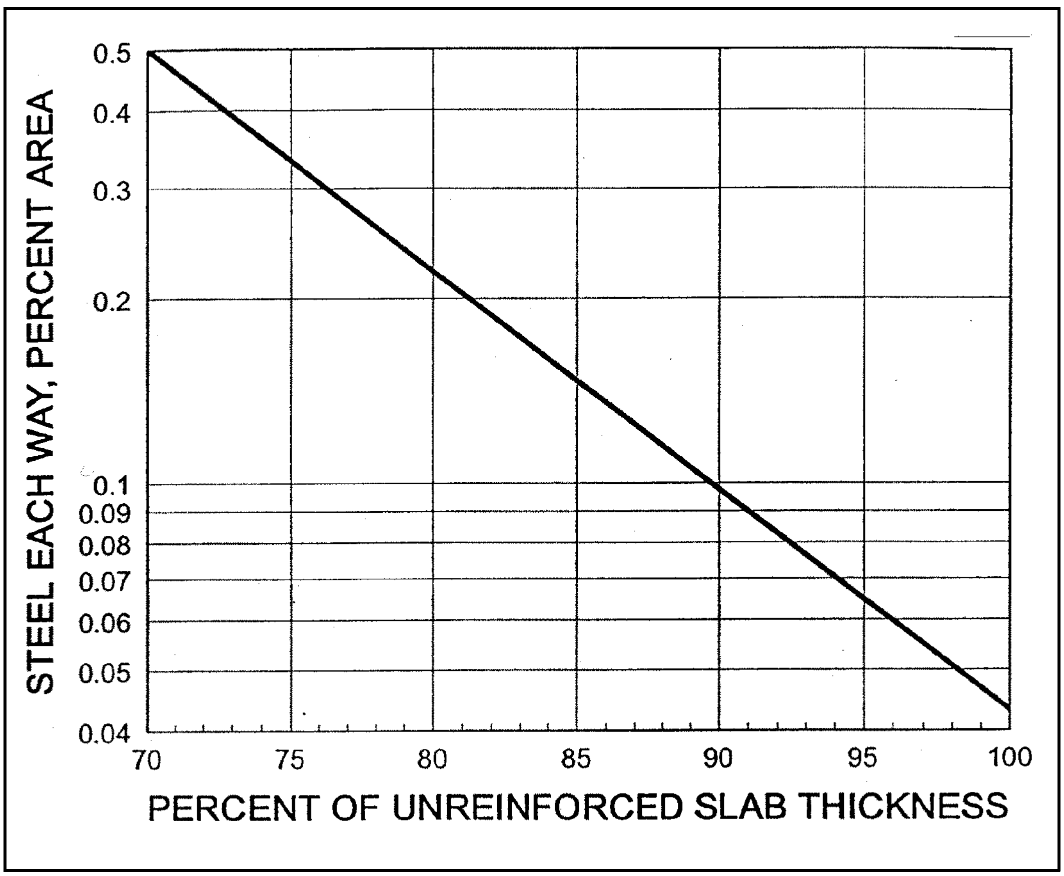


Figure 19-7. Effect of steel reinforcement on rigid pavements

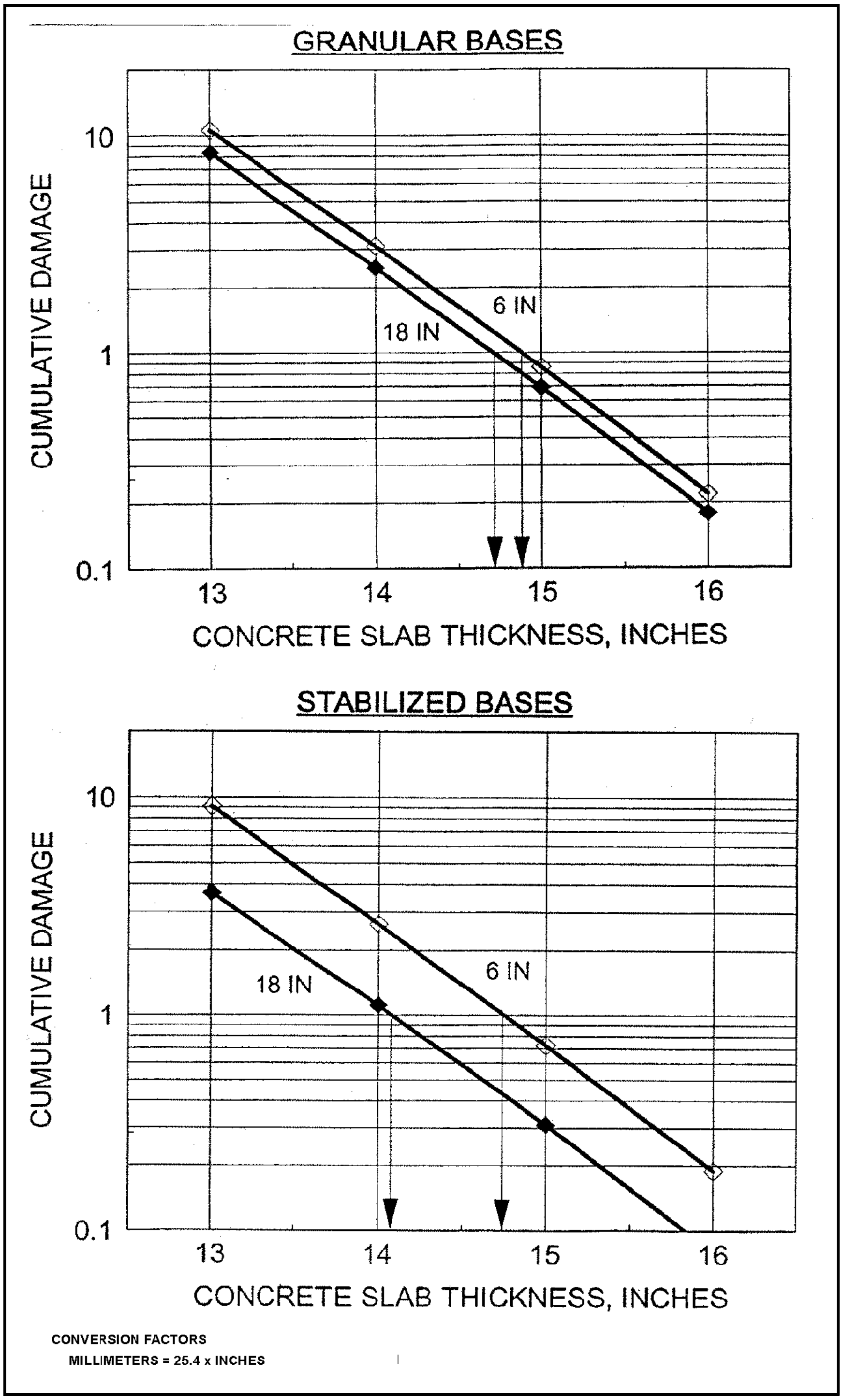


Figure 19-8. Relationship between cumulative damage and concrete slab thickness for granular and stabilized bases (see Design Example 1)

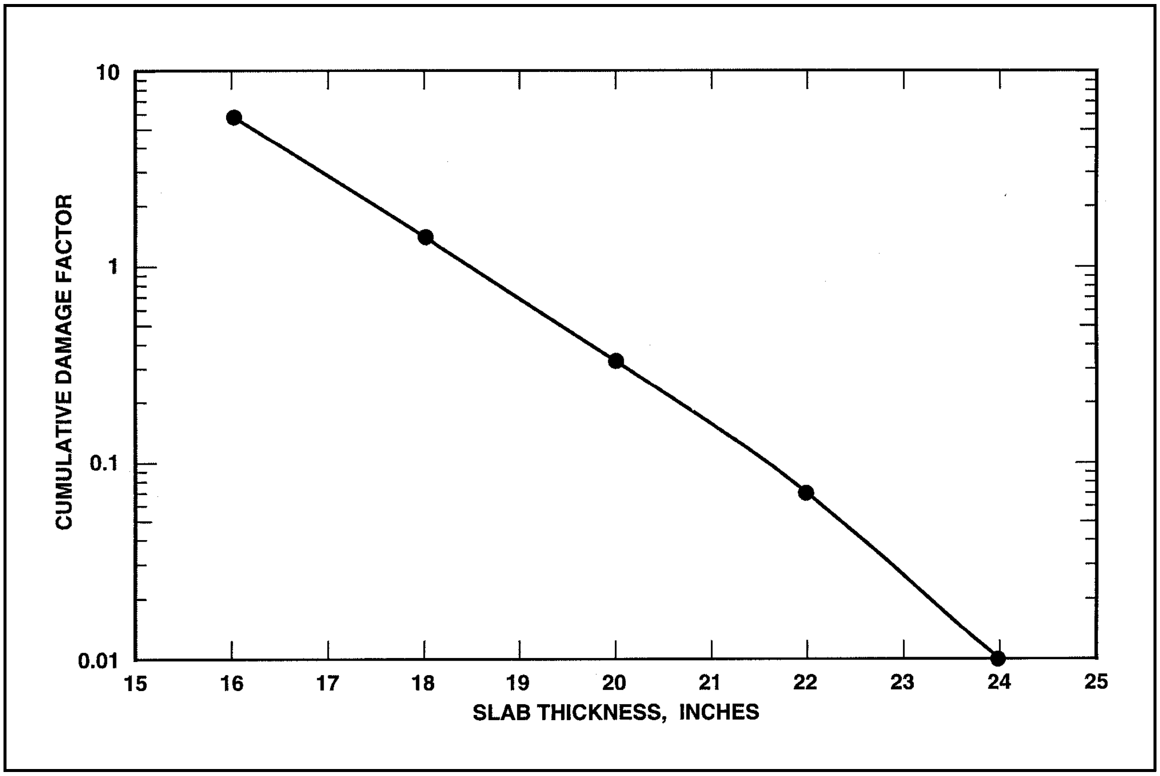


Figure 19-9. Relationship between cumulative damage and pavement thickness, mixed aircraft traffic (see Design Example 2)

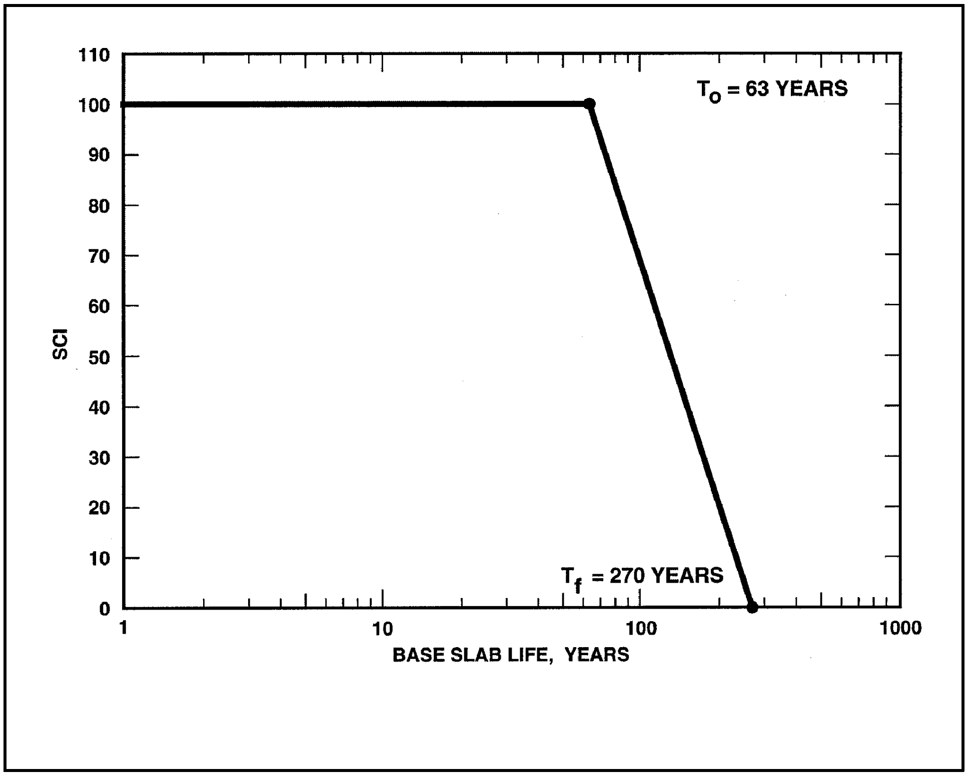


Figure 19-10. Base slab performance curve for the 356-millimeter (14-inch) overlay

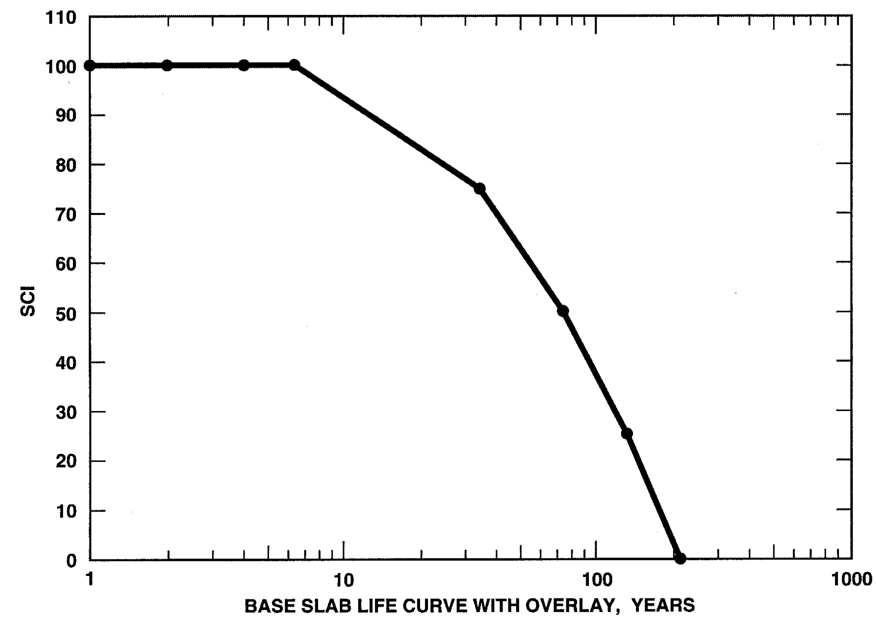


Figure 19-11. Actual performance curve with the 356-millimeter (14-inch) overlay in place

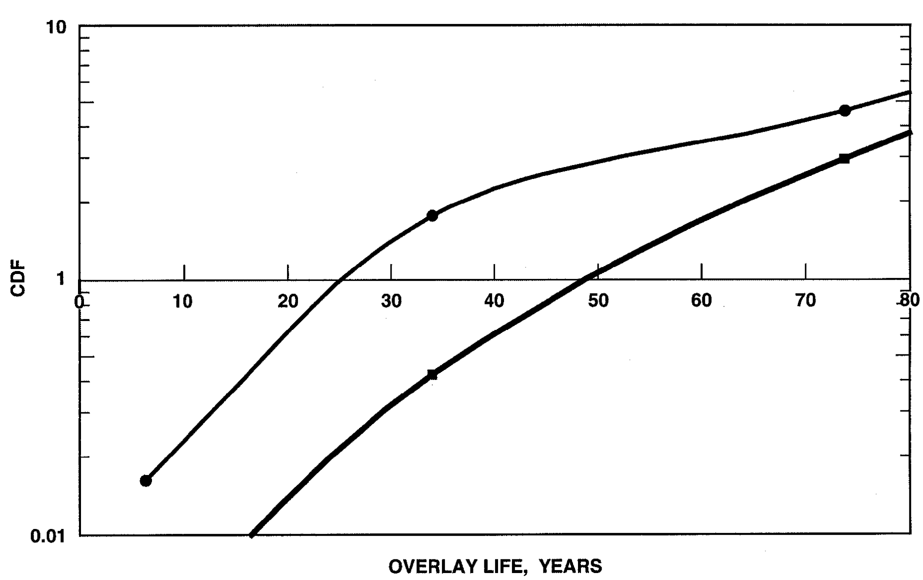


Figure 19-12. Cumulative damage plot for the 356-millimeter (14-inch) overlay

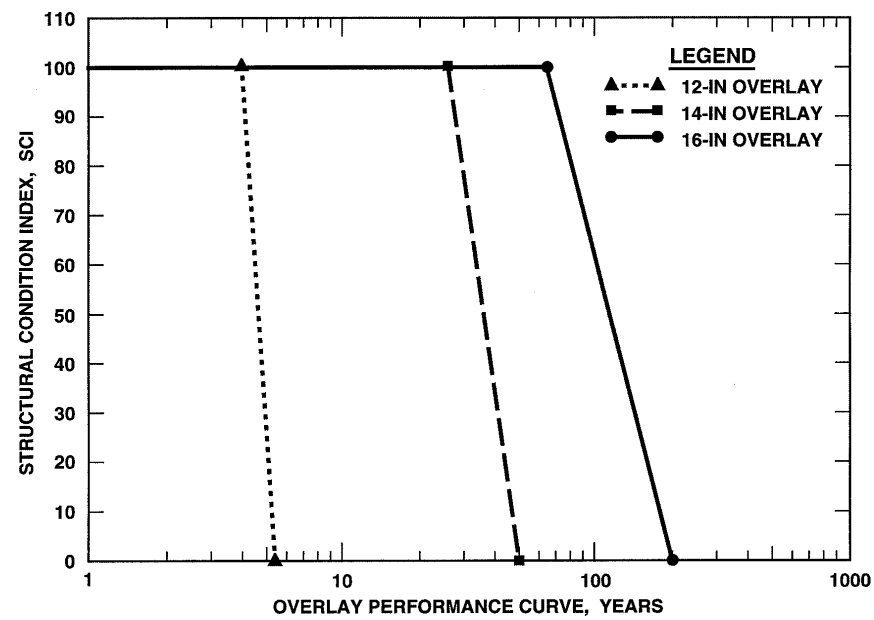


Figure 19-13. Results of the analysis performed on the 305-, 356-, and 406-millimeter (12-, 14-, and 16-inch) overlay trials

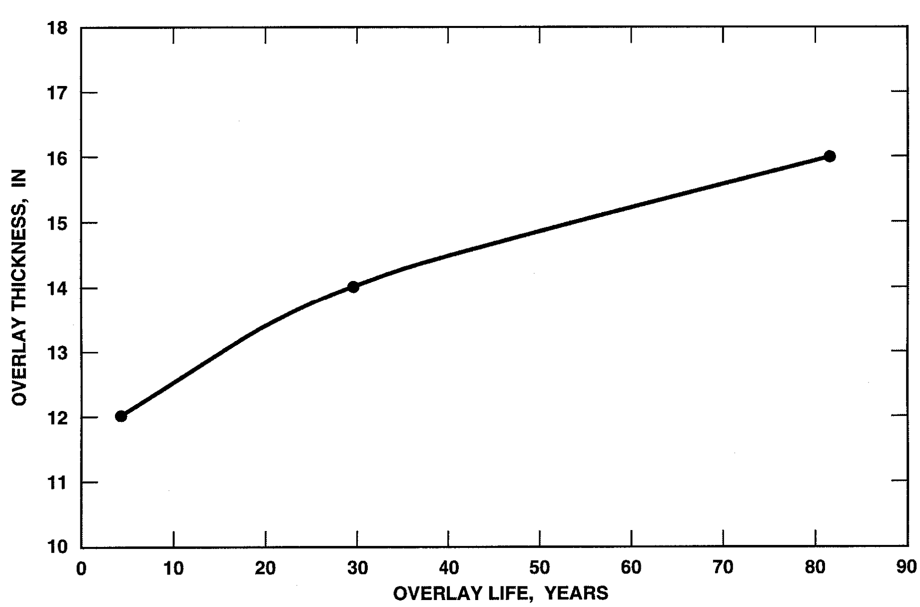


Figure 19-14. Plot showing the overlay thickness versus the overlay life

CHAPTER 20

SEASONAL FROST CONDITIONS

1. GENERAL. This chapter presents criteria and procedures required for the design and construction of pavements placed on subgrade materials subject to seasonal frost action. If frost does not penetrate into the subgrade using thicknesses necessary for nonfrost design, pavement design need not consider effects of frost action unless the base, subbase courses contain other than NFS, PFS, S1, or S2 materials. The designer must select subbase materials which do not allow pumping of subbase course or subgrade fines during periods of saturated or nearly saturated conditions. The detrimental effects of frost action in frost susceptible subsurface materials are manifested by nonuniform heave of pavements during the winter and/or loss of strength of affected soils during the ensuing thaw periods. Studies have shown that the modulus of subgrade reaction is reduced substantially during the thaw period. Application of load on thaw-weakened pavements can lead to premature failure. Other effects of frost on pavements are possible loss of compaction, pumping, increased pavement roughness, restriction of drainage by frozen layers, and cracking of asphalt concrete pavements. In extreme conditions, these problems can cause hazardous operating conditions, or Foreign Object Damage (FOD) to aircraft, and can lead to extensive maintenance of the pavement surface. Except in cases where other criteria are specifically established, pavements should be designed so that there will be no interruptions of traffic at any time due to differential heave or to reduction in load-supporting capacity. Pavements should also be designed so that the rate of deterioration during critical periods of thaw weakening and thermally induced cracking will not be so high that the useful life of the pavement is less than that assumed as the design objectives. For interior pavements which fall within a geographical area subject to subgrade frost action, the “reduced subgrade strength” or the “limited subgrade frost penetration” pavement design criteria should be used for all aircraft hangar pavements in heated or unheated areas.

2. FROST-SUSCEPTIBILITY CLASSIFICATION. For frost design purposes, soils are divided into eight groups as shown in Table 20-1. Soils are listed in approximate order of increasing frost susceptibility and decreasing bearing capacity during periods of thaw.

a. The frost susceptibility of the soils classified in Table 20-1, based on laboratory tests, are shown in Table 20-2. The NFS, S1, and S2 groups are negligible to very low frost susceptible soils. Based on laboratory tests, the heave rates range between 1 and 4 mm/day and the thawed CBR ranges between 12 to 20 percent. These soils are considered to be suitable as base and subbase course material. Soils categorized as F1, F2, F3, and F4 are unsuitable as base or subbase materials.

b. Under special conditions the frost group classifications adopted for design may be permitted to differ from that obtained by application of the above frost group definitions provided a written waiver is obtained and a valid justification is presented in the design analysis. Such justification may take into account special conditions of subgrade moisture or soil uniformity, in addition to soil gradation and plasticity, and should include data on performance of existing pavements near those proposed to be constructed. This will require the approval of HQUSACE (CEMP-ET), the appropriate Air Force Major Command or the Naval Facilities Engineering Command.

3. METHODS OF THICKNESS DESIGN. Three methods are prescribed for determining the thickness of a pavement that will have adequate resistance to distortion by frost heave, cracking from differential frost heave and distortion under traffic load as affected by seasonal variation of

Table 20-1
Frost Design Classification

Frost Group	Kind of Soil	Percentage Finer than 0.02 mm by Weight	Typical Soil Types Under Unified Soil Classification System
NFS[1]	(a) Gravels Crushed Stone Crushed Rock	0-1.5	GW, GP
	(b) Sands	0-3	SW, SP
PFS[2]	(a) Gravel Crushed Stone Crushed Rock	1.5-3	GW-GP
	(b) Sands	3-10	SW-SP
S1	Gravely Soils	3-6	GW, GP, GW-GM, GP-GM
S2	Sandy Soils	3-6	SW, SP, SW-SM, SP-SM
F1	Gravely Soils	6-10	GM, GW-GM, GP-GM
F2	(a) Gravely Soils	10-20	GM, GW-GM, GP-GM
	(b) Sands	6-15	SM, SW-SM, SP-SM
F3	(a) Gravely Soils	Over 20	GM, GC
	(b) Sands, except very fine silty sands	Over 15	SM, SC
	(c) Clays, PI>12	--	CL, CH
F4	(a) Silts	--	ML, MH
	(b) Very fine silty	Over 15	SM
	sands	--	CL, CL-ML
	(c) Clays, PI<12	--	CL, ML, CL-ML,
	(d) Varved clays and other fine grained, banded sediments		CL, ML, and SM, CL, CH, and ML, CL, CH, ML, and SM

[1] Nonfrost susceptible.
[2] Possibly frost susceptible, requires laboratory test to determine frost design soil classification.

supporting capacity, including severe weakening during frost melting periods. The three methods are (a) complete frost penetration method, (b) reduced subgrade strength method, and (c) limited subgrade frost penetration method.

a. Complete Frost Penetration Method. In the complete frost penetration method, frost is not allowed to penetrate into frost susceptible subgrade soils. This method completely prevents affects of frost action, i.e., frost heave and thaw weakening in the subgrade, subbase, or base course. The total pavement thickness from this method is seldom used in the final design since prevention of frost penetration into the subgrade is nearly always uneconomical and unnecessary.

Table 20-2
Frost Susceptibility Classification

Heave Rate (mm/day)	Thawed CBR	Frost Susceptibility Classification	Frost Group
<1	>20	Negligible	NFS, PFS
<2	>15	Very Low	S1, PFS
<4	>12	Very Low	S2, PFS
<6	>10	Low	F1
<8	>6	Medium	F2
<16	>3	High	F3
No Limit	<3	Very High	F4

It will not be used to design pavements to serve conventional traffic, except when approved by appropriate written waiver.

b. Reduced Subgrade Strength Method. The reduced subgrade strength method does not seek to limit the penetration of frost into the subgrade. It determines the thickness of pavement, base, and subbase that will adequately carry traffic. This approach relies on uniform subgrade conditions, adequate subgrade preparation, and transitions for adequate control of pavement roughness resulting from differential frost heave.

c. Limited Subgrade Frost Penetration Method. The limited subgrade frost penetration method requires a sufficient thickness of pavement, base, and subbase to limit the penetration of frost into the frost susceptible subgrade.

4. SELECTION OF DESIGN METHOD. In most cases the choice of the pavement design method will be made in favor of the one that gives the lower cost. The limited subgrade frost penetration method will be used, even at higher costs, in areas where the subgrade soils are extremely variable (e.g., in some glaciated areas) and the required subgrade preparation could not be expected to sufficiently restrict differential frost heave, and when special operational demands on the pavement might dictate unusually severe restrictions on pavement roughness, requiring that subgrade frost penetration be severely restricted or even prevented. If the use of limited subgrade frost penetration method is not required, tentative designs must be prepared using both methods for comparison of costs.

5. REDUCED SUBGRADE STRENGTH METHOD. The thickness design is based on the seasonally varying subgrade bearing capacity that includes sharply reduced values during frost melting periods. This design procedure usually requires less thickness of pavement and base than that needed for limited subgrade frost penetration. The method may be used for pavements where the subgrade is reasonably uniform or can be made reasonably uniform horizontally by the required subgrade preparation techniques discussed later in this chapter. This will prevent or minimize significant or objectionable differential heaving and resultant cracking of pavements. When the reduced

subgrade strength method is used with an F3 or F4 subgrade soil, rigorous control of subgrade preparation is required. In situations, based on previous experience, where use of the reduced subgrade strength procedure has resulted in pavement thicknesses allowing objectionable frost heave, but use of the greater base-course thickness obtained from the limited subgrade frost penetration method is considered over conservative, intermediate design base-course thickness may be used. However, these must be justified on the basis of frost heaving experience developed from existing pavements where climatic and soil conditions are comparable.

a. Thickness of Flexible Pavements. The thickness design procedure is identical to the thickness design for nonfrost conditions, with the exception that instead of using the subgrade CBR, Frost Areas Soil Support Index (FASSI) values are used. The flexible pavement design curves are used in connection with the reduced subgrade strength procedure. In place of the estimated or determined subgrade CBR, use the applicable FASSI values outlined in Table 20-3 with the design curves. The FASSI values for the F1 to F4 subgrade soils were backcalculated from performance data of in-service pavements, and are the weighted average CBR valued for an annual cycle. These values cannot be determined by CBR tests. The FASSI values for S1 and S2 materials meeting current specifications for base and subbase will be determined by conventional CBR procedures. The reduced subgrade strength design procedure is included in the design computer program PDSF discussed in Chapter 1.

Table 20-3
Frost Area Soil Support Indexes (FASSI) for Subgrade Soils

Frost Group of Subgrade Soil	FASSI Values
F1 and S1	9.0
F2 and S2	6.5
F3 and F4	3.5

Once the overall thickness of the pavement structure has been determined, criteria for nonfrost design should be used to determine the thickness of individual layers. It should also be ascertained whether it will be advantageous to incorporate bound base layer(s) in the system. Although the use of bound bases will reduce the thickness of the base and subbase layers, it is possible that deeper frost penetration may occur leading to increased frost heave. The base-course requirements set forth in this chapter must be followed rigorously.

(1) Design of overrun pavements. The runway overrun pavement thicknesses for providing adequate strength during frost melting periods are determined from the appropriate flexible pavement design curves and the applicable FASSI values outlined in Table 20-3. The thickness established by this procedure shall have the following limitations:

(a) It shall not be less than required for nonfrost condition design.

(b) It shall not exceed the thickness required under the limited subgrade frost penetration design method.

(c) It shall not be less than that required for normal operation of snowplows and other support vehicles.

The subgrade preparation techniques and transition details outlined in this chapter are required for overrun pavements.

(2) Control of surface roughness in overruns. For a frost group F3 and F4 subgrade, differential heave can generally be controlled to 75 millimeters (3 inches) in 15.2 meters (50 feet) by providing a thickness of base and subbase equal to 60 percent of the base-course thickness required by the limited subgrade frost penetration design method. For well drained F1 and F2 subgrade soils, the minimum thickness of pavement and base course in overruns should not be less than 40 percent of the total thickness required for limited subgrade frost penetration design.

(3) Design of shoulder pavements. When paved shoulders are required, the paved shoulder pavement, base, and subbase, shall have the combined thickness obtained from the flexible pavement design curve and the appropriate FASSI value in Table 20-3. The subgrade preparation techniques and transition details outlined in this chapter are required. If the subgrade is highly susceptible to frost heave, local experience may indicate a need for a shoulder section that incorporates an insulating layer or an additional granular unbound material to moderate the frost heave. The base-course requirements set forth in this chapter must be followed.

(4) Control of differential frost heave at small structures located within shoulder pavements. To prevent objectionable heave of small structures inserted in shoulder pavements, such as drain inlets and bases for airfield lights, the shoulder base and subbase courses extending at least 1.5 meters (5 feet) radially from the structures should be designed and constructed entirely with nonfrost susceptible material to a depth to prevent subgrade freezing. Gradual transitions are required. Alternatively, synthetic insulation could be placed below a base of the minimum prescribed thickness to prevent the advance of freezing temperatures into the subgrade; suitable transitions to the adjoining uninsulated pavement would be needed.

(5) Drainage. Subsurface drainage must be provided in flexible pavements in accordance with EI 02C202/AFJMAN 32-1016.

b. Rigid Pavement Thickness Design. The thickness design procedure is identical to the thickness design for nonfrost conditions, with the exception that instead of using the modulus of subgrade reaction k, Frost Area Index of Reaction (FAIR) values are used. The design curves for plain concrete and for fibrous concrete are used in connection with the reduced subgrade strength procedure. In place of the estimated or determined subgrade k in the design curves, use the applicable FAIR values from Figure 20-1. The FAIR values can also be estimated from the following equations:

S1 or F1 material:

$$\text{FAIR (pci)} = 6.7 + 10.7 \times \text{base-course thickness (in.)}$$

or (20-1)

$$\text{FAIR}\left(\frac{\text{MN}}{\text{m}^3}\right) = 1.8 + 114 \times \text{base-course thickness (m)}$$

S2 or F2 material:

$$\text{FAIR (pci)} = 4.5 + 8.0 \times \text{base-course thickness (in.)}$$

or (20-2)

$$\text{FAIR}\left(\frac{\text{MN}}{\text{m}^3}\right) = 1.2 + 83.8 \times \text{base-course thickness (m)}$$

F3 or F4 material:

$$\text{FAIR (pci)} = 5.4 + 5.7 \times \text{base-course thickness (in.)}$$

or (20-3)

$$\text{FAIR}\left(\frac{\text{MN}}{\text{m}^3}\right) = 1.5 + 60.8 \times \text{base-course thickness (m)}$$

The FAIR values for the S1, and F1 to F4 subgrade soils were determined from field measurements and are the weighted average k values for an annual cycle. These values cannot be determined from plate bearing tests.

(1) It is good practice to use a combined base thickness equal in thickness to the slab. The design procedure is as follows:

(a) Determine frost group soil classification of subgrade, Table 20-1.

(b) Assume three combined base thicknesses, enter Figure 20-1 or use appropriate equations, determine the FAIR value for each thickness.

(c) Use the FAIR values with appropriate design curves to determine pavement thickness.

(d) Plot combined base thickness and pavement thickness. From the figure, pick out base-course and pavement thickness of similar values.

(e) If unable to converge to a solution, repeat steps b to d with new base-course thickness.

(f) A minimum of 203 millimeters (8 inches) of combined base (100-millimeter (4-inch) drainage layer plus 100-millimeter (4-inch) separation layer) is required for rigid pavements in frost areas.

(2) The combined base must meet the drainage and filter requirements outlined in EI 02C202/AFJMAN 32-1016. A 100-millimeter (4-inch) separation layer meeting the filter requirements must be placed between the subgrade and base or subbase course. A geotextile separator can also be used in lieu of the granular filter. No structural advantage will be attained in the design when a geotextile is used. Guidance for selection of geotextile fabric materials

proposed for a specific project is provided in EI 02C202/AFJMAN 32-1016 and TM 5-818-8/ AFJMAN 32-1030.

(3) Bound base also has significant structural value and is considered to be a low-strength concrete for design purposes. A minimum 200-millimeter (8-inch) drainage plus separation layers must be placed between the bound base and the subgrade.

(4) If sufficient high-quality base material is not locally available, the nonfrost design base layer thickness can be used. The appropriate FAIR value will be used for the base to determine the PCC thickness.

(5) The subgrade preparation techniques and transition details outlined in this chapter are also required for the design of overrun pavements.

(6) The control of differential frost heave at small structures is located within shoulder pavements. To prevent objectionable heave of small structures inserted in shoulder pavements, such as drain inlets and bases for airfield lights, the shoulder base and subbase courses extending at least 1.5 meters (5 feet) radially from the structures should be designed and constructed entirely with nonfrost susceptible material to a depth to prevent subgrade freezing. Gradual transitions are required. Alternatively, synthetic insulation could be placed below a base to prevent the advance of freezing temperatures into the subgrade; suitable transitions to the adjoining uninsulated pavement would be needed.

6. LIMITED SUBGRADE FROST PENETRATION METHOD. This design method permits a small amount of frost penetration into frost susceptible subgrades. The procedure uses a design freezing index (DFI) as illustrated in Figure 20-2. Typical DFI values are shown in Figures 20-3 and 20-4. The procedure is described in the following subparagraphs. A computer program (PDSF) for providing the limited subgrade frost penetration design thickness is discussed in Chapter 1.

a. Step One. Determine frost penetration depths. The maximum frost penetration depths with respect to the design freezing index shown in Figure 20-5 are calculated from the Modified Berggren formula and computational procedures outlined in TM 5-852-6/AFM 88-19, Chap. 6. Frost penetration depths presented in Figure 20-5 are measured from the pavement surface. The pavement is considered free of snow and ice. Computations also assume that all soil beneath the pavement within the depth of frost penetration are granular and nonfrost susceptible. It was assumed in the computations that all soil moisture freezes at 0 degrees Celsius (32 degrees Fahrenheit). Use straight-line interpolation where necessary. The frost penetration depth a in meters for SI units and inches for English units can also be estimated from the following equations:

(1) For $\gamma = 2{,}160$ kg/m^3 (135 lb/ft^3) and $\omega = 3$ percent,

$$a = 0.157 + 9E{-}5(DFI) - 4E{-}10(DFI)^2 \text{ in SI units} \tag{20-4}$$

$$a = 6.183 + 0.047(DFI) - 2.91E{-}6(DFI)^2 \text{ in English units} \tag{20-5}$$

(2) For $\gamma = 2{,}160$ kg/m^3 (135 lb/ft^3) and $\omega = 7$ percent,

$$a = 0.1852 + 8E\text{-}5(DFI) - 4E\text{-}10(DFI)^2 \text{ in SI units} \tag{20-6}$$

$$a = 7.291 + 0.044(DFI) - 2.58E\text{-}6(DFI)^2 \text{ in English units} \tag{20-7}$$

(3) For γ = 2,400 kg/m^3 (150 lb/ft^3) and ω = 3 percent,

$$a = 0.1725 + 0.0001(DFI) - 5E\text{-}10(DFI)^2 \text{ in SI units} \tag{20-8}$$

$$a = 6.793 + 0.055(DFI) - 3.41E\text{-}6(DFI)^2 \text{ in English units} \tag{20-9}$$

(4) For γ = 2,400 kg/m^3 (150 lb/ft^3) and ω = 7 percent,

$$a = 0.1583 + 9E\text{-}5(DFI) - 4E\text{-}10(DFI)^2 \text{ in SI units} \tag{20-10}$$

$$a = 6.231 + 0.049(DFI) - 2.98E\text{-}6(DFI)^2 \text{ in English units} \tag{20-11}$$

where

DFI = °C-hours in SI units or °F-days in English units.

γ = soil density

ω = soil moisture content

In Figure 20-5, the frost penetration curves for γ = 2,160 kg/m^3 (135 lb/ft^3) and ω = 3 and 7 percent are combined because the curves were very close together. Also, note that these densities and moisture contents represent an approximation of a weighted average value of combined base.

b. Step Two. Estimate the moisture content and dry density of the nonfrost susceptible base-course material. For a conservative design, the 3 percent moisture content, 2,400 kg/m^3 (150 lb/ft^3) base material should be selected. Determine frost penetration depth for complete frost penetration from Figure 20-5.

c. Step Three. Compute thickness of combined base (combined thickness of base, subbase, drainage layer and separation layer) required for zero frost penetration into the subgrade (Figure 20-6) as follows:

$$c = a - p \tag{20-12}$$

where

c = thickness of unbound base, millimeters (inches)

a = thickness for complete frost protection, millimeters (inches)

p = thickness of asphalt or concrete for nonfrost design

d. Step Four. For limited frost penetration into the subgrade, determine the average moisture content of the subgrade prior to freezing. Compute water content ratio r.

$$r = \frac{\text{moisture content of subgrade}}{\text{moisture content of base}} \tag{20-13}$$

where

moisture content of the base = same as that assumed for nonfrost base material in step 2.

If the computed r exceeds 2.0, use 2.0 for types A, B, and primary traffic areas. If r exceeds 3.0, use 3.0 for all pavements other than those in types A, B, or primary traffic areas.

e. Step Five. Enter Figure 20-6, with c (from step 3) as the abscissa and, at the applicable value of r, find the design combined base thickness b on the left scale and the allowable frost penetration into the subgrade s on the right scale or use Equations 20-10 and 20-11. This procedure will result in a sufficient thickness of material between the frost susceptible subgrade and the pavement so that for average field conditions subgrade frost penetration of the amount s should not cause excessive differential heave of the pavement surface during the design freezing index year.

$$b = c \times f \tag{20-14}$$

$$s = c \times g \tag{20-15}$$

where

b = design combined base thickness

c = combined base thickness for zero penetration

s = limited subgrade frost penetration depth

f and g = factors from the following tabulation

Water Content Ratio (*r*)	***f***	***g***
0.6	0.881	0.216
0.8	0.850	0.209
1.0	0.806	0.200
1.2	0.781	0.197
1.4	0.756	0.188
1.6	0.725	0.181
1.8	0.706	0.178
2.0	0.644	0.175
2.5	0.613	0.156
3.0	0.550	0.144

g. Step Six. When the maximum combined thickness of pavement layers required by this design procedure exceeds 1.5 meters (60 inches), a total combined thickness to 1.5 meters (60 inches) will be used. Limiting the combined thickness of pavement and base to 1.5 meters (60 inches) may result in a greater surface roughness because of the greater subgrade frost penetration. To minimize pavement damage and roughness, steel reinforcements can be used in the concrete slabs to prevent large cracks. Smaller unreinforced slabs can also be considered. Alternatively, the design could incorporate subbase layers of uniform fine sand with a high moisture content to reduce frost penetration into the subgrade. These materials would be allowed only in the lower 500 millimeters (20 inches) of the subbase. When using this alternative the designer must be certain that materials of Frost Groups S2 or better are used as subbase layers. If either the high moisture retention subbase course or a combined thickness over 1.5 meters (60 inches) is selected for frost design purposes, specific approval of HQUSACE (CEMP-ET), the appropriate Air Force Major Command, or Naval Facilities Engineering Command shall be obtained.

h. Step Seven. The combined thickness of pavement layers required for limited subgrade frost penetration is then compared with that obtained for nonfrost conditions, and the thicker of the two cross sections will be adopted as the design thickness.

7. GRANULAR BASE- AND SUBBASE-COURSE REQUIREMENTS. The base-course material used in pavements in seasonal frost areas will meet the requirements for base course outlined in Chapter 8. In addition, the following requirements must be met:

(1) The top 50 percent of the combined base thickness must be nonfrost susceptible.

(2) The lower 50 percent thickness of combined base may be either nonfrost susceptible material, partially frost susceptible material, S1 or S2 material. If the separation layer meets the minimum S1 or S2 frost susceptibility criterion, then it can be considered to be part of the combined base. If not, then an additional 100-millimeter (4-inch) separation layer is required.

(3) Base- and subbase-course materials of borderline quality should be tested frequently after compaction to ensure that the compacted material meets requirement (1). For material expected to exhibit serious degradation during placement and compaction (>3 percent finer than 0.02 millimeters by weight), a test embankment may be needed to study the formation of fines by the proposed compaction method. If the test embankment shows serious degradation, the material gradation should be changed to account for the fines obtained during compaction. If experience indicates that the base- or subbase-course materials degrade rapidly under traffic loads or due to environmental effects, consideration should be given to stabilizing the material with asphalt or Portland cement.

(4) Mixing of base or subbase course material with frost susceptible subgrade soils should be avoided. The subgrade should be properly graded and compacted prior to the placement of the base or subbase course. Separation layer requirements must be met.

8. DRAINAGE LAYER REQUIREMENTS. A minimum 100-millimeter (4-inch) thick nonfrost susceptible drainage layer must be placed at the bottom of the asphalt concrete layer, the PCC layer or below the bound base for all pavements constructed in frost areas. The rapid draining nonfrost susceptible material must meet the gradation requirements shown in EI 02C202/AFJMAN 32-1016. The drainage layer will be designed in accordance with the requirements in EI 02C202/AFJMAN 32-1016. The layer is considered as a structural component of the pavement and will serve as part of the base course. In seasonal frost areas, as frost penetrates into the frost susceptible subgrades, water is drawn to the cold front and ice lenses form. During the frost melting period, the ice lenses will melt and the water will have to be removed. In extremely wet conditions or with F3 and F4 subgrade soils, a drainage layer should be considered between the subbase and the subgrade in lieu of a drainage layer under the surfacing as illustrated in Figure 20-7.

9. SEPARATION LAYER. If subgrade freezing will occur, a minimum of a 100-millimeter (4-inch) granular separation layer as specified in EI 02C202/AFJMAN 32-1016 will be placed between the subgrade and the overlying base course. Over weak subgrades, a 152-millimeter (6-inch) or greater thickness may be necessary to support construction equipment and to provide a working platform for placement and compaction of the base course. This layer is not intended to be a drainage layer. The gradation of this separation layer should meet the requirements in EI 02C202/AFJMAN 32-1016. An additional requirement is that the separation layers must be nonfrost susceptible or of frost group S1 or S2. Alternatively, where stable foundation already exists, geotextile fabrics meeting the requirements of EI 02C202/AFJMAN 32-1016 can be used in lieu of a granular material as a separation layer. No structural advantage will be attained in the design when a geotextile fabric is used. The fabrics must meet the requirements of EI 02C202/AFJMAN 32-1016.

10. SUBGRADE REQUIREMENTS. In addition to the requirement outlined for subgrades in nonfrost areas in Chapter 6, the following additional requirements shall be required for subgrades in frost areas. It is a basic requirement for all pavements constructed in frost areas that subgrades in which freezing will occur be as uniform as possible. This will be done by mixing nonhomogeneous soils, eliminating isolated pockets of soil of higher or lower frost susceptibility, and blending the various types of soils into a single, relatively homogeneous mass. This attempts to produce a subgrade of uniform frost susceptibility and thus create conditions tending to make both surface heave and subgrade thaw weakening as uniform as possible over the paved area. To achieve uniformity in some cases, it will be necessary to remove high frost-susceptible soils or soils of low frost susceptibility. In that case, the pockets of soil to be removed should be excavated to the full

depth of frost penetration and replaced with material similar to the material left in place. This replacement should be completed before any required mixing and blending of the subgrade. This will minimize the potential for large variations in frost heave and subgrade support. In fill sections, the least frost susceptible soils shall be placed in the upper portion of the subgrade by temporarily stockpiling, cross hauling, and selective grading. If the upper layers of fill contain frost susceptible soils, the completed fill section shall be subjected to the subgrade preparation procedures, outlined below for cut sections. In cut sections, no matter the type of frost susceptible subgrade soil, the subgrade shall be scarified and excavated to a prescribed depth, and the excavated material windrowed and bladed successively until thoroughly blended, and relaid and compacted. Alternatively, a soil mixing and pulverizing machine may be used to blend the material in place. Multiple passes of the machine will be required for proper blending.

a. Depth of Subgrade Preparation. The depth of subgrade preparation is applicable for limited subgrade penetration and reduced subgrade strength design. The depth of subgrade preparation measured downward from the top of the subgrade shall be lesser of:

(1) 0.6 meter (24 inches).

(2) Two-thirds of the frost penetration less the actual combined thickness of pavement, base course, drainage layers, and subbase course under types A, B, or primary traffic areas.

(3) Under type C, D, and secondary traffic areas and under overruns and shoulder pavements, it will be one-half the frost penetration less the actual combined thickness of pavement, base course, drainage layers, and subbase course.

(4) 1.8 meters (72 inches) less the actual combined thickness of pavement, base course, drainage layers, and subbase course.

The prepared subgrade must meet the designated compaction requirements for nonfrost areas discussed in Chapter 6. The construction inspection personnel should be alert to verify that the processing of the subgrade will yield uniform soil conditions throughout the section.

b. Exceptional Conditions. An exception to the basic requirements for subgrade preparation are subgrades that are nonfrost susceptible or of very low frost susceptibility (NFS, S1, S2) to the depth prescribed for subgrade preparation. These subgrades contain no frost susceptible layers or lenses, as demonstrated and verified by extensive and thorough subsurface investigations and by the performance of nearby existing pavements. Also, fine-grained subgrades containing moisture well in excess of the optimum for compaction, with no feasible means of drainage nor of otherwise reducing the moisture content, and which consequently are not feasible to scarify and recompact, are also exceptions. If a wet fine-grained subgrade exists at the site, it will be necessary to prevent frost penetration with fill material. This may be done by raising the grade by an amount equal to the depth of subgrade preparation that otherwise would be prescribed, or by undercutting and replacing the wet fine-grained subgrade to that same depth. In either case, the fill or backfill material may be nonfrost susceptible or frost susceptible material. If the fill or backfill is frost susceptible, it should be subjected to the same subgrade preparation procedures prescribed above.

c. Cobbles or Boulders. A critical condition requiring the attention of designers and inspection personnel is the presence of cobbles or boulders in the subgrade. All stones larger than about 150 millimeters (6 inches) in diameter should be removed from fill materials for the full depth of frost penetration, either at the source or as the material is spread in the embankment. Any such large stones exposed during subgrade preparation work must also be removed, down to the full depth to which subgrade preparation is required. Failure to remove stones or large roots can result in increasingly severe pavement roughness as the stones or roots are heaved gradually upward toward the pavement surface. They eventually break through the surface in extreme cases, necessitating complete reconstruction.

d. Soil Conditions. Abrupt changes in soil conditions must not be permitted. Where the subgrade changes from a cut to a fill section, a wedge of subgrade soil in the cut section with the dimensions shown in Figure 20-8 should be removed and replaced with fill material. Discontinuities in subgrade conditions require the most careful attention of designers and construction inspection personnel, as failure to enforce strict compliance with the requirements for transitions may result in serious pavement distress.

e. Rock Excavation. In areas where rock excavation is required, the character of the rock and seepage conditions should be considered. In any case, the excavation should be made so that positive transverse drainage is provided and no pockets are left on the rock surface that will permit ponding of water within the depth of freezing. The irregular ground water availability created by such conditions may result in markedly irregular heaving under freezing conditions. It may be necessary to fill drainage pockets with lean concrete. At intersections of fills with rock cuts, the tapered transitions illustrated in Figure 20-8 are essential. Rock subgrades where large quantities of seepage are involved should be blanketed with a highly pervious material to permit the escape of water. Frequently, the fractures and joints in the rock contain frost susceptible soils. These materials should be cleaned out of the joints to the depth of frost penetration and replaced with nonfrost susceptible material. If this is impractical, it may be necessary to remove the rock to the full depth of frost penetration. An alternative method of treating rock subgrades, in-place fragmentation, has been used effectively in airfield construction. Blast holes 0.9 to 1.8 meters (3 to 6 feet) deep are commonly used. They are spaced suitable for achieving thorough fragmentation of the rock to permit effective drainage of water through the shattered rock and out of the zone of freezing in the subgrade. A tapered transition should be provided between the shattered rock cut and the adjacent fill. Underdrains are essential to quickly remove excess water.

11. CONTROL OF DIFFERENTIAL HEAVE AT DRAINS, CULVERTS, DUCTS, INLETS, HYDRANTS, AND LIGHTS.

a. Design Details and Transitions for Drains, Culverts, and Ducts. Drains, culverts, or utility ducts placed under pavements on frost-susceptible subgrades frequently experience differential heaving. Wherever possible, the placing of such facilities beneath pavements should be avoided. Where this cannot be avoided, construction of drains should be in accordance with the”correct” method indicated in Figure 20-9, while treatment of culverts and large ducts should conform with Figure 20-10. All drains of similar features should be placed first and the base and subbase course materials carried across them without bread so as to obtain maximum uniformity of pavement support. The practice of constructing the base and subbase course and then excavating back through them to lay drains, pipes, etc. is unsatisfactory as a marked discontinuity in support will result. It is almost impossible to compact material in a trench to the same degree as the surrounding base and subbase course materials. Also, the amount of fines in the excavated and backfilled material may be increased by incorporation of subgrade soil during the trench excavation or by manufacture of fines by the added handling. The poor experience record of combination drains—those intercepting both surface and subsurface water—indicates that the filter material should never be carried to the surface as illustrated in the “incorrect” column in Figure 20-9. Under winter conditions, this detail may allow thaw water accumulating at the edge of the pavement to feed into the base course. This detail is also undesirable because the filter is a poor surface and is subject to clogging, and the drain is located too close to the pavement to permit easy repair. Recommended practice is shown in the "correct" column in Figure 20-9.

b. Frost Protection and Transitions for Inlets, Hydrants, and Lights. Experience has shown that drain inlets, fueling hydrants, and pavement lighting systems, which have different thermal properties that the pavements in which they are inserted, are likely to be locations of abrupt differential heave. Usually, the roughness results from progressive movement of the inserted items. To prevent these damaging movements, the pavement section beneath the inserts and extending at least 1.5 meters (5 feet) radially from them should be designed to prevent freezing of frost-susceptible materials by sue of an adequate thickness of nonfrost-susceptible base course, and by use of insulation. Consideration should also be given to anchoring footings with spread bases at appropriate depths. Gradual transitions are required to surrounding pavements that are subject to frost heave.

12. PAVEMENT THICKNESS TRANSITIONS.

a. Longitudinal Transitions. Where interruptions in pavement uniformity cannot be avoided, differential frost heaving should be controlled by use of gradual transitions. Length of longitudinal transitions should vary directly with the speed of traffic and the amount of heave differential. Transition sections should begin and end directly under the pavement joints, and should in no case be shorter than one slab length. As an example, at an airfield where differentials of heave of 25 millimeters (1 inch) may be expected at changes from one subgrade soil condition to another, gradual changes in base thicknesses should be effected over distances of 61 meters (200 feet) for the runway area, 30.5 meters (100 feet) for taxiways, and 15.25 meters (50 feet) for aprons. The transition in each case should be located in the section having the lesser total thickness of pavement and base. Pavements designed to lower standards of frost heave control, such as shoulders and overruns, have less stringent requirements, but may nevertheless need transition sections.

b. Transverse Transitions. A need for transitions in the transverse direction arises at changes in total thickness of pavement and base, and at longitudinal drains and culverts. Any transverse transition beneath pavements that carry the principal wheel assemblies of aircraft traveling at moderate to high speed should meet the same requirements applicable to longitudinal transitions. Transverse transitions between the traffic areas C and D should be located entirely within the limits of traffic area D and should be sloped no steeper than 10 horizontal to 1 vertical. Transverse transitions between pavements carrying aircraft traffic and adjacent shoulder pavements should be located in the shoulder and should not be sloped steeper than 4 horizontal to 1 vertical.

13. OTHER MEASURES TO REDUCE FROST HEAVE. Another measure to reduce the effects of heave is the use of insulation to control depth of frost penetration. Insulation can only be used in shoulders and overruns. The use of synthetic insulating materials within a pavement cross section must have the approval of HQUSACE (CEMP-ET) or the appropriate Air Force Major Command. When synthetic insulating materials are used, transitions between cut and fill, changes in character and stratification of subgrade soils, subgrade preparation, and boulder removal should also receive special attention in field construction control.

14. REPLACEMENT OR RECONSTRUCTION OF EXISTING PAVEMENTS. Objectionable differential heave has been noticed where existing airfield pavements have been partially reconstructed or new segments added. These discontinuities in elevation can result in problems of snow removal,

ponding of water, surface icing, and loss of control of aircraft or unnecessary stresses to the aircraft or vehicles using the pavement. This objectionable and abrupt differential movement is caused by the use of different material in the base and subbase and/or the use of different thicknesses than existing material. Longitudinal abrupt differences have been noted where the keel section has been replaced on airfields. Transverse abrupt differences have been noticed in newly added taxiways where the total thickness of pavement, base, and subbase has been different from that previously used. The differences are most pronounced when the pavement type is changed from PCC to asphalt concrete. PCC pavements generally require smaller base and subbase thicknesses than asphalt concrete pavements resulting in deeper frost penetration and potentially greater frost heave. To minimize these abrupt differences in pavement elevation, pavement surface elevation surveys should be conducted in the summer and again in the winter when frost penetration is near its maximum depth. Both surveys should be completed before the new facility is designed. The difference in the two surveys will indicate the potential for abrupt differences in pavement surface elevation resulting from differing designs. The abrupt differences can be eliminated or substantially reduced by using proper transitions, or by using the same materials previously used. However, care must be taken if consideration is being given to the use of similar materials that resulted in the initial distress. Materials which are frost susceptible and placed too near the pavement surface can result in premature failure.

15. COMPACTION. Subgrade, subbase, and base-course materials must meet the applicable compaction requirements for nonfrost materials.

16. FLEXIBLE PAVEMENT DESIGN EXAMPLES FOR SEASONAL FROST CONDITIONS.

a. Example 1. Design an Air Force heavy-load pavement type B traffic area. The design freezing index at the site is 9,331-degree Celsius hours (700-degree Fahrenheit days). The highest elevation of ground water is about 915 millimeters (3 feet) below the surface of the subgrade. The subgrade is a lean clay (CL), with a plasticity index of 18. The average moisture content of the subgrade is 18 percent. The nonfrost design CBR of the lean clay subgrade is 13. A high quality crushed base-course material with a normal period CBR of 100 is to be used.

(1) Reduced subgrade strength design.

(a) The subgrade is classified as an F3 frost susceptible soil from Table 20-1. From Table 20-3, the FASSI value for an F3 soil is 3.5.

(b) Use the FASSI value with Figure 10-19 as though it were a CBR. Locate the value of 3.5 and move down to type B curve; the combined thickness of pavement required is 1.78 meters (70 inches).

(c) From Table 8-5, the minimum thickness of the surface course is 127 millimeters (5 inches). Therefore, the required base and subbase course thickness is 1.65 meters (65 inches).

(d) Compare pavement thickness with the limited subgrade frost penetration design.

(2) Limited subgrade frost penetration design.

(a) The moisture content of the base course is 3 percent, and the density of the base course is 2,400 kg/m^3 (150 lb/ft^3). From Table 8-5, a minimum thickness of a 127-millimeter

(5-inch) asphalt concrete layer is required. The frost penetration a from Figure 20-5 is 1,143 millimeters (45 inches).

(b) The required base thickness c for zero frost penetration from Equation 20-8 is:

$$c = a - p = 1{,}145 - 127 = 1{,}016 \text{ millimeters (40 inches)}$$

$$p = \text{asphalt concrete thickness of 127 millimeters (5 inches)}$$

(c) Compute water content ratio r from Equation 20-13. $r = 18/3 = 6$. Since $r > 2.0$ for type B traffic area, use $r = 2.0$ with Figure 20-6. From Figure 20-6, the allowable subgrade frost penetration is approximately 178 millimeters (7 inches). Again, from Figure 20-6, the design base thickness b as determined by the limited subgrade frost penetration method is 685 millimeters (27 inches).

(d) The base thickness of 685 millimeters (27 inches) is less than the thickness of 1,651 millimeters (65 inches) from the reduced subgrade design. In this case, the thickness from limiting subgrade frost penetration design is more economical than from the reduced subgrade design. Also, the thickness from the limited subgrade frost penetration is greater than that obtained from the nonfrost design (see Paragraph 5a, Example 1, Chapter 12). Therefore, the combined thickness (combined asphalt plus base and subbase material) of 813 millimeters (32 inches) will be used as the design thickness.

(e) The pavement structure could be made up of 127 millimeters (5 inches) of surface course, 102 millimeters (4 inches) of a NFS drainage layer beneath the surface course, 254 millimeters (10 inches) of NFS base course, 228 millimeters (9 inches) of S1 or S2 subbase, 102 millimeters (4 inches) of a NFS drainage layer. A geotextile fabric separation layer shall be placed between the subgrade and the drainage layer.

(f) No subgrade preparation is required because the 813-millimeter (32-inch) combined thickness of pavement and base exceeds two-thirds of the design frost penetration depth of 762 millimeters (30 inches).

b. Example 2. Design a type A traffic area on an Army Class III airfield as defined in Paragraph 4c, Chapter 2. The design freezing index of the area is 39,990-degree Celsius hours (3,000-degree Fahrenheit days). The subgrade is a mixture of poorly graded gravely sand and silty sand with a fine content of about 9 percent. The average moisture content of the subgrade is 9 percent. The nonfrost design CBR of the subgrade is 16.

(1) Reduced subgrade strength design.

(a) The subgrade can be classified as SP-SM soil. It also classifies as an F2 frost susceptible soil from Table 20-1. From Table 20-3, the FASSI value for an F2 soil is 6.5.

(b) From Figure 10-3 with a FASSI (CBR) value of 6.5, the combined thickness of pavement required is 330 millimeters (13.0 inches).

(c) From Table 8-3, the minimum thickness of the surface course is 51 millimeters (2 inches). Therefore, the required base and subbase course thickness is 279 millimeters (11.0 inches).

(d) Compare pavement thickness with the limited subgrade frost penetration design.

(2) Limited subgrade frost penetration design.

(a) The moisture content of the base course is assumed to be 3 percent. The density of the base course is assumed to be 2,403 kg/m^3 (150 lb/ft^3). From Table 8-3, a minimum thickness of a 51-millimeter (2-inch) asphalt concrete layer is required. The frost penetration a from Figure 20-5 is 3.6 meters (142 inches).

(b) The required base thickness c for zero frost penetration from Equation 20-8 is:

$$c = a - p = 142 - 2 = 140 \text{ inches in English units}$$

$$= 3{,}600 - 51 = 3{,}549 \text{ millimeters in SI units}$$

(c) In this case the base thickness of 3,549 millimeters (140 inches) is more than the thickness of 339 millimeters (13 inches) from the reduced subgrade design. Therefore, the thickness from reduced subgrade design is more economical than from the limiting subgrade frost penetration design. Also, the thickness from the reduced subgrade design is greater than that obtained from the nonfrost design. Therefore, the combined thickness of 330 millimeters (13.0 inches) will be used as the design thickness. The pavement structure could be made up of 51 millimeters (2 inches) of surface course, 100 millimeters (4 inches) of an NFS drainage layer beneath the surface course, and 178 millimeters (7.0 inches) of NFS base over a separation layer. A geotextile fabric could be placed between the subgrade and base course as a separation layer. Subgrade preparation is required to a depth of 610 millimeters (24 inches) based on the subgrade preparation criteria described in Paragraph 10a.

17. RIGID PAVEMENT DESIGN EXAMPLES FOR SEASONAL FROST CONDITIONS.

a. Example 1. Design an Air Force medium-load pavement. The design air freezing index at the site is 9,330-degree Celsius hours (700-degree Fahrenheit days). The highest elevation of groundwater is about 914 millimeters (3 feet) below the surface of the subgrade. The subgrade is a silty sand with 20 percent finer than 0.02 mm by weight. The average moisture content of the subgrade is 15 percent. The nonfrost design modulus of soil reaction k is 54 MN/m^3 (200 $lb/in.^3$). The 90-day concrete flexural strength R is 4.8 MPa (700 psi).

(1) Reduced subgrade strength design.

(a) From Table 20-1, the subgrade is classified as a F3 frost susceptible soil.

(b) Select several combined base thicknesses and obtain FAIR values from Figure 20-5 or from Equation 20-1. For example:

Combined Base Thickness, mm (in.)	FAIR Values, MN/m^3 (lb/in.^{3})
100 (4)	7.6 (28)
150 (6)	10.6 (40)
200 (8)	13.7 (51)
300 (12)	19.7 (74)
460 (18)	29.5 (108)
610 (24)	38.6 (142)

(c) Use the FAIR value with Figure 12-7 as though it were a k value and determine the thickness of PCC pavement.

Combined Base Thickness, mm (in.)	FAIR Value MN/m^3 (lb/in.^{3})	Traffic Area PCC Thickness, mm (in.)			
		A	B	C	D
100 (4)	7.6 (28)	627 (24.7)	620 (24.4)	500 (19.7)	386 (15.2)
150 (6)	10.6 (40)	594 (23.4)	584 (23.0)	465 (18.3)	353 (13.9)
200 (8)	13.7 (51)	566 (22.3)	556 (21.9)	439 (17.3)	330 (13.0)
300 (12)	19.7 (74)	523 (20.6)	516 (20.3)	399 (15.7)	292 (11.5)
460 (18)	29.5 (108)	475 (18.7)	467 (18.4)	356 (14.0)	254 (10.0)
610 (24)	38.6 (142)	439 (17.3)	432 (17.0)	320 (12.6)	244 (9.6)

(d) Plot combined base versus PCC thickness for the different traffic areas as shown in Figure 20-11. Locate equal or nearly equal thickness of PCC and base course as shown in the figure. From Figure 20-11, the minimum thickness for the combined base course and PCC layer are as follows:

Traffic Area	Combined Base Thickness, mm (in.)	PCC Pavement Thickness, mm (in.)
A	483 (19.0)	483 (19.0)
B	470 (18.5)	470 (18.5)
C	381 (15.0)	381 (15.0)
D	292 (11.5)	292 (11.5)
Shoulder[1]	152 (6.0)	152 (6.0)

[1] The thickness of the shoulder was determined in a similar fashion as for the other traffic areas. Use Figure 12-17 for determining pavement thickness.

(e) Compare these reduced subgrade strength pavement thicknesses with those required for the Limited Subgrade Frost Penetration Design procedure.

(2) Limited subgrade frost penetration design.

(a) From Figure 12-7, the minimum thickness of PCC concrete layer required in nonfrost areas are:

Traffic Area	PCC Thickness, mm (in.)
A	406 (16.0)
B	394 (15.5)
C	305 (12.0)
D	241 (9.5)

The average moisture content and density of the combined base is assumed to be 3 percent and 2,403 kg/m^3 (150 lb/ft^3), respectively. The frost penetration a is obtained from Figure 20-5 or from Equation 20-9. For pavement thickness exceeding 305 millimeters (12 inches), deduct 133-degree Celsius hours (10-degree Fahrenheit days) from the design freezing index for each inch in excess of 305 millimeters (12 inches).

Traffic Area	PCC Thickness mm (inches)	Design Freezing Index °C-hr (°F-days)	Frost Penetration, a, mm (in.)[1]
A	406 (16.0)	8,800 (660)	1,067 (42)
B	394 (15.5)	8,865 (665)	1,067 (42)
C	305 (12.0)	9,331 (700)	1,118 (44)
D	241 (9.5)	9,331 (700)	1,118 (44)

[1] Obtained from Equation 20-9.

(b) The required combined base thickness c for complete frost penetration into the subgrade from Equation 20-12 is:

$c = a - p$ $\qquad$ p = PCC thickness

Traffic Area	Frost Penetration, a, mm (in.)	PCC Thickness, p, mm (in.)	Combined Base Thickness c, mm (in.)
A	1,067 (42)	406 (16.0)	661 (26.0)
B	1,067 (42)	394 (15.5)	673 (26.5)
C	1,118 (44)	305 (12.0)	813 (32.0)
D	1,118 (44)	241 (9.5)	877 (34.5)

(c) Compute water content ratio r from Equation 20-13.

r = water content of subgrade/water content of base

= 15/3 = 5

For r ≥ 2.0, for types A and B traffic areas, use r = 2.0 with Figure 20-6. For r ≥ 3.0, for types C and D traffic areas use r = 3.0 with Figure 20-6. Determine the design combined base-course thickness (b) and amount of subgrade frost penetration (s) for the combined base thickness.

Traffic Area	Design Combined Base Thickness b mm (in.)	Subgrade Frost Penetration Depths mm (in.)
A	432 (17)	114 (4.5)
B	432 (17)	127 (5.0)
C	457 (18)	127 (5.0)
D and Overruns	508 (20)	127 (5.0)

(d) Compare these design pavement thicknesses with those obtained with the reduced subgrade strength design procedures.

In this case, the thicknesses required for traffic areas A, B, and C using the limited subgrade frost penetration design are more economical than from the reduced subgrade strength design. For traffic area D, even though the limited subgrade frost penetration design requires the greatest thickness of pavement and base, it may still be the most economical design as it requires only 241 millimeters (9.5 inches) of PCC versus the 292 millimeters (11.5 inches) required by the reduced subgrade strength design procedure. The designer must make a decision based upon a comparison of costs between the PCC and the base material. The design pavement thickness selection is shown below. The final thickness of PCC for the same base-course thickness for nonfrost conditions is also shown. The thicker value of the two will be used.

	Reduced Subgrade Strength Method mm (in.)			Limited Subgrade Frost Penetration mm (in.)		
Traffic Area	PCC	Combined Base	Total	PCC	Combined Base	Total
A	483 (19.0)	483 (19.0)	966 (38.0)	406 (16.0)	432 (17.0)	838 (33.0)
B	470 (18.5)	470 (18.5)	940 (37.0)	394 (15.5)	432 (17.0)	826 (32.5)
C	381 (15.0)	381 (15.0)	762 (30.0)	305 (12.0)	457 (18.0)	762 (30.0)
D	292 (11.5)	292 (11.5)	584 (23.0)	241 (9.5)	508 (20.0)	749 (29.5)

		Frost Design Thickness, mm (in.)		Nonfrost Design Thickness, mm (in.)	
Traffic Area	Design Method	PCC	Combined Base	PCC	Combined Base
A	LSFP	406 (16.0)	432 (17.0)	318 (12.5)	432 (17.0)
B	LSFP	394 (15.5)	432 (17.0)	318 (12.5)	432 (17.0)
C	LSFP	305 (12.0)	457 (18.0)	254 (10.0)	457 (18.0)
D	RSS or LSFP	292 (11.5) 241 (9.5)	292 (11.5) 508 (20.0)	203 (8.0)	292 (11.5)

(e) The combined base course can be divided into several layers having thicknesses as given in the following table. With F3 soils, in lieu of drainage layer under the PCC pavement, a drainage layer between the subbase and the separation layer should be considered. The divisions shown are one of many possibilities. Judgment must be used when layer thicknesses are selected.

Traffic Area	Combined Base Thickness mm (in.)	NFS Base Layer mm (in.)	S1 or S2 Subbase Layer mm (in.)	Drainage Layer mm (in.)	Separator Layer mm (in.)
A	432 (17.0)	229 (9.0)	--	102 (4)	102 (4)
B	432 (17.0)	229 (9.0)	--	102 (4)	102 (4)
C	457 (18.0)	254 (10.0)	--	102 (4)	102 (4)
D	292 (11.5)	89 (3.5)	--	102 (4)	102 (4)

(f) Compute the required depth of subgrade preparation.

Traffic Area	Total Pavement Thickness, mm (in.)	Frost Penetration, mm (in.)	Depth of Subgrade Preparation[1] mm (in.)
A	965 (38.0)	1,067 (42.0)	-102 (-4.0)
B	940 (37.0)	1,067 (42.0)	-127 (-5.0)
C	762 (30.0)	1,118 (44.0)	-356 (-14.0)
D	584 (23.0)	1,118 (44.0)	-533 (-21.0)

[1] No subgrade preparation required.

b. Example 2. Design an Air Force heavy-load pavement airfield. The design air freezing index at the site is 26,660-degree Celsius hours (2,000-degree Fahrenheit days). The highest elevation of groundwater is about 1.5 meters (5 feet) below the surface of the subgrade. The subgrade is a very fine silty sand with 20 percent finer than 0.02 mm by weight. The average moisture content of the subgrade is 21 percent. The nonfrost design modulus of soil reaction is 27.1 MN/m^3 (100 lb/in.^{3}). The 90-day concrete flexural strength R is 4.83 MPa (700 psi).

(1) Reduced subgrade design.

(a) From Table 20-1, the subgrade is classified as F4 frost susceptible soil.

(b) Select 6 combined base-course thicknesses and obtain FAIR values from Figure 20-1 or from Equation 20-3.

Combined Base Thickness, mm (in.)	FAIR Values, MN/m^3 (lb/in.^{3})
102 (4)	7.6 (28)
152 (6)	10.6 (40)
203 (8)	13.7 (51)
305 (12)	19.7 (74)
457 (18)	29.5 (108)
610 (24)	38.6 (142)

(c) Use FAIR values with Figure 20-7 as though they were k values and determine the thickness of PCC pavement.

Combined Base Thickness, mm (in.)	FAIR Value MN/m^3 (lb/in.^{3})	Traffic Area PCC Thickness, mm (in.)			
		A	B	C	D
102 (4)	7.6 (28)	693 (27.3)	688 (27.1)	572 (22.5)	450 (17.7)
152 (6)	10.6 (40)	671 (26.4)	666 (26.2)	546 (21.5)	432 (17.0)
203 (8)	13.7 (51)	653 (25.7)	648 (25.5)	531 (20.9)	419 (16.5)
305 (12)	19.7 (74)	622 (24.5)	617 (24.3)	508 (20.0)	399 (15.7)
457 (18)	29.5 (108)	594 (23.4)	589 (23.2)	485 (19.1)	379 (14.9)
610 (24)	38.6 (142)	574 (22.6)	572 (22.5)	467 (18.4)	363 (14.3)

(d) Plot base course versus PCC thickness for the different traffic areas as shown in Figure 20-12. Locate equal or nearly equal thickness of PCC and combined base course as shown in the figure. The minimum thicknesses for the base and PCC layers are as follows:

Traffic Area	Combined Base Thickness, mm (in.)	PCC Pavement Thickness, mm (in.)
A	579 (22.8)	579 (22.8)
B	577 (22.7)	577 (22.7)
C	483 (19.0)	483 (19.0)
D	386 (15.2)	386 (15.2)
Shoulder[1]	152 (6)	152 (6)

[1] The thickness of the shoulder was determined in a similar fashion as for the other traffic areas. Use Figure 12-16 to determine minimum pavement thickness.

(e) Compare these reduced subgrade strength pavement thicknesses with those required for the limited subgrade frost penetration design.

(2) Limited subgrade frost penetration design.

(a) From Figure 20-7, the minimum PCC thickness for nonfrost conditions is as follows:

Traffic Area	PCC Thickness, mm (in.)
A	599 (23.6)
B	597 (23.5)
C	490 (19.3)
D	384 (15.1)

For pavement thicknesses greater than 305 millimeters (12 inches), deduct 133-degree Celsius hours (10-degree Fahrenheit days) from the design freezing index for each 25 millimeters (1 inch) in excess of 508 millimeters (12 inches).

(b) Assuming the average moisture content and density of the combined base course is 7 percent and 2,403 kg/m^3 (150 lb/ft^3), respectively, the maximum frost penetration a is obtained from Figure 20-5 or from Equation 20-10.

Traffic Area	PCC Thickness mm (in.)	Design Freezing Index °C hr (°F-days)	Frost Penetration mm (in.)
A	592 (23.6)	25,114 (1,884)	2,235 (88)
B	597 (23.5)	25,127 (1,885)	2,235 (88)
C	490 (19.3)	25,687 (1,927)	2,286 (90)
D	384 (15.1)	26,246 (1,969)	2,311 (91)

(c) The required base thickness c for zero frost penetration into the subgrade from Equation 20-12 is as shown in the following tabulation:

Traffic Area	Frost Penetration, a mm (in.)	PCC Thickness, p mm (in.)	Combined Base Thickness, c mm (in.)
A	2,235 (88)	599 (23.6)	1,636 (64.4)
B	2,235 (88)	557 (23.5)	1,638 (64.5)
C	2,286 (90)	490 (19.3)	1,796 (70.7)
D	2,311 (91)	384 (15.1)	1,928 (75.9)

(d) Compute water content ratio r.

r = water content of subgrade/water content of base

= 21/7 = 3

For $r \geq 2.0$, for type A and B traffic areas, use $r = 2.0$ with Figure 20-6. For $r \geq 3.0$, for type C and D traffic areas use $r = 3.0$ with Figure 20-6. Determine the design combined base-course thickness b and amount of subgrade frost penetration s for the combined base thickness.

Traffic Area	Design Base Thickness b, mm (in.)	Subgrade Frost Penetration s, mm (in.)
A	1,054 (41.5)	287 (11.3)
B	1,054 (41.5)	287 (11.3)
C	988 (38.9)	259 (10.2)
D	1,059 (41.7)	277 (10.9)

(e) Compare these design pavement thicknesses with those obtained with the reduced subgrade strength design procedure.

	Reduced Subgrade Strength Method			Limited Subgrade Frost Penetration		
Traffic Area	PCC mm (in.)	Combined Base mm (in.)	Total mm (in.)	PCC mm (in.)	Combined Base mm (in.)	Total mm (in.)
A	579 (22.8)	579 (22.8)	1,158 (45.6)	599 (23.6)	1,054 (41.5)	1,654 (65.1)
B	577 (22.7)	577 (22.7)	1,153 (45.4)	597 (23.5)	1,054 (41.5)	1,651 (65.0)
C	483 (19.0)	483 (19.0)	965 (38.0)	490 (19.3)	988 (38.9)	1,478 (58.2)
D	386 (15.2)	386 (15.2)	772 (30.4)	384 (15.1)	1,059 (41.7)	1,443 (56.8)

The reduced subgrade strength method produced the more economical design for all traffic areas. A comparison must be made with the nonfrost pavement thickness. With F4 subgrade soils, in lieu of drainage layer under the PCC pavement, a drainage layer between the subbase and the separation layer should be considered. The divisions shown are one of many possibilities. Judgment must be used when layer thicknesses are selected.

Traffic Area	Total "Combined Base" Thickness mm (in.)	NFS Base Layer mm (in.)	S1 or S2 Subbase Layer mm (in.)	Drainage Layer mm (in.)	Separator Layer mm (in.)
A	1,168 (46.0)	610 (24.0)	356 (14)	102 (4)	102 (4)
B	1,156 (45.5)	622 (24.5)	330 (13)	102 (4)	102 (4)
C	965 (38.0)	508 (20.0)	250 (10)	102 (4)	102 (4)
D	775 (30.5)	419 (16.5)	152 (6)	102 (4)	102 (4)

(3) Subgrade preparation. The depth of subgrade preparation D will be the lesser of the following:

(a) D = 610 millimeters (24.0 inches).

(b) D = [2/3 · (maximum frost penetration)] - (Combined thickness of PCC, base, subbase and drainage layers).

Traffic Area	Frost Penetration mm (in.)	Combined Pavement Thickness, mm (in.)	Subgrade Preparation Depth, mm (in.)
A	2,235 (88)	1,168 (46.0)	330 (13.0)
B	2,235 (88)	1,156 (45.5)	330 (13.0)
C[1]	2,285 (90)	965 (38.0)	178 (7.0)
D[1]	2,311 (91)	775 (30.5)	381 (15.0)

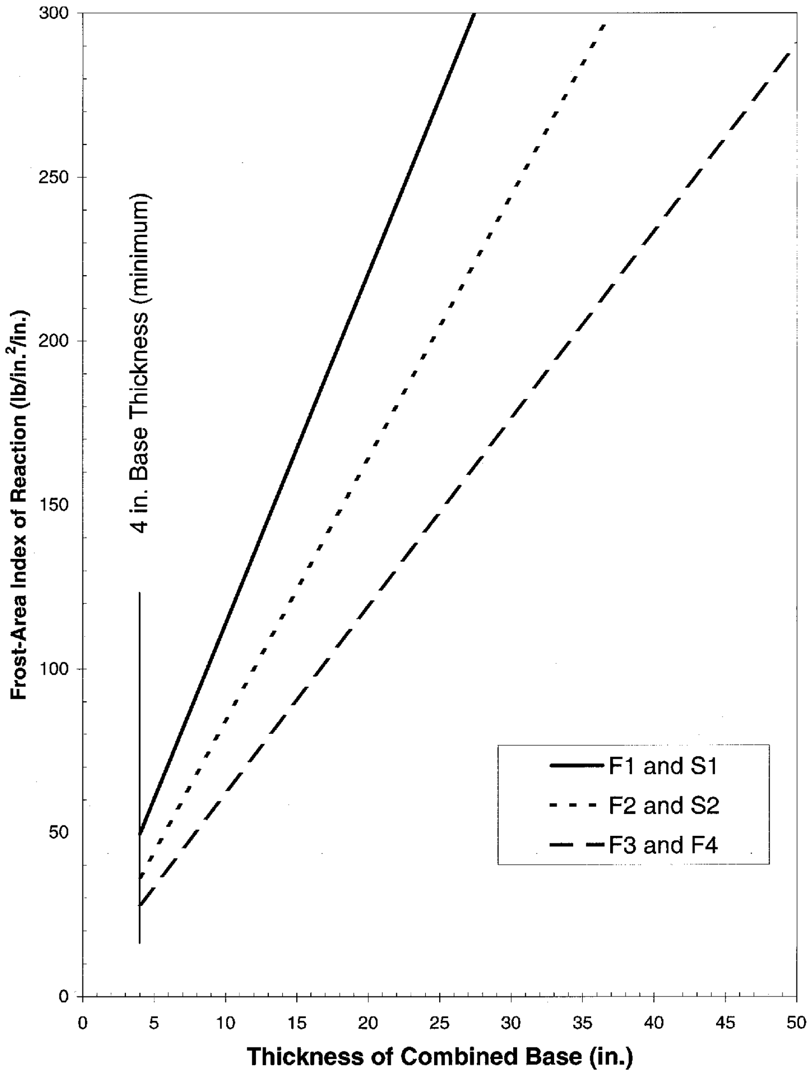
[1] Use one-half rather than two-thirds frost penetration for traffic areas C and D.

(c) D = 1,829 millimeters (72 inches) - (Combined Pavement Thickness).

Traffic Area	Combined Pavement Thickness, mm (in.)	D, mm (in.)
A	1,168 (46.0)	660 (26.0)
B	1,156 (45.5)	673 (26.5)
C	965 (38.0)	864 (34.0)
D and Overruns	775 (30.5)	1,054 (41.5)

The Final Depth of Subgrade Preparation D will be:

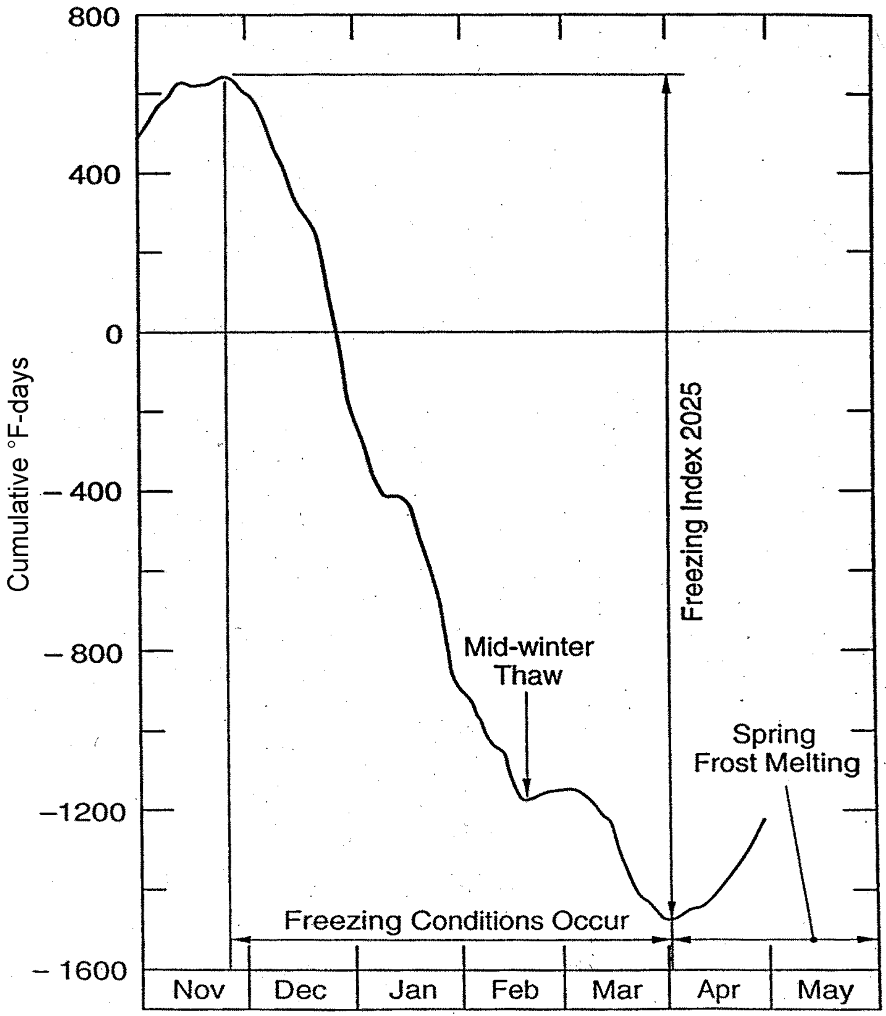
Traffic Area	**D, mm (in.)**
A	330 (13.0)
B	330 (13.0)
C	179 (7.0)
D	381 (15.0)



CONVERSION FACTORS

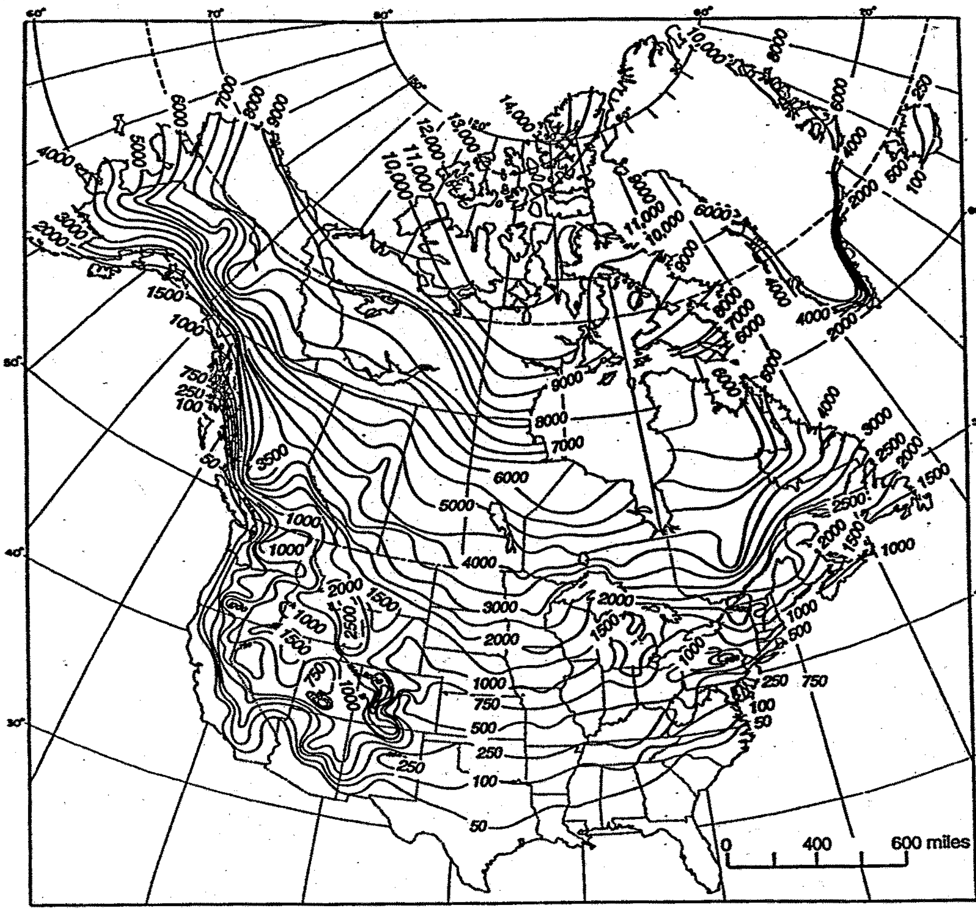
MEGANEWTONS PER CUBIC METER = 0.271 x PCI
MILLIMETERS = 25.4 x INCHES

Figure 20-1. Frost area index of reaction (FAIR) for design of rigid pavements



CONVERSION FACTORS
°C - HOURS = 13.33 x °F DAYS

Figure 20-2. Determination of freezing index



CONVERSION FACTORS
°C - HOURS = 13.33 x °F DAYS

Figure 20-3. Distribution of design freezing indexes in North America

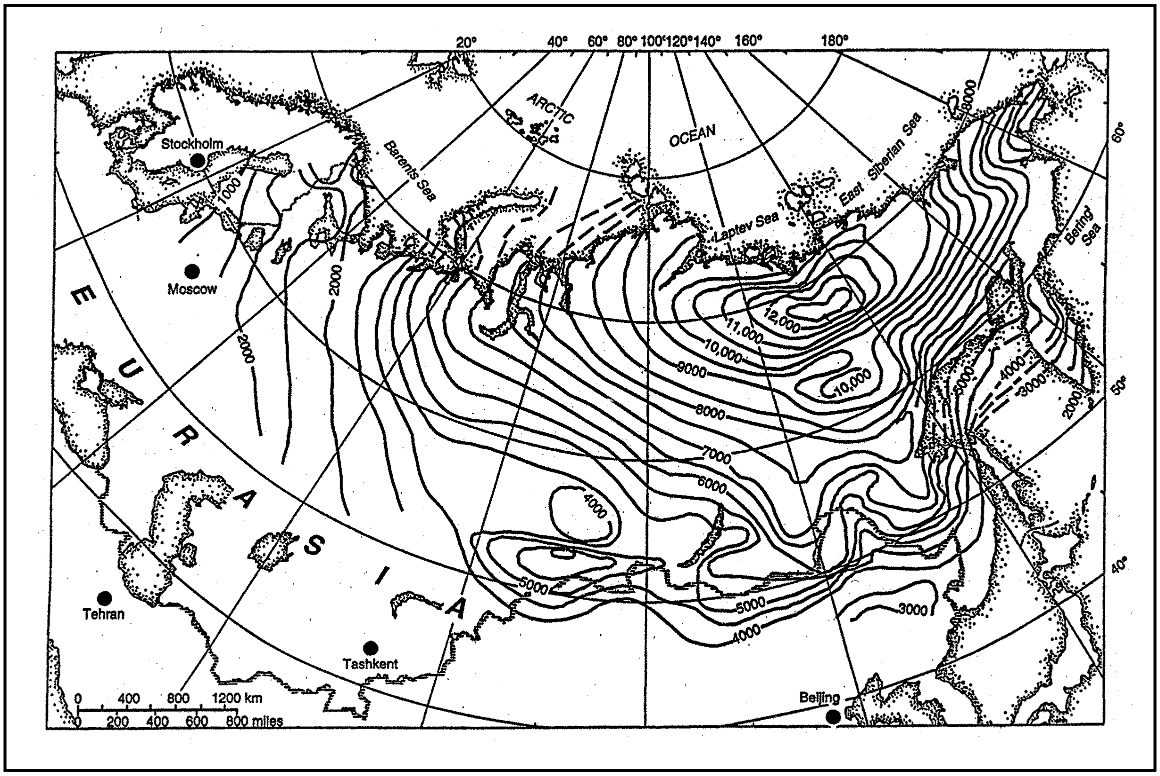
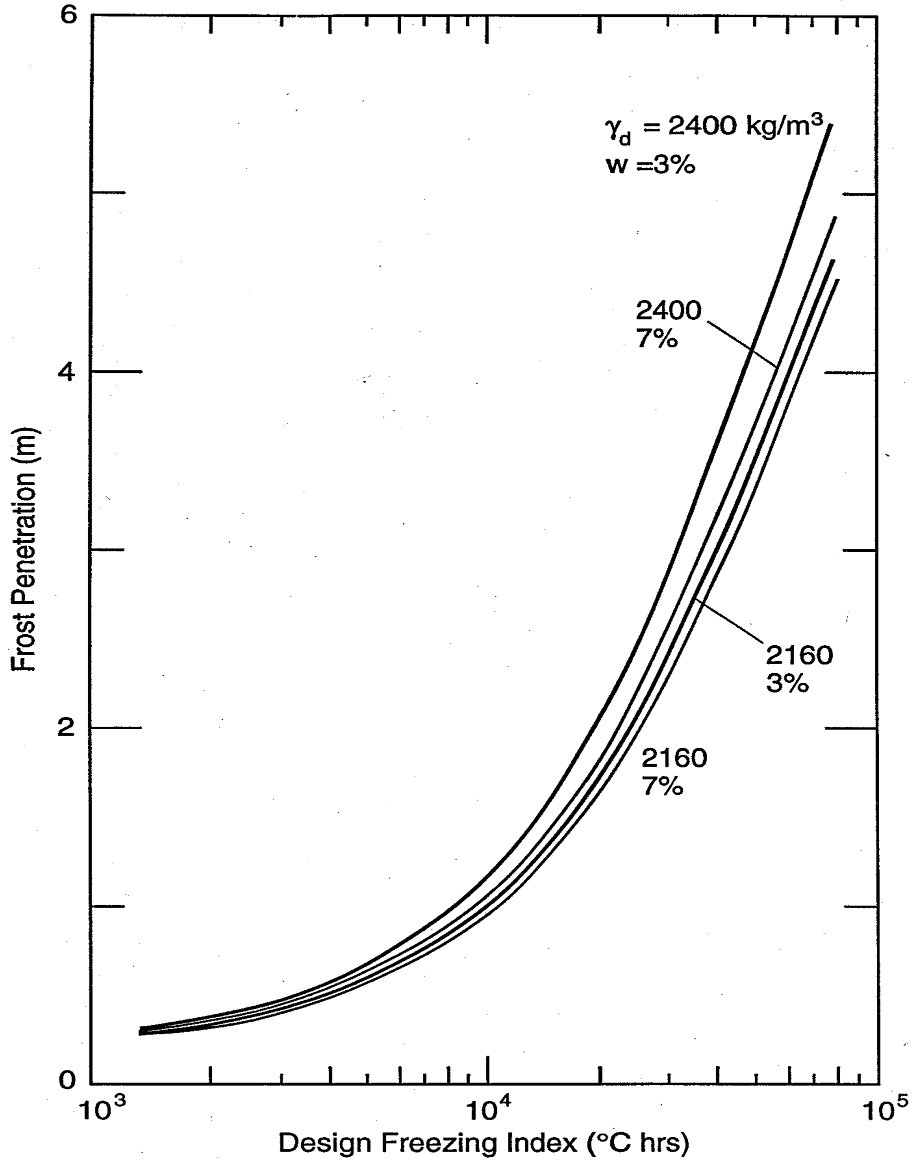


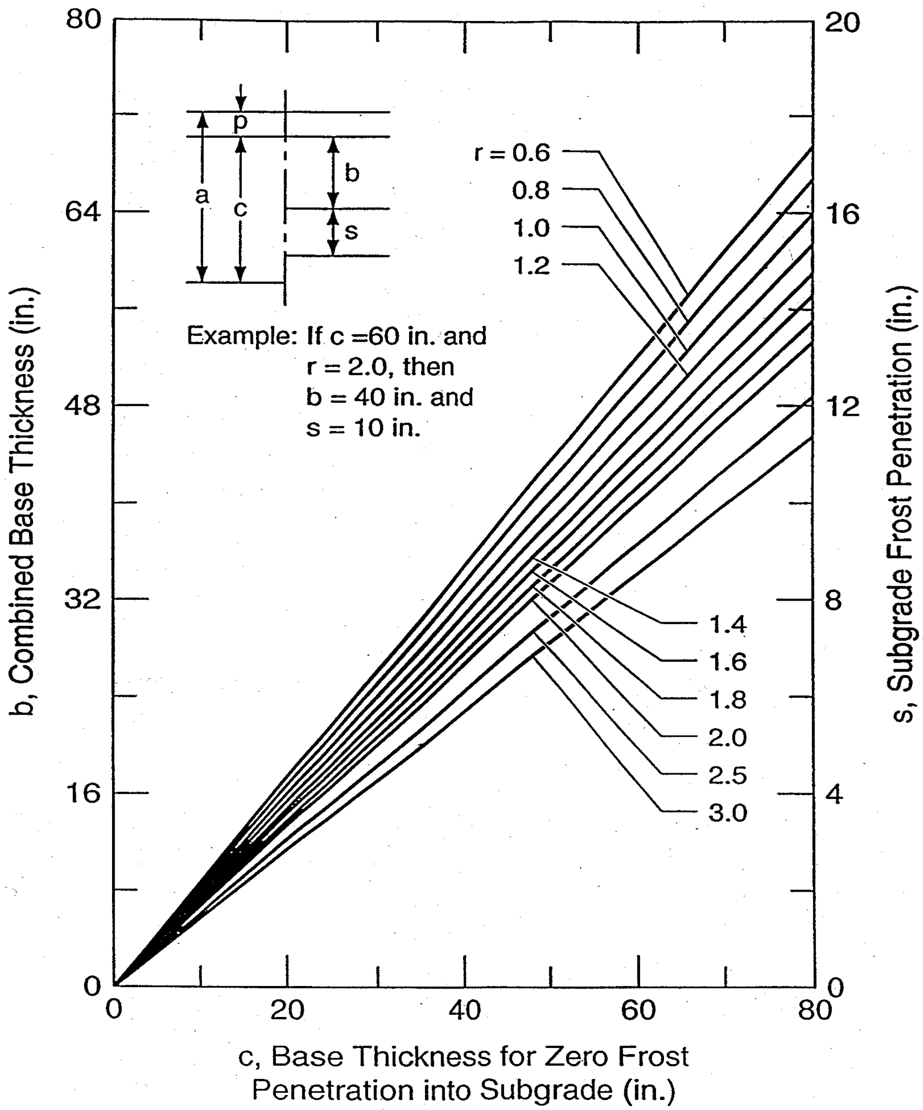
Figure 20-4. Distribution of mean freezing indexes in Northern Eurasia



CONVERSION FACTORS

°C HOURS = 13.33 x °F DAYS
MILLIMETERS = 25.4 x INCHES

Figure 20-5. Frost penetration beneath pavements



CONVERSION FACTOR

MILLIMETERS = 25.4 x INCHES

Figure 20-6. Design of combined base thickness for limited subgrade frost penetration

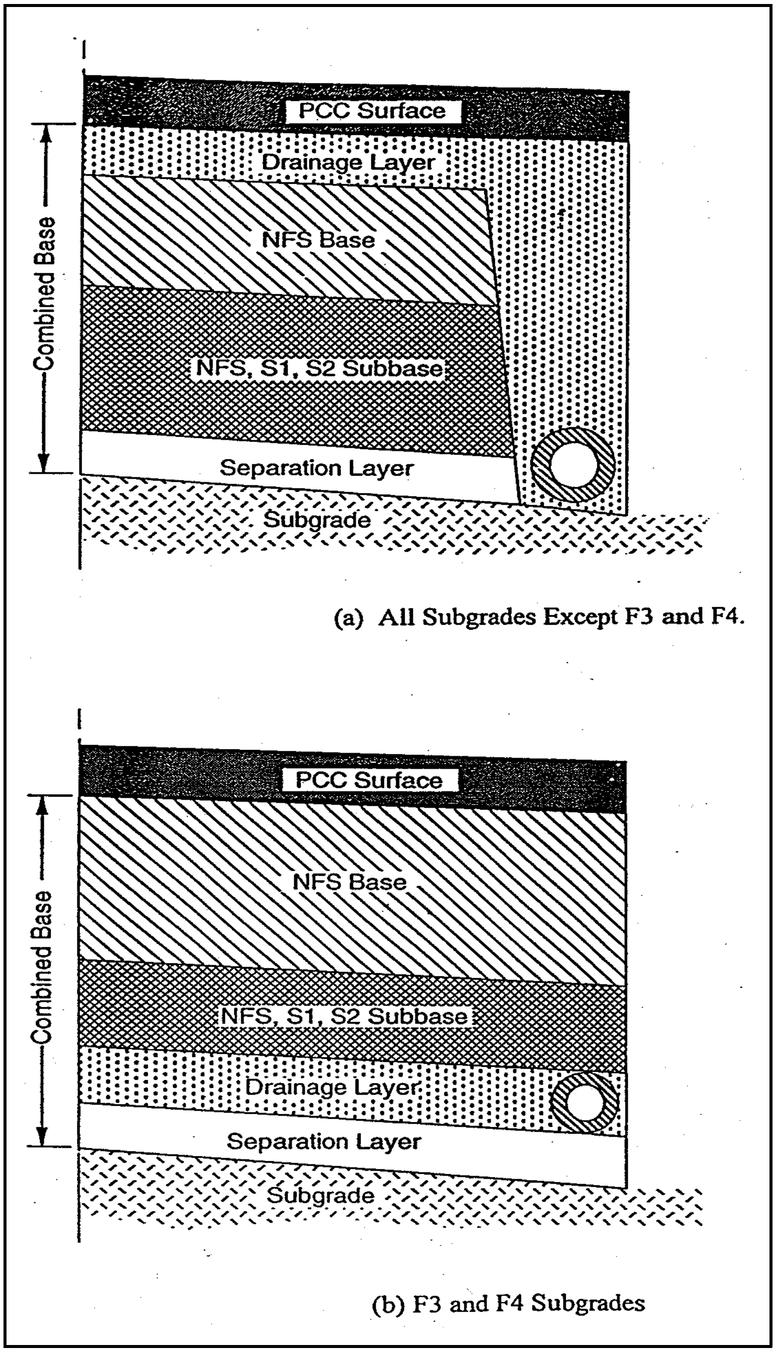


Figure 20-7. Placement of drainage layer in frost areas

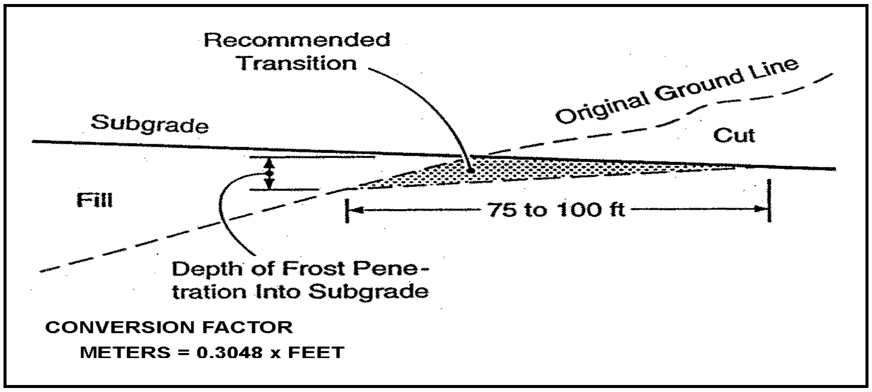
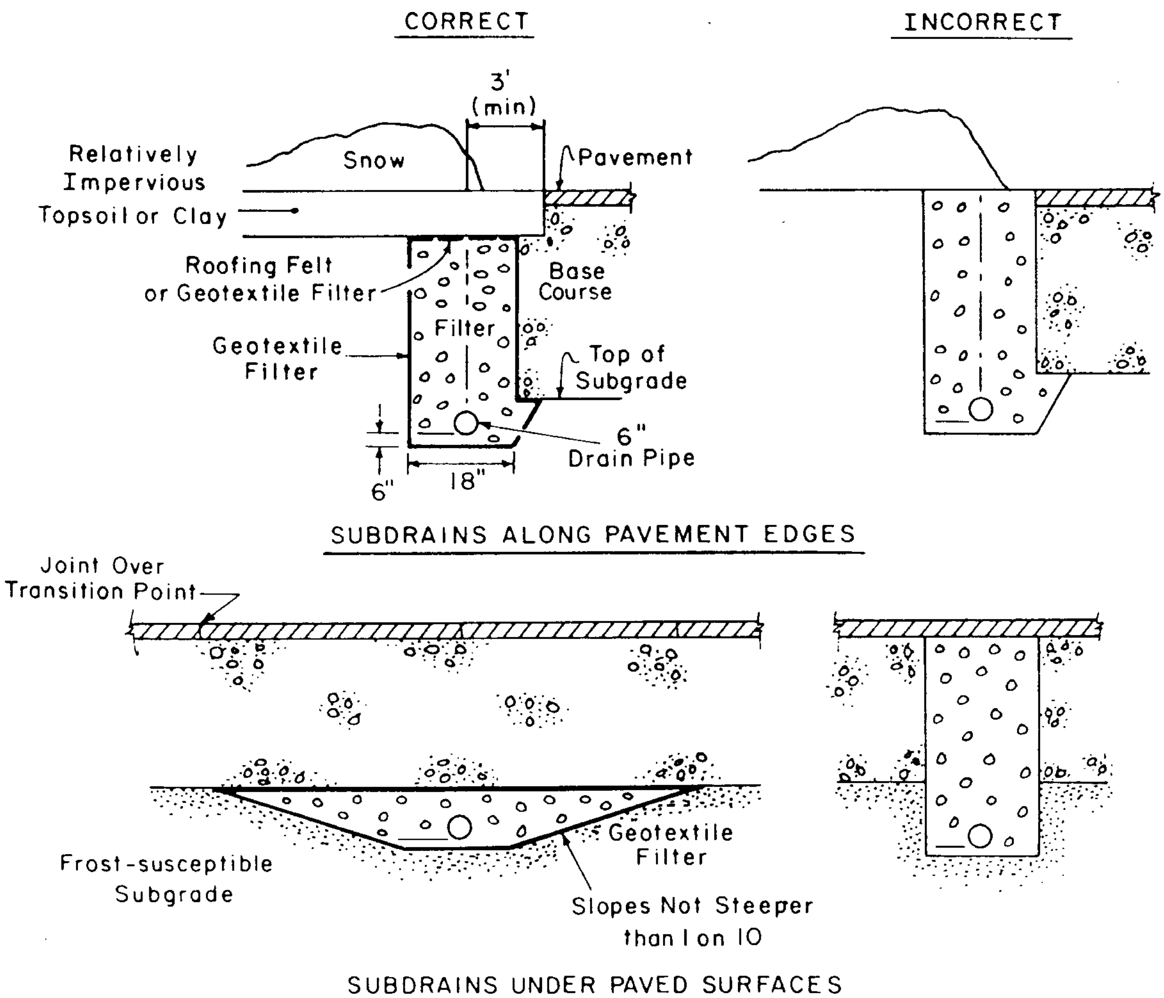


Figure 20-8. Tapered transition used where embankment material differs from natural subgrade in cut



NOTES

1. For additional details on design and depth of subdrains and filter courses see TM 5-820-2 (AFM 88-5, Chap. 2).

2. Granular or geotextile fabric filter may be necessary between base course and subgrade (para. 5-4).

3. Upper 4 inches of base course must have free-draining characteristics (para. 5-1).

Figure 20-9. Subgrade details for cold regions

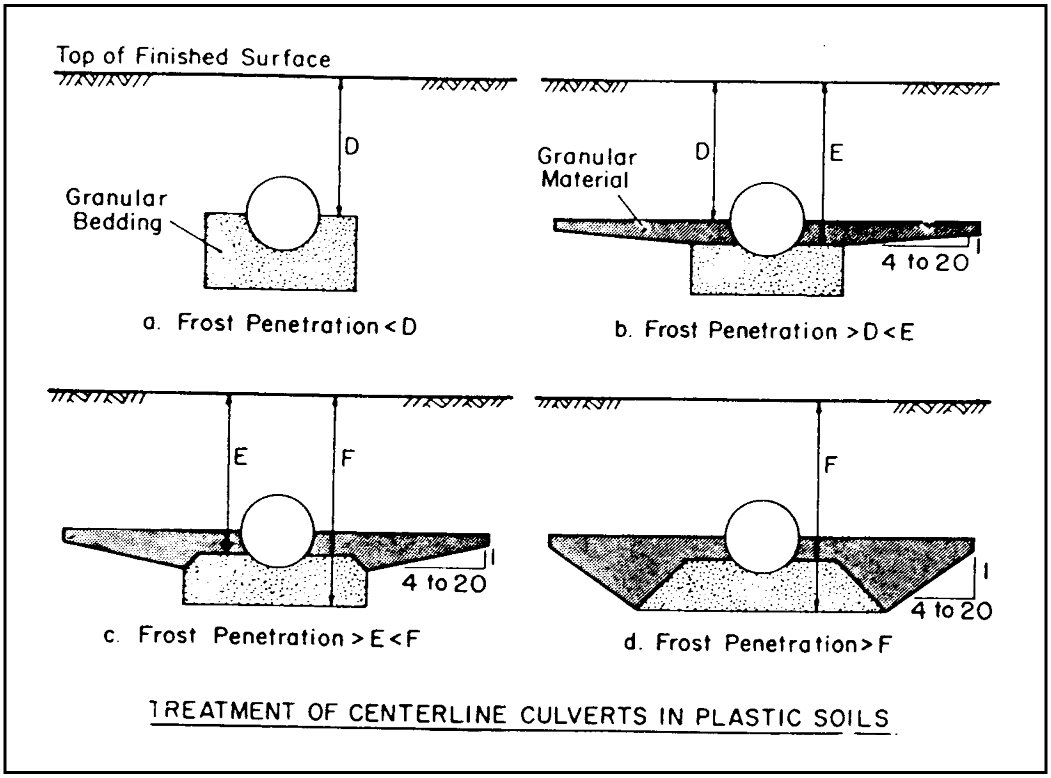
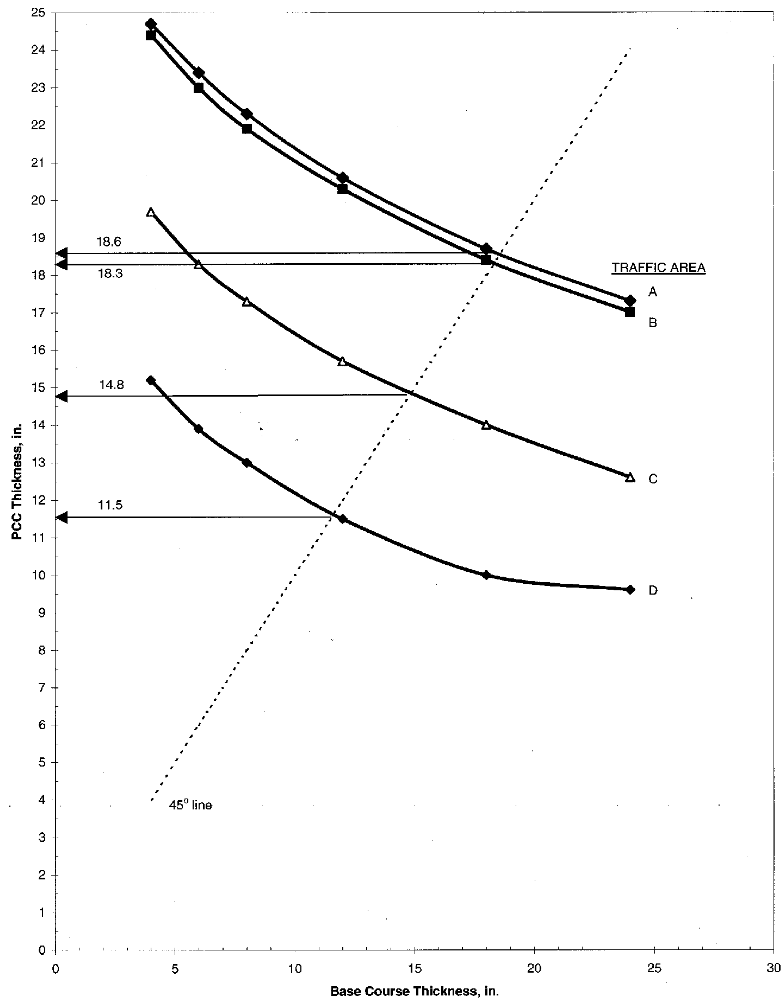
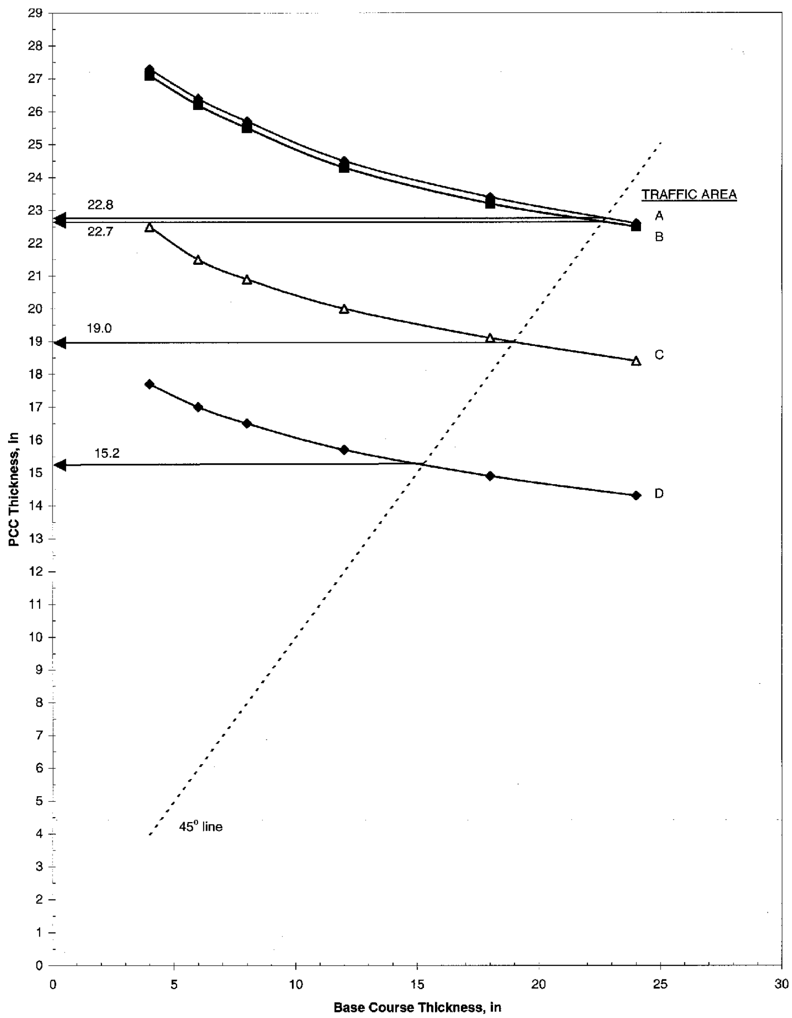


Figure 20-10. Transitions for culverts beneath pavements



CONVERSION FACTOR
MILLIMETERS = 25.4 x INCHES

Figure 20-11. Relationship between base course thickness and PCC thickness for example 1



CONVERSION FACTOR

MILLIMETERS = 25.4 x INCHES

Figure 20-12. Relationship between base course thickness and PCC thickness for example 2

CHAPTER 21

IMPROVING SKID RESISTANCE/REDUCING HYDROPLANING POTENTIAL OF RUNWAYS

1. GENERAL. This chapter presents procedures for improving skid resistance and reducing hydroplaning tendency of runways. It applies to the Army and Air Force. Navy guidance is contained in NAVFAC Criteria Office Memorandum dated 24 March 1999, Subject: INTERIM TECHNICAL GUIDANCE (ITG)-SKID RESISTANCE CRITERIA FOR AIRFIELD PAVEMENTS.

a. Skid resistance is the resistance to sliding by aircraft tires on a pavement surface. Skid resistance is related to the frictional resistance of the pavements. A high coefficient of friction is indicative of high skid resistance. Low friction resistance may result from polishing of the surface aggregate, rubber buildup, improper seal coating, or poor drainage.

b. Hydroplaning occurs when a tire looses contact with the surface as a result of the buildup of water pressure in the tire-ground contact area. The potential for hydroplaning is a function of speed, water depth, pavement texture, tire inflation pressure, and tread design.

c. Procedures for conducting friction testing and an approved equipment list are contained in Federal Aviation Administration Advisory Circular, AC 150/5320-12C, "Measurement, Construction, and Maintenance of Skid-Resistant Airport Pavement Surfaces".

2. IMPROVING RUNWAY FRACTION CHARACTERISTICS. New, reconstructed, or resurfaced runways must be grooved except when resurfaced with a Porous Friction Surface (PFS). The grooving is required to provide an acceptable surface for safe operation of aircraft. Friction characteristics of existing runways need to be improved when tests indicate the surface has a potential for hydroplaning. Considerations for improving the friction characteristics include grooving, Porous Friction Surfaces, retexturing, improving runway slopes, and rubber removal. Table 21-1, developed by the National Aeronautics and Space Administration, provides guidance on friction ratings for friction measuring equipment. Improving friction characteristics of existing runways should be considered when friction ratings are less than Good.

Table 21-1
Nominal Test Speed, 65 km/h (40 mph)

	Ground Vehicle Readings									
Braking Action Level	RCR	Grip-Tester	James Brake Index	MU-Meter	Surface Friction Tester	Runway Friction Tester	BV-11 Skiddo-Meter	Decel Meters	Locked Wheel Devices	ICAO INDE
Good	>17	>0.49	.0.58	>0.50	>0.55	>0.51	>0.59	>0.53	>0.51	5
Fair	12-17	0.34-0.49	0.40-0.58	0.35-0.50	0.38-0.54	0.35-0.51	0.42-0.59	0.37-0.53	0.37-0.51	3-4
Poor	6-11	0.16-0.33	0.20-0.39	0.15-0.34	0.18-0.37	0.18-0.34	0.21-0.41	0.17-0.36	0.18-0.36	2-3
NL	≤5	≤0.14	≤0.17	≤0.14	≤0.16	≤0.15	≤0.19	≤0.16	≤0.15	

a. Sawcut grooving is a proven way of reducing the hydroplaning potential of runways. Grooves drain water laterally, permit water to escape under tires, prevent buildup of surface water, and increase the texture of the pavement.

(1) Pavement condition. Grooves should only be applied to structurally adequate pavement free from defects. Pavements requiring corrective action should be overlaid or rehabilitated prior to grooving. Porous Friction Surfaces should not be grooved.

(2) Grooving flexible pavements. Studies indicate that grooving of flexible pavements does not cause any appreciable deterioration of the pavement nor has maintenance effort been increased. No problems have occurred from ice and snow removal. Minor distortion and creeping of grooves have been observed, but these conditions have not required maintenance or adversely affected pavement performance.

(3) Groove pattern. Grooves will be continuous for the entire length of the usable runway and perpendicular to the centerline. Grooves should terminate within 1.5 to 3 meters (5 to 10 feet) of pavement edge to allow for operation of grooving equipment. The standard groove configuration is 6 millimeters (¼ inch) ± 2 millimeters (± 1/16 inch) in depth by 6 millimeters (¼ inch) + 2 millimeters – 0 millimeters (+1/16 inch, -0 inch) in width by 38 millimeters (1 1/2 inch) – 3 millimeters + 0 millimeters (-1/8 inch, + 0 inch) center-to-center spacing. The recommended groove detail for airfield pavements is shown in Figure 21-1.

(4) Limitations. Do not groove within 6 inches (± 3 inches) of the runway centerline. Do not groove within 152 millimeters (6 inches) of transverse joints or working cracks, through compression seals, in-runway lighting fixtures or similar items, or the first 3 meters (10 feet) either side of an arresting barrier cable which requires hook engagement for operation. There is no need for grooving on either side of barrier cables that are placed on overruns.

b. Porous Friction Surfaces. A porous friction course is an open-graded, free draining asphalt mixture that can be placed on an existing pavement to minimize hydroplaning and to improve skid resistance. A PFS is placed in a layer varying from 19 to 25 millimeters (3/4 to 1 inch) thick. It has a coarse surface texture and is sufficiently porous to permit internal drainage as well as along the surface. Existing pavements should be in good condition before placing the mix. Concerns with PFS include rubber buildup that might prevent internal drainage, possible freezing of water trapped in voids, and loss of expertise in designing and constructing these surfaces. PFS should not be placed within 3 meters (10 feet) of an arresting gear cable.

c. Retexturing. Retexturing of runways has been successfully accomplished using several types of equipment. Contact the MAJCOM Pavements Engineers for guidance on Air Force projects and the TSMCX on Army projects.

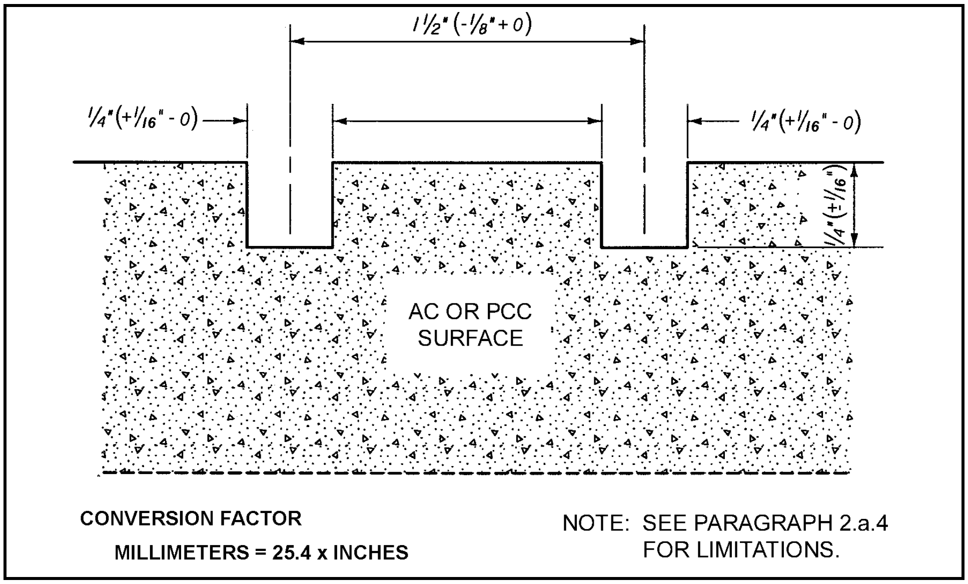


Figure 21-1. Groove configuration for airfields

APPENDIX A

REFERENCES

GOVERNMENT PUBLICATIONS

United Facility Criteria

Efforts were begun in FY00 to unify all Army, Navy, and Air Force design and construction technical criteria. The United Facility Criteria (UFC) number, old corresponding document number, and title for those documents referenced in this publication that now have UFC numbers are as follows:

UFC 3-260-01 (TM 5-803-7/ AFMAN 32-1123(I)/NAVFAC P-971)	Airfield and Heliport Planning and Design
UFC 3-260-03 (TI 826-01/ AFMAN 32-1121V1(I)/ NAVFAC DM 21.7)	Airfield Pavement Evaluation

Departments of the Army, Navy, and the Air Force

TM 5-803-4	Planning of Army Aviation Facilities
TM 5-820-1/AFM 88-5, Chap. 1	Surface Drainage Facilities for Airfields and Heliports
TM 5-820-2/AFM 88-5, Chap. 2	Subsurface Drainage Facilities for Airfields
TM 5-818-1/AFM 88-3, Chap. 7	Soils and Geology: Procedures for Foundation Design of Buildings and Other Structures (Except Hydraulic Structures)
TM 5-818-7	Foundations in Expansive Soils
TM 5-818-8/AFJMAN 32-1030	Engineering Use of Geotextiles
TM 5-820-1/AFM 88-5, Chap. 1	Surface Drainage Facilities for Airfields and Heliports
TM 820-3/AFM 880-5, Chap. 3	Drainage and Erosion Control Structures for Airfields and Heliports
TM 5-822-12	Design of Aggregate Surfaced Roads and Airfields
TM 5-822-14/AFJMAN 32-1019	Soil Stabilization for Pavements
TM 5-822-7/AFM 88-6, Chap. 8	Standard Practice for Concrete Pavements

TM 5-822-8/AFM 88-6, Chap. 9	Bituminous Pavements Standard Practice
TM 5-825-1/AFMAN 32-8008, Vol 1	General Provisions for Airfield/Heliport Pavement Design, Appendix D, Operations Plan for Runway Friction Characteristics Testing
TM 5-826-1/AFM 88-24, Chap. 1	Army Airfield Pavement Evaluation Concepts
TM 5-826-2/AFM 88-24, Chap. 2	Airfield Flexible Pavement Evaluation
TM 5-826-3/AFM 88-24, Chap. 3	Airfield Rigid Pavement Evaluation
TM 5-852-6/AFM 88-19, Chap. 6	Arctic and Subarctic Construction, Calculation Methods for Determination of Depth of Freeze and Thaw
EI 02C013/AFJMAN 32-1013/ NAVFAC P971	Airfield and Heliport Planning Criteria
EI 02C202/AFJMAN 32-1016	Subsurface Drainage for Pavements
EI 02C029/AFJMAN 32-1029	Asphalt Concrete Pavements Standard Practice
ETL 1110-3-475	Roller Compacted Concrete Pavement Design and Construction
TI 822-08/AFMAN 32-1131 V8(I)/DM 21.11	Standard Practice Manual for Flexible Pavements
FM 5-430-00-2/AFJPAM 32-8013, Vol II	Planning and Design of Roads, Airfields and Heliports in the Theater of Operations
AFM 86-2	Standard Facility Requirements
AFR 86-5	Planning Criteria and Waivers for Airfield Support Facilities
AFR 86-14	Airfield and Heliport Planning Criteria
AFR 93-5	Airfield Pavement Evaluation Program
AF ETL 98-5	C-130 and C-17 Contingency and Training Airfield Dimensional Criteria
MIL-HDBK-1021/2	General Concepts for Airfield Pavement Design
NAVFAC DM 21.06	Airifield Pavement Design for Frost Conditions and Subsurface Drainage
NAVFAC DM 21.09	Skid Resistant Runway Surfaces

NAVFAC DM 5.04	Civil Engineering - Pavements
NAVFAC DM 7.01	Soil Mechanics
NAVFAC NFGS 02522	Joints, Reinforcement, and Mooring Eyes in Concrete Pavement
NAVFAC NFSC02562	Resealing of Joints in Rigid Pavements
NAVFAC P-272	Design Definitives for Navy and Marine Corps Shore Facilities
NAVFAC P-971	Airfield and Heliport Planning and Design

General Services Administration

Fed. Spec. SS-S-200E	Sealing Compounds, Two-Component, Elastomeric, Polymer Type, Jet-Fuel-Resistant, Cold-Applied
Federal Aviation Administration Advisory Circular AC 150/5320-12C	Measurement, Construction, and Maintenance of Skid-Resistance Airport Pavement Surfaces
Corps of Engineers CEGS 02721	Subbase Courses

U.S. Army Engineers, Waterways Experiment Station, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199

CRD-C 21	Method of Test of Modulus of Elasticity of Concrete in Flexure
CRD-C 525	Corps of Engineers Test Method 4, Evaluation of Hot-applied Joint Sealants for Bubbling due to Heating
CRD-C 653	Standard Test Method for Determination of Moisture Density Relations of Soils
CRD-C 654	Standard Test Method for Determining the California Bearing Ratio of Soils
CRD-655	Standard Test Method for Determining the Modulus of Soil Reaction
CRD-656	Standard Test Method for Determining the California Bearing Ratio and for Sampling Pavement by the Small Aperture Method

Nongovernment Publications

American Society for Testing and Materials (ASTM), 1916 Race Street, Philadelphia, PA 19103

A 82	Cold-Drawn Wire for Concrete Reinforcement
A 184	Fabricated Deformed Steel Bar Mats for Concrete Reinforcement
A 185	Welded Steel Wire Fabric for Concrete Reinforcement
A 416	Uncoated Seven-Wire Stress-Relieved Strand for Prestressed Concrete
A421	Uncoated Stress-Relieved Wire for Prestressed Concrete
A497	Welded Deformed Steel Wire Fabric for Concrete Reinforcement
A 615	Deformed and Plain Billet-Steel Bars for Concrete Reinforcement
A 616	Rail-Steel Deformed and Plain Bars for Concrete Reinforcement
A617	Specification for Axle-Steel Deformed and Plain Bars For Concrete Reinforcement
C 29	Test for Unit Weight and Voids in Aggregates
C 33	Specification for Concrete Aggregates
C 78	Flexural Strength of Concrete (using Single-Beam with Third Point Loading)
C 88	Test for Soundness of Aggregate by use of Sodium Sulfate or Magnesium Sulfate
C 127-88	Test for Specific Gravity and Absorption of Coarse Aggregate
C 128-88	Test for Specific Gravity and Absorption of Fine Aggregate
C 131-89	Test for Resistance to Abrasion of Small Size Coarse Aggregate by Use of the Los Angeles Machine

C 150	Portland Cement
C 289	Test Method for Potential Reactivity of Aggregates (Chemical Method)
C-294	Descriptive Nomenclature of Constituents of Natural Mineral Aggregates
C 617-85	Capping Cylindrical Concrete Specimens
C 618	Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete
C 977	Test method for Sulfide Resistance of Ceramic Decorations on Glass
C 989	Specification for Ground Iron Blast-Furnace Slag for Use in Concrete and Mortars
D 5-86	Penetration of Bituminous Materials
D 36-86	Softening Paint of Bitumen
D 75-87	Sampling Aggregates
D 242-85	Specifications for Mineral Filler for Bituminous Paving Mixtures
D 422-63	Particle Size Analysis of Soils
D 560-89	Freezing and Thawing Tests of Compacted Soil Cement Mixtures
D 558	Test Method for Moisture-Density Relations of Soil Cement Mixtures
D 946	Penetration-Graded Asphalt Cement for Use in Pavement Construction
D 977	Emulsified Asphalt
D 1140-54	Amount of Material in Soils Finer than the No. 200 Sieve
D 1190-97	Specifications for Concrete Joint Sealer, Hot-Applied Elastic Type

D 1196	Nonrepetative Static Plates Load Tests of Soils and Flexible Pavement Components for Use in Evaluation and Design of Airport and Highway Pavements
D 1452-80	Soil Investigations and Sampling by Auger Borings
D 1556-90	Density and Unit Weight of Soil in Place by the Sand Cone Method
D 1557-78	Moisture Density Relations of Soils and Soil Aggregate Mixtures
D 1559-89	Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus
D 1560-81	Resistance to Deformation and Cohesion of Bituminous Mixtures by Means of Hveem Apparatus
D 1561-81	Preparation of Bituminous Mixture Test Specimens by Means of California Kneading Compactor
D 1586-84	Penetration Test and Split-Barrell Sampling of Soils
D 1587-83	Thin-Walled Tube Sampling of Soils
D1632-87	Making and Curing Soil-Cement Compression and Flexure Test Specimens in the Laboratory
D 1633-84	Compressive Strength of Molded Soil-Cement Cylinders
D 1883-87	California Bearing Ratio of Laboratory Compacted Soils
D 2026	Cutback Asphalt (Slow-Curing Type)
D 2027	Cutback Asphalt (Medium-Curing Type)
D 2028	Cutback Asphalt (Rapid-Curing Type)
D 2397	Specifications for Cationic Emulsified Asphalt
D 2628-98	Specification for Preformed Polychloroprene Elastomeric Joint Seals for Concrete Pavements

D 2835-89	Lubricant for Installation of Preformed Compression Seals in Concrete Pavements
D 2922-81	Density of Soil and Soil-Aggregate In-Place by Nuclear Methods
D 2937-83	Density of Soil In-Place by the Drive-Cylinder Method
D 2940	Specification for Graded Aggregate Material for Bases or Subbases for Highways or Airports
D 3017-78	Moisture Content of Soil and Soil Aggregate In-Place by Nuclear Methods
D 3202	Recommended Practice for Preparation of Bituminous Mixture Beam Specimens by Means of the California Kneading Compactor
D 3405-96	Specifications for Joint Sealants, Hot-Applied, for Concrete and Asphalt Pavements
D 3406-95	Specifications for Joint Sealants, Hot-Applied, Elastomeric-Type, for Portland Cement Concrete Pavements
D 3381-83	Viscosity-Graded Asphalt Cement for Use in Pavement Construction
D 3515	Specification for Hot-Mixed, Hot-Laid Bituminous Paving Mixtures
D 3569-95	Specifications for Joint Sealants, Hot-Applied, Elastomeric, Jet-Fuel-Resistant-Type for Portland Cement Concrete Pavements
D 3581-96	Specifications for Joint Sealants, Hot-Applied, Elastomeric, Jet-Fuel-Resistant Type for Portland Cement and Tar-Concrete Pavements
D 5893-96	Specifications for Cold-Applied, Single Component Chemically Curing Silicon Joint Sealant for Portland Cement Concrete Pavement
D 4318-84	Liquid Limit, Plastic Limit, and Plasticity Index of Soils
D 4429-84	Bearing Ratio of Soils in Place

D 5340-94	Airport Pavement Condition Index Surveys
E 11-87	Wire Cloth Sieves for Testing Purposes

McLeod, N. W. "Using Paving Asphalt Rheology to Impair or Improve Asphalt Pavement Design and Performance," *Asphalt Rheology: Relationship to Mixture*, ASTM STP 941, O. E. Briscoe, Ed., American Society for Testing and Materials, Philadelphia, 1987.

McLeod, N. W. "A 4-Year Survey of Low-Temperature Transverse Pavement Cracking on Three Ontario Test Roads," *Proceedings, Association of Asphalt Paving Technologists*, Vol 41, 1972.

Asphalt Institute, Asphalt Institute Building, College Park, MD 20740

MS-2	Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types

American Concrete Institute, P.O. Box 19150, Redford Station, Detroit, MI 48219

ACI 318	Building Code Requirements for Reinforced Concrete
ACI 544.IR-82	State of the Art Report on Fiber Reinforced Concrete

American Association of State Highway and Transportation Officials (AASHTO), 444 North Capitol Street, N.W., Suite 249, Washington, DC 20001

PP6	Grading or Verifying the Performance Grade of an Asphalt Binder

APPENDIX B

AIRFIELD/HELIPORT DESIGN ANALYSIS OUTLINE

B-1. INTRODUCTION.

a. Purpose of Report. To describe the project design in sufficient detail for review, evaluation, and documentation of the design.

b. Scope of Report.

(1) State the design phase that the report covers.

(2) List topics discussed in report.

c. Project Description.

(1) Extent of proposed construction (new construction; runway extension; apron expansion; overlay; rehabilitation and repair; upgrade lighting; drainage, security, and navigational aids improvements; etc.)

(2) Purpose of proposed construction or improvements.

(3) Types and amount of construction activities (demolition, excavation and embankment, grading, paving, patching, marking, fencing, seeding, etc.)

d. Project Authorization (reference authorization letter, directive, or other pertinent items, with dates).

e. Design Criteria. (Reference the key criteria and directives used in the design, with dates. Since criteria are constantly being revised and updated, the key criteria should be documented so that the basis of the design can become a historical record.)

(1) Correspondence and Directives.

(2) Engineering Technical Letters (ETLs).

(3) Technical Manuals (TM's and AFMs).

(4) Engineering Circulars (ECs).

(5) Pavement Evaluations/Condition Surveys.

(6) Computer Programs.

(7) Other special design criteria.

B-2. SITE DESCRIPTION.

a. Location (location map with graphical scale).

(1) Existing airfield/heliport facilities (layout, type, etc.)

(2) Location of proposed project with respect to existing facilities, utilities, or improvements.

(3) Extent of proposed construction (size, dimensions, etc.).

b. Topography/Drainage of Site.

(1) Topography (hilly, rolling, flat, terrace, floodplain, etc.).

(2) Surface drainage (characteristics and direction).

(3) Subsurface drainage (characteristics, groundwater conditions and elevations, including seasonal variations).

(4) Existing surface and subsurface drainage facilities (type, location, capacity, condition, etc.).

c. Climate (use National Oceanographic and Atmospheric Administration or Military installation's weather service center for climatological data where available).

(1) Temperatures (especially with reference to frost condition and design air freezing index).

(2) Rainfall (particularly with respect to its effect on construction operations).

(3) Seasonal variations.

d. Vegetation (wooded, open, brush, cultivated fields).

e. Geology.

(1) Sequence and character of surface and near-surface deposits. Soil overburden (glacial, stream, loess deposits, etc.).

(2) Rock outcroppings.

B-3. FIELD INVESTIGATIONS.

a. Subgrade explorations (type of investigations, number, locations, depth, samples obtained).

b. Borrow explorations for fill (type of investigations, number, locations, depth, samples obtained).

c. Availability of construction materials (type of material, location; name and description of pits, quarries, or other sources; samples obtained).

(1) Sand and gravel deposits.

(2) Aggregates (base-course, concrete, and bituminous mixtures).

(3) Cementitious materials (portland cement, fly ash, and asphalt; type; class; grade).

(4) Water.

d. Evaluations of Existing Pavements (describe all evaluations conducted).

(1) Destructive.

(2) Nondestructive.

B-4. TESTING.

a. Laboratory (describe lab testing conducted).

b. Field (describe field testing conducted).

B-5. RESULTS OF INVESTIGATIONS AND TESTING.

a. Material Characterization.

(1) Subgrade characteristics (soil classifications, unit weights, moisture-density relationships, gradations, Atterberg limits, CBR and/or modulus of subgrade reaction, permeability, etc.).

(2) Characteristics of borrow (same as above).

(3) Characteristics of base and subbase material (same as above).

(4) Characteristics of pavement surfacing materials.

b. Groundwater and Subsurface Drainage Conditions.

c. Frost Conditions (where applicable).

(1) Frost susceptibility of materials (based on gradation and frost classification, laboratory freeze tests, heave measurements, observations or ice lense formations in test pits, etc.).

(2) Frost penetration (based on field observations or design air-freezing index and modified Berggen equation).

(3) Moisture availability.

(4) Mean annual temperature.

(5) Duration of freezing season.

(6) Number of freeze-thaw cycles.

d. Existing Pavement Evaluation/Characterization.

e. Summarize Adopted Design Parameters.

B-6. PAVEMENT THICKNESS DESIGN CRITERIA.

a. Load (include copy of Airfield/Heliport Mission List).

(1) Airfield/heliport/helipad class or type.

(2) Design aircraft or aircraft mix.

(3) Pass levels.

(4) Mission operational weights.

(5) Traffic areas.

B-7. PAVEMENT THICKNESS DESIGN.

a. Flexible Pavement Design (for each pavement feature).

(1) Design of curves or computer programs used.

(2) Layers (thicknesses, type, design CBR-values).

(3) Compaction requirements.

(4) Proof rolling requirements.

(5) Bituminous mixture requirements (gradation, stability).

(6) Selection of AC grade.

(7) Tack and prime coat requirements (type, grade).

(8) Grooving requirements.

b. Rigid Pavement Design (for each pavement feature).

(1) Design curves or computer programs used.

(2) Flexural strength.

(3) Layers (thicknesses, type, subgrade modulus values).

(4) Compaction requirements.

(5) Joint design (spacing, type).

(6) Joint sealant (type).

(7) Grooving requirements.

c. Overlay design (for each pavement feature).

(1) Type of design (flexible, rigid, bonded, unbonded).

(2) Existing paving system characteristics.

(3) Design curves or computer programs used.

(4) Overlay layers (thicknesses, type, etc.).

(5) Surface preparation requirements.

d. Frost Design (for each pavement feature).

(1) Design methodology limited subgrade frost penetration (LSFP) or reduced subgrade strength (RSS).

(2) Design air-freezing index (for LSFP method).

(3) FASSI or FAIR value (for RSS method).

(4) Design curves or computer program used.

(5) Layers (number, thickness, type).

(6) Special subgrade, subbase, and base course preparation for frost design.

B-8. DRAINAGE DESIGN.

a. General Criteria.

b. Hydrology.

c. Surface Drainage (including drainage plans and profiles).

d. Subsurface Drainage.

B-9. PROPOSED GRADES.

a. Longitudinal (for each pavement feature).

b. Transverse (for each pavement feature).

B-10. AIRFIELD LIGHTING AND NAVAIDS IMPROVEMENTS.

B-11. CONSTRUCTION MATERIALS.

a. Rigid Pavement.

(1) Coarse aggregate (type, gradation, deleterious limits, wear, particle shape).

(2) Fine aggregate (type, gradation, deleterious limits).

(3) Cement (type).

(4) Fly ash (class).

(5) Admixtures (type).

(6) Curing compound (type).

(7) Dowels (size, type).

(8) Reinforcing (size, type).

(9) Joint filler.

(10) Joint seals (type).

b. Flexible Pavement.

(1) Aggregates (type, gradation, percent fractured faces, wear).

(2) Mineral filler.

(3) Asphalt cement (grade).

(4) Prime coat material (type, grade).

(5) Tack coat material (type, grade).

c. Base Courses.

(1) Graded crushed-aggregate base course (gradation, percent fractured faces, wear).

(2) Rapid draining base course (RDM or OGM gradation, percent fractured faces, wear).

(3) Separation layer (gradation, design CBR-value).

(4) Subbase course (gradation, design CBR-value).

d. Borrow Material.

e. Surface and Subsurface Drainage System.

(1) Pipe (size, type).

(2) Structure construction.

(3) Bedding material.

(4) Filter material.

(5) Manhole construction.

f. Pavement Marking Materials.

B-12. LIST OF REQUIRED WAIVERS.

a. Reference regulation document (title, page, para.).

b. State the regulation in violation.

c. State the reason the waiver is required.

B-13. COST ESTIMATES.

a. Capital costs.

b. Life-cycle costs.

APPENDIX C

RECOMMENDED CONTRACT DRAWING OUTLINE

FOR AIRFIELD/HELIPORT PAVEMENTS

The list of drawings that follows should be used as a guide. All drawings may not be needed for all jobs.

C-1. TITLE SHEET.

a. Project Title.

b. Location.

c. Year

d. Volume Number.

C-2. INDEX SHEET.

a. Listing of Sheet Names.

b. Assigned Sheet Numbers (in sequential order).

C-3. COMBINED TITLE/INDEX SHEETS.

C-4. LEGEND.

a. Civil.

b. Electrical.

c. Mechanical.

d. Architectural.

C-5. LOCATION/SITE PLAN.

a. Base Map with State (Vicinity) Map.

b. Project Location.

c. Contractor Access Routes.

d. Location of Base Gates and any Restrictions.

e. Borrow/Waste Areas.

f. Batch Plant Area.

g. Contractor's Staging and/or Storage Area.

h. Utility Hookup Locations.

I. General or Special Notes.

j. Concurrent Construction (Not in Contract).

C-6. PHASING PLAN AND DETAILS.

a. Location and Sequencing of Work Areas.

b. Scheduling for each Phase of Project.

c. General Listing of Tasks to be Performed under each Phase.

d. Concurrent Construction that may Affect each Phase.

e. Location and Type of Area Control (Security) Measures.

(1) Temporary Barricades and Fencing.

(2) Obstruction Lighting.

(3) Temporary Pavement Markings (Closure Markings).

f. Traffic Circulation (Aircraft and Vehicular).

g. Special Notes.

(1) Security Measures.

(2) Contractor's Housekeeping Measures.

(3) Controls on Contractor's Traffic.

C-7. HORIZONTAL AND VERTICAL CONTROLS.

a. Layout.

b. Bench Marks (USGS Datum) with only one Master Bench Mark.

c. Control Stationing.

d. Horizontal Control (Coordinates).

C-8. GEOMETRIC LAYOUT PLAN (OPTIONAL).

a. Curve Data.

b. Control Stationing.

c. Geometric Layout.

C-9. BORING LOCATION PLAN AND BORING LOG DATA.

C-10. PAVEMENT REMOVAL PLAN.

a. Pavement Removal Limits (Dimensions, Stationing, etc.).

b. Type and Thickness of Pavement Removed.

c. Utilities and Structures Affected by the Removal.

(1) Manholes.

(2) Barrier Arresting Cables.

(3) Blast Deflectors.

(4) Runway/Taxiway Lighting.

(5) Communication Cables.

(6) Water/Sewer Lines.

(7) In Ground Aircraft Support Systems.

d. Special Notes Regarding Removals.

e. Location of Removal Sections.

C-11. REMOVAL SECTIONS AND DETAILS. Sections should be specific, not general or typical. Show several sections. Show new sections for changes in pavement type, thickness, or any other condition that has an impact on pavement construction. Sections should be complete both laterally and vertically for the entire pavement structure including subgrade preparation.

a. Removal Limits (Lateral Dimensions, Depth).

b. Show Make-Up of the Existing Pavement.

(1) Pavement Type and Thickness.

(2) Joint Type (Doweled, Tied, Contraction, etc.).

(3) Existing Reinforcing (if any).

c. Special Notes.

(1) Equipment Type/Size.

(2) Procedures.

(3) Housekeeping.

(4) Other.

C-12. EXISTING UTILITIES PLAN.

a. Show Existing Utility Locations and Type.

b. Show Pavement Penetrations.

C-13. PAVING PLAN.

a. Thickness.

b. Type.

c. Location.

d. Location of Section Cuts.

e. Stationing.

f. Dimensions.

C-14. PAVING SECTIONS. Make the sections specific. Do not overuse "Typical Sections." Cut a section wherever there is a change from one pavement section to another in any direction and on all pavement edges. The same section may be referenced numerous places on the plan sheets, but each location must be marked and properly annotated. Remember, only by including everything in the plans can the design be built as envisioned. One hour spent by the designer will save several hours work by the field engineer.

a. Include the entire paving section from surface through subgrade.

(1) Thickness of Surface.

(2) Prime Coat Requirements.

(3) Thickness of Bases and Subbases.

(4) Thickness of Drainage Layer.

(5) Depth and Type of Subgrade Preparation.

b. Jointing Locations and Type.

c. Surface Grades/Slope.

d. Subsurface Drainage/Subdrain Provisions.

C-15. PLAN AND PROFILE SHEETS.

a. Plan.

(1) Outline of Pavement.

(2) Utilities.

(3) Stationing.

(4) Geometrics.

b. Profile.

(1) Stationing.

(2) Elevations (new and existing).

(3) Vertical Curve Data.

(4) Utility Depth and Location.

C-16. GRADING AND DRAINAGE PLANS.

a. Contours (new and existing).

b. Surface and Subsurface Drainage System Layouts, Structure Locations, Types, and Sizes.

c. Ditch Alignment.

C-17. GRADING SECTIONS.

a. Cut/Fill Requirements.

b. Topsoil Requirements.

C-18. PAVEMENT SURFACE ELEVATIONS.

a. Spot Elevation Plan (joint intersections or grid pattern).

b. Spot Elevation Schedule.

C-19. PAVEMENT JOINTING PLANS.

a. Legend with Joint Types.

b. Joint Location.

C-20. JOINT AND JOINT SEALANT DETAILS.

C-21. REINFORCING DETAILS.

a. Dowels.

b. Reinforcement.

c. Tie Bars.

d. Complete Pavement Joint Details.

C-22. SURFACE AND SUBSURFACE DRAINAGE SYSTEMS.

a. Profiles.

b. Schedules.

c. Details.

C-23. AIRFIELD REPAIR PLAN AND DETAILS.

C-24. PAVEMENT MARKING.

a. Plan.

b. Details.

C-25. AIRCRAFT MOORING AND GROUNDING POINTS.

a. Plan.

b. Details.

C-26. GROOVING PLAN AND DETAILS.

C-27. RUNWAY/TAXIWAY LIGHTING.

a. Plan.

b. Schedule.

c. Details.

C-28. MECHANICAL (FUEL).

a. Plans.

b. Profiles.

c. Schedules.

d. Details.

APPENDIX D

WAIVER PROCESSING PROCEDURES

D.1. Army:

D.1.1. Waiver Procedures:

D.1.1.1. Installation. The installation's design agent, aviation representative (Safety Officer, Operations Officer, and/or Air Traffic and Airspace AT&A Officer) and DEH Master Planner will:

D.1.1.1.1. Jointly prepare/initiate waiver requests.

D.1.1.1.2. Submit requests through the installation to the Major Command (MACOM).

D.1.1.1.3. Maintain a complete record of all waivers requested and their disposition (approved or disapproved). A list of waivers to be requested and those approved for a project should also be included in the project design analysis prepared by the design agent, aviation representative, or DEH Master Planner.

D.1.1.2. The MACOM will:

D.1.1.2.1. Ensure that all required coordination has been accomplished.

D.1.1.2.2. Ensure that the type of waiver requested is clearly identified as either "Temporary" or "Permanent." "Permanent Waivers" are required where no further mitigative actions are intended or necessary.

D.1.1.2.2.1. "Temporary Waivers" are for a specified period during which additional actions to mitigate the situation must be initiated to fully comply with criteria or to obtain a permanent waiver. Followup inspections will be necessary to ensure that mitigative actions proposed for each Temporary Waiver granted have been accomplished.

D.1.1.2.3. Review waiver requests and forward all viable requests to U. S. Army Aeronautical Service Agency (USAASA) for action. To expedite the waiver process, MACOMs are urged to simultaneously forward copies of the request to:

D.1.1.2.3.1. Director, U. S. Army Aeronautical Services Agency (USAASA), ATTN: ATAS-AI, 9325 Gunston Road, Suite N319, Fort Belvior, VA 22060-5582.

D.1.1.2.3.2. Commander, U.S. Army Safety Center (USASC), ATTN: CSSC-SPC, Bldg. 4905, 5th Ave., Fort Rucker, AL 36362-5363.

D.1.1.2.3.3. Director, U. S. Army Aviation Center (USAAVNC), ATTN: ATZQ-ATC-AT, Fort Rucker, AL 36362-5265.

D.1.1.2.3.4. Director, USACE Transportation Systems Center (TSMCX), ATTN: CENWO-ED-TX, 215 N 17th St., Omaha, NE 68102.

D.1.1.3. USAASA. USAASA is responsible for coordinating the following reviews for the waiver request:

D.1.1.3.1. Air traffic control assessment by USATCA.

D.1.1.3.2. Safety and risk assessment by USASC.

D.1.1.3.3. Technical engineering review by TSMCX.

D.1.1.3.4. From these reviews, USAASA formulates a consolidated position and makes the final determination on all waiver requests and is responsible for all waiver actions for Army operational airfield/airspace criteria.

D.1.2. Contents of Waiver Requests. Each request must contain the following information:

D.1.2.1. Reference to the specific standard and/or criterion to be waived by publication, paragraph, and page.

D.1.2.2. Complete justification for noncompliance with the airfield/airspace criteria and/or design standards. Demonstrate that noncompliance will provide an acceptable level of safety, economics, durability and quality for meeting the Army mission. This would include reference to special studies made to support the decision. Specific justification for waivers to criteria and allowances must be included as follows:

D.1.2.2.1. When specific site conditions (physical and functional constraints) make compliance with existing criteria impractical and/or unsafe; for example: the need to provide hangar space for all aircraft because of recurring adverse weather conditions; the need to expand hangar space closer to and within the runway clearances due to lack of land; maintaining fixed-wing Class A clearances when support of Class B fixed-wing aircraft operations are over 10% of the airfield operations.

D.1.2.2.2. When deviation(s) from criteria fall within a reasonable margin of safety and do not impair construction of long range facility requirements; for example, locating security fencing around and within established clearance areas.

D.1.2.2.3. When construction that does not conform to criteria is the only alternative to meet mission requirements. Evidence of analysis and efforts taken to follow criteria and standards must be documented and referenced.

D.1.2.3. The rationale for the waiver request, including specific impacts upon assigned mission, safety, and/or environment.

D.1.3. Additional Requirements:

D.1.3.1. Operational Factors. Include information on the following existing and/or proposed operational factors used in the assessment:

D.1.3.1.1. Mission urgency.
D.1.3.1.2. All aircraft by type and operational characteristics.
D.1.3.1.3. Density of aircraft operations at each air operational facility.
D.1.3.1.4. Facility capability (VFR or IFR).
D.1.3.1.5. Use of self-powered parking versus manual parking.
D.1.3.1.6. Safety of operations (risk management).
D.1.3.1.7. Existing NAVAIDS.

D.1.3.2. Documentation. Record all alternatives considered, their consequences, necessary mitigative efforts, and evidence of coordination.

D.2. Air Force:

D.2.1. Waivers to Criteria and Standards. When obstructions violate airfield imaginary surfaces or safe clearance criteria established in this manual, they must be analyzed to determine impact to aircraft operations. Facilities listed as permissible deviations (see attachment 14) do not require waiver if sited properly. Facilities constructed under previous standards should be documented as exemptions and programmed for replacement away from the airfield environment at the end of their normal life cycle, or when mission needs dictate earlier replacement. When documenting waiverable items, consider grouping adjacent supporting items with a controlling obstruction, or grouping related items such as a series of drainage structures, as one waiver. ***Example:*** The base operations building violates the 7H:1V Transitional Surface and apron clearance criteria. There are also four utility poles, a 36-inch tall fire hydrant, and numerous trees and shrubs located on the side of the building that is farthest away from the apron. These items are essential to provide architectural enhancement and utilities for this structure, but they also violate apron clearance criteria. Because these items are isolated from aircraft operations by the base operations building, they would not become a hazard to aircraft operations until the base operations building is relocated. Therefore, the base operations building is the controlling obstruction. Document the base operations building as an exemption (constructed under previous standards) and develop one waiver request for all supporting structures to analyze impact to aircraft operations.

D.2.1.1. Temporary Waivers (One Year or Less). Establish temporary waivers for obstructions caused by construction activities by documenting the deviations and establishing a plan (including the issuance of NOTAMs or airfield advisories) that will allow safe operations during the temporary period. Coordinate the plan with airfield management, flying safety, and flight operations before asking the Wing Commander for approval.

D.2.1.2. Permanent Waivers. Use a permanent waiver when:

D.2.1.2.1. Natural geographical features violate criteria, and it is not economical or practical to remove them.

D.2.1.2.2. Existing facilities deviate from criteria but removal is not feasible.

D.2.1.2.3. Installation, construction, or erection of a required facility or equipment item according to criteria in this manual is not practical.

D.2.1.2.4. Removal of the cause of the violation of criteria is not economical or practical.

D.2.2. Waiver Authority. Major Commands (MAJCOM) may waive deviation from airfield and airspace criteria in this manual. The responsible MAJCOM Civil Engineer approves the waiver after coordination with all appropriate staff offices and concurrence by the MAJCOM Directors of Operations and Safety. The appropriate staff office for the Air National Guard (ANG) is ANGRC/CEPD. This authority is not delegated below MAJCOM level unless published as a MAJCOM policy. The following are exceptions:

D.2.2.1. Permissible deviations to airfield and airspace criteria, which do not require waivers, are listed in Attachment 14 to this manual.

D.2.2.2. Permanent waivers may require approval or coordination from various field operating agencies when AFI 32-1042, *Standards for Marking Airfields* or AFI 32-1076, *Visual Air Navigation Facilitie*s, standards apply.

D.2.2.3. Waiver approval is required according to AFMAN 11-230, *Instrument Procedure*s, when deviations from criteria in AFMAN 32-1076 would constitute deviations from the instrument procedure criteria or obstructions to air navigational criteria in AFMAN 11-230 or AFJMAN 11-226, *United States Standard for Terminal Instrument Procedures (TERPS*).

D.2.2.4. Authority is delegated to the Wing Commander when temporary waivers for construction activities are involved.

D.2.3. Deviations From Criteria for Land Not Under Air Force Jurisdiction. Refer waivers to airfield and airspace criteria on land not under Air Force jurisdiction to the next level of command for ultimate resolution.

D.2.4. Effective Length of Waiver. Waivers will be reviewed annually.

D.2.5. Responsibilities:

D.2.5.1. HQ AFCESA/CESC:

D.2.5.1.1. Recommends policy on waivers and provides technical assistance on the waiver program.

D.2.5.2. HQ AFFSA/XA:

D.2.5.2.1. Reviews all requests for waivers (operational requirements) to sighting criteria and airspace requirements.

D.2.5.2.2. Approves all requests for waivers to instrument procedure criteria in AFMAN 11- 230 or AFJMAN 11-226.

D.2.5.2.3. Processes requests for waivers according to AFMAN 11-230.

D.2.5.3. MAJCOM/CE:

D.2.5.3.1. Coordinates with flight operations and flight safety offices to grant waivers.

D.2.5.3.2. Sets and enforces reasonable safety precautions.

D.2.5.3.3. Monitors actions to correct temporarily waived items within specified periods.

D.2.5.3.4. Establishes procedures to ensure an annual review of all waived items.
D.2.5.3.5. Establishes the administrative procedures for processing waivers.
D.2.5.3.6. Maintains (for record) one copy of all pertinent documents relative to each waiver, including a record of staff coordination on actions at base and command levels.

D.2.5.4. Base Civil Engineer:

D.2.5.4.1. Coordinates with base flight safety, airfield management, and flight operations offices to request waivers.
D.2.5.4.2. Following Airfield Management, Flight Safety, and Civil Engineer analysis and recommendation about a waiverable condition, annotates proposed waiver location on appropriate E series map for MAJCOM evaluation.
D.2.5.4.3. Establishes maps of approved waivered items in accordance with AFI 32-7062, Base Comprehensive Planning, and maintains this information on the appropriate E-series map (see AFI 32-7062, Attachment 7). Also see AFJMAN 11-226 US Standard for Terminal Instrument Procedures (TERPS), and AFMAN 11-230, Instrument Procedures.
D.2.5.4.4. Develops a Military Construction Program or other project to systematically correct non-permanent waivers.
D.2.5.4.5. Presents a summary of waived items to the Facility Board each year for information and action.
D.2.5.4.6. Establishes a procedure for recording, reviewing, and acting on waivers. Maintains records similar to those required at the MAJCOM.
D.2.5.4.7. Requests a temporary waiver from the facility commander for any construction projects which violate any airfield clearance criteria during or after the completion of the construction project. The base must request a temporary waiver at least 45 days before the scheduled construction start date, or an emergency temporary waiver when 45 days are not possible. **NOTE:** Quick reaction or emergency maintenance and repair requirements are exempt from this requirement; however, the Base Civil Engineer will coordinate with base flight safety and flight operations offices to ensure implementation of safety measures.
D.2.5.4.8. Advises the MAJCOM of any canceled waivers.

D.2.5.5. ANGRC/CEP (for ANG facilities):

D.2.5.5.1. Develops policy on waivers and manages the ANG waiver program.
D.2.5.5.2. Processes and coordinates inquiries and actions for deviations to criteria and standards.

D.3. Navy and Marine Corps:

D.3.1. Applicability:

D.3.1.1. Use of Criteria. The criteria in this manual apply to Navy and Marine Corps aviation facilities located in the United States, its territories, trusts, and possessions. Where a Navy or Marine Corps aviation facility is a tenant on a civil airport, use these criteria to the extent practicable; otherwise, FAA criteria apply. Where a Navy or Marine Corps aviation facility is host to a civilian airport, these criteria will apply. Apply these standards to the extent practical at overseas locations where the Navy and Marine Corps have vested base rights. While the criteria in this manual are not intended for use in a theater-of-operations situation, they may be used as a guideline where prolonged use is anticipated and no other standard has been designated.
D.3.1.2. Criteria at Existing Facilities. The criteria will be used for planning new aviation facilities and new airfield pavements at existing aviation facilities (exception: primary surface width for Class B runway). Existing aviation facilities have been developed using previous standards which may not conform to the criteria herein. Safety clearances at existing aviation facilities need not be upgraded solely for the purpose of conforming to this criteria. However, at existing aviation

facilities where few structures have been constructed in accordance with previous safety clearances, it may be feasible to apply the revised standards herein.

D.3.2. Approval. Approval from Headquarters NAVFACENGCOM must be obtained prior to revising safety clearances at existing airfield pavements to conform with new standards herein. NAVFACENGCOM will coordinate the approval with the Naval Air Systems Command and CNO/CMC as required.

D.3.3. Obtaining Waiver. Once safety clearances have been established for an aviation facility, there may be occasions where it is not feasible to meet the designated standards. In these cases a waiver must be obtained from the Naval Air Systems Command. The waiver and its relation to the site approval process is defined in NAVFACINST 1010.44, *Shore Facilities Planning Manual*.

D.3.4. Exemptions From Waiver. Certain navigational and operational aids normally are sited in violation of airspace safety clearances in order to operate effectively. The following aids are within this group and require no waiver from NAVAIR, provided they are sited in accordance with NAVFAC Definitive Designs (P-272) and/or the NAVFAC Design Manuals (DM Series):

D.3.4.1. Approach lighting systems.

D.3.4.2. Visual Approach Slope Indicator (VASI) systems and Precision Approach Path Indicator (PAPI).

D.3.4.3. Permanent Optical Lighting System (OLS), portable OLS and Fresnel lens equipment.

D.3.4.4. Runway distance markers.

D.3.4.5. Arresting Gear systems including signs.

D.3.4.6. Taxiway guidance, holding, and orientation signs.

D.3.4.7. All beacons and obstruction lights.

D.3.4.8. Arming and de-arming pad.

APPENDIX E

DETERMINATION OF FLEXURAL STRENGTH AND MODULUS OF ELASTICITY OF BITUMINOUS CONCRETE

E-1. SCOPE. These procedures describe preparation and testing of bituminous concrete to determine flexural strength and modulus of elasticity. The procedures are an adaptation from tests conducted on portland cement concrete (PCC) specimens.

E-2. APPLICABLE STANDARDS. The standard applicable to this procedure is ASTM C 78.

E-3. APPARATUS. The following apparatus are required:

a. A testing machine capable of applying repetitive loadings for compaction of beam specimens 152 by 152 by 533 millimeters (6 by 6 by 21 inches) to the design density (an Instron electromechanical testing machine meets this requirement).

b. A steel mold, suitably reinforced to withstand compaction of specimens without distortion.

c. Two linear variable differential transformers (LVDTs).

d. A 22,240-Newton (5,000-pound) load cell.

e. An X-Y recorder.

f. A testing machine for load applications conforming to ASTM C 78 (a Baldwin or Tinius Olsen hydraulic testing machine is suitable for this purpose).

E-4. MATERIALS. Sufficient aggregate and bitumen meeting applicable specifications to produce six 152- by 152- by 533-millimeter (6- by 6- by 21-inch) test specimens are required. In the event the proportioning of aggregate and bitumen, bitumen content, and density of compacted specimens are not known, additional materials will be required to conduct conventional Marshall tests to develop the needed mix design data.

E-5. SAMPLE PREPARATION.

a. Prepare in a laboratory mixer four portions of paving mixture for one 152- by 152- by 533-millimeter (6- by 6- by 21-inch) beam test specimen consisting of aggregate and bitumen in the proportions indicated for optimum bitumen content. The total quantity of paving mixture should be such that when compacted to a uniform 152- by 152-millimeter (6- by 6-inch) cross section, the density of the beam will be as specified from previous laboratory mix design tests or other sources. The temperature of the paving mixture at the time of mixing should be such that subsequent compaction can be accomplished at 121 ± 2.8 degrees Celsius (250 ± 5 degrees Fahrenheit). Place two of the four portions in the 152- by 152- by 533-millimeter (6- by 6- by 21-inch) reinforced steel mold and compact to a 76-millimeter (3-inch) thickness with a 152- by 152-millimeter (6- by 6-inch) foot attached to the repetitive loading machine. Shift the mold between load applications to distribute the compaction effort uniformly. Add the remaining two portions and continue compaction until the paving mixture is compacted to exactly a 152- by

152-millimeter (6- by 6-inch) cross section. After compaction, place a 152- by 533-millimeter (6- by 21-inch) steel plate on the surface of the paving mixture and apply a leveling load of 8,896 Newtons (2,000 pounds) to the plate. Prepare six beam test specimens in the manner described.

b. After cooling, remove the beams from the molds and rotate 90 degrees so that the smooth, parallel sides will become the top and bottom. Cement an L-shaped metal tab with quick-setting epoxy glue to each 152- by 533-millimeter (6- by 21-inch) side of the beams on the beams' neutral axes at midspan. The taps should be drilled for attachment of the LVDTS. Cure the beams at 10 ± 1.7 degrees Celsius (50 ± 3 degrees Fahrenheit) for 4 days prior to testing.

E-6. TEST PROCEDURES.

a. Condition three specimens each at 10 and 24 ± 1.7 degrees Celsius (50 and 75 ± 3 degrees Fahrenheit) for at least 12 hours prior to testing. If testing occurs immediately after curing the specimens at 10 ± 1.7 degrees Celsius (50 ± 3 degrees Fahrenheit) for 4 days, no additional conditioning is required for the specimens tested at this temperature.

b. Place the specimen in the test machine as described in ASTM C 78. Place thin Teflon strips at the point of contact between the test specimens and the load-applying and load-support blocks. While the beams are being prepared for testing, place an additional support block at midspan to prevent premature sagging of the beams. Remove this support block immediately prior to the initiation of load application. Mount the LVDTs on laboratory stands on each side of the beams, and attach the LVDTs to the L-shaped tabs on the sides of the beams. Connect the LVDTs and load cell to the X-Y recorder. Make final adjustments and checks on specimens and test equipment. Apply loading in accordance with ASTM C 78, omitting the initial 4,448-Newton (1,000-pound) load.

E-7. CALCULATIONS

a. The modulus of rupture R is calculated from the following equation (from ASTM C 78):

$$R = \frac{PL}{bd^2} \qquad \text{(E-1)}$$

where

R = modulus of rupture, MPa (psi)

P = maximum applied load, Newtons (pounds)

L = span length, millimeters (inches) (457 millimeters (18 inches))

b = average width of beam, millimeters (inches)

d = average depth (height) of beam, millimeters (inches)

b. The modulus of elasticity E is calculated from the following equation:

$$E = \frac{23PL^3}{1296\Delta I}\,k \qquad \text{(E-2)}$$

where

E = static Young's modulus of elasticity, MPa (psi)

P = applied load, Newtons (pounds)

L = span length, millimeters (inches) (457 millimeters (18 inches))

Δ = deflection of neutral axis, millimeters (inches), under load, P

I = moment of inertia, millimeter^4 (inch^4) (=$bd^3/12$)

b = average width of beam, millimeters (inches)

d = average depth (height) of beam, millimeters (inches)

k = Pickett's correction for shear (third-point loading). (Values of E for bituminous beams should be calculated without using Pickett's correction K for shear).

E-8. REPORT. The report shall include the following:

a. Gradation of Aggregate.

b. Type and Properties of Bituminous Cement.

c. Bituminous Concrete Mix Design Properties.

d. Bituminous Concrete Beam Properties.

e. Modulus of Rupture.

f. Modulus of Elasticity.

APPENDIX F

CURVES FOR DETERMINING EFFECTIVE STRAIN REPETITIONS

F-1. GENERAL. This appendix contains plots (Figures F-1 through F-22) for converting aircraft operations to effective repetitions of strain when given the type of aircraft, the effective thickness of the pavement, and the offset from the center of the runway or taxiway.

F-2. COMPUTER PLOTS. A computer program was developed by the U.S. Army Engineer Research and Development Center (ERDC) for producing the plots for effective strain repetitions. Should the plots not be adequate, the computer program could be used to determine the conversion factors for any design situation. Information for accessing the computer programs is described in Chapter 1.

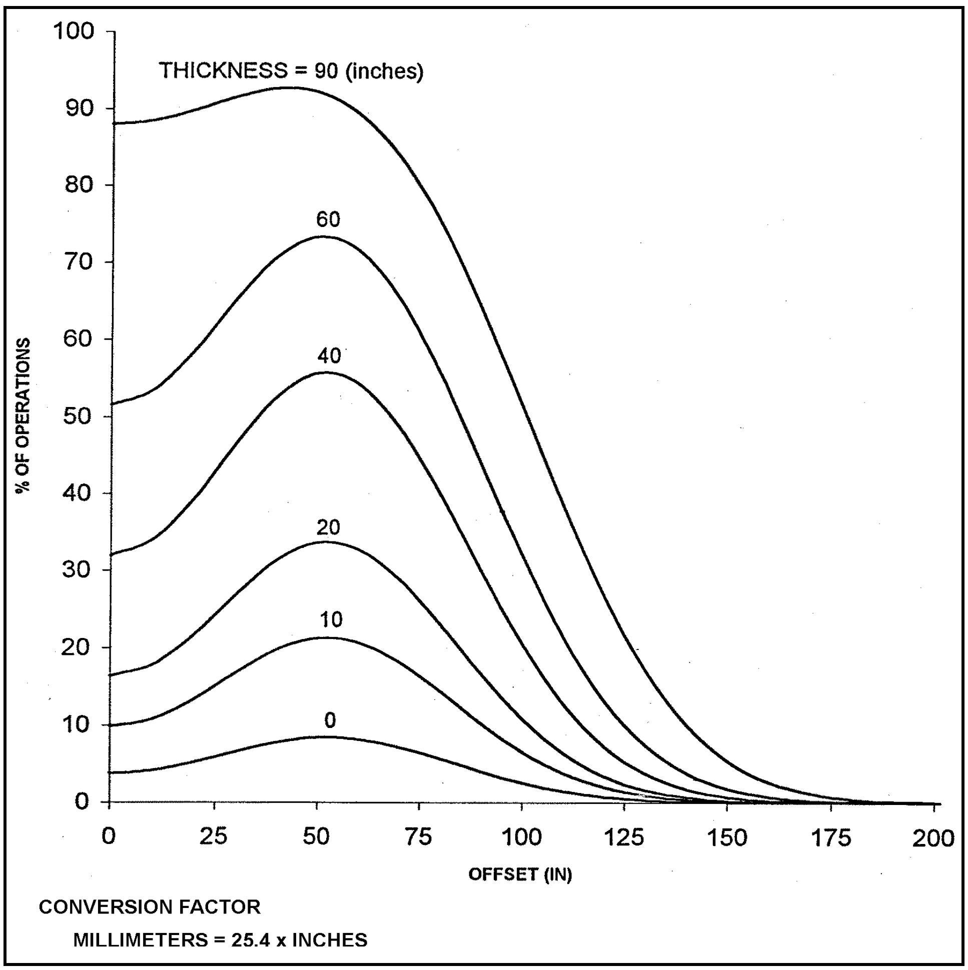


Figure F-1. Effective repetitions of the strain for UH-60 aircraft, types B, C, and secondary traffic areas.

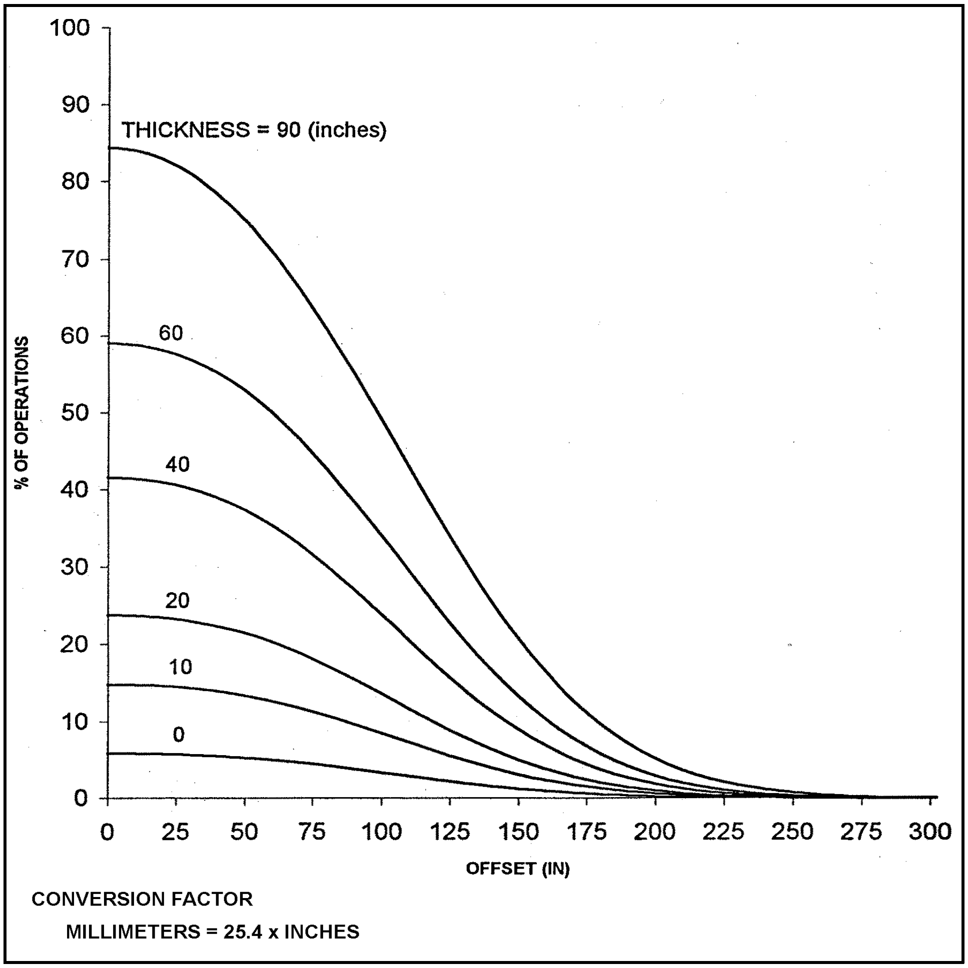


Figure F-2. Effective repetitions of strain for UH-60 aircraft, type A or primary traffic areas

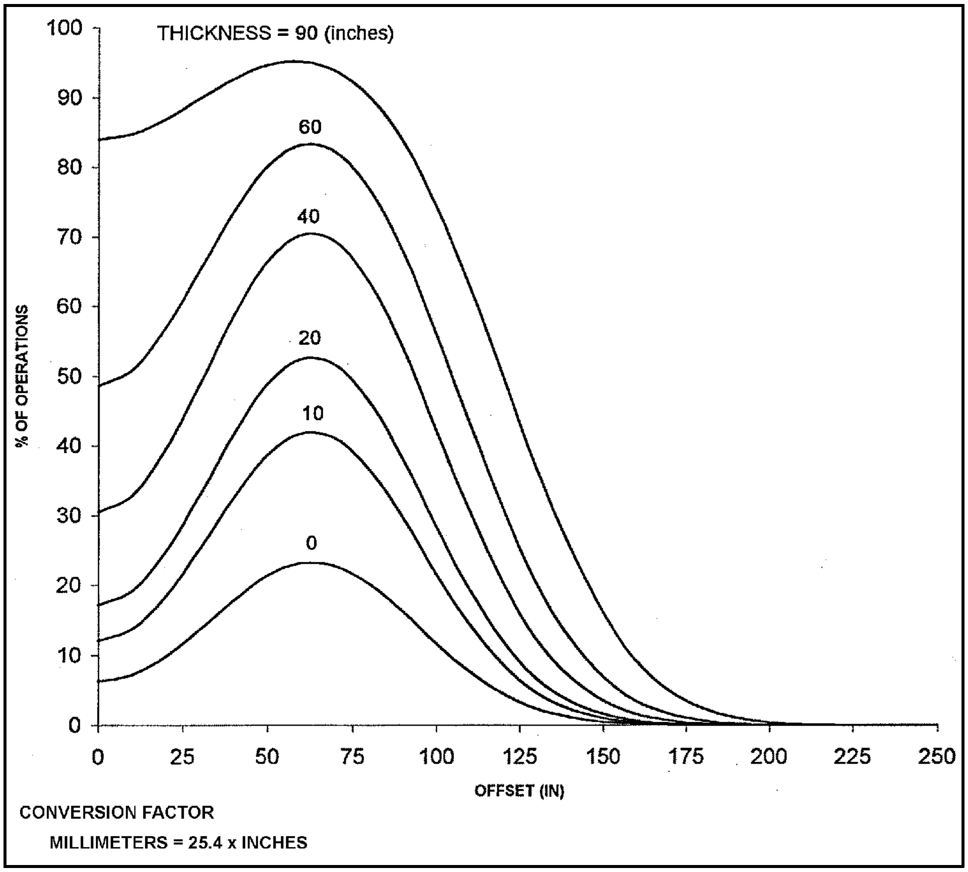


Figure F-3. Effective repetitions of strain for CH-47 aircraft, types B, C, or secondary traffic areas

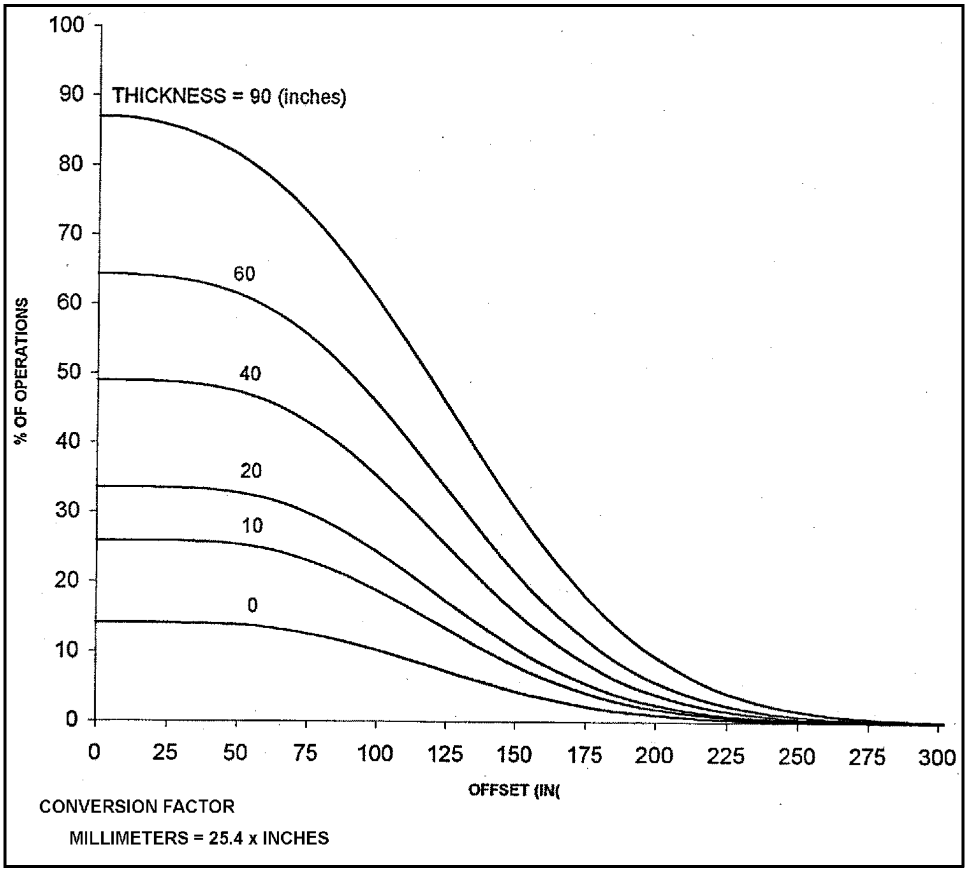


Figure F-4. Effective repetitions of strain for CH-47 aircraft, type A or primary traffic areas

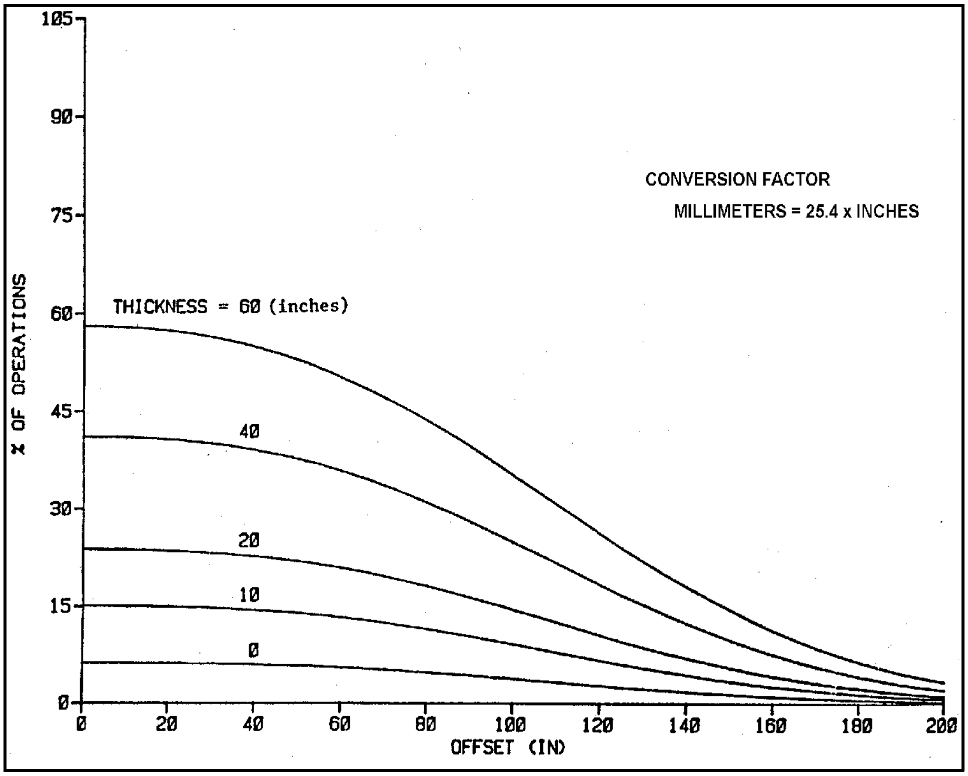


Figure F-5. Effective repetitions of strain for OV-1 aircraft, types B, C, or secondary traffic areas

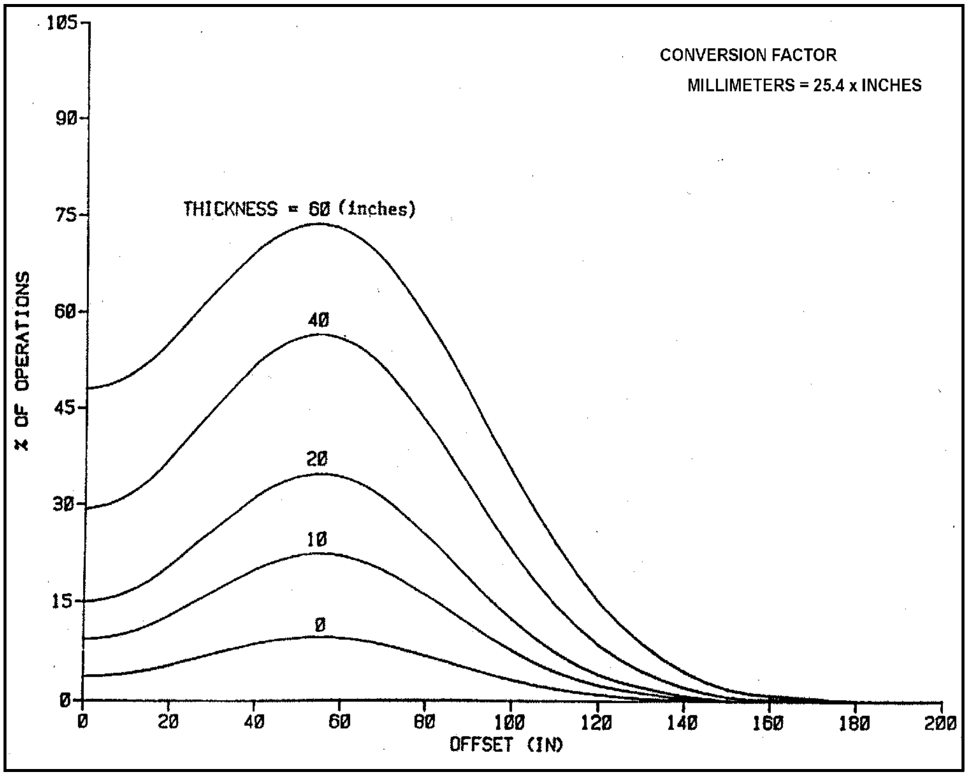


Figure F-6. Effective repetitions of strain for OV-1 aircraft, type A or primary traffic areas

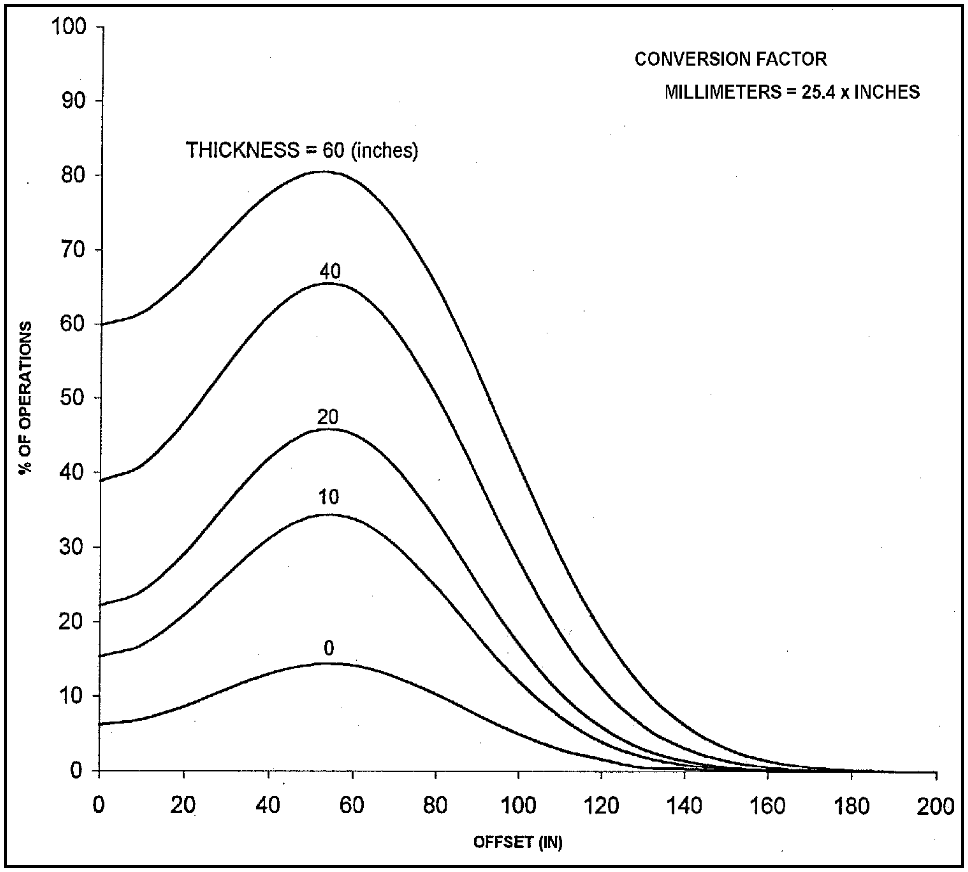


Figure F-7. Effective repetitions of strain for C-12 aircraft, types B, C, or secondary traffic areas

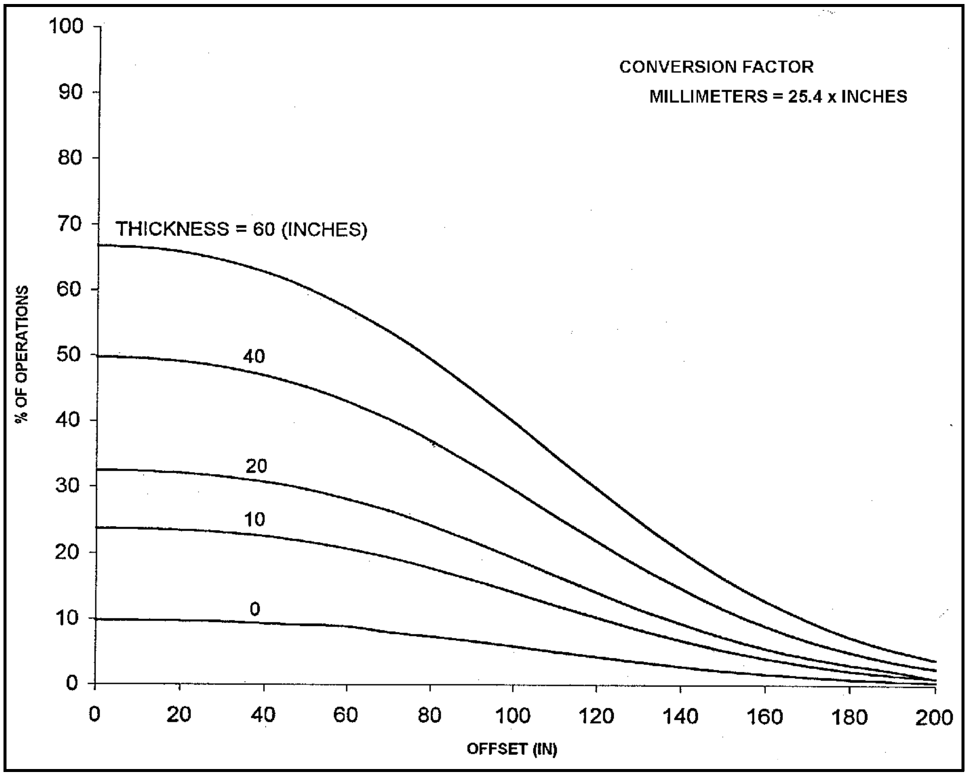


Figure F-8. Effective repetitions of strain for C-12 aircraft, type A or primary traffic areas

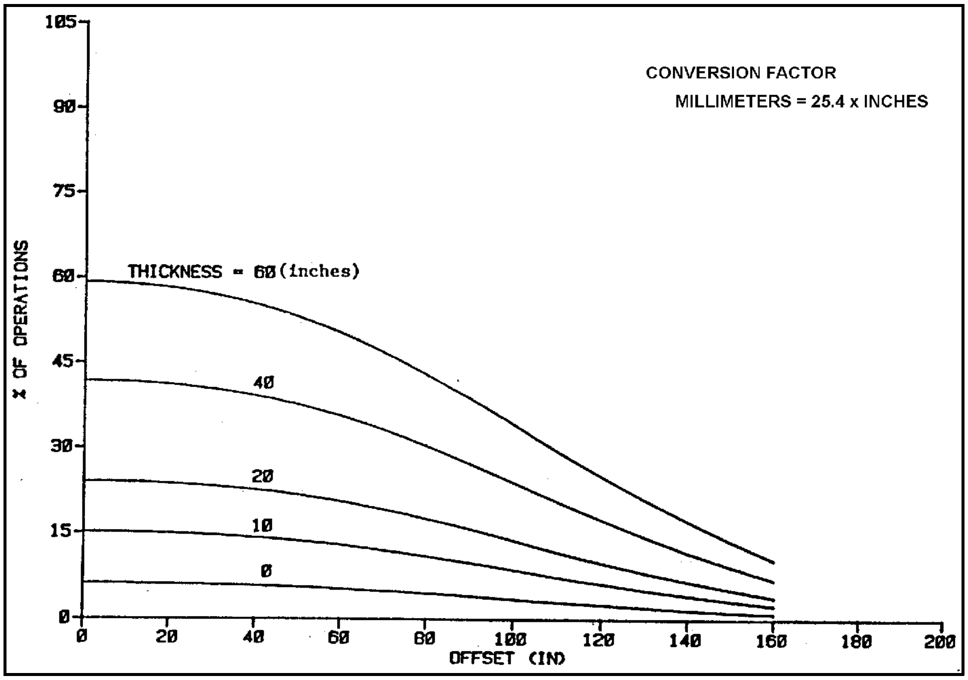


Figure F-9. Effective repetitions of strain for C-130 aircraft, types B, C, or secondary traffic areas

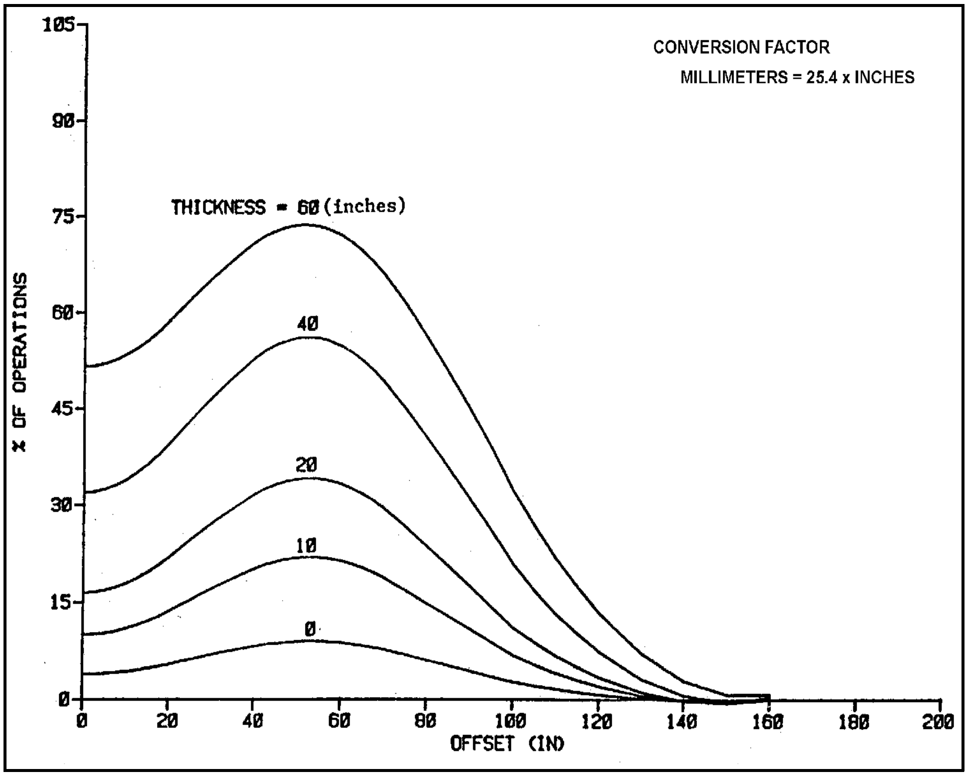


Figure F-10. Effective repetitions of strain for C-130 aircraft, type A or primary traffic areas

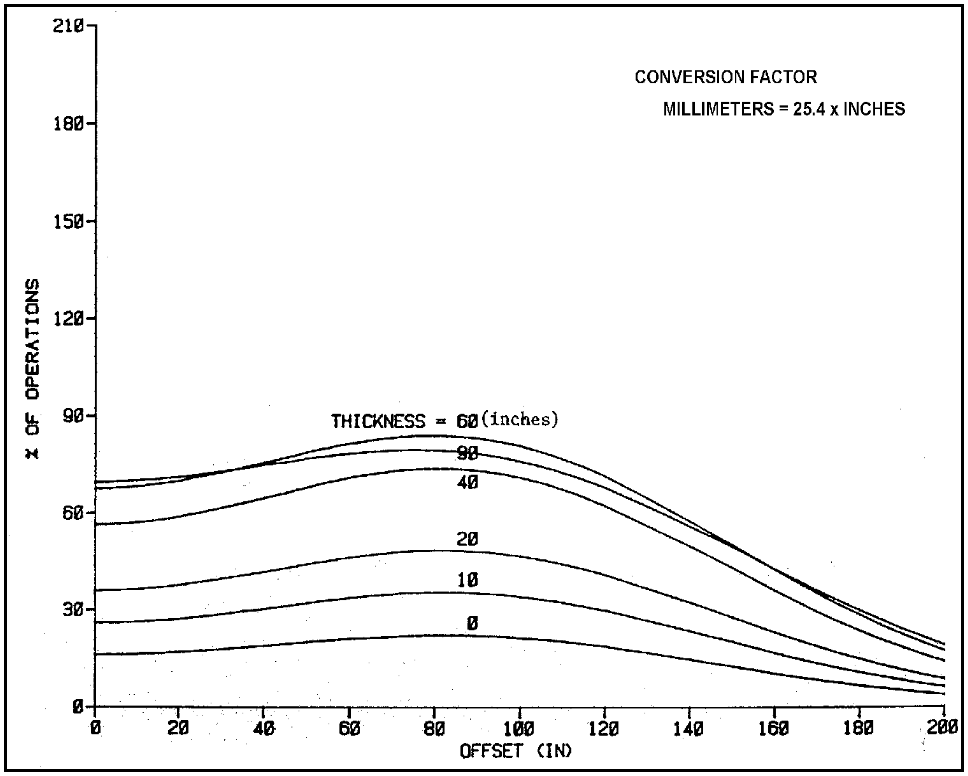


Figure F-11. Effective repetitions of strain for F-15 aircraft, Air Force types B and C traffic areas

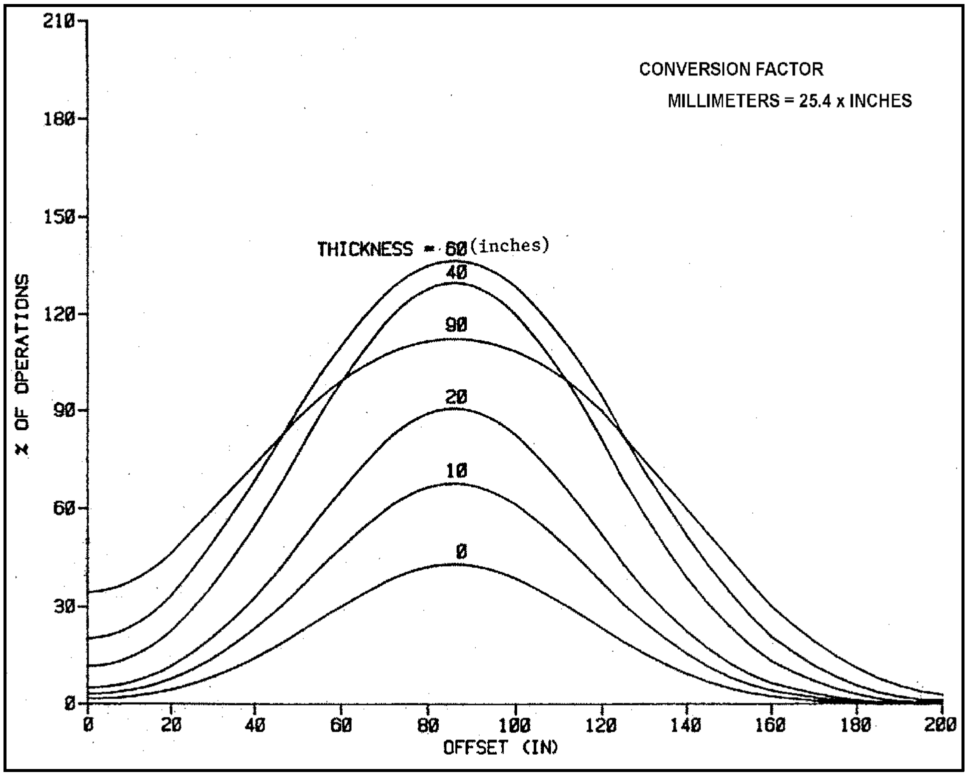


Figure F-12. Effective repetitions of strain for F-15 aircraft, Air Force type A traffic areas

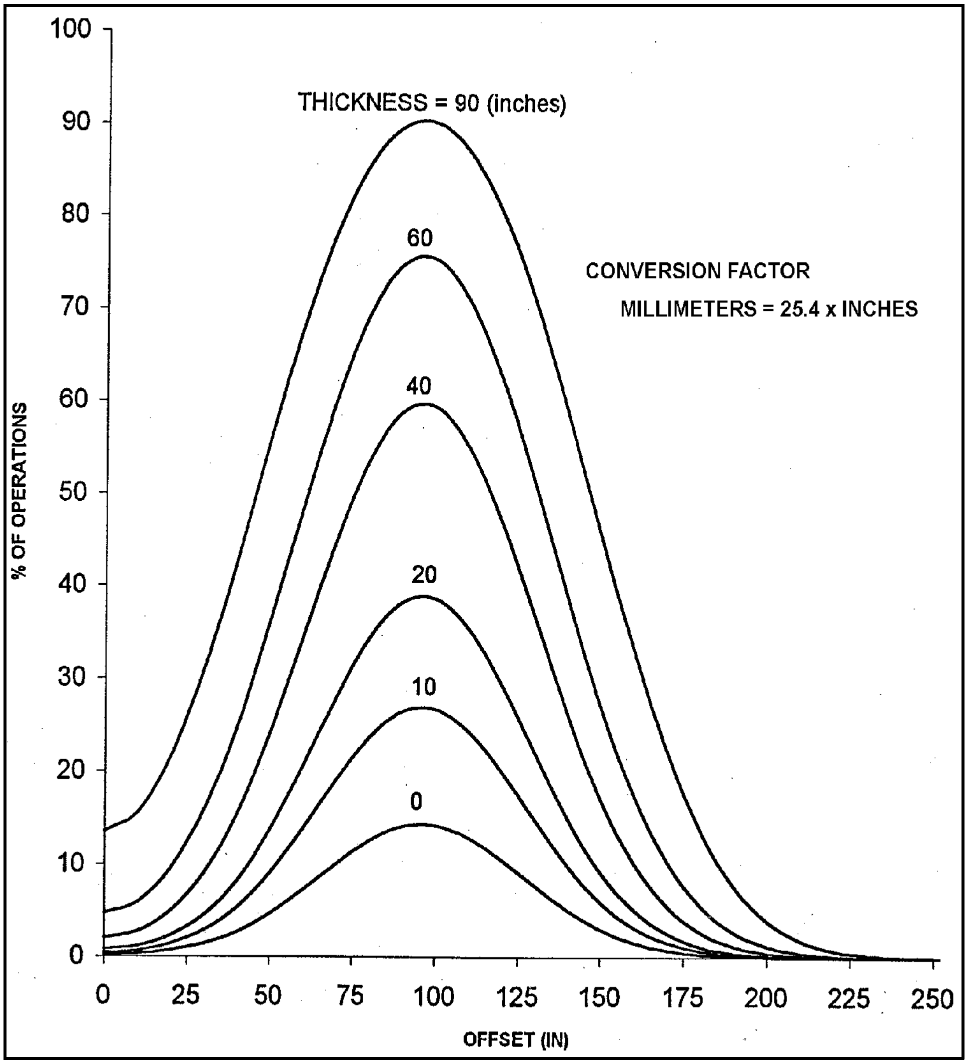


Figure F-13. Effective repetitions of strain for F-14 aircraft, types B, C and secondary traffic areas

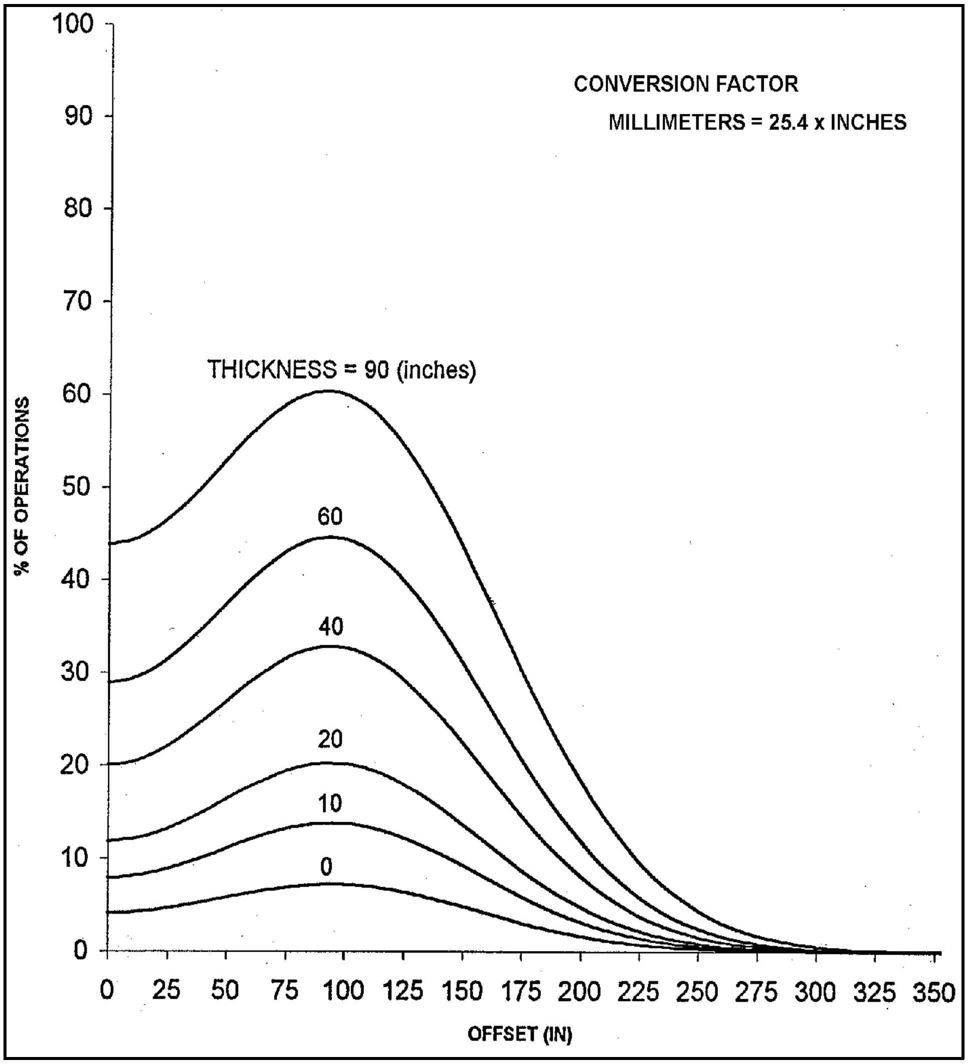


Figure F-14. Effective repetitions of strain for F-14 aircraft, type A or primary traffic areas

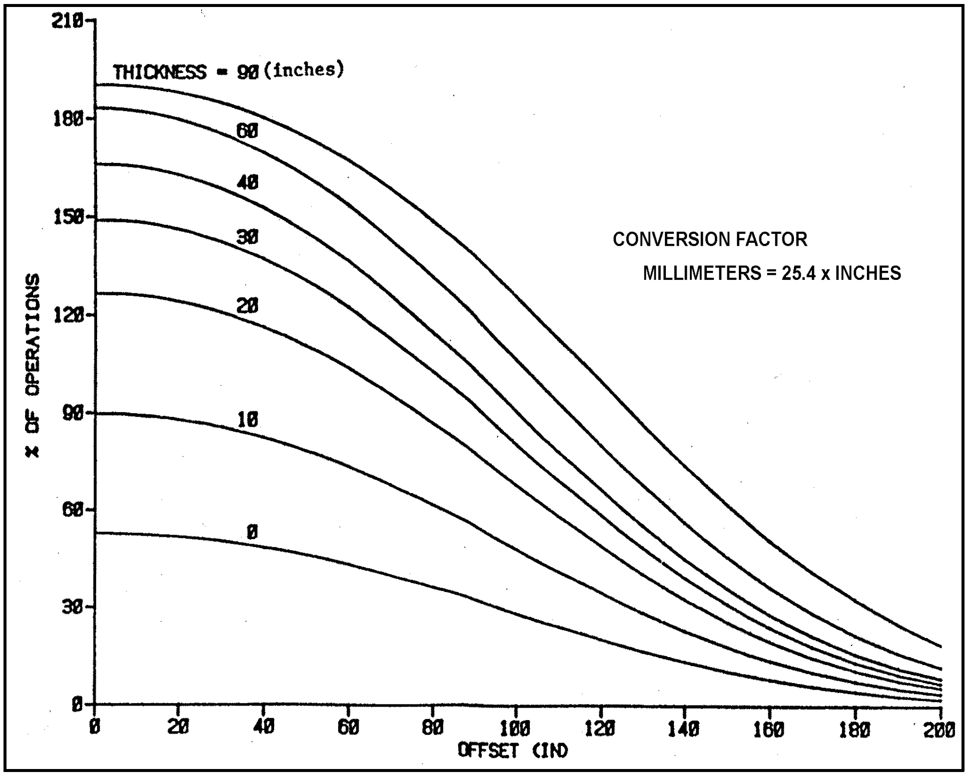


Figure F-15. Effective repetitions of strain for B-52 aircraft, types B, C or secondary traffic areas

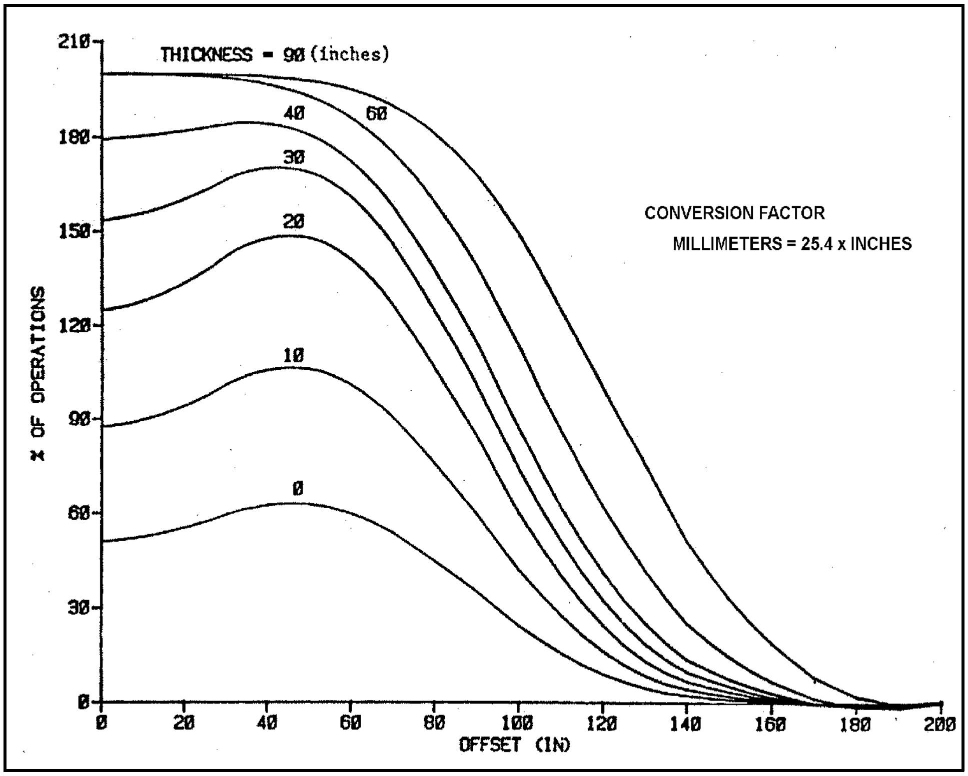


Figure F-16. Effective repetitions of strain for B-52 aircraft, type A or primary traffic areas

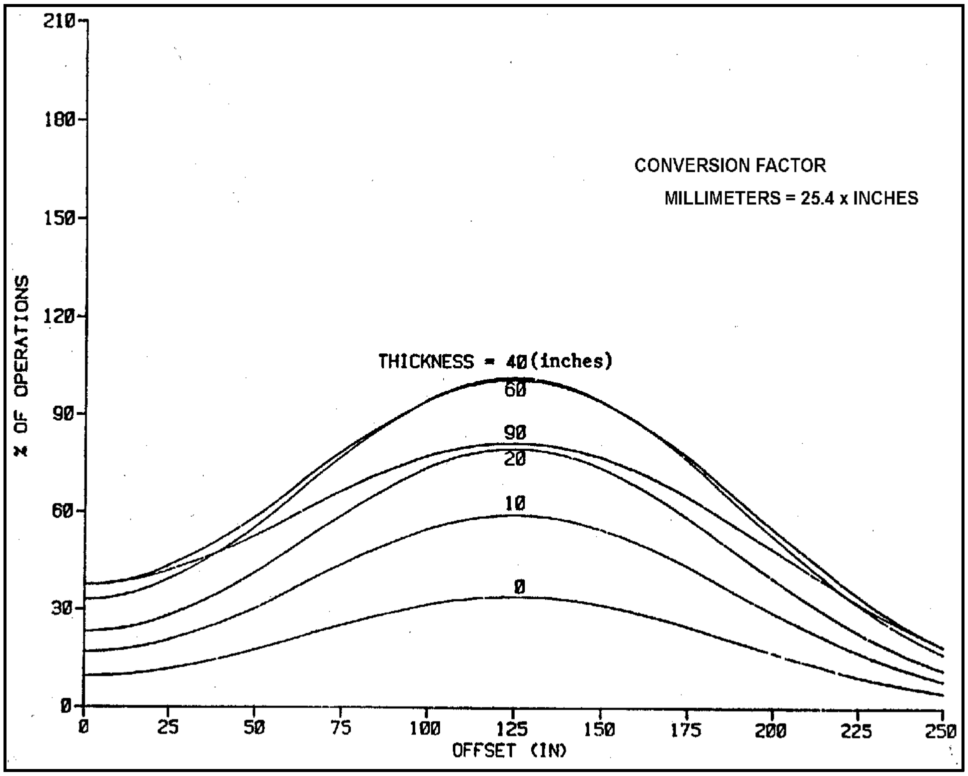


Figure F-17. Effective repetitions of strain for B-1 and C-141 aircraft, types B, C, or secondary traffic areas

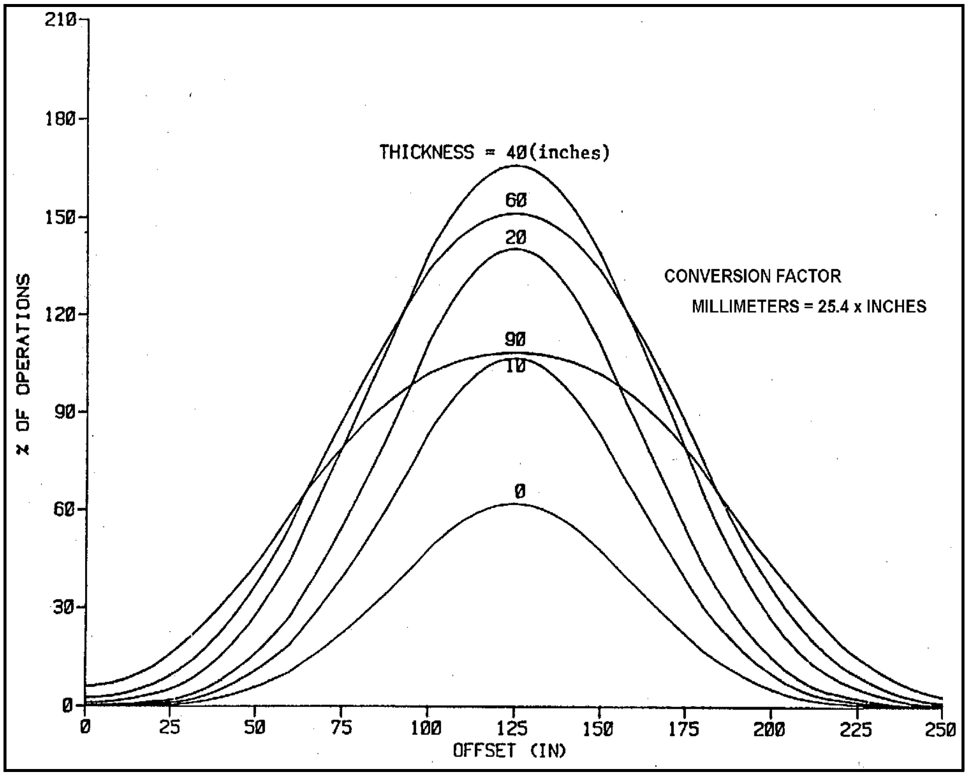


Figure F-18. Effective repetitions of strain for B-1 and C-141 aircraft, type A or primary traffic areas

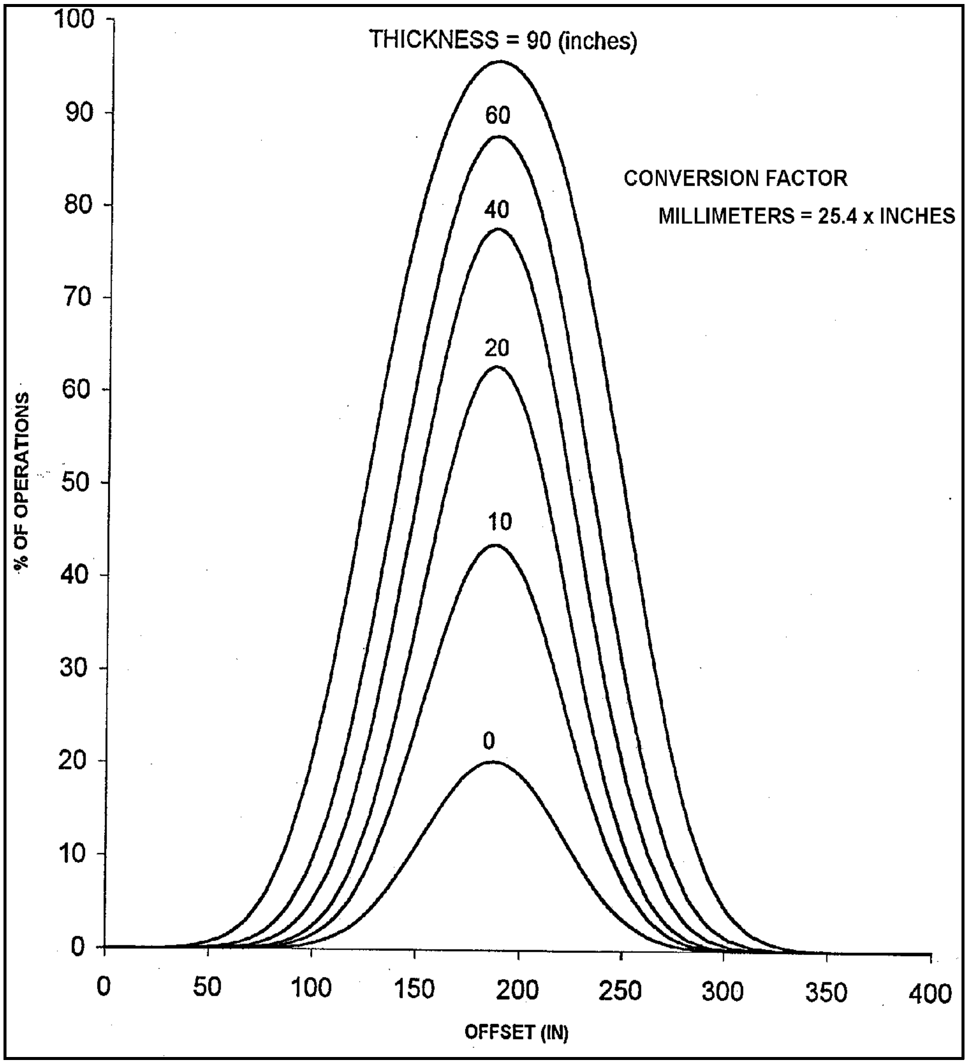


Figure F-19. Effective repetitions of strain for P-3 aircraft, types B, C, or secondary traffic areas

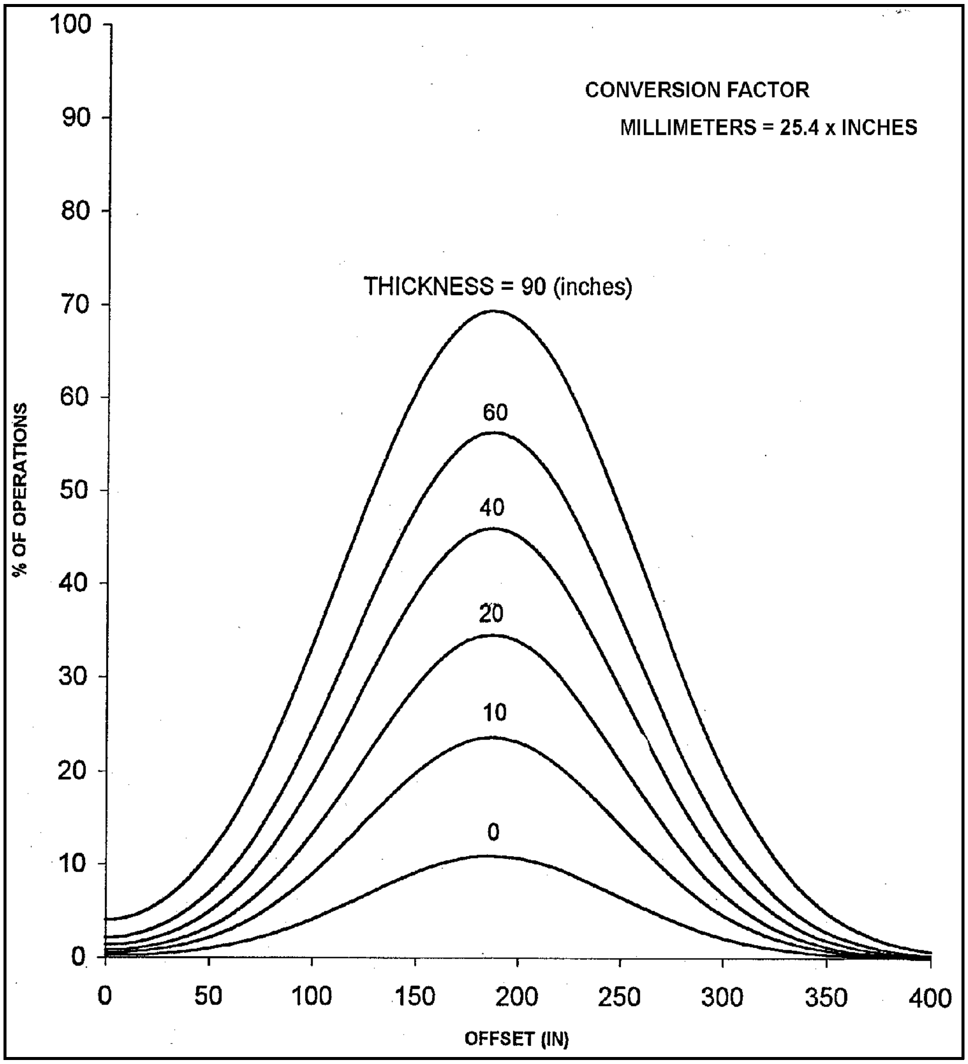


Figure F-20. Effective repetitions of strain for P-3 aircraft, type A or primary traffic areas

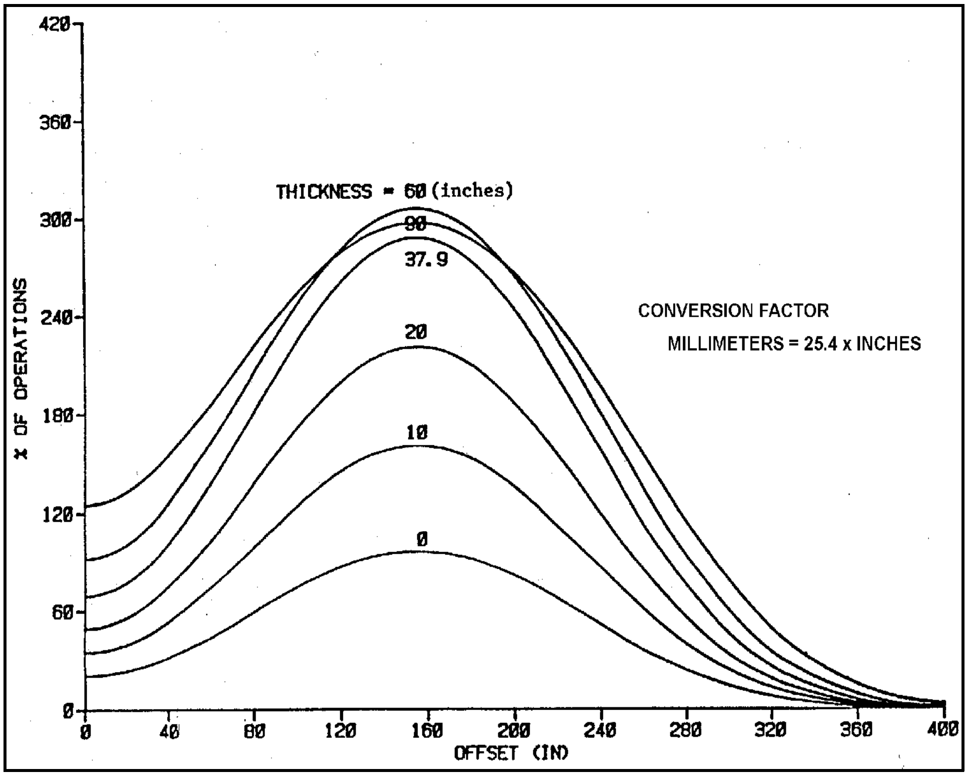


Figure F-21. Effective repetitions of strain for C-5 aircraft, types B, C, or secondary traffic areas

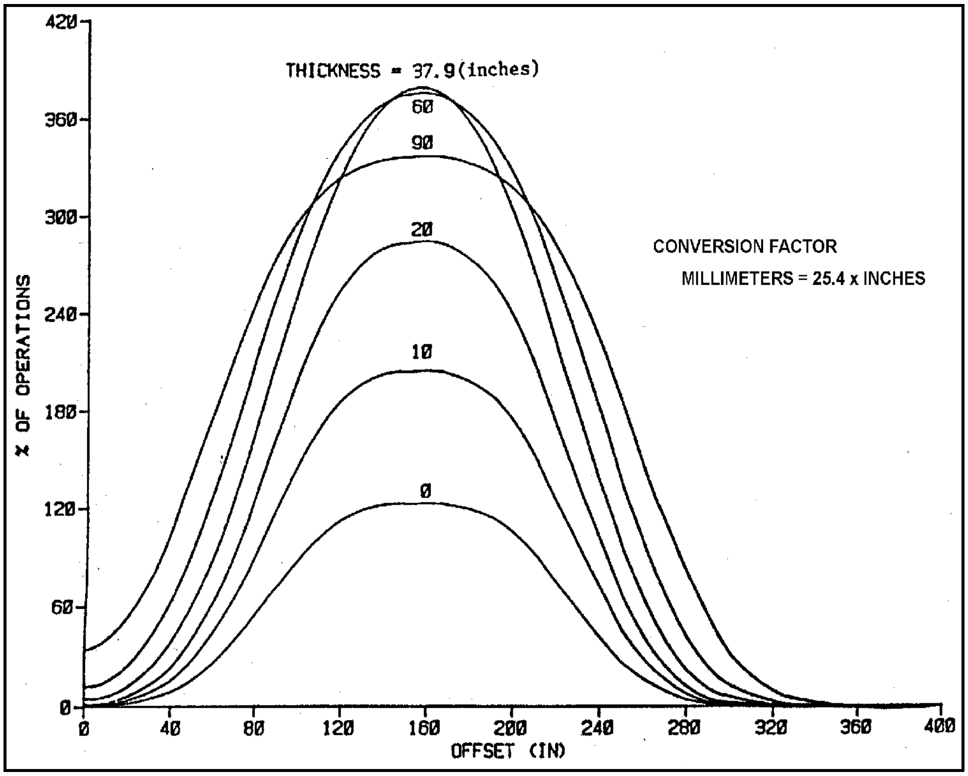


Figure F-22. Effective repetitions of strain for C-5 aircraft, type A or primary traffic areas

APPENDIX G

PROCEDURE FOR PREPARATION OF BITUMINOUS

CYLINDRICAL SPECIMENS

G-1. SCOPE. This procedure describes the preparation of cylindrical specimens of bituminous paving mixture suitable for dynamic modulus testing. The procedure is intended for densegraded bituminous concrete mixture containing up to 25-millimeter (1-inch) maximum-size aggregate.

G-2. APPLICABLE STANDARDS. The following ASTM publications are applicable to this procedure: D 1559, D 1560, and D 1561.

G-3. SPECIMENS. Approximately 4,000 grams of bituminous mixture should be prepared as specified by ASTM D 1560. Cylindrical specimens should be 102 millimeters (4 inches) in diameter by 203 millimeters (8 inches) in height.

G-4. APPARATUS.

a. Testing Apparatus. The apparatus used in preparing the specimens should be as specified by ASTM D 1561, except that steel molding cylinders with 6.3-millimeter (1/4-inch) wall thickness having an inside diameter of 102 millimeters (4 inches) and height of 254 millimeters (10 inches) should be used.

b. Measurement System. The measurement system should consist of a two-channel recorder, stress and strain measuring devices, and suitable signal amplification and excitation equipment. The measurement system should have the capability for determining loading up to 13,344 Newtons (3,000 pounds) from a recording with a minimum sensitivity of 2 percent of the test load per millimeter of chart paper. This system should also be capable of use in determining strains over a range of full-scale recorder outputs from 300 to 5,000 microunits of strain. At the highest sensitivity setting, the system should be able to display 4 microunits of strain or less per millimeter on the recorder chart.

c. Recorder Amplitude. The recorder amplitude should be independent of frequency for tests conducted up to 20 hertz.

d. Measurement of Axial Strain. The values of axial strain should be measured by bonding two wire strain gauges at midheight opposite each other on the specimens. (The Baldwin Lima Hamilton SR-4 Type A-1S 13 strain gauge has been found satisfactory for this purpose). The gauges are wired in a wheatstone bridge circuit with two active gauges on the test specimen exposed to the same environment as the test specimen. The temperature-compensating gauges should be at the same position on the specimen as the active gauges. The sensitivity and type of measurement device should be selected to provide the strain readout required above.

e. Load Measurements. Loads should be measured with an electronic load cell meeting requirements for load and stress measurements above.

G-5. PROCEDURE.

a. Procedure. The compaction temperature for the bituminous mixture should be as specified by ASTM D 1561. For the first step in molding specimens, heat the compaction mold to the same temperature as the mix. Next, place the compaction mold in position in the mold holder and insert a paper disk 102 millimeters (4 inches) in diameter to cover the baseplate of the mold holder. Weigh out one-half of the required amount of bituminous mixture for one specimen at the specified temperature and place uniformly in the insulated feeder trough, which has been preheated to the compaction temperature for the mixture. By means of the variable transformer controlling the heater, maintain the compactor foot sufficiently hot to prevent the mixture from adhering to it. By means of a paddle of suitable dimensions to fit the cross section of the trough, push 30 approximately equal portions of the mixture continuously and uniformly into the mold while 30 tamping blows at a pressure of 1.7 Mpa (250 psi) are applied. Immediately place the remaining one-half of the mixture uniformly in the feeder trough. Push 30 approximately equal portions of the mixture into the mold in a continuous and uniform manner while applying tamping blows at a pressure of 1.7 MPa (250 psi). If sandy or unstable material is involved and there is undue movement of the mixture under the compactor foot, reduce the compaction temperature and compactor foot pressure until kneading compaction can be accomplished.

b. Immediately after compaction with the California kneading compactor, apply a static load to the specimen using a compression testing machine. Apply the load by the double-plunger method in which metal followers are employed as free-fitting plungers on the top and bottom of the specimen. Apply the load on the specimen at a rate of 13 millimeters (0.5 inches) per minute until an applied pressure of 6.9 MPa (1,000 psi) is reached. Release the load immediately. After the compacted specimen has cooled sufficiently so that it will not deform on handling, remove it from the mold. Place the specimen on a smooth flat surface and allow to cool to room temperature. Cylindrical specimens will have approximately the same bulk specific gravity as specimens prepared as specified by ASTM D 1559 and ASTM D 1561.

APPENDIX H

PROCEDURE FOR DETERMINING THE DYNAMIC MODULUS

OF BITUMINOUS CONCRETE MIXTURES

H-1. GENERAL. The purpose of this procedure is to determine dynamic modulus values of bituminous concrete mixtures. The procedure described covers a range of both temperature and loading frequency. The minimum recommended test series consists of testing at 4.5, 21, and 37.8 degrees Celsius (40, 70, and 100 degrees Fahrenheit) at loading frequencies of 2 and 10 hertz for each temperature. The method is applicable to bituminous paving mixtures similar to the 25.4, 19, 12.7, and 9.5 millimeter (1-, 3/4-, 1/2-, and 3/8-inch), and No. 4 mixes as defined by Table 3 of ASTM D 3515.

H-2. APPLICABLE STANDARDS. The following ASTM standards are applicable to this procedure: C 617, D 1559, D 1561, and D 3515.

H-3. SUMMARY PROCEDURE. The dynamic modulus test is run by applying a sinusoidal (haversine) axial compressive stress to a specimen of bituminous concrete at a given temperature and loading frequency. The resulting recoverable axial strain response of the specimen is measured and used to calculate the dynamic modulus.

H-4. DEFINITIONS. The following terms are used in this procedure:

a. Dynamic Modulus. The absolute value of the complex modulus which defines the elastic properties of a linear viscoelastic material subjected to a sinusoidal loading.

b. Complex Modulus. A complex number which defines the relationship between stress and strain for a linear viscoelastic material.

c. Linear material. A material whose stress-to-strain ratio is independent of the loading stress applied.

H-5. APPARATUS. An electrohydraulic testing machine with a frequency generator capable of producing a haversine wave form has proven to be most suitable for use in dynamic modulus testing. The testing machine should have the capability of applying loads over a range of frequencies from 1 to 20 hertz and stress levels up to 0.69 MPa (100 psi). The temperature control system should be capable of a temperature range of 0.0 to 49 degrees Celsius (32 to 120 degrees Fahrenheit). The temperature chamber should be large enough to hold six specimens. A hardened steel disk with a diameter equal to that of the test specimen should be used to transfer the load from the testing machine to the specimen.

H-6. SPECIMENS. The laboratory-molded specimens should be prepared according to Appendix H. A minimum of three specimens is required for testing. The molding procedure is as follows: Cap all specimens with a sulfur mortar meeting ASTM C 617 requirements prior to testing. Bond the strain gauges with epoxy cement to the sides of the specimen near midheight in position to measure axial strains. (Baldwin Lima Hamilton EPY 150 Epoxy Cement has been found satisfactory for this purpose. On specimens with large-size aggregate, care must be taken so that the gauges are attached over areas between the aggregate faces). Wire the strain gauges as required in paragraph G-5 and attach suitable lead wires and connectors.

H-7. PROCEDURE. The following testing procedure is recommended:

a. Place test specimens in a controlled temperature cabinet, and bring them to the specified test temperature. A dummy specimen with a thermocouple in the center can be used to determine when the desired test temperature is reached.

b. Place a specimen in the loading apparatus, and connect the strain gage wires to the measurement system. Put the hardened steel disk on top of the specimen and center both under the loading apparatus. Adjust and balance the electronic measuring system as necessary.

c. Apply the haversine loading to the specimen without impact and with loads varying between (0 and 35 psi) for each load application for a minimum of 30 seconds and not exceeding 45 seconds at temperature of 4.5, 21, and 37.8 degrees Celsius (40, 70, and 100 degrees Fahrenheit) and at loading frequencies of 2 hertz for taxiway design and 10 hertz for runway design. If excessive deformation (greater than 2,500 microunits of strain) occurs, reduce the maximum loading stress level to 0.12 MPa (17.5 psi).

d. Test three specimens at each temperature and frequency condition twice. Start at the lowest temperature and repeat the test at the next highest temperature. Bring the specimens to the specified test temperature before each test is commenced.

e. Monitor both the loading stress and the axial strain during the test. Increase the recorder chart speed so that one cycle covers 25 to 50 millimeters of chart paper for five to ten repetitions before the end of the test.

f. Complete the loading for each test within 2 minutes from the time specimens are removed from the temperature control cabinet. The 2-minute testing time limit is waived if loading is conducted within a temperature control cabinet meeting requirements in paragraph H-5.

H-8. CALCULATIONS. Measure the average amplitude of the load and the strain over the last three loading cycles to the nearest 1/2 millimeter. Calculate the loading stress σ_o using the equation

$$\sigma_o = \frac{H_1 L}{H_2 A} \qquad \text{(H-1)}$$

where

H_1 = measured height of load, millimeters (inches)

H_2 = measured chart height, millimeters (inches)

L = full-scale load amplitude determined by settings on the recording equipment, Newtons (pounds)

A = cross-section area of the test specimen, square millimeters (square inches)

Calculate the recoverable axial strain ϵ_o using the equation

$$\epsilon_o = \frac{H_3 S}{H_4}$$

where

H_3 = measured height of recoverable strain, millimeters (inches)

H_4 = measured chart height, millimeters (inches)

S = full-scale strain amplitude determined by settings on the recording equipment

Calculate the dynamic modulus $|E^*|$ using the equation

$$|E*| = \frac{\sigma_o}{\epsilon_o} \qquad \text{(H-3)}$$

where

σ_o = axial loading stress, MPa (psi)

ϵ_o = recoverable axial strain, millimeters per millimeter (inches per inch)

Report the average dynamic modulus at temperatures of 4.5, 21, and 37.8 degrees Celsius (40, 70, and 100 degrees Fahrenheit) for each loading frequency at each temperature.

APPENDIX I

PROCEDURE FOR ESTIMATING THE MODULUS OF ELASTICITY OF BITUMINOUS CONCRETE

I-1. GENERAL. The procedure for estimating the modulus of elasticity of bituminous concrete presented here is based on relationships developed by Shell.[1] Parameters needed for input into this method are:

a. Ring-and-ball softening point in degrees Celsius (degrees Fahrenheit) of the bituminous material used in the mix in accordance with ASTM D 36.

b. Penetration of the bituminous material, in 1/10 millimeters in accordance with ASTM D 5.

c. Volume concentration of the aggregate C_v used in the mix defined by

$$C_v = \frac{\text{aggregate volume}}{\text{aggregate volume} + \text{bitumen volume}} \qquad \text{(I-1)}$$

I-2. STEPS OF PROCEDURE. The steps in using this method are as follows:

a. Penetration Index. With known values of penetration and ring-and-ball softening point, enter Figure I-1 and determine the penetration index PI.

b. Stiffness Modulus. The next step involves the use of the nomograph presented in Figure H-2. In addition to the PI, two other values are required: the temperature of the bituminous concrete mix for which the modulus value is desired and the estimated loading frequency or time of loading to which the prototype pavement will be subjected. Use of a loading frequency of 2 hertz is recommended for taxiway design and 10 hertz for runway design. With values for the loading frequency and the difference in temperature between the bituminous concrete and the ring-and-ball softening point, a stiffness value for the bitumen S_{bit} can be determined from the appropriate PI line at the top of the nomograph. The value of S_{bit} is then used to determine the modulus of the mix S_{mix}.

c. Determining Modulus of Mix S_{mix}. A value for S_{mix} may be determined by

$$s_{mix} = s_{bit}\left[1 + \left(\frac{2.5}{n}\right)\left(\frac{c_v}{1 - c_v}\right)\right]^n \qquad \text{(I-2)}$$

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[1] Heukelom, W., and Klomp, A. J. G. (1964). "Road Design and Dynamic Loading." *Proceedings, Association of Asphalt Paving Technologists*. Vol 33, 92-125.

where

$$n = 0.83 \log \left(\frac{400{,}000}{s_{bit}} \right) \tag{I-3}$$

The value thus determined for S_{mix} is in units of kilograms per square centimeter.

d. Corrected Aggregate Volume Concentration. This expression should be used for aggregate volume concentrations of 0.7 to 0.9 and air void contents of 3 percent or less. For larger air void contents, use a corrected aggregate volume concentration (C'_v)

$$C'_v = \frac{c_v}{1 + \Delta air\ void\ content} \tag{I-4}$$

where Δair void content is the actual air void content (expressed in decimal form) minus 0.03. Equation I-4 is valid only when

$$c_B \geq \frac{2}{3}\,(1 - c'_v) \tag{I-5}$$

where

$$c_B = \frac{bitumen\ volume}{aggregate\ volume + bitumen\ volume} \tag{I-6}$$

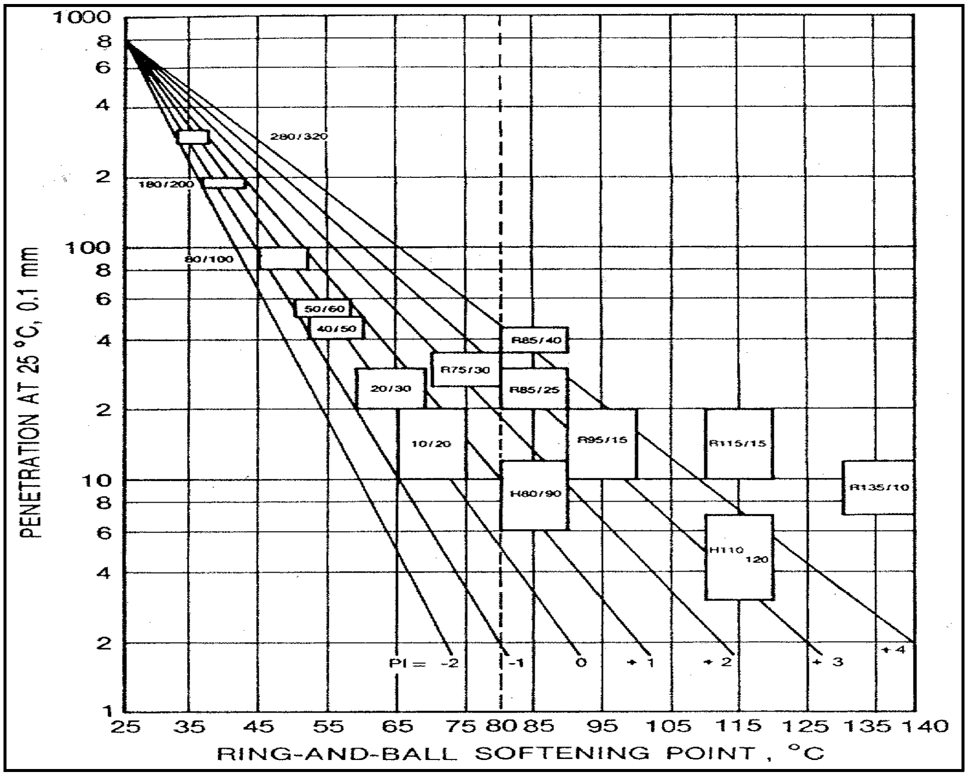


Figure I-1. Relationship between penetration at 25 degrees C and ring-and-ball softening point for bitumens with different PI's

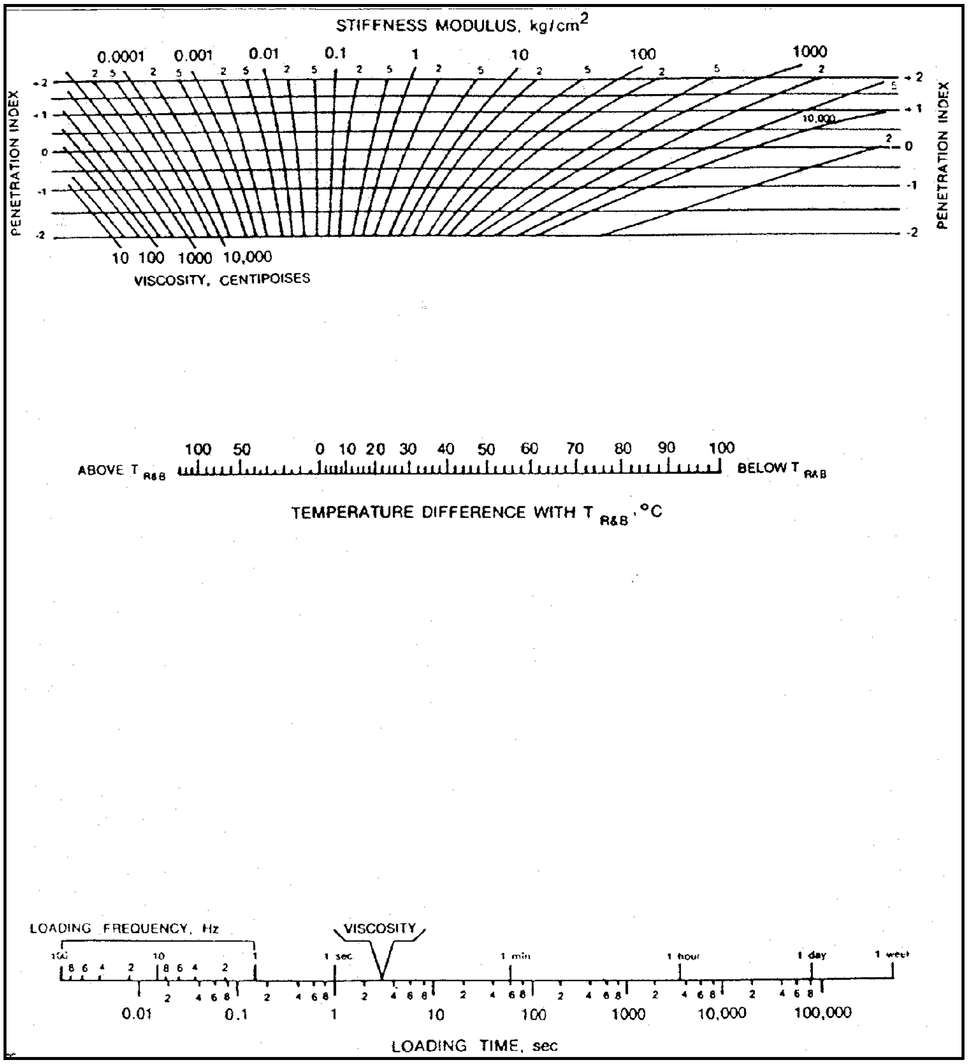


Figure I-2. Nomograph for determining the stiffness modulus of bitumens

APPENDIX J

PROCEDURE FOR DETERMINING THE MODULUS OF ELASTICITY OF UNBOUND GRANULAR BASE AND SUBBASE COURSE MATERIALS

J-1. PROCEDURE.

a. Relationships. The procedure is based on relationships developed for the resilient modulus of unbound granular layers as a function of the thickness of the layer and type of material. The modulus relationships are shown in Figure J-1. Modulus values for layer n (the upper layer) are indicated on the ordinate, and those for layer n + 1 (the lower layer) are indicated on the abscissa. Essentially linear relationships are indicated for various thicknesses of base- and subbase-course materials. For subbase courses, relationships are shown for thicknesses of 102, 127, 152, 178, and 203 millimeters (4, 5, 6, 7, and 8 inches). For subbase courses having a design thickness of 203 millimeters (8 inches) or less, the applicable curve or appropriate interpolation can be used directly. For a design subbase-course thickness in excess of 203 millimeters (8 inches), the layer should be divided into sublayers of approximately equal thickness and the modulus of each sublayer determined individually. For base courses, relationships are shown for thicknesses of 102, 152, and 254 millimeters (4, 6, and 10 inches). These relationships can be used directly or by interpolation for design base course thicknesses up to 254 millimeters (10 inches). For design thicknesses in excess of 254 millimeters (10 inches), the layer should also be divided into sublayers of approximately equal thickness and the modulus of each sublayer determined individually.

b. Modulus Values. To determine modulus values from this procedure, Figure J-1 is entered along the abscissa using modulus values of the subgrade or underlying layer (modulus of layer n + 1). At the intersection of the curve applicable to this value with the appropriate thickness relationship, the value of the modulus of the overlying layer is read from the ordinate (modulus of layer n). This procedure is repeated using the modulus value just determined as the modulus of layer n + 1 to determine the modulus value of the next overlying layer.

J-2. EXAMPLES.

a. Thickness. Assume a pavement having a base-course thickness of 102 millimeters (4 inches) and a subbase-course thickness of 203 millimeters (8 inches) over a subgrade having a modulus of 69 MPa (10,000 psi). Initially, the subgrade is assumed to be layer n + 1 and the subbase course to be layer n. Entering Figure I-1 with a modulus of layer n + 1 of 69 MPa (10,000 psi) and using the 203-millimeter (8-inch) subbase course curve, the modulus of the subbase (layer n) is 127.5 MPa (18,500 psi). In order to determine the modulus value of the base course, the subbase course is now assumed to be layer n + 1 and the base course to be layer n. Entering Figure J-1 with a modulus value of layer n + 1 of 127.5 MPa (18,500 psi) and using the 102 millimeter (4-inch) base-course relationship, the modulus of the base course is 248 MPa (36,000 psi). Modulus values determined for each layer are indicated in Figure J-2.

b. Design Thickness. If, in the first example, the design thickness of the subbase course had been 305 millimeters (12 inches), it would have been necessary to divide this layer into two 152-millimeter- (6-inch-) thick sublayers. Then, using the procedure described above for the second example, the modulus values determined for the lower and upper sublayers of the subbase course and for the base course are 121, 176, and 303 MPa (17,500, 25,500, and 44,000 psi), respectively. These values are shown in Figure J-3.

c. Relationships. The relationships indicated in Figure I-1 can be expressed as

$$E_n = E_{n+1}\ (1 + 10.52 \log t - 2.10 \log E_{n+1} \log t) \quad \text{(J-1)}$$

where

n = a layer in the pavement system

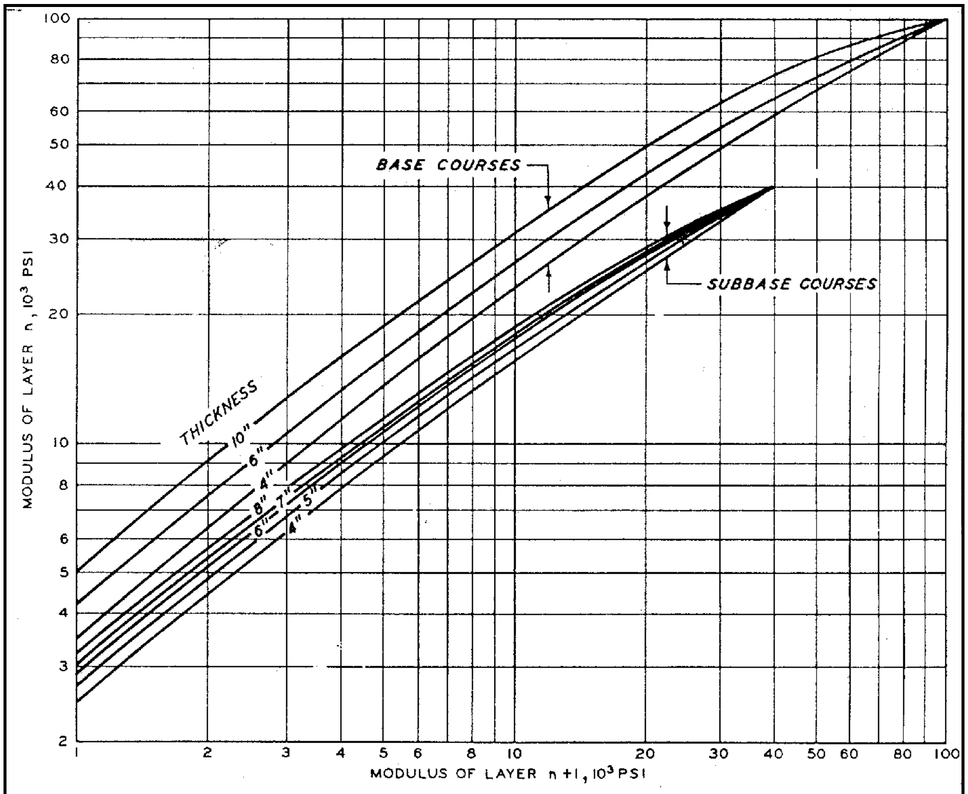
E_n = resilient modulus (in psi) of layer n

E_{n+l} = the resilient modulus (in psi) of the layer beneath layer n

t = the thickness (in inches) of layer n for base-course materials and as

$$E_n = E_{n+1}\ (1 + 7.18 \log t - 1.56 \log E_{n+1} \log t) \quad \text{(J-2)}$$

for subbase-course materials. Use of these equation for direct computation of modulus values for the examples given above yields the value indicated in parentheses in Figures I-2 and I-3. It can be seen that comparable values are obtained with either graphical or computational determination of the modulus value for either material.



CONVERSION FACTORS

MEGAPASCALS = 0.006894 x PSI
MILLIMETERS = 25.4 x INCHES

Figure J-1. Relationships between modulus of layer n and modulus of layer n + 1 for various thicknesses of unbound base course and subbase course

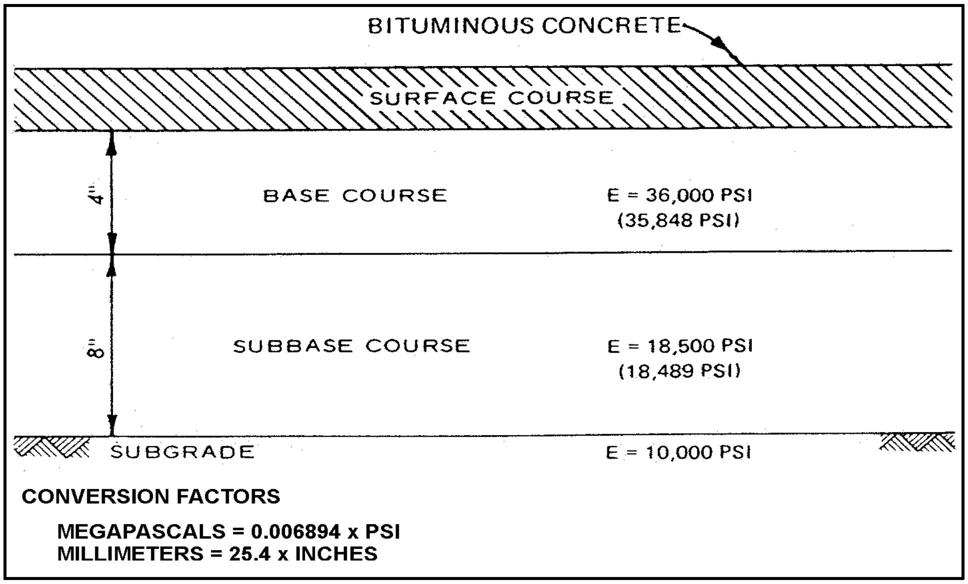


Figure J-2. Modulus values determined for first example

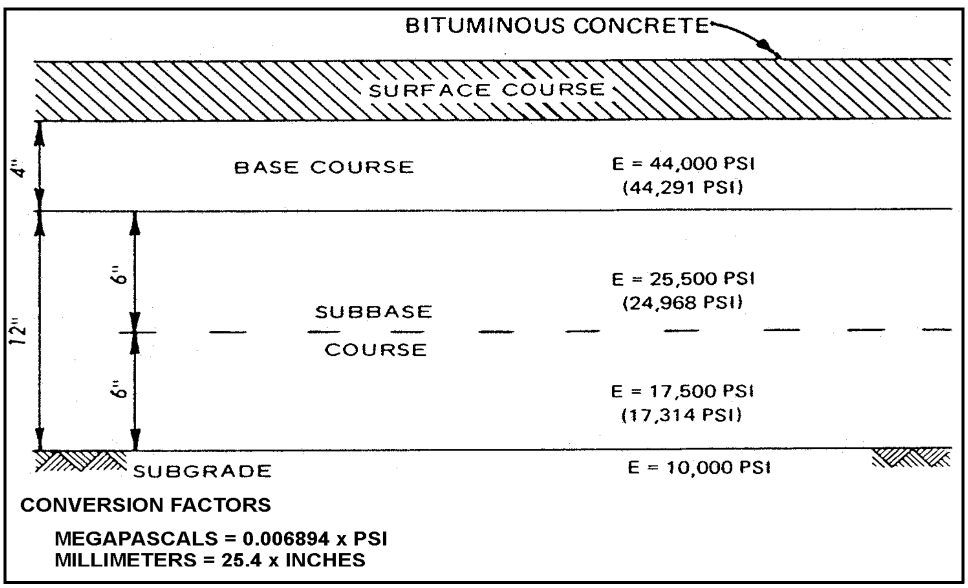


Figure J-3. Modulus values determined for second example

APPENDIX K

PROCEDURE FOR DETERMINING THE FLEXURAL MODULUS AND FATIGUE CHARACTERISTICS OF STABILIZED SOILS

K-1. LABORATORY PROCEDURE.

a. General. The procedure involves application of a repetitive loading to a laboratory-prepared beam specimen under controlled stress conditions. Applied load and deflection along the neutral axis and at the lower surface are monitored, and the results are used to determine the flexural modulus and fatigue characteristics.

b. Specimen Preparation. Beam specimens should be prepared following the general procedures indicated in ASTM D 1632. This method describes procedures for molding 76- by 76- by 286-millimeter (3- by 3- by 11-1/4-inch) specimens; however, any size mold may be used for the test. For soils containing aggregate particles larger than 19 millimeters (3/4 inch), it is recommended that molds on the order of 102 by 102 to 152 by 152 millimeters (4 by 4 to 6 by 6 inches) be used. In general, specimens should have an approximately square crosssectional configuration and a length adequate to accommodate an effective test span equal to three times the height or width. Specimens should be molded to the stabilizer treatment level, moisture content, and density expected in the field structures. Cement-treated materials should be moist-cured for 7 days. Lime-treated materials should be cured for 28 days at 23 degrees Celsius (73 degrees Fahrenheit).

c. Equipment. The following equipment is required:

(1) Loading frame capable of receiving specimen for third-point loading test.

(2) Electrohydraulic testing machine. This machine must be capable of applying static and haversine loads.

(3) Load cell (approximately 907-kilogram (2,000-pound) capacity).

(4) Two LVDT's and one SR-4 type strain gauge.

(5) Recording equipment for monitoring deflection, strain, and load.

(6) Miscellaneous pins and yokes, as described in the equipment setup below for mounting the LVDT'S.

d. Equipment Setup. Details of the equipment setup are shown in Figures K-1 to K-3. The beam should be positioned so that the molding laminations are horizontal. The three yokes are positioned over the top of the beam and held in place by threaded pins, positioned along the neutral axis. The end pins, pins A and C, are positioned directly over the end reaction points, and the middle pin, pin B, is positioned at the center of the beam. A metal bar rests on top of the pin. At the A position, the bar is equipped with a lower vertical tab having a hole that slips loosely over the pin. A nut is placed on the end of the pin to prevent the bar from slipping. At the center or B position, the bar is equipped with a vertical tap onto which an LVDT is cemented in a vertical position. At this point on the bar, there is a hole through which the LVDT core pin falls to rest on the B pin. This pin must be fabricated with flat sides on the shaft to provide a horizontal surface on which the LVDT core pin rests. At the C position, the end of the bar simply rests on the unthreaded portion of the C pin. A nut is placed on the end of the C pin to prevent excessive side movement of the bar end. This type of bar, pin, and LVDT arrangement is provided on both sides of the beam. Although no dimensions are provided in Figures K-1 to K-3, this type of equipment can easily be dimensioned and fabricated to fit any size beam. Either steel or aluminum may be used. The beam should be positioned and arranged to accommodate third point loading as indicated in Figure K-2. As the beam bends under loading, defection at the center is measured by determining the movement of the LVDT stems from their original positions. The LVDTs are connected to the monitoring system to give an average deflection reading. Since it is also desired to determine the maximum tensile strain of the beam under loading, an SR-4 strain gauge should be attached to the lower beam surface with epoxy or some other suitable cement and should also be connected to the monitoring system. If it is not possible to determine strain directly, a strain value may be found using Equation K-2.

e. Test Procedure. The flexural beam test is a stress-controlled test. Therefore, an initial specimen should be statically loaded to failure, and the stress level for the initial repetitive load tests should be set at 50 percent of the maximum rupture load. The repetitive load test should be conducted using a haversine wave form, a loading duration of 0.5 second, and a frequency of about 1 hertz. To develop a strain repetition pattern, it is recommended that tests be conducted at 40, 50, 60, and 70 percent of the maximum rupture value; however, stress levels can be varied to higher or lower levels. Data to be monitored include load, deflection along the neutral axis, strain at the lower surface of the specimen, and number of repetitions.

f. Reporting of Test Results.

(1) Flexural Modulus. The flexural modulus should be determined at 100, 1,000, and 10,000 load repetitions or at failure. This value may be determined from load deflection data monitored at these repetition levels using the expression

$$E_f = \frac{23PL^3}{1296dI}\left(1 + 2.11\ \frac{h}{(L)}\right)^2 \qquad \text{(K-1)}$$

where

E_f = flexural modulus, MPa (psi)

P = maximum load amplitude, kilograms (pounds)

L = specimen length, millimeters (inches)

d = deflection at the neutral axis, millimeters (inches)

I = moment of inertia, millimeters^4 (inch^4)

h = specimen height, millimeters (inch)

The value to be used for E_f in the performance model is the arithmetic mean of all values obtained during the test.

(2) Fatigue characteristics. Fatigue characteristics are presented as a plot of strain indicated at the bottom surface of the specimen versus load repetitions at failure. Generally, the value of the strain obtained during the first few load repetitions is the value to be plotted. If no direct means of measuring strain is available, a strain value ϵ may be computed using the expression

$$\epsilon = \frac{PLh}{6E_f I} \qquad \text{(K-2)}$$

K-2. GRAPHICAL DETERMINATION OF FLEXURAL MODULUS FOR CHEMICALLY STABILIZED SOILS (CRACKED SECTION). The procedure for determining a flexural modulus value for chemically stabilized soils based on the cracked section concept involves the use of a relationship between unconfined compressive strength and flexural modulus determined analytically. This relationship is shown in Figure K-2. To use this relationship, specimens of the stabilized material should be molded and tested following procedures indicated in ASTM D 1633. Values obtained from the unconfined compression test can then be used to determine the values of the equivalent cracked section modulus using Figure K-2.

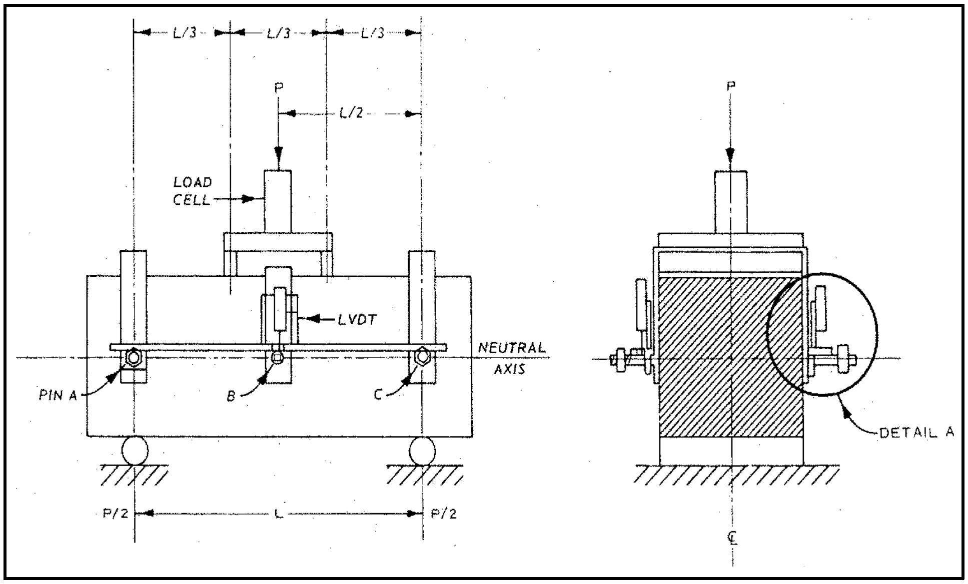


Figure K-1. General view of equipment setup

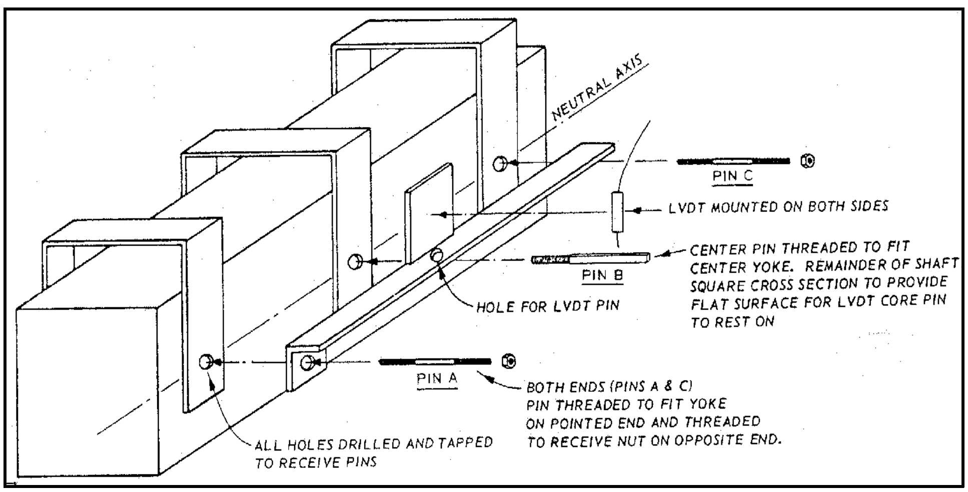


Figure K-2. Details of equipment setup

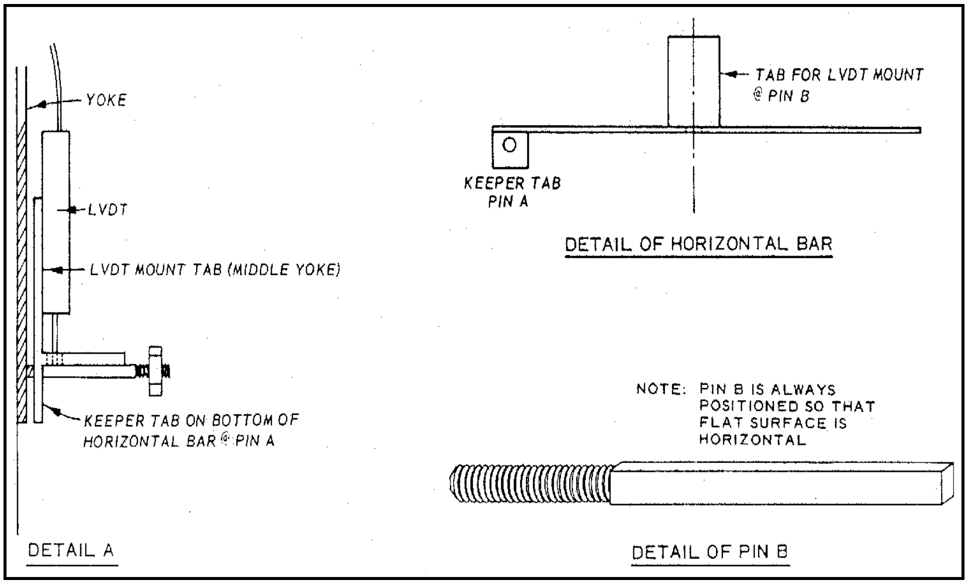


Figure K-3. Miscellaneous details

APPENDIX L

PROCEDURE FOR DETERMINING RESILIENT

MODULUS OF SUBGRADE MATERIAL

L-1. GENERAL. The objective of this test procedure is to determine a modulus value for subgrade soils by means of resilient triaxial techniques. The test is similar to a standard triaxial compression test, the primary exception being that the deviator stress is applied repetitively and at several stress levels. This procedure allows testing of soil specimens in a repetitive stress state similar to that encountered by a soil in a pavement under a moving wheel load.

L-2. DEFINITIONS. The following symbols and terms are used in the description of this procedure:

σ_1 = total axial stress

σ_3 = total radial stress; i.e., confining pressure in the triaxial test chamber

$\sigma_d = \sigma_1 - \sigma_3$ = deviator strain; i.e, the repeated axial stress in this procedure

ϵ_1 = total axial strain due to σ_d

ϵ_R = resilient or recoverable axial strain due to σ_d

ϵ_{R1} = resilient or recoverable axial strain due to σ_d in the direction perpendicular to ϵ_R

$M_R = \sigma_d/\epsilon_{Rl}$ = resilient modulus

$\theta = \sigma_1 + 2\sigma_3 = \sigma_d + 3\sigma_3$ = sum of the principal stresses in the triaxial state of stress

σ_1/σ_3 = principal stress ratio

Load duration = time interval over which the specimen is subject to a deviator stress

Cycle duration = time interval between successive applications of a deviator stress

L-3. SPECIMENS. Various diameter soil specimens may be used in this test with the specimen height at least twice the diameter. Undisturbed or laboratory molded specimens can be used. Methods for laboratory preparation of molded specimens and for backpressure saturation of specimens are given in the following paragraphs.

L-4. PREPARATION OF SPECIMENS. Specimens shall have an initial height of not less than 2.1 times the initial diameter, though the minimum initial height of a specimen must be 2.25 times the diameter if the soil contains particles retained on the No. 4 sieve. The maximum particle size permitted in any specimen shall be no greater than one-sixth of the specimen diameter. Triaxial specimens 35.5, 71, 102, 152, 305, and 381 millimeters (1.4, 2.8, 4, 6, 12, and 15 inches) in diameter are most commonly used.

a. Cohesive Soils Containing Negligible Amounts of Gravel. Specimens 35.5 millimeters (1.4 inches) in diameter are generally satisfactory for testing cohesive soils containing a negligible amount of gravel, while specimens of larger diameter may be advisable for undisturbed soils having marked stratification, fissures, or other discontinuities. Depending on the type of sample, specimens shall be prepared by either of the following procedures:

(1) Trimming Specimens of Cohesive Soil. A sample that is uniform in character and sufficient in amount to provide a minimum of three specimens is required. For undisturbed soils, samples about 127 millimeters (5 inches) in diameter are preferred for triaxial tests using 35.5-millimeter-(1.4-inch-) diameter specimens. Specimens shall be prepared in a humid room and tested as soon as possible thereafter to prevent evaporation of moisture. Extreme care shall be taken in preparing the specimens to preclude the least possible disturbance to the structure of the soil. The specimens shall be prepared as follows:

(a) Cut a section of suitable length from the sample. As a rule, the specimens should be cut with the long axes parallel to the long axis of the sample; any influence of stratification is commonly disregarded. However, comparative tests can be made, if necessary, to determine the effects of stratification. When a 127-millimeter- (5-inch-) diameter undisturbed sample is to be used for 35.5-millimeter- (1.4-inch-) diameter specimens, cut the sample axially into quadrants using a wire saw or other convenient cutting tool. Use three of the quadrants for specimens; seal the fourth quadrant in wax and preserve it for a possible check test.

(b) Carefully trim each specimen to the required diameter, using a trimming frame or similar equipment. Use one side of the trimming frame for preliminary cutting and the other side for final trimming. Ordinarily, the specimen is trimmed by pressing the wire saw or trimming knife against the edges of the frame and cutting from top to bottom. In trimming stiff or varved clays, move the wire saw from the top and bottom toward the middle of the specimen to prevent breaking off pieces at the ends. Remove any small shells or pebbles encountered during the trimming operations. Carefully fill voids on the surface of the specimen with remolded soil obtained from the trimming. Cut specimen to the required length (usually 76 to 89 millimeters (3 to 3-1/2 inches) for 35.5-millimeter- (1.4-inch-) diameter specimens and 152 to 178 millimeters (6 to 7 inches) for 71-millimeter- (2.8-inch-) diameter specimens) using a miter box.

(c) From the soil trimmings, obtain 200 grams of material for specific gravity and water content determination.

(d) Weigh the specimen to an accuracy of ± 0.01 gram for 35.5-millimeter- (1.4-inch-) diameter specimens and ± 0.1 grams for 71-millimeter- (2.8-inch-) diameter specimens.

(e) Measure the height and diameter of the specimen to an accuracy of ± 0.25 millimeters (0.01 inch). Specimen dimensions based on measurements of the trimming frame guides and miter box length are not sufficiently accurate. The average height H_o of the specimen should be determined from at least four measurements, while the average diameter should be determined from measurements at the top, center, and bottom of the specimen, as follows:

$$D_o = \frac{D_t + 2D_c + D_b}{4} \qquad \text{(L-1)}$$

where

D_o = average diameter

D_t = diameter at top

D_C = diameter at center

D_b = diameter at bottom

(2) Compacting Specimens of Cohesive Soil. Specimens of compacted soil may be trimmed, as described above, from samples formed in a compaction mold (a 102-millimeter- (4-inch-) diameter sample is satisfactory for 35.5-millimeter- (1.4-inch-) diameter specimens), though it is preferable to compact individual specimens in a split mold having inside dimensions equal to the dimensions of the desired specimen. The method of compacting the soil into the mold should duplicate as closely as possible the method that will be used in the field. In general, the standard impact type of compaction will not produce the same soil structure and stress-deformation characteristics as the kneading action of the field compaction equipment. Therefore, the soil should preferably be compacted into the mold (whether a specimen-size or a standard compaction mold) in at least six layers, using a pressing or kneading action of a tamper having an area in contact with the soil of less than one-sixth the area of the mold, and thoroughly scarifying the surface of each layer before placing the next. The sample shall be prepared, thoroughly mixed with sufficient water to produce the desired water content, and then stored in an airtight container for at least 16 hours. The desired density may be produced by either kneading or tamping each layer until accumulative weight of soil placed in the mold is compacted to a known volume, or adjusting the number of layers, the number of tamps per layer, and the force per tamp. For the latter method of control, special constant-force tampers (such as the Harvard miniature compactor for 35.5-millimeter- (1.4-inch-) diameter specimens or similar compactors for 71-millimeter- (2.8-inch-) diameter and larger specimens) are necessary. After each specimen compacted to finished dimensions has been removed from the mold, proceed in accordance with steps c through e of (1) above.

b. Cohesionless Soils Containing Negligible Amounts of Gravel. Soils which possess little or no cohesion are difficult if not impossible to trim into a specimen. If undisturbed samples of such materials are available in sampling tubes, satisfactory specimens can usually be obtained by freezing the sample to permit cutting out suitable specimens. Samples should be drained before freezing. The frozen specimens are placed in the triaxial chamber, allowed to thaw after application of the chamber pressure, and then tested as desired. Some slight disturbance probably occurs as a result of the freezing, but the natural stratification and structure of the material are retained. In most cases, however, it is permissible to test cohesionless soils in the remolded state by forming the specimen at the desired density or at a series of densities which will permit interpolation to the desired density. Specimens prepared in this manner should generally be 71 millimeters (8 inches) in diameter or larger, depending on the maximum particle size. The procedure for forming the test specimen shall consist of the following steps:

(1) Oven-dry and weigh an amount of material sufficient to provide somewhat more than the desired volume of specimen.

(2) Place the forming jacket, with the membrane inside, over the specimen base of the triaxial compression device.

(3) Evacuate the air between the membrane and the inside face of the forming jacket.

(4) After mixing the dried material to avoid segregation, place the specimen, by means of a funnel or special spoon, inside the forming jacket in equal layers. For 71-millimeter- (8-inch-) diameter specimens, 10 layers of equal thickness are adequate. Starting with the bottom layer, compact each layer by blows with a tamping hammer, increasing the number of blows per layer linearly with the height of the layer above the bottom layer. The total number of blows required for a specimen of a given material will depend on the density desired. Considerable experience is usually required to establish the proper procedure for compacting a material to a desired uniform density by this method. A specimen formed properly in the above-specified manner, when confined and axially loaded, will deform symmetrically with respect to its midheight, indicating that a uniform density has been obtained along the height of the specimens.

(5) As an alternate procedure, the entire specimen may be placed in a loose condition by means of a funnel or special spoon. The desired density may then be achieved by vibrating the specimen in the forming jacket to obtain a specimen of predetermined height and corresponding density. A specimen formed properly in this manner, when confined and axially loaded, will deform symmetrically with respect to its mid height.

(6) Subtract weight of unused material from original weight of the sample to obtain weight of material in the specimen.

(7) After the forming jacket is filled to the desired height, place the specimen cap on the top of the specimen, roll the ends of the membrane over the specimen cap and base, and fasten the ends with rubber bands or o-rings. Apply a low vacuum to the specimen through the base and remove the forming jacket.

(8) Measure height and diameter as specified in paragraph L-4.

c. Soils Containing Gravel. The size of specimens containing appreciable amounts of gravel is governed by the requirements of this paragraph. If the material to be tested is in an undisturbed state, the specimens shall be prepared according to the applicable requirements of a and b above, with the size of specimen based on an estimate of the largest particle size. In testing compacted soils, the largest particle size is usually known, and the entire sample should be tested, whenever possible, without removing any of the coarser particles. However, it may be necessary to remove the particles larger than a certain size to comply with the requirements for specimen size, though such practice will result in lower measured values of the shear strength and should be avoided if possible. Oversize particles should be removed and, if comprising more than 10 percent by weight of the sample, be replaced by an equal percentage by weight of material retained on the No. 4 sieve and passing the maximum allowable sieve size. The percentage of material finer than the No. 4 sieve thus remains constant. It will generally be necessary to prepare compacted samples of material containing gravel inside a forming jacket placed on the specimen base. If the material is cohesionless, it should be oven-dried and compacted in layers inside the membrane and forming jacket using the procedure in b above as a guide. When specimens of very high density are required, the samples should be compacted preferably by vibration to avoid rupturing the membrane. The use of two membranes will provide additional insurance against possible leakage during the test as a result of membrane rupture. If the sample contains a significant amount of fine-grained material, the soil usually must posses the proper water content before it can be compacted to the desired density. Then, a special split compaction mold is used for forming the specimen. The inside dimensions of the mold are equal to the dimensions of the triaxial specimen desired. No membrane is used inside the mold, as the membrane can be readily placed over the compacted specimen after it is removed from the split mold. The specimen should be compacted to the desired density in accordance with paragraph L-4.

L-5. Q TEST WITH BACK-PRESSURE SATURATION.

a. Equipment Setup. For the Q test with back-pressure saturation, the apparatus should be set up similar to that shown in Figure L-1. Filter strips should not be used and as little volume changes as possible should be permitted during the test. Complete the steps outlined in paragraph L-4 and the following steps:

(1) Record all identifying information for the sample project number or name, boring number, and other pertinent data on a sheet.

(2) Place one of the prepared specimens on the base.

(3) Place a rubber membrane in the membrane stretcher, turn both ends of the membrane over the ends of the stretcher, and apply a vacuum to the stretcher. Carefully lower the stretcher and membrane over the specimen. Place the specimen cap on the top of the specimen and release the vacuum on the membrane stretcher. Turn the ends of the membrane down around the base and up around the specimen cap and fasten the ends with o-rings or rubber bands. With a 35.5-millimeter- (1.4-inch-) diameter specimen of relatively insensitive soils, it is easier to roll the membrane over the specimen.

(4) Assemble the triaxial chamber and place it in position in the loading device. Connect the tube from the pressure reservoir to the base of the triaxial chamber. With valve C on the pressure reservoir closed and valves A and B open, increase the pressure inside the reservoir and allow the pressure fluid to fill the triaxial chamber. Allow a few drops of the pressure fluid to escape through the vent valve (valve B) to ensure complete filling of the chamber with fluid. Close valve A and the vent valve.

b. Back-Pressure Procedure. Then apply a 0.02-MPa (3-psi) chamber pressure to the specimen with all drainage valves closed. Allow a minimum of 30 minutes for stabilization of the specimen pore water pressure, measure the change of deformation ΔH, and begin back-pressure procedures as follows:

(1) Estimate the magnitude of the required back pressure by theoretical relations. Specimens should be completely saturated before any appreciable consolidation is permitted for ease and uniformity of saturation as well as to allow volume changes during consolidation to be measured with the burette; therefore, the difference between the chamber pressure and the back pressure should not exceed 0.034 MPa (5 psi) during the saturation phase. To ensure that a specimen is not prestressed during the saturation phase, the back pressure must be applied in small increments, with adequate time between increments to permit equalization of pore water pressure throughout the specimen.

(2) With all valves closed, adjust the pressure regulators to a chamber pressure of about 0.048 MPa (7 psi) and a back pressure of about 0.013 MPa (2 psi). Record these pressures on a data sheet. Next, open valve A to apply the back pressure through the specimen cap. Immediately, open valve G and read and record the pore pressure at the specimen base. When the measured pore pressure becomes essentially constant, close valves F and G and record the burette

reading. (If an electrical pressure transducer is used to measure the pore pressure, valve G may be safely left open during the entire saturation procedure).

(3) Using the technique described above, increase the chamber pressure and the back pressure in increments, maintaining the back pressure at about 0.034 MPa (5 psi) less than the chamber pressure. The size of each increment might be 0.034, 0.069, or even 0.138 MPa (5, 10, or even 20 psi) depending on the compressibility of the soil specimen and the magnitude of the desired consolidation pressure. Open valve G and measure the pore pressure at the base immediately upon application of each increment of back pressure and observe the pore pressure until it becomes essentially constant. The time required for stabilization of the pore pressure may range from a few minutes to several hours depending on the permeability of the soil. Continue adding increments of chamber pressure and back pressure until, under any increment, the pore pressure reading equals the applied back pressure immediately upon opening valve G.

(4) Verify the completeness of saturation by closing valve F and increasing the chamber pressure by about 0.034 MPa (5 psi). The specimen shall not be considered completely saturated unless the increase in pore pressure immediately equals the increase in chamber pressure.

c. Chamber Pressure. After verification of saturation, and remeasurement of ΔH, close all drainage lines leading to the back pressure and pore water measurement apparatus. Holding the maximum applied back pressure constant, increase the chamber pressure until the difference between the chamber pressure and the back pressure equals the desired effective confining pressure as follows. With valves A and C closed, adjust the pressure regulator to preset the desired chamber pressure. The range of chamber pressures for the three specimens will depend on the loadings expected in the field. The maximum confining pressure should be at least equal to the maximum normal load expected in the field so that the shear strength data need not be extrapolated for use in design analysis. Record the chamber pressure on data sheets. Now open valve A and apply the preset pressure to the chamber. Application of the chamber pressure will force the piston upward into contact with the ram of the loading device. This upward force is equal to the chamber pressure acting on the cross-sectional area of the piston minus the weight of the piston minus piston friction.

d. Operation.

(1) Start the test with the piston approximately 2.5 millimeters (0.1 inch) above the specimen cap. This allows compensation for the effects of piston friction, exclusive of that which may later develop as a result of lateral forces. Set the load indicator to zero when the piston comes into contact with the specimen cap. In this manner, the upward thrust of the chamber pressure on the piston is also eliminated from further consideration. Contact of the piston with the specimen cap is indicated by a slight movement of the load indicator. Set the strain indicator and record on the data sheet the initial dial reading at contact. Axially strain the specimen at a rate of about 1 percent per minute for plastic materials or about 0.3 percent per minute for brittle materials that achieve maximum deviator stress at about 3 to 6 percent strain; at these rates, the elapsed time to reach maximum deviator stress would be about 15 to 20 minutes.

(2) Observe and record the resulting load at every 0.3 percent strain for about the first 3 percent and, thereafter, at every 1 percent or, for large strains, at every 2 percent strain; sufficient readings should be taken to completely define the shape of the stress-strain curve so frequent readings may be necessary as failure is approached. Continue the test until an axial strain of 15 percent has been reached; however, when the deviator stress decreases after attaining a

maximum value and is continuing to decrease at 15 percent strain, the test shall be continued to 20 percent.

(3) For brittle soils (i.e., those in which maximum deviator stress is reached at 6 percent axial strain or less), tests should be performed at rates of strain sufficient to produce times to failure as set forth above; however, when the maximum deviator stress has been clearly defined, the rate may be increased such that the remainder of the test is completed in the same length of time as that taken to reach maximum deviator stress. However, for each group of tests about 20 percent of the samples should be tested at the rates set forth above.

(4) Upon completion of axial loading, release the chamber pressure by shutting off the air supply with the regulator and opening valve C. Open valve B and draw the pressure fluid back into the pressure reservoir by applying a low vacuum at valve C. Dismantle the triaxial chamber. Make a sketch of the specimen, showing the mode of failure.

(5) Remove the membrane from the specimen. For 35.5-millimeter- (1.4-inch-) diameter specimens, carefully blot any excess moisture from the surface of the specimen and determine the water content of the whole specimen. For 71-millimeter- (2.8-inch-) diameter or larger specimens, it is permissible to use a representative portion of the specimen for the water content determination. It is essential that the final water content be determined accurately, and weighings should be verified, preferably by a different technician.

(6) Repeat the test on the two remaining specimens at different chamber pressures, though using the same rate of strain.

L-6. EQUIPMENT.

a. Triaxial Test Cell.

(1) A triaxial cell suitable for use in resilience testing of soils is shown in Figure L-2. This equipment is similar to most standard cells, except that it is somewhat larger so that it can facilitate the internally mounted load and deformation measuring equipment and the equipment has additional outlets for the electrical leads from the measuring devices. For the type of equipment shown, air or nitrogen is used as the cell fluid.

(2) The external loading source may be any device capable of providing a variable load of fixed cycle and load duration, ranging from a simple cam-and-switch control of static weights or air pistons to a closed-loop electrohydraulic system. A load duration of 0.2 seconds and a cycle duration of 3 seconds have been satisfactory for most applications. A square-wave load form is recommended.

b. Deformation-Measuring Equipment.

(1) The deformation-measuring equipment consists of LVDTs attached to the soil specimen by a pair of clamps. Two LVDTs are used for the measurement of axial deformation. The clamps and LVDTs are shown in position on a soil specimen in Figure L-2. Details of the clamps are shown in Figure L-3. Load is measured by placing a load cell between the specimen cap and the loading piston as shown in Figure L-2.

(2) Use of the type of measuring equipment described above offers several advantages:

(a) It is not necessary to reference deformations to the equipment, which deforms during loading.

(b) The effect of end-cap restrain on soil response is virtually eliminated.

(c) Any effects of piston friction are eliminated by measuring loads inside the triaxial cell.

(3) In addition to the measuring devices it is also necessary to maintain suitable recording equipment. Simultaneous recording of load and deformation is desirable. The number of recording channels can be reduced by wiring the leads from the LVDTs so that only the average signal from each pair is recorded. The introduction of switching and balancing units permits use of a single-chamber recorder.

c. Additional Equipment. In addition to the equipment described above, the following items are also used:

(1) A 9- to 27-metric ton- (10- to 30-short ton-) capacity loading machine.

(2) Calipers, a micrometer gauge, and a steel rule (calibrated to 0.25 millimeter (0.01 inch)).

(3) Rubber membranes, 0.25 to 0.635 millimeter (0.01 to 0.025 inch) thick.

(4) Rubber O-rings.

(5) A vacuum source with a bubble chamber and regulator.

(6) A back-pressure chamber with pressure transducers.

(7) A membrane stretcher.

(8) Porous stones.

L-7. PREPARATION OF SPECIMENS AND PLACEMENT IN TRIAXIAL CELL. The following steps should be followed in preparing and placing specimens:

a. In accordance with procedures specified in paragraph L-5, prepare the specimen and place it on the baseplate complete with porous stones, cap, and base and equipped with a rubber membrane secured with o-rings. Check for leakage. If back-pressure saturation is anticipated for cohesive soils, procedures indicated in paragraph L-5a should be followed. For purely noncohesive soils, it will be necessary to maintain the vacuum during placement of the LVDTs. The specimen is now ready to receive the LVDTs.

b. Extend the lower LVDT clamp and slide it carefully down over the specimen to approximately the lower third point of the specimen.

c. Repeat this step for the upper clamp, placing it at the upper third point. Ensure that both clamps lie in horizontal planes.

d. Connect the LVDTs to the recording unit, and balance the recording bridges. This step will require recorder adjustments and adjustment of the LVDT stems. When a recording bridge balance has been obtained, determine (to the nearest 0.25 millimeter (0.01 inch)) the vertical spacing between the LVDT clamps and record this value.

e. Place the triaxial chamber in position. Set the load cell in place on the specimen.

f. Place the cover plate on the chamber. Insert the loading piston and obtain a firm connection with the load cell.

g. Tighten the tie rods firmly.

h. Slide the assembled apparatus into position under the axial loading device. Bring the loading device to a position in which it nearly contacts the loading piston.

I. If the specimen is to be back-pressure saturated, proceed in accordance with paragraph L-5.

j. After saturation has been completed, rebalance the recorder bridge to the load cell and LVDTs.

L-8. RESILIENCE TESTING OF COHESIVE SOILS.

a. General. The resilient properties of cohesive soils are only slightly affected by the magnitude of the confining pressure σ_3. For most applications, this effect can be disregarded. When back-pressure saturation is not used, the confining pressure used should approximate the expected in situ horizontal stresses. These will generally be on the order of 0.0069 to 0.034 MPa (1 to 5 psi). A chamber pressure of 0.021 MPa (3 psi) is a reasonable value for most testing. If back-pressure saturation is used, the chamber pressure will depend on the required saturation pressure.

b. Resilient Properties. Resilient properties are highly dependent on the magnitude of the deviator stress σ_d. It is therefore necessary to conduct the tests for a range in deviator stress values. The following procedure should be followed:

(1) If back-pressure saturation is not used, connect the chamber pressure supply line and apply the confining pressure (equal to the chamber pressure). If back-pressure saturation is used, the chamber pressure will already have been established.

(2) Rebalance the recording bridges for the LVDTs and balance the load cell recording bridge.

(3) Begin the test by applying 500 to 1,000 repetitions of a deviator stress of not more than one-half the unconfined compressive strength.

(4) Decrease the deviator load to the lowest value to be used. Apply 200 repetitions of load, recording the recovered vertical deformation at or near the last repetition.

(5) Increase the deviator load, recording deformations as in step 4. Repeat over the range of deviator stresses to be used.

(6) At the completion of the loading, reduce the chamber pressure to zero. Remove the chamber LVDTs and load cell. Use the entire specimen for the purpose of determining the moisture content.

c. The results of the resilience tests can be presented in the form of a summary table, such as Table L-1, and graphically as is shown in Figure L-4 for the resilient modulus.

L-9. RESILIENCE TESTING OF COHESIONLESS SOILS.

a. General. The resilient modulus of cohesionless soils M_R is dependent upon the magnitude of the confining pressure σ_3 and is nearly independent of the magnitude of the repeated axial stress. Therefore, it is necessary to test cohesionless materials over a range of confining and axial stresses. (The confining pressure is equal to the chamber pressure less the back pressure for saturated specimens). The following procedure should be used for this type of test:

(1) Use confining pressures of 0.034, 0.069, 0.103, and 0.138 MPa (5, 10, 15, and 20 psi) at each confining pressure, and test at five values of the principal stress difference corresponding to multiples (1, 2, 3, 4) of the cell pressure.

(2) Before beginning to record deformations, apply a series of conditioning stresses to the material to eliminate initial loading effects. The greatest amount of volume change occurs during the application of the conditioning stresses. Simulation of field conditions suggest that drainage of saturated specimens should be permitted during the application of these loads but that the test loading (beginning in step 6 below) should be conducted in an undrained state.

(3) Set the axial load generator to apply a deviator stress of 0.069 MPa (10 psi) (i.e., a stress ratio equal to 3). Activate the load generator and apply 200 repetitions of this load. Stop the loading.

(4) Set the axial load generator to apply a deviator stress of 0.138 MPa (20 psi) (i.e., a stress ratio equal to 5). Activate the load generator and apply 200 repetitions of this load. Stop the loading.

(5) Repeat as in step 4 above maintaining a stress ratio equal to 6 and using the following order and magnitude of confining pressures: 0.069, 0.138, 0.069, 0.034, 0.021, and 0.0069 MPa (10, 20, 10, 5, 3, and 1 psi).

(6) Begin the record test using a confining pressure of 0.0069 MPA (1 psi) and an equal value of deviator stress. Record the resilient deformation after 200 repetitions. Increase the deviator stress to twice the confining pressure and record the resilient deformation after 200 repetitions. Repeat until a deviator stress of four times the confining pressure is reached (stress ratio of 5).

(7) Repeat as in step 6 above for each value of confining pressure.

(8) When the test is completed, decrease the back pressure to zero, reduce the chamber pressure to zero, and dismantle the cell. Remove the LVDT clamps, etc. Remove the soil specimen, and use the entire amount of soil to determine the moisture content.

b. Calculations. Calculations can be performed using a similar tabular arrangement as was shown in Table L-1. Test results should be presented in the form of a plot of log M_R versus log of the sum of the principal stresses as shown in Figure L-5.

L-10. INTERPRETATION OF TEST RESULTS.

a. Cohesive Soils. As previously indicated, test results for cohesive soils are presented in the form of a plot of resilient modulus M_R versus deviator stress σ_d. Normally for cohesive soils, the test results will indicate that the resilient modulus decreases rapidly with increases in deviator stress. Thus, selection of a resilient modulus from the laboratory tests results requires an estimate of the deviator stress at the top of the subgrade with respect to the design aircraft. For a properly designed pavement, the deviator stress at the top of the subgrade will primarily be a function of the subgrade modulus and the design traffic level. Shown in Figure L-6 are relationships between deviator stress at the top of the subgrade and applicable subgrade modulus values determined from an analysis of the pavement sections. The relationships shown in Figure L-6 were determined using a layered elastic pavement model with the modulus values as input parameters and the deviator stress values as computed responses. Thus, these relationships are essentially limiting criteria. Relationships are shown for 1,000, 10,000, 100,000, and 1,000,000 repetitions of strain. To determine the appropriate modulus value to use in the performance model, the test results from the resilient modulus tests on the laboratory specimens are superimposed on the appropriate relationship from Figure L-6, and the design modulus value is taken from the intersection of the plotted functions.

b. Example on Cohesive Soils. Assume a design problem involving 100,000 repetitions of strain. Figure L-7 shows a plot of relationships taken from Figure L-6 superimposed on test results from a laboratory resilient modulus test. For this particular design, a subgrade modulus value of 62 MPa (9,000 psi) would be used.

c. Cohesionless Soils. For cohesionless soils, laboratory test results are presented in the form of a plot of resilient modulus versus the first stress invariant, i.e., sum of the principal stress θ. For cohesionless soils, this relationship is generally linear in form on a log-log plot, with the resilient modulus being directly proportional to the sum of the principal stresses. Selection of a specific resilient modulus value for use in the design model requires an estimate of the sum of the principal stresses at the top of the subgrade. Since a cohesionless material is involved, the influence of both applied stresses and estimated overburden stresses from the pavement structure must be considered. In Figure L-8, a relationship is shown between the pavement thickness and the sum of the principal stresses at the top of the subgrade due to overburden. In Figure L-9, relationships are shown between the subgrade modulus and limiting values of the sum of the principal stresses due to applied force. For each figure, relationships are shown for 1,000, 10,000, 100,000, and 1,000,000 repetitions of stress. Using the value of the estimated pavement thickness, that part of the total sum of the principal stresses due to overburden can be obtained from Figure L-8. The applicable relationship from Figure L-9 is then selected and adjusted to include the influence of overburden by increasing all values of the principal stress sum by the value obtained from Figure L-8. Thus, a new limiting relationship is obtained and replotted. The results of the laboratory modulus test are superimposed on the plot, and the design subgrade modulus values are taken at the intersection of these relationships.

d. Example on Cohesionless Soils. Assume a design problem involving a pavement having an estimated initial thickness of 762 millimeters (30 inches). The design aircraft has a dual-wheel main gear assembly, and the design life is for 100,000 repetitions of strain. From Figure L-8, the value of the sum of the principal stresses due to overburden is 0.045 MPa (6.5 psi). Using the 100,000 strain repetition curve from Figure L-9, the value obtained from Figure L-8 is added to all values of the sum of the principal stresses indicated in the relationship and the adjusted curve is replotted (Figure L-10). The result of adjusting the original relationship is to shift it to the right of its original position. In Figure G-10, the results of laboratory resilient modulus tests on specimens of the subgrade soil are also shown. From the intersection of these two relationships, a design modulus M_R of 103 MPa (15,000 psi) is determined.

e. Special Considerations. In some situations, the laboratory curve may not converge with the limiting stress-modulus relationship within the range of values indicated. Obviously, two possibilities are involved in this situation: the laboratory relationships could plot above or below the limiting criteria curve. In the former case, since all values of the sum of the principal stresses indicated by the laboratory curve would exceed the stress criteria within the region under consideration, the value of 207 MPa (30,000 psi) should be used for the subgrade modulus. In the latter case, the initial design thickness value should be increased and the limiting criteria curve readjusted until convergence with the laboratory relationships is obtained.

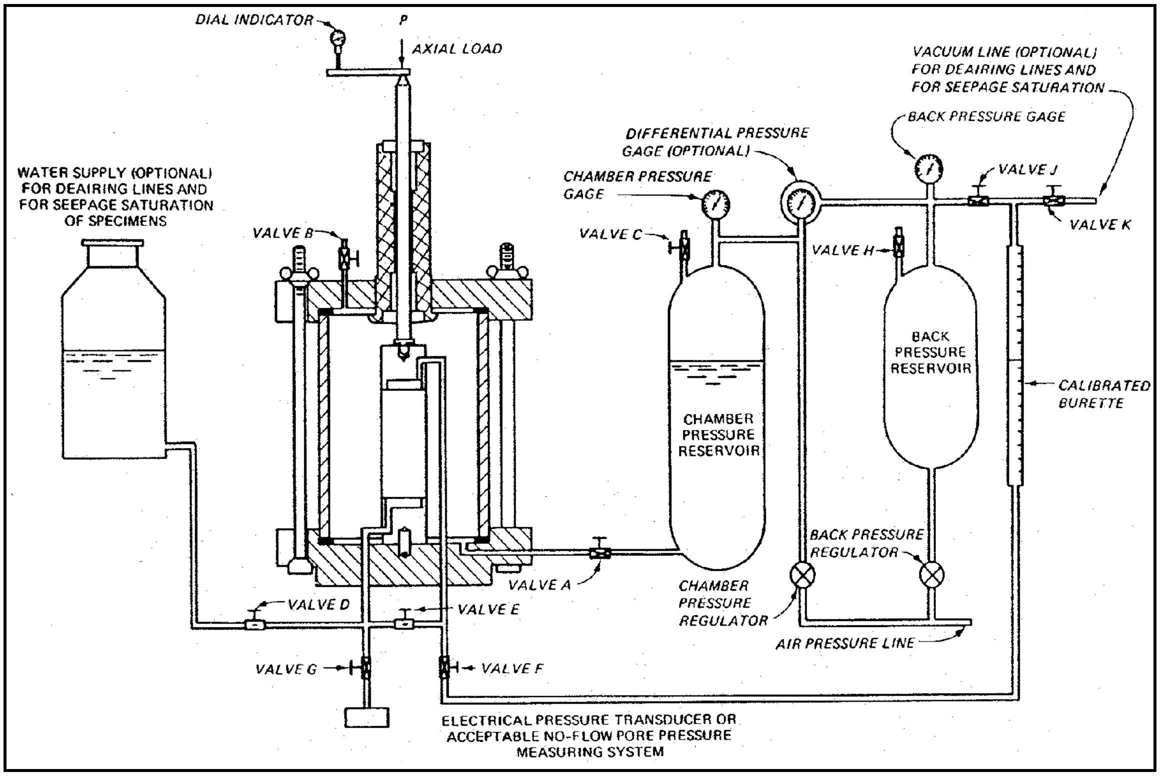


Figure L-1. Schematic diagram of typical triaxial compression apparatus

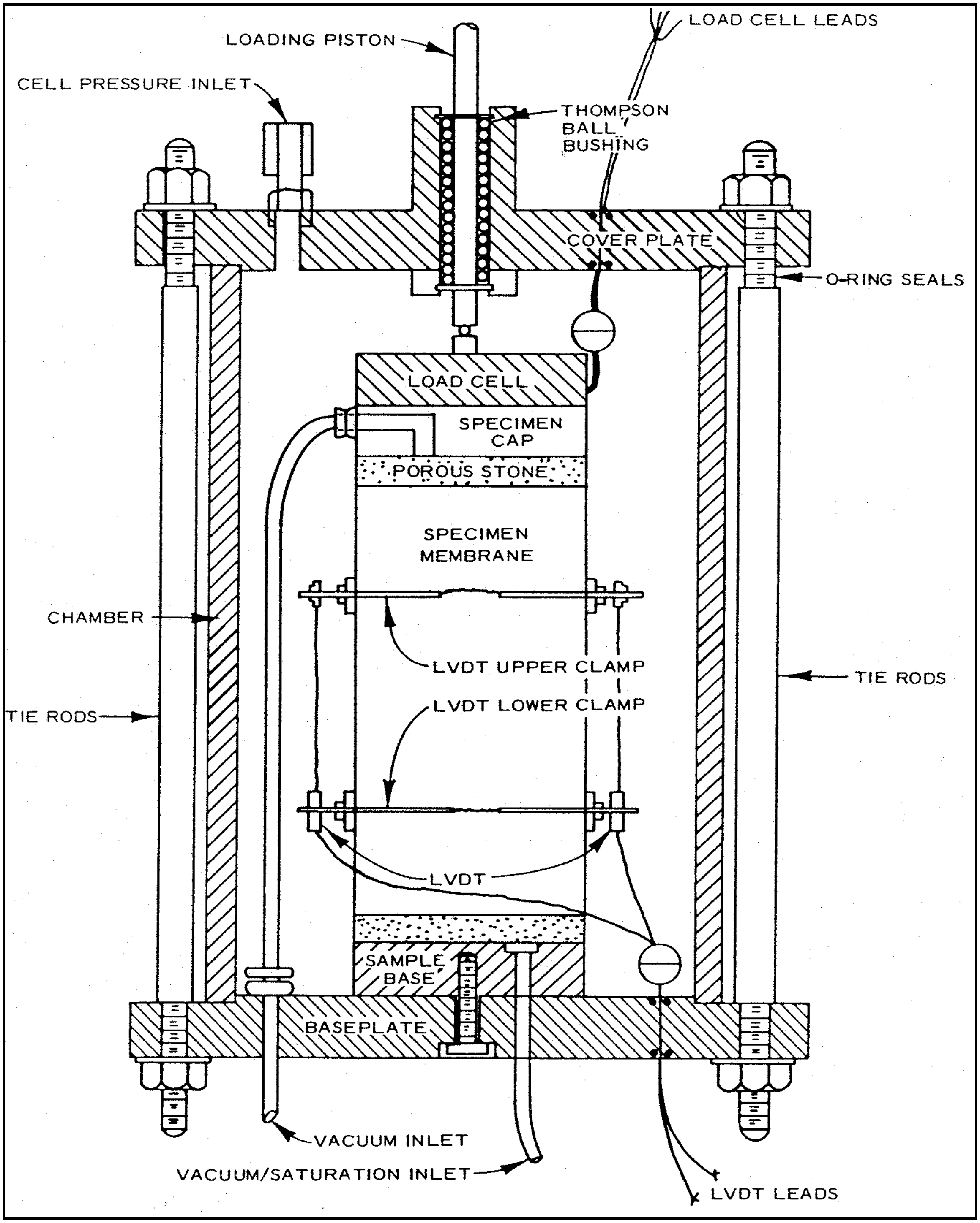


Figure L-2. Triaxial cell

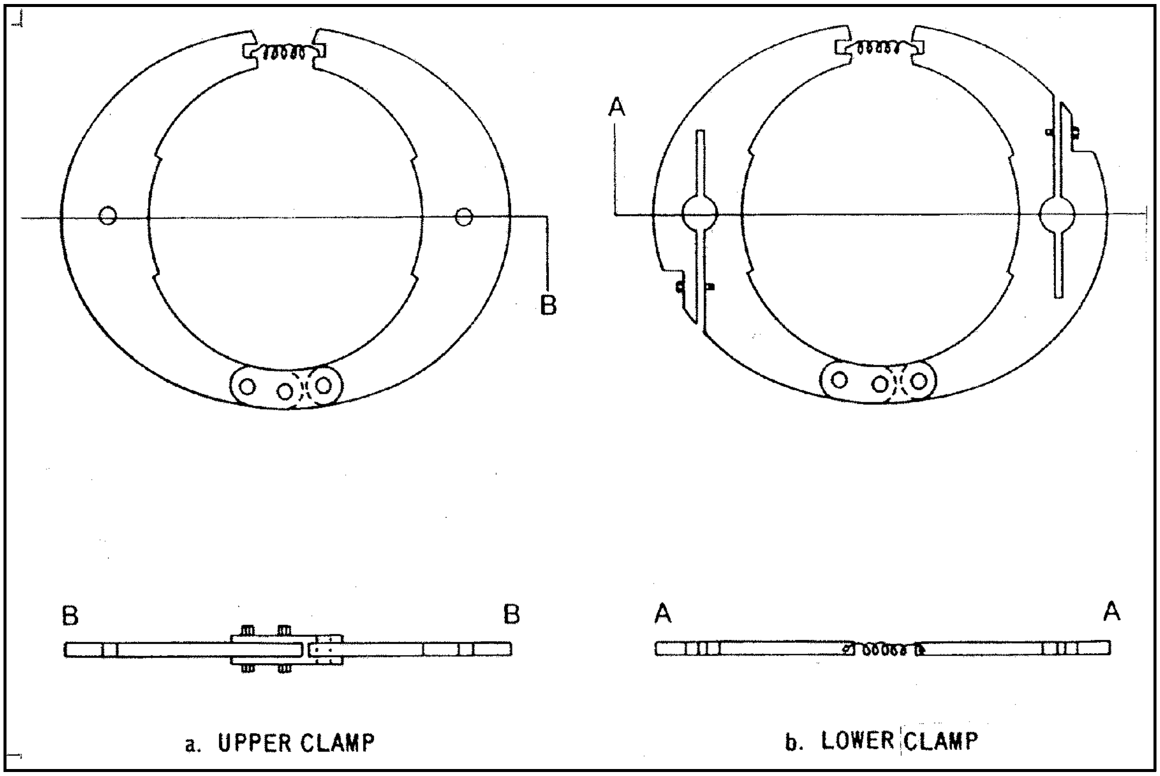


Figure L-3. LVDT clamps

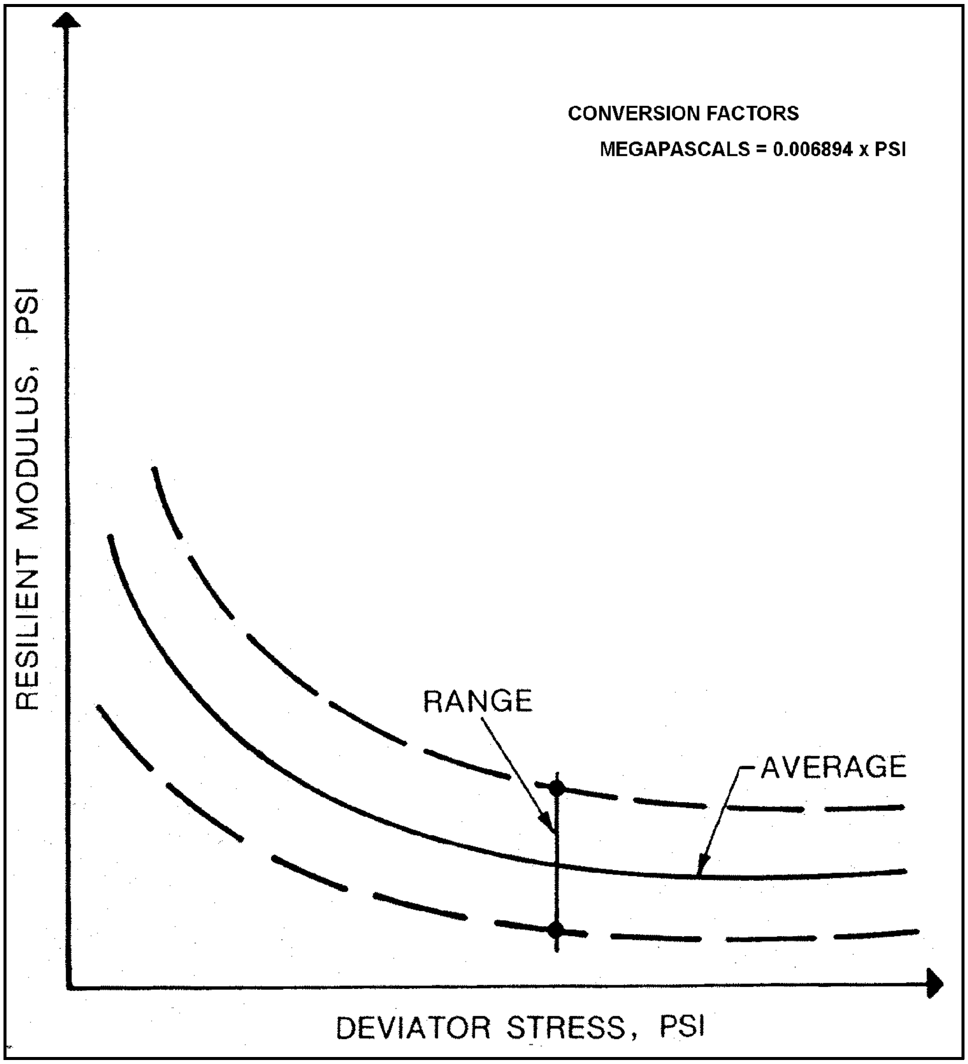


Figure L-4. Presentation of results of resilience tests on cohesive soils

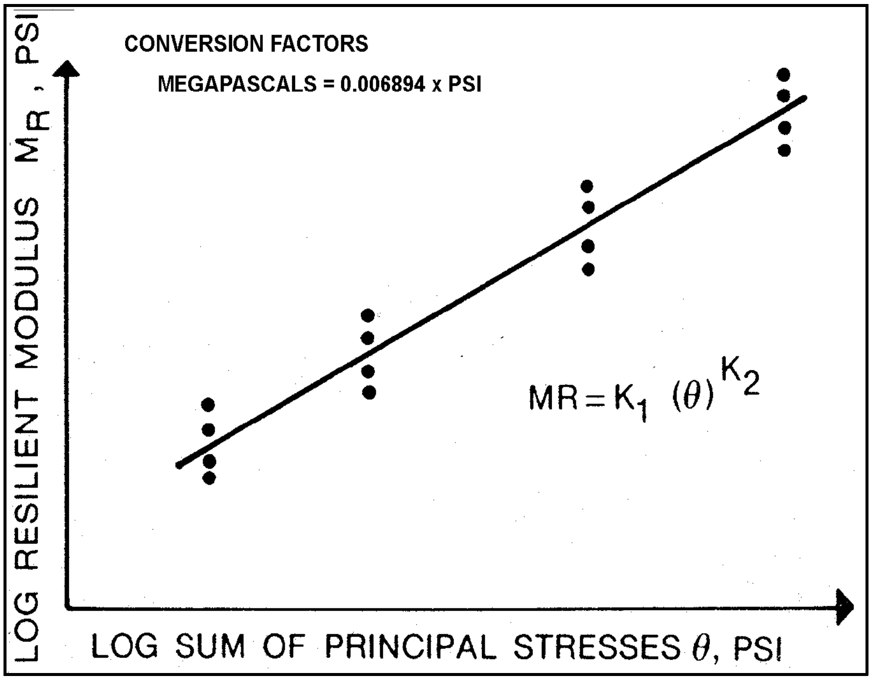


Figure L-5. Presentation of results of resilience tests on cohesionless soils

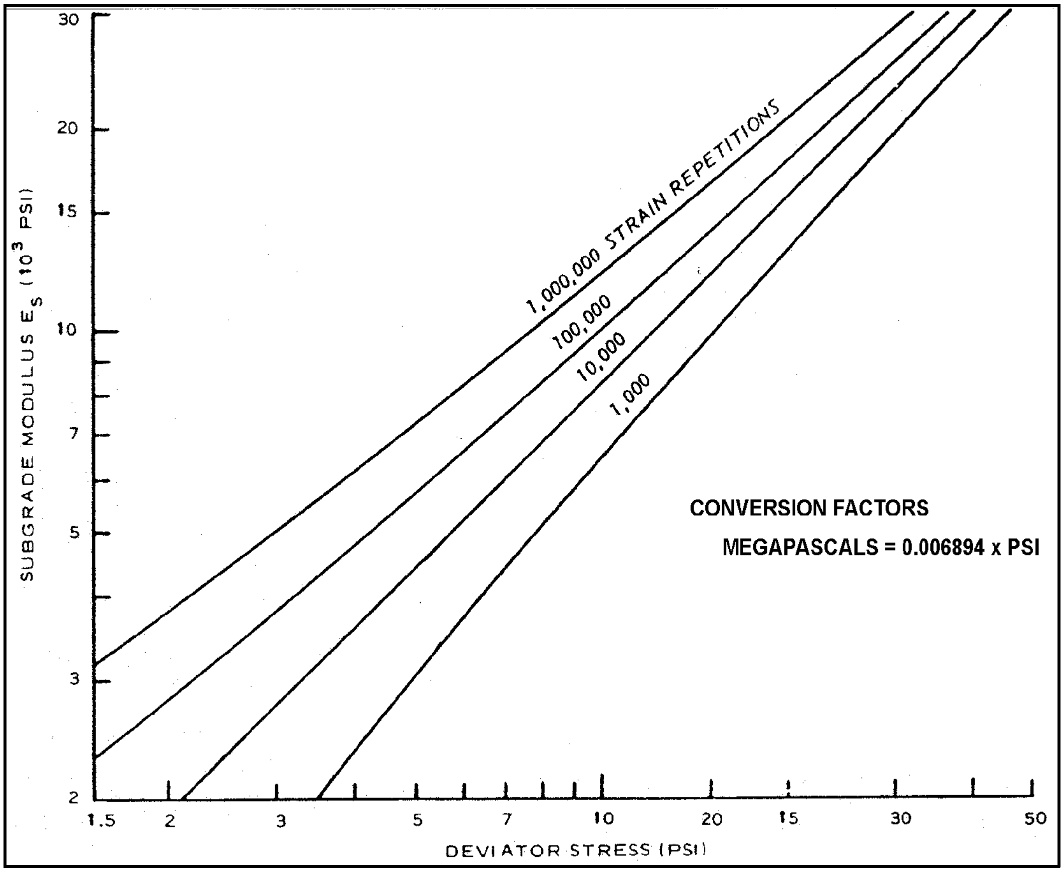


Figure L-6. Estimated deviator stress at top of subgrade

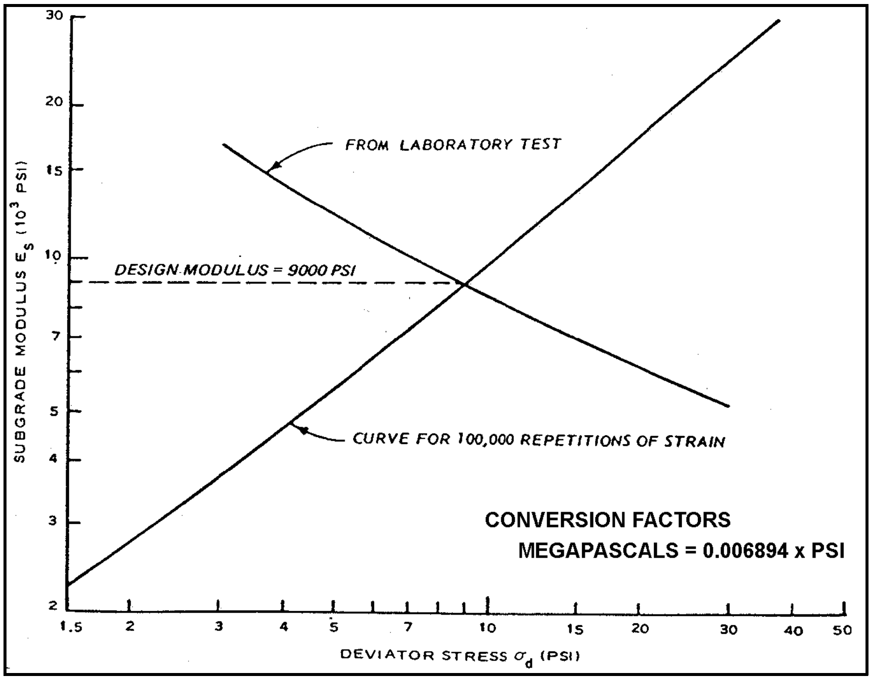


Figure L-7. Determination of subgrade modulus for cohesive soils

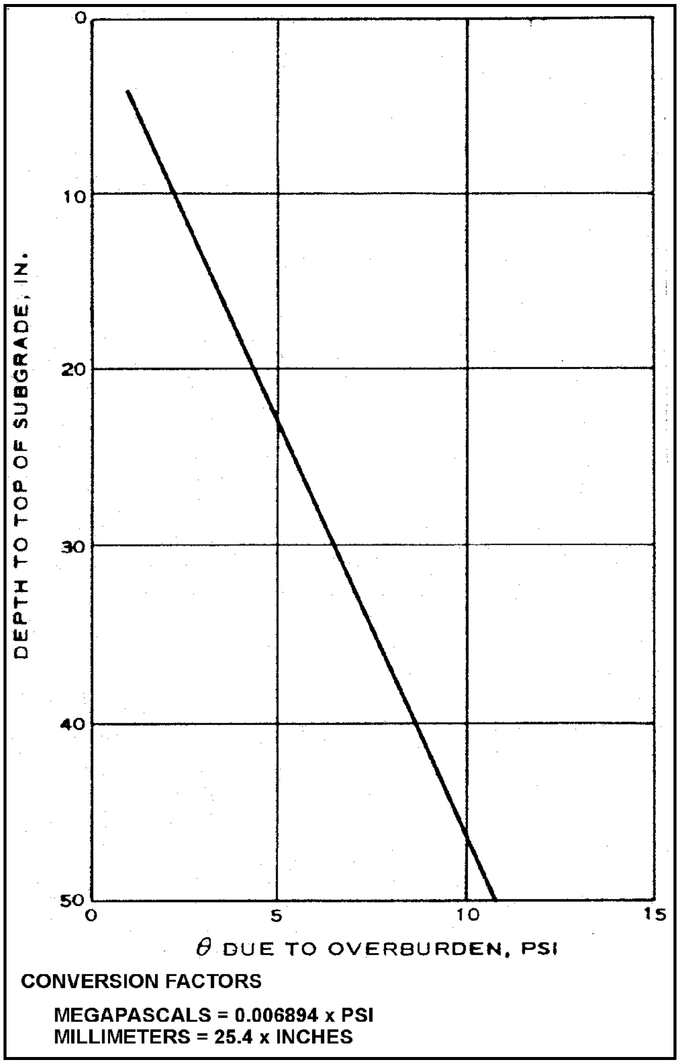


Figure L-8. Relationship for estimating θ due to overburden

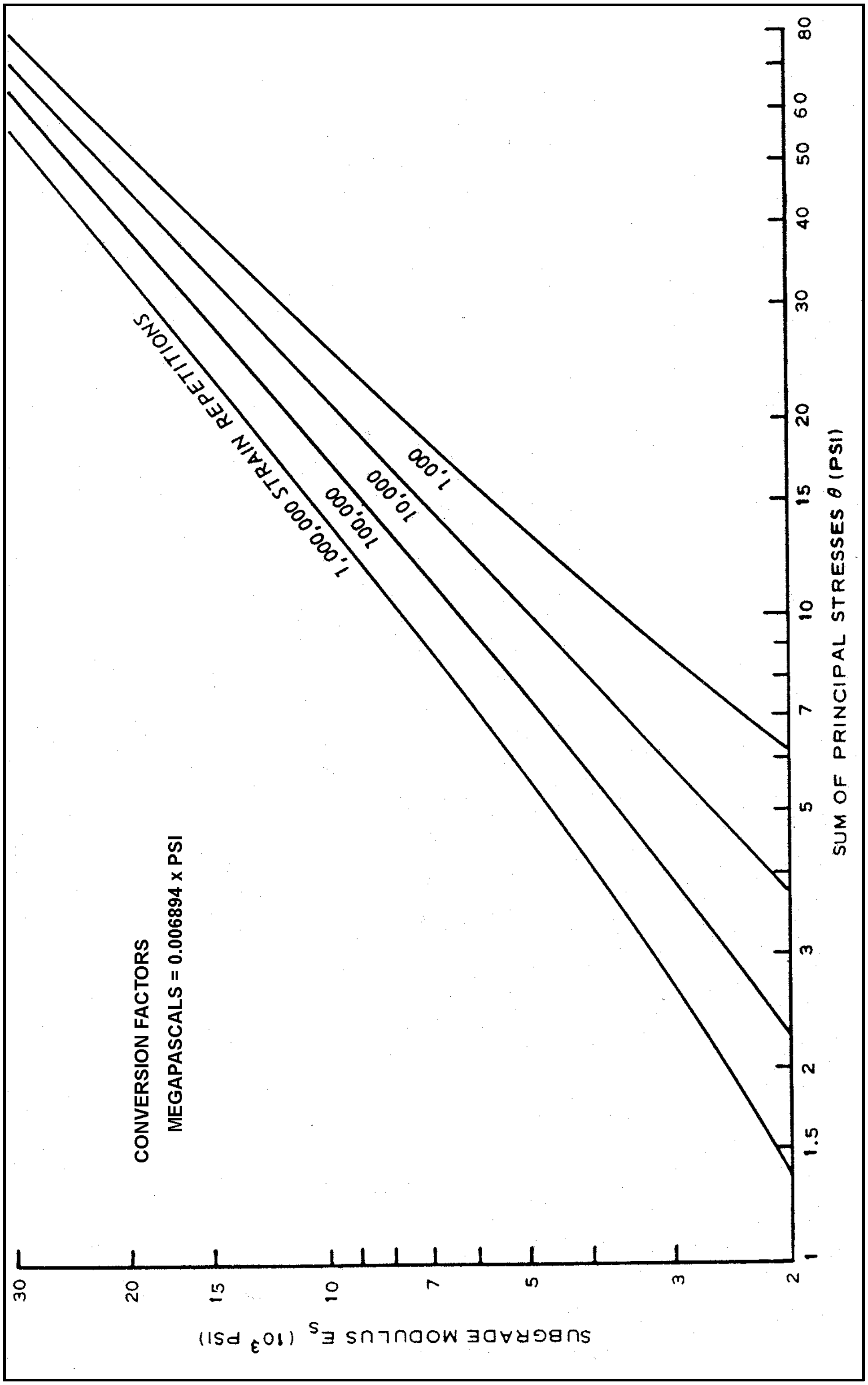


Figure L-9. Estimated θ at top of subgrade

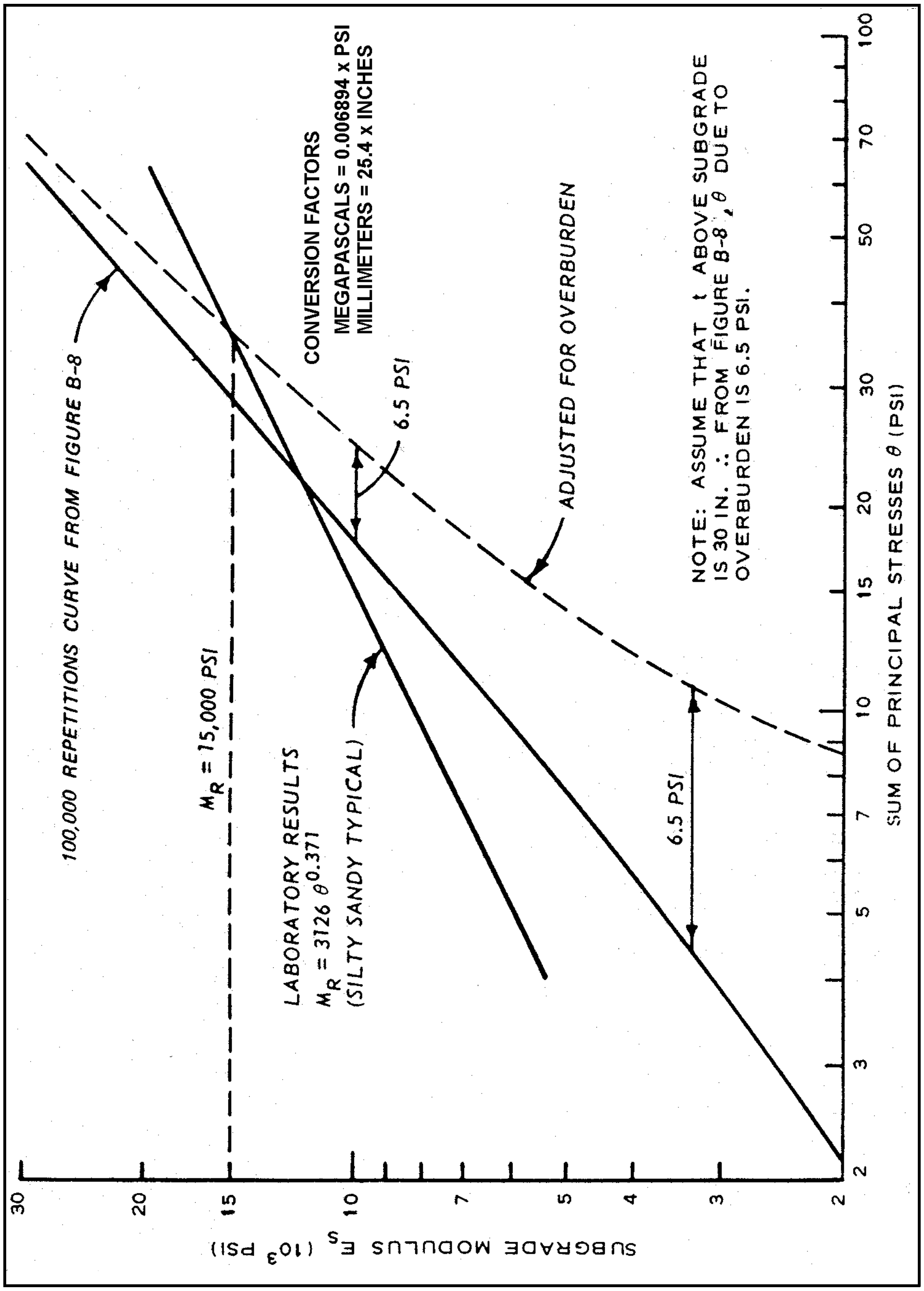


Figure L-10. Selection of M_R for silty-sand subgrade with estimated thickness of 762 millimeters (30 inches) for 100,000 repetitions of strain

APPENDIX M

PROCEDURES FOR DETERMINING THE FATIGUE LIFE OF BITUMINOUS CONCRETE

M-1. LABORATORY TEST METHOD.

a. General. A laboratory procedure for determining the fatigue life of bituminous concrete paving mixtures containing aggregate with maximum sizes up to 31.8 millimeters (1-1/2 inches) is described in this chapter. The fatigue life of a simply supported beam specimen subjected to third-point loading applied during controlled stress-mode flexural fatigue tests is determined.

b. Definitions. The following symbols are used in the description of this procedure:

(1) ϵ = initial extreme fiber strain (tensile and compressive, inches per inch)

(2) N_f = fatigue life of the specimen, number of load repetitions to fracture.

Extreme fiber strain of simply supported beam specimens subjected to third-point loadings, which produces uniaxial bending stresses, is calculated from

$$\epsilon = \frac{12td}{(3L^2 - 4a^2)} \qquad \text{(M-1)}$$

where

t = specimen depth, millimeters (inches)

d = dynamic deflection of beam center, millimeters (inches)

L = reaction span length, millimeters (inches)

a = L/3, millimeters (inches)

c. Test Equipment.

(1) The repeated flexure apparatus is shown in Figure M-1. It accommodates beam specimens 381 millimeters (15 inches) long with widths and depths not exceeding 76 millimeters (3 inches). A 1,361-kilogram- (3,000-pound-) capacity electrohydraulic testing machine capable of applying repeated tension-compression loads in the form of haversine waves for 0.1-second durations with 0.4-second rest periods is used for flexural fatigue tests. Any dynamic testing machine or pneumatic pressure system with similar loading capabilities is also suitable. Third-point loading, i.e., loads applied at distances of L/3 from the reaction points, produces an approximately constant bending moment over the center 102 millimeters (4 inches) of a 381-millimeter- (15-inch-) long beam specimen with widths and depths not exceeding 76 millimeters (3 inches). A sufficient load, approximately 10 percent of the load deflecting the beam upward, is applied in the opposite

direction, forcing the beam to return to its original horizontal position and holding it at that position during the rest period. Adjustable stop nuts installed on the flexure apparatus loading rod prevent the beam from bending below the initial horizontal position during the rest period.

(2) The dynamic deflection of the beam's center is measured with an LVDT. An LVDT suitable for this purpose is the Sheavitz type 100 M-L. The LVDT core is attached to a nut bonded with epoxy cement to the center of the specimen. Outputs of the LVDT and the electrohydraulic testing machine's load cell, through which loads are applied and controlled, can be fed to any suitable recorder. The repeated flexure apparatus is enclosed in a controlled-temperature cabinet capable of controlling temperatures within ±0.28 degrees Celsius (±½ degree Fahrenheit). A Missimer's model 100 by 500 carbon dioxide plug-in temperature conditioner has been found to provide suitable temperature control.

d. Specimen Preparation. Beam specimens 380 millimeters (15 inches) long with 59-millimeter (3-1/2-inch) depths and 83 millimeter (3-1/4-inch) widths are prepared according to ASTM D 3202. If there is undue movement of the mixture under the compactor foot during beam compaction, the temperature, foot pressure, and number of tamping blows should be reduced. Similar modifications to compaction procedures should be made if specimens with less density are desired. A diamond-blade masonry saw is used to cut 76-millimeter (3-inch) or slightly less deep by 76 millimeters (3-inch) or slightly less wide test specimens from the 380-millimeter- (15-inch-) long beams. Specimens with suitable dimensions can also be cut from pavement samples. The widths and depths of the specimens are measured to the nearest 0.25 millimeter (0.01 inch) at the center and at 51 millimeters (2 inches) from both sides of the center. Mean values are determined and used for subsequent calculations.

e. Test Procedures.

(1) Repeated flexure apparatus loading clamps are adjusted to the same level as the reaction clamps. The specimen is clamped in the fixture using a jig to position the centers of the two loading clamps 51 millimeters (2 inches) from the beam center and to position the centers of the two reactions clamps 165 millimeters (6-1/2 inches) from the beam center. Double layers of Teflon sheets are placed between the specimen and the loading clamps to reduce friction and longitudinal restraint caused by the clamps.

(2) After the beam has reached the desired test temperature, repeated loads are applied. Duration of a load repetition is 0.1 second with 0.4-second rest periods between loads. The applied load should be that which produces an extreme fiber stress level suitable for flexural fatigue tests. For fatigue tests on typical bituminous concrete paving mixtures, the following ranges of extreme fiber stress levels are suggested:

Temperatures, degrees Celsius (degrees Fahrenheit)	**Stress Level Range MPa (psi)**
13 (55)	1.03 to 3.1 (150 to 450)
21 (70)	0.52 to 2.1 (75 to 300)
30 (85)	0.24 to 1.38 (35 to 200)

The beam center point deflection and applied dynamic load are measured immediately after 200 load repetitions for calculation of extreme fiber strain ϵ. The test is continued at the constant stress level until the specimen fractures. The apparatus and procedures described have been found suitable for flexural fatigue tests at temperatures ranging from 4.4 to 38 degrees Celsius (40 to 100 degrees Fahrenheit) and for extreme fiber stress levels up to 3.1 MPa (450 psi). Extreme fiber stress levels for flexural fatigue tests at any temperature should not exceed that which causes specimen fracture before at least 1,000 load repetitions are applied.

(3) A set of 8 to 12 fatigue tests should be run for each temperature to adequately describe the relationship between extreme fiber strain and the number of load repetitions to fracture. The extreme fiber stress should be varied such that the resulting number of load repetitions to fracture ranges from 1,000 to 1,000,000.

f. Report and Presentation of Results. The report of flexural fatigue test results should include the following:

(1) Density of test specimens.

(2) Number of load repetitions to fracture, N_f.

(3) Specimen temperature.

(4) Extreme fiber stress, σ.

The flexural fatigue relationship is plotted in Figure M-2.

M-2. PROVISIONAL FATIGUE DATA FOR BITUMINOUS CONCRETE. Use of the graph shown in Figure M-3 to determine a limiting strain value for bituminous concrete involves first determining a value for the elastic modulus of the bituminous concrete. Using this value and the design pavement service life in terms of load repetitions the limiting tensile strain in the bituminous concrete can be read from the ordinate of the graph.

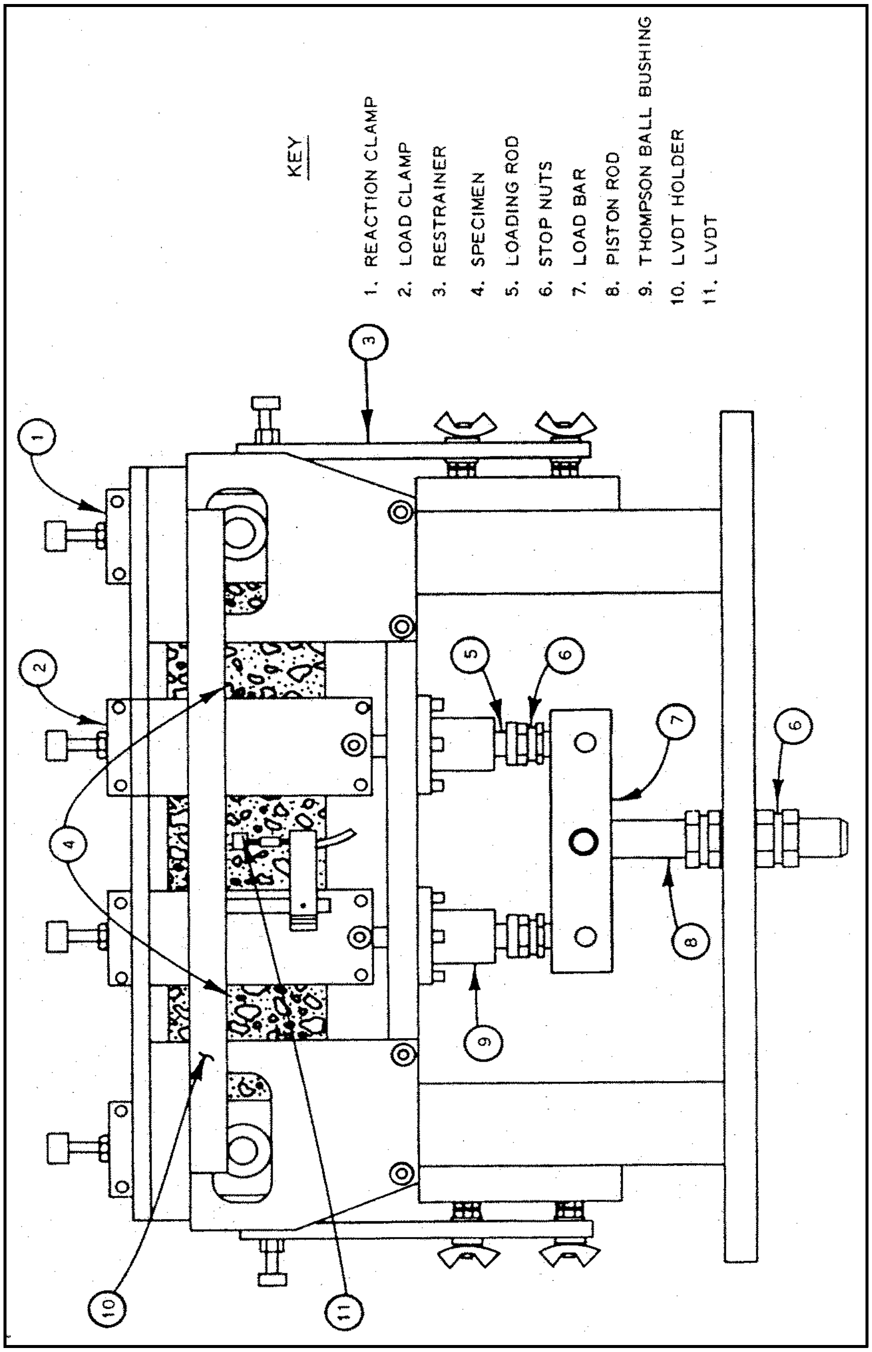


Figure M-1. Repeated flexure apparatus

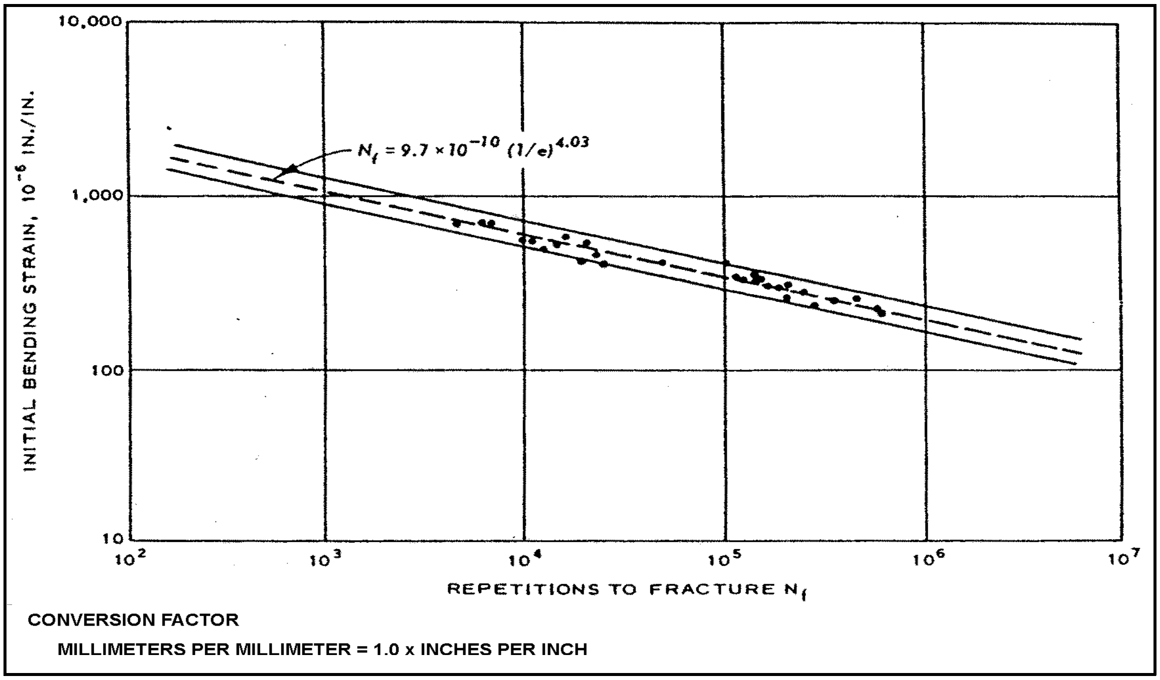
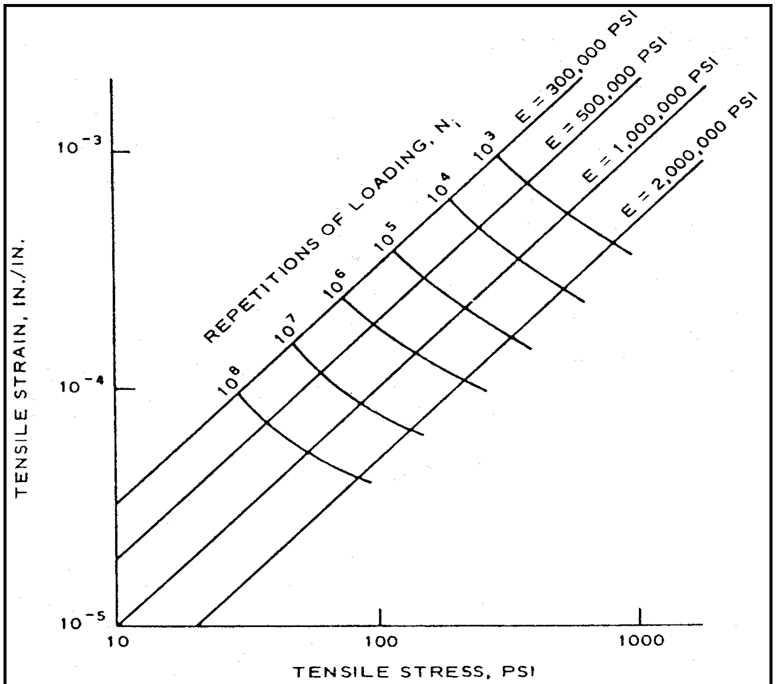


Figure M-2. Initial mixture bending strain versus repetitions to fracture in controlled stress tests



CONVERSION FACTORS

MEGAPASCALS = 0.006894 x PSI
MILLIMETERS PER MILLIMETER = 1.0 x INCHES PER INCH

Figure M-3. Provisional fatigue data for bituminous base-course materials

APPENDIX N

PROCEDURE FOR DETERMINING THE RESILIENT MODULUS

OF GRANULAR BASE MATERIAL

N-1. PROCEDURE. This procedure is designed to determine resilient properties of granular base (subbase) materials. The test is similar to a standard triaxial compression test, the primary exception being that the deviator stress is applied repetitively at several stress levels. The procedure allows testing under a repetitive stress state similar to that encountered in a base (subbase) course layer in a pavement under a moving wheel load.

N-2. DEFINITIONS. The following symbols and terms are used in the description of this procedure:

a. σ_1 = total axial stress.

b. σ_3 = total radial stress, i.e., confining pressure in the triaxial test.

c. σ_d = deviator stress (σ_1 - σ_3), i.e., the repeated axial stress in this procedure.

d. ϵ_1 = total axial strain due to σ_d.

e. ϵ_R = resilient axial strain due to σ_d.

f. ϵ_ℓ = resilient lateral strain due to σ_d.

g. M_R = the resilient modulus = σ_d/ϵ_R.

h. v_R = the resilient Poisson's ratio = ϵ_ℓ/ϵ_R.

i θ = sum of the principal stresses in the triaxial state of stress ($\sigma_1 + 2\sigma_3 = \sigma_d + 3\sigma_3$).

j. σ_1/σ_3 = principal stress ratio.

k. Load duration = time interval during which the sample is subjected to a stress deviator.

l. Cycle duration = time interval between successive applications of the deviator stress.

N-3. SPECIMENS. For base-course materials, 152-millimeter- (6-inch-) diameter specimens are generally required with the maximum particle size being limited to 25 millimeters (1 inch). The specimen height should be at least twice the diameter.

N-4. EQUIPMENT.

a. Triaxial Test Cell. The triaxial cell shown schematically in Figure N-1 is suitable for use in resilient testing of soils. The equipment is similar to most standard cells. However, there are a few specialized criteria that must be met to provide acceptable test results. Generally, the equipment is slightly larger than most standard cells to accommodate the 152-millimeter- (6-inch-) diameter specimens and the internally mounted load and deformation measuring equipment.

Additional outlets for the electrical leads from these measuring devices are required. Cell pressures of 80 psi are generally sufficient to duplicate the maximum confining pressures under aircraft loadings. Compressed air is generally used as the confining fluid to avoid detrimental effects of water on the internally mounted electronic measuring equipment.

b. End Platens. End platens should be "frictionless," as "barreling" caused by end restraint jeopardizes resilient Poisson's ratio values by causing lateral deformations to be concentrated in the middle of the specimen. Furthermore, nonuniform displacements can create problems with axial strain measurements due to realignment of the LVDT clamps. Whereas "frictionless" platens (Figure N-2) may not be entirely frictionless under short-term repetitive loadings, they constitute an improvement over conventional end platens. The essential features of "frictionless" end platens are hard polished end plates, coated by high-vacuum silicone grease, and covered by a thin rubber sheet. If externally mounted axial deformation measuring devices such as an LVDT or potentiometer mounted on the loading piston, or devices measuring the total specimen displacements are used, the use of frictionless caps and bases with grease invalidates any measurements. In this case, the deformation due to the grease and rubber sheet or Teflon probably exceeds the actual deformation of the specimen. Hence, frictionless caps and bases are restricted to use with internally mounted deformation sensors.

c. Repetitive Loading Equipment. The external loading source may be any device capable of providing a variable load of fixed cycle and load duration, ranging from simple switch control of static weights or air pistons to a close-loop electrohydraulic system. A load duration of 0.1 to 0.2 second and a cycle duration of 3 seconds have been found satisfactory for most applications. A haversine wave form is recommended; however, a rectangular wave form can be used.

d. Deformation and Load Measuring Equipment. The deformation measuring equipment consists of four LVDTs attached to the soil specimen with a pair of clamps, as shown in Figure N-1. Two LVDTs are used to measure axial deformations, and two are used to measure lateral deformations. Figures N-3 and N-4 show the details of the clamps for attaching the LVDTs to the soil specimens. Only alternating current transducers that have a minimum sensitivity of 0.2 millivolt per 0.025 millimeter (0.001 inch) per volt should be used. Load is measured with an internally mounted load cell that is sufficiently lightweight so as not to provide any significant inertia forces. It should have a capacity no greater than two to three times that of the maximum applied load and a minimum sensitivity of 2 millivolts per volt.

e. Additional Equipment. In addition to the equipment described above, the following items are also used:

(1) Calipers, a micrometer gauge, and a steel rule (calibrated to 0.25 millimeter (0.01 inch)).

(2) Rubber membranes (0.03 to 0.06 millimeter (0.012 to 0.025 inch) thick) and a membrane stretcher.

(3) Rubber O-rings.

(4) Guide rods for positioning LVDT clamps.

(5) Epoxy for cementing clamps to membrane.

(6) A vacuum source with a bubble chamber (optional) and regulator.

(7) Specimen forming jacket.

f. Recommendations. It is also necessary to have a fast recording system for accurate testing. It is recommended, for analog recording equipment, that the resolution of the parameter being controlled be better than 1.5 percent of the maximum value of the parameter being measured and that any variable amplitude signals be changed from high to low resolution as required during the test. If multichannel recorders are not available, by introducing switching and balancing units, a single-channel recorder can be used.

N-5. PREPARATION OF SPECIMENS AND PLACEMENT IN TRIAXIAL CELL. The following procedures describe a step-by-step account for preparing remolded specimens. Generally, for base-course materials, 152-millimeter- (6-inch-) diameter specimens are required with the maximum particle size being limited to 25 millimeters (1 inch) in diameter.

a. Material Preparation. The material should be air-dried and subsequently sufficient water added to bring the material to the desired compaction water content (usually field condition). Sealing the material in a container for 24 hours prior to compaction will allow the moisture to equilibrate. For well-graded materials, it may be necessary to break the material down into several sieve sizes and recombine for each layer to prevent serious segregation of material in the specimen. If the compaction effort required to duplicate the desired testing water content and density is not known, sufficient material for several specimens may have to be prepared. The compaction effort required will then be established on a trial-and-error basis.

b. Specimen Compaction. Generally, base-course materials are compacted on the triaxial cell baseplate using a split mold. If the particles are angular, two membranes may be required: one used during compaction and the second placed after compaction to seal any holes punctured in the membrane. A successful procedure has been to use a Teflon-lined mold and a thin sheet of wrapping paper instead of a membrane. Often the density is sufficiently high and the water content such that effective cohesion will permit a free-standing specimen to be prepared. In this case, the wrapping paper is carefully removed and a membrane substituted. In most cases, impact or kneading compaction is used. Vibratory compaction is only permitted on uniform materials where segregation is not a problem. The specimens should be compacted in layers, the height of which exceeds the maximum particle size.

(1) It may be necessary to place a thin layer of fine sand in the bottom layer to provide a smooth bearing surface. Likewise, after compacting and trimming the topmost layer (it may be necessary to remove large particles from this layer), fine sand can be sieved on the surface to fill in the voids and provide a smooth bearing surface for the top cap.

(2) The top cap should be centered and lightly tapped to level and ensure a good smooth contact of the cap on the specimen. A level placed on top of the cap is used to check leveling. The forming mold is then removed, the membrane placed using a membrane stretcher and sealed with O-rings or a hose clamp, and a vacuum applied. Leakage should be checked by using a bubble chamber or closing the vacuum line and observing if a vacuum is maintained in the specimen. Specimen dimensions should be measured to determine density conditions. A π-tape has been found most useful for diametrical measurements.

c. Placement of LVDT Measurement Clamps.

(1) Measure the diameter as accurately as possible at the location of the LVDT clamps for calculation of radial strains. Place the lower LVDT clamp in the specimen at approximately the lower third point of the specimen. A “jig” or gauge rods have been used successfully to assist in placing the clamps. The lower LVDT clamp generally holds the LVDT body. Repeat the procedure for the upper clamp being careful to align the clamps so that the LVDT core matches the LVDT body. It is essential that the clamps lie in a horizontal plane and their spacing be precisely known for calculating the axial strain. Again, gauge rods or a “jig” in conjunction with a small level have been used successfully for this operation. With the clamps in a position and secured by the springs, a small amount of epoxy (a “5-minute” epoxy has been used; rubber cement was found unacceptable) is placed on top of the four contact points and allowed to dry.

(2) Install the LVDTs and connect the recording unit. Generally, ±0.10-millimeter (0.040-inch) LVDTs are used for radial deformation, and ± 0.25-millimeter (0.100-inch) LVDTs are used for axial deformations. Balance the vertical spacing between LVDT clamps or check gauge rods for secure contact, and record LVDT readings and spacing. Remove gauge rods and assemble triaxial chamber. Any shifting of LVDT clamps during chamber assembly will be noted by LVDT reading changes and can be accounted for.

d. Resilient Testing. The resilient properties of granular materials are dependent primarily upon confining pressure and to a lesser extent upon cyclic deviator stress. Therefore, it is necessary to conduct the tests for a range of confining pressures and deviator stress values. Generally, chamber pressure values of 0.014, 0.027, 0.041, and 0.069 MPa (2, 4, 6, and 10 psi) are suitable. Ratios of σ_1/σ_3 of 2, 3, 4, and 5 are typically used for the cyclic deviator stress. Tests should be conducted in an undrained condition with excess pressures relieved after application of each stress state. The testing procedure is as follows:

(1) Balance the recorders and recording bridges and record calibration steps.

(2) Apply about 0.014 MPa (2 psi) axial load σ_d as a seating load simulating the weight of the pavement and ensuring contact is maintained between the loading piston and top cap during testing.

(3) Condition the specimen by applying 500 to 1,000 load repetitions with drainage lines open. This conditioning stress should be the maximum stress expected to be applied to the specimen in the field by traffic. If this is unknown, a chamber pressure of 0.034 to 0.069 MPa (5 to 10 psi) and a deviator stress (σ_1 - σ_3) twice the chamber pressure can be used.

(4) Decrease the chamber pressure to the lowest value to be used. Apply 200 load repetitions of the smallest deviator stress under undrained conditions, recording the resilient deformations and load at or near the 200th repetition. After 200 load repetitions, relieve any pore pressures, increase the deviator stress to the next highest value, and repeat procedure over the range of deviator stresses to be used.

(5) After completing the stress states for the initial confining pressure, repeat for each succeedingly higher chamber pressure.

(6) After completion of the loading, remove the axial load, apply a vacuum to the specimen, release the confining pressure, and disassemble the triaxial chamber.

(7) Check the calibration of the LVDTs and load cell.

(8) Dry the entire specimen for determination of the water content.

N-6. COMPUTATIONS AND PRESENTATION OF RESULTS.

a. Computation. The computations consist of the following:

(1) From the measured dimensions and weights, compute and record the initial dry density, degree of saturation, and water content.

(2) The resilient modulus is computed and recorded for each stress state using the following formulas:

(a) Resilient axial strain $\epsilon_R = \Delta H_r/H_i$.

(b) Resilient lateral strain $\epsilon_L = \Delta D_r/D_i$.

(c) Deviator stress $\sigma_d = \Delta P/A_O$.

(d) Resilient modulus $M_R = \sigma_d/\epsilon_R$.

(e) Resilient Poisson's ratio $v_R = \epsilon_L/\epsilon_R$.

where

ΔH_r = resilient change in gauge height (distance between LVDT clamps) after specified number of load repetitions.

H_i = instantaneous gauge height after specified number of load repetitions. Can be calculated from $H_O - \Delta H$. If ΔH is small, H_o can be used.

H_O = initial gauge height or distance between LVDTs less adjustment occurring during triaxial chamber assembly.

ΔH = permanent change in gauge height.

ΔP = change in axial load, maximum axial load minus surcharge load.

A_O = original cross-sectional area of specimen.

ΔD_r = resilient change in diameter after specified number of load repetitions.

D_i = instantaneous diameter after specified number of load repetitions. Can be calculated from $D_O + \Delta D$.

D_o = initial specimen diameter.

ΔD = permanent change in specimen diameter.

b. Presentation of Results. Test results should be presented in the form of plots of log M_R versus log of the sum of the principal stresses and v_r versus the principal stress ratio (Figure N-5). The equation of the line for resilient modulus is $M_R = K_1\theta^{K_2}$ where K_1 is the intercept when θ = 1 psi and K_2 is the slope of the line.

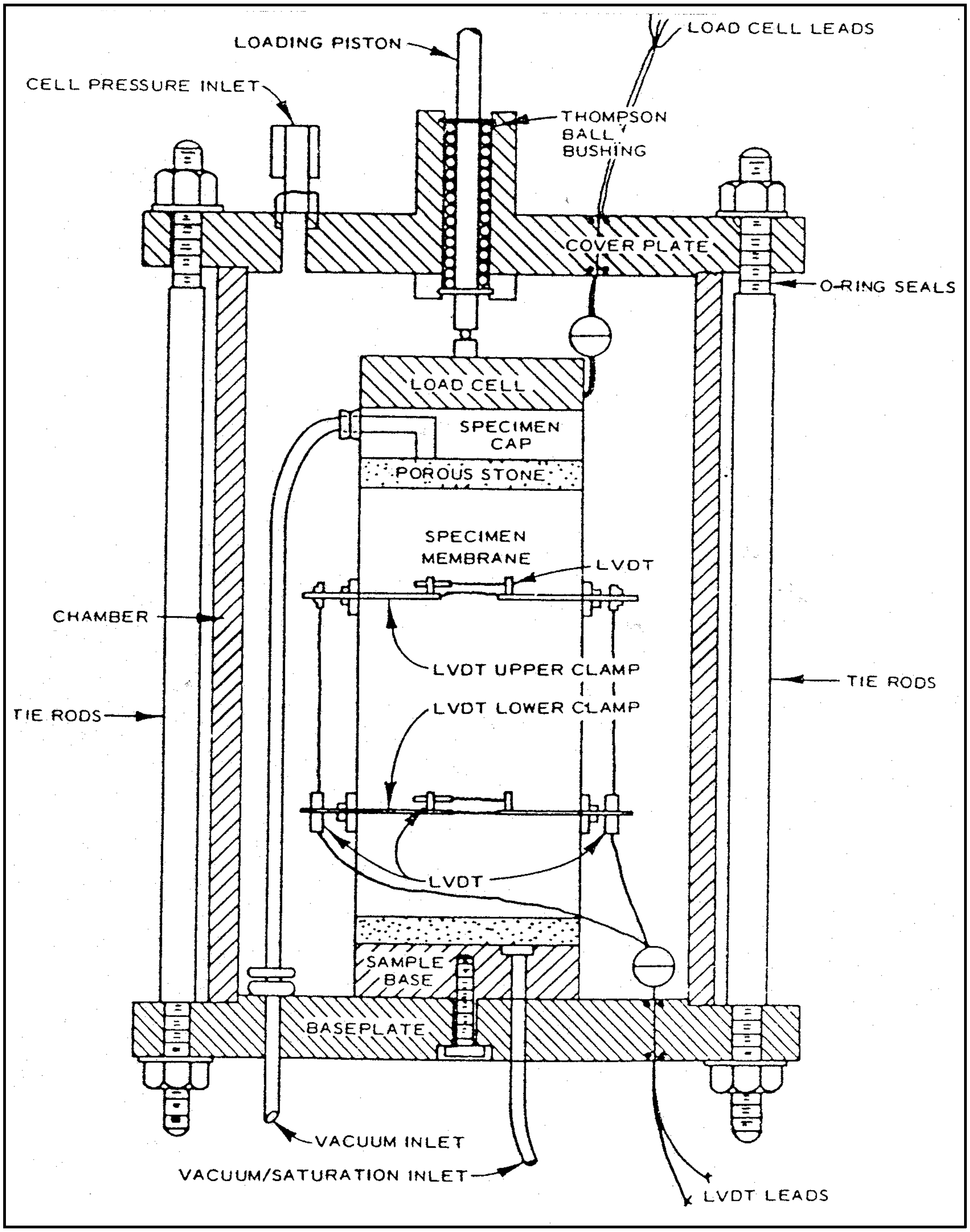


Figure N-1. Triaxial cell used in resilience testing of granular base material

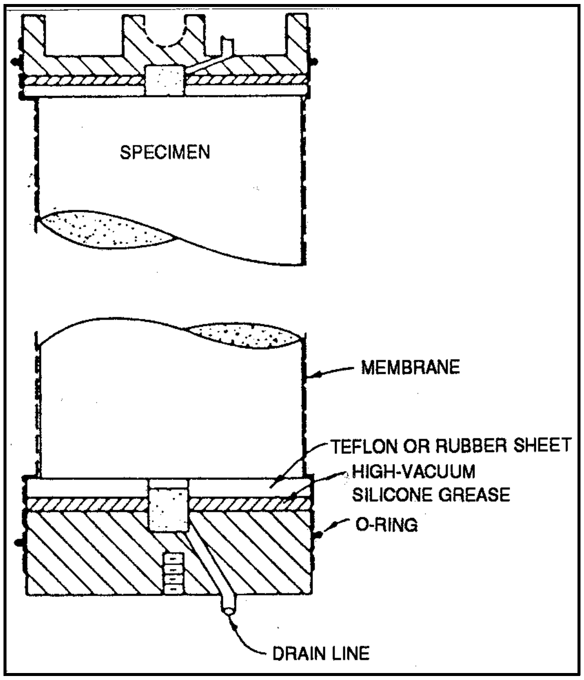


Figure N-2. Schematic of frictionless cap and base

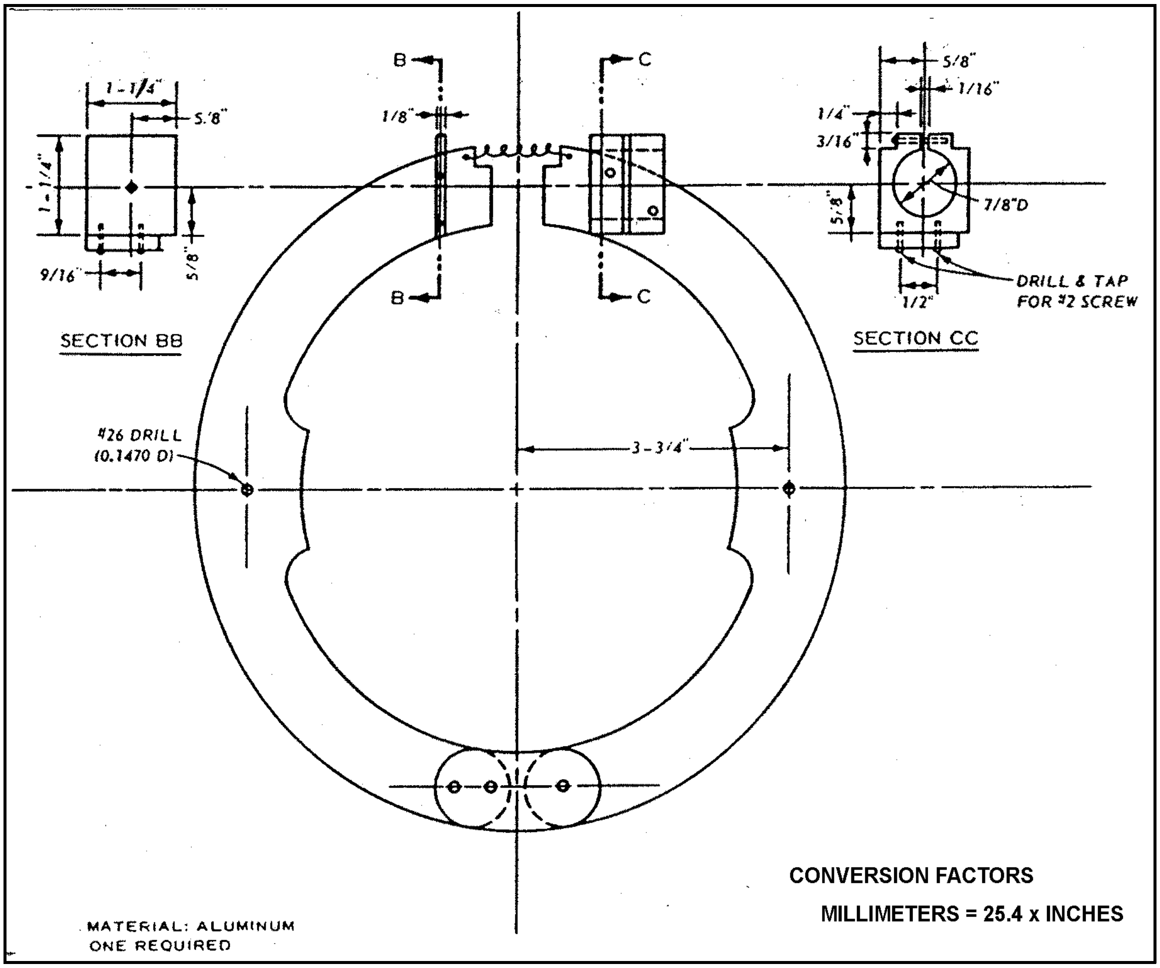
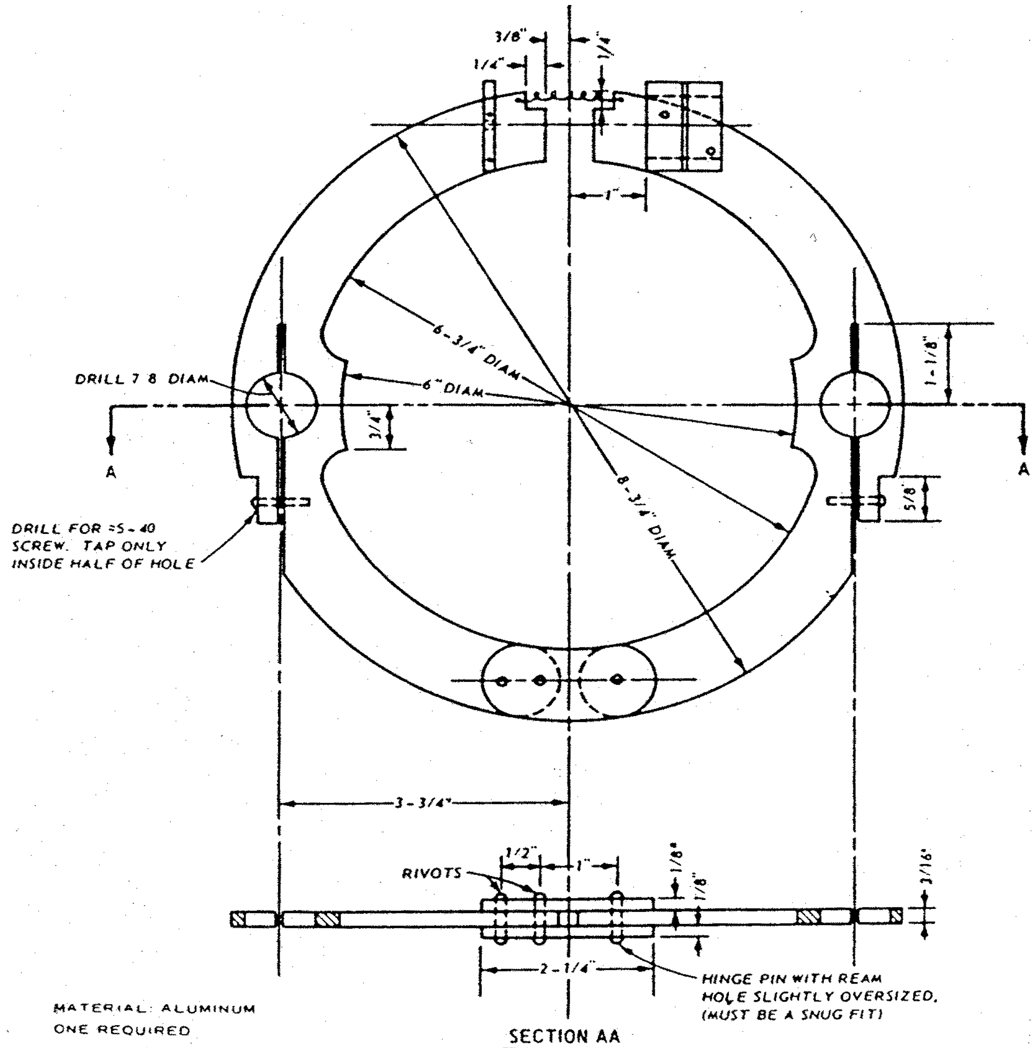


Figure N-3. Details of Top LVDT ring clamp



CONVERSION FACTORS

MILLIMETERS = 25.4 x INCHES

Figure N-4. Details of bottom LVDT ring clamp

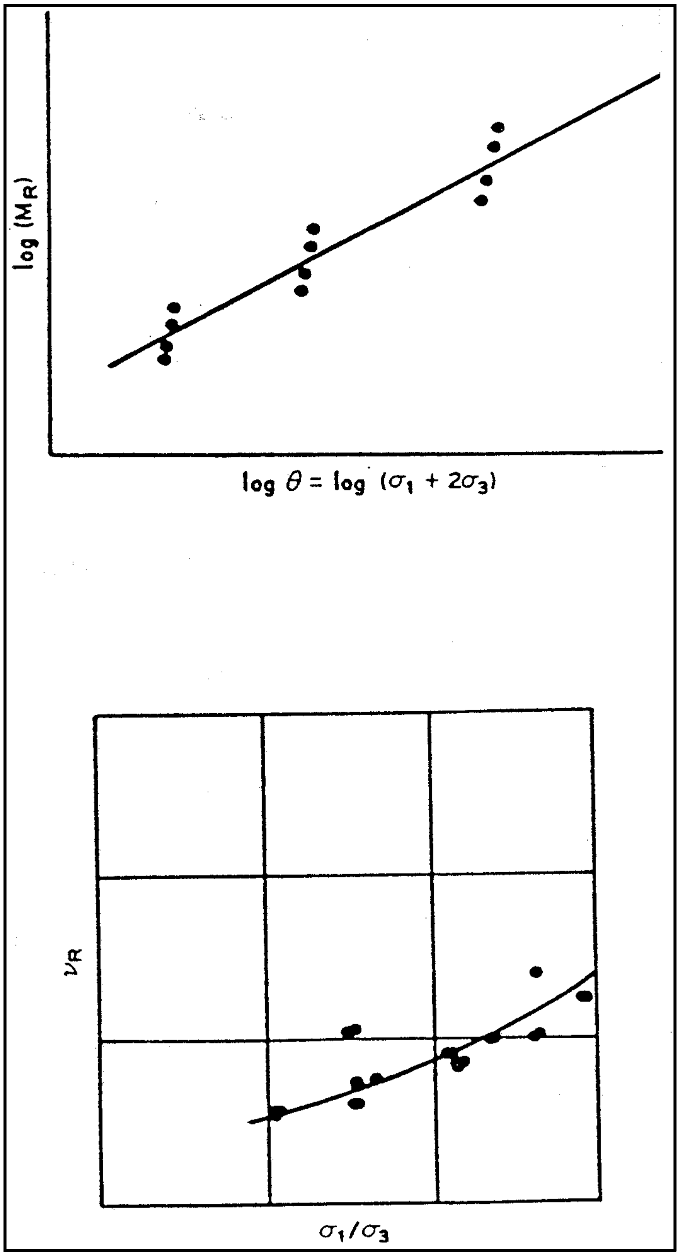


Figure N-5. Representation of results of resilience test on cohesionless soils

UFC 3-260-03
21 August 2023

UNIFIED FACILITIES CRITERIA (UFC)

O&M MANUAL: STANDARD PRACTICE FOR AIRFIELD PAVEMENT EVALUATION

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UNIFIED FACILITIES CRITERIA (UFC)
O&M MANUAL: STANDARD PRACTICE FOR AIRFIELD PAVEMENT EVALUATION

Indicate the Military Department Preparing Activity responsible for the document.

U.S. ARMY CORPS OF ENGINEERS (Preparing Activity)

NAVAL FACILITIES ENGINEERING SYSTEMS COMMAND

AIR FORCE CIVIL ENGINEER CENTER

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

Change No.	**Date**	**Location**

This UFC supersedes UFC 3-260-03, *Airfield Pavement Evaluation*, dated 15 April 2001.

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FOREWORD

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

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

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

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

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

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CHAPTER 1 INTRODUCTION

1-1 REISSUES AND CANCELS.

This UFC reissues and cancels UFC 3-260-03, *Airfield Pavement Evaluation*, dated 15 April 2001.

1-2 PURPOSE AND SCOPE.

This document provides guidance in the structural evaluation of existing pavements. It incorporates recent and applied research that has resulted in improved reliability in evaluation results obtained with DoD engineering tools that address the purpose and scope of this UFC for all DoD Services.

UFC 3-260-03 presents criteria for evaluating the load-carrying capability of airfield pavements in terms of allowable traffic that a pavement can sustain for given loading conditions or the allowable load for a specified traffic mix, without producing unexpected or uncontrolled distress. It is not for use in contractor quality assurance or quality control (QA/QC). This document outlines procedures for nondestructive testing (NDT) and direct testing to gather data for use in conventional and layered elastic pavement analysis. The Pavement-Transportation Computer Assisted Structural Engineering (PCASE) application implements the pavement evaluation criteria in this document.

1-3 APPLICABILITY.

This document applies to evaluations of DoD airfields and heliports or those used by DoD aircraft or missions.

1-4 NATO AIRFIELDS AND OPERATIONS.

Comply with NATO STANAG 7131, *Aircraft Classification Number (ACN)/Pavement Classification Number (PCN)*, and NATO STANDARD AEP-46, *ACN/PCN*, when evaluating airfields used by NATO forces or NATO campaigns. Comply with TSPWG M 3-260-00.NS7210*, Standards for NATO Deployed Air Operations*.

1-5 PAVEMENT TYPES.

The pavement types considered in this UFC are the following.

1-5.1 Flexible Pavement.

A pavement with an asphalt concrete (AC) surface course and one or more supporting base or subbase courses, placed over a prepared subgrade.

1-5.2 Plain Concrete Pavement.

A single thickness of non-reinforced portland cement concrete (PCC) resting directly on a prepared subgrade, granular base course, or stabilized layer.

1-5.3 Rigid Overlay on Rigid Pavement.

A rigid overlay pavement placed on an existing rigid pavement. Placing a rigid overlay can include or exclude a bond-breaking course between the existing rigid pavement and the overlay. If the thickness of the bond-breaking course between the two rigid pavements is 4 inches (102 millimeters) or more, evaluate the entire pavement as a composite pavement (see paragraph 1-5.6 and paragraph 7-8).

1-5.4 Non-rigid Overlay on Rigid Pavement.

An AC surface layer or combination of AC layer and granular base course placed on an existing rigid pavement.

1-5.5 Rigid Overlay on Non-rigid Pavement.

A rigid overlay pavement placed on an existing non-rigid pavement.

1-5.6 Composite Pavement.

A composite pavement consists of a rigid overlay placed on an existing pavement that already has an existing flexible overlay on a rigid base slab. The existing flexible overlay may be asphalt for its full depth or a combination of asphalt and granular base course over the rigid base slab. When the thickness of the flexible overlay is less than 4 inches (102 millimeters), consider the entire pavement as an unbonded rigid overlay on rigid pavement. The asphalt overlay material is considered a bond-breaking course.

1-5.7 Reinforced Concrete Pavement.

A concrete pavement reinforced with deformed steel bar or welded-wire fabric. Measure the diameter and spacing of the steel in both the longitudinal and transverse directions to determine the percent steel.

1-5.8 Fiber Reinforced Concrete.

A concrete pavement reinforced with fibers. Previous evaluation manuals contained curves for evaluating concrete pavements with steel fibers. These curves are no longer used because there are no airfield pavements in DoD with steel fibers due to the fibers causing surface problems. Do not use steel fibers unless approved by the Pavements Discipline Working Group (DWG) or its designated representative. If using other types of fibers in pavements, do not reduce the pavement thickness requirement.

1-6 GLOSSARY.

Appendix F contains acronyms, abbreviations, and terms.

1-7 REFERENCES.

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

CHAPTER 2 EVALUATION CONCEPTS AND PROCESS

2-1 RELATIONSHIP OF DESIGN TO EVALUATION.

Pavement design requires selecting materials with the necessary strength and placing them at the proper thickness, density, and depth to construct a pavement capable of carrying the anticipated number of passes of a given load. Due to variations in material and placement conditions, the strengths and thicknesses of the as-constructed pavement may differ from the design. Over time, the strength of layers in the pavement structure will change. An evaluation determines the physical properties of a pavement as constructed and in its current condition to verify its aircraft load-supporting capability.

2-2 CONCEPTS.

The primary function of a pavement is to distribute the wheel loads over a larger area than the wheel contact area. Each airfield has its own natural soil and environmental conditions, and the in situ soils must ultimately sustain the stresses resulting from loads applied to the pavement. Since the strengths of native soils can vary widely from site to site, the ability to support loads also varies widely. In most cases, aircraft tire loads cannot be sustained directly on the native soils.

2-2.1 Pavement Structure.

A pavement design limits the tensile strain in an AC surface layer and tensile stress in a PCC surface layer to prevent excessive shear deformation (e.g., vertical strain) in the underlying unbound layers, including the subgrade. Flexible and rigid pavement structures are designed to limit tensile strains and stress for a defined mix of aircraft at specified loads and passes. Based on the magnitude of the applied surface load, contact pressure, and gear configuration, a pavement structure must distribute surface loads to that which the subgrade soil can accept for the aircraft mix. The evaluation process looks at load capability of an existing pavement in two ways. First, given a specified aircraft mix at a specified load, determine the allowable passes. Second, given a specified aircraft mix at a required number of passes, determine the allowable load.

Flexible pavements distribute load by broadening the effective area supporting the load, from the tire contact area on the surface to a wider area on the base, to a still wider area on the subbase, and so on. Each layer must be of sufficient quality to sustain the load intensity or stress and each must be thick enough to broaden or distribute the load and reduce intensity to that which its supporting layer can sustain without excessive permanent deformation. Rigid pavements are stiffer and have a “beam action” or flexural capability that spreads or distributes load more widely but must still have sufficient support to distribute the load and reduce flexural and tensile stresses in the slab.

2-2.2 Performance Models.

Performance models act as a “transfer function” between pavement response models and actual pavement performance. DoD uses several different pavement evaluation models, all of which are mechanistic-empirical models that associate an empirically derived pavement failure indicator (e.g., vertical stress) that defines the response with the required performance (e.g., coverages to failure). These performance models include the following:

- CBR-Alpha-Beta Hybrid model for flexible pavements that uses the California Bearing Ratio (CBR) as a strength index for base, subbase, and subgrade layers
- Westergaard Medium-Thick Plate Solution for rigid pavements that uses the modulus of subgrade reaction (k) as a strength index for layers supporting the slab
- CBR-Alpha model for unsurfaced and mat pavements that uses the CBR as strength index for all supporting layers
- Layered Elastic model for both rigid and flexible pavements that uses a material's Modulus of Elasticity (E) and Poisson's Ratio (*v*) values to characterize each layer

2-3 PAVEMENT EVALUATION PROCESS.

Pavement evaluation requires a structured approach to gather and organize information, perform testing and analysis, and generate report products for a variety of stakeholders to use in decision making. In addition to the structural evaluation process and procedures defined in this UFC, UFC 3-260-16, *O&M Manual: Standard Practice for Airfield Pavement Condition Surveys*, outlines the guidance for pavement condition index (PCI) inspections and UFC 3-270-08, *Pavement Maintenance Management*, provides guidance on using PCI and structural evaluation results in the overall pavement management process. The processes and procedures in all three of these documents are interrelated, follow the same general steps, and use the same inventory organization.

2-3.1 Evaluation Planning.

Gather and review information regarding the site and the pavement at the site from the sources outlined below. These data are used to determine the scope and validity of available data and develop a test plan. While this step in the process begins prior to any field work, it typically continues through the other phases of the evaluation as you contact people at the installation and get access to additional information.

2-3.1.1 Previous Evaluation Reports, Design, and Construction Documents.

Begin the planning process by gathering any previous evaluation reports. They typically have much of the background data needed for planning and conducting the evaluation. In addition to physical property and surface condition data, they contain site, construction history (also known as work history), and previous traffic information. Design and construction documents are another good source of information, including, but not limited to, the following:

- Pavement, base, and subbase layer thicknesses

- Asphalt physical properties such as mix design aggregate gradation and testing, binder properties, and asphalt mix properties such as density and voids
- PCC physical properties such as mix design, aggregate gradation, and slump
- Base and subbase strength and material properties
- Rigid pavement flexural strength
- Rigid pavement joint layout and load transfer devices or thickened edges

These data are particularly useful for forensic analysis when testing uncovers issues with existing pavements. This type of information is also available in the sources described below when no previous evaluations exist and is also used to validate and supplement information in previous reports.

2-3.1.2 Geographic Location and Mapping.

Determine the geographic location of the airfield and obtain mapping data. Geospatially correct mapping is normally furnished by the installation when performing an evaluation at a DoD installation or forward operating location with a current DoD mission. Obtain imagery and mapping from other sources such as the National Geospatial-Intelligence Agency (NGA) when not available from the installation or operating location.

2-3.1.3 Geological Data.

Identifying the general geology in the vicinity of the airfield is critical to determine the general type of soil deposition (e.g., alluvial, residual), the parent rock from which the soil derives, and other pertinent information. Soil type data is available in U.S. Geological Survey publications or Department of Agriculture soil maps as well as from state geological departments, state highway departments, subsurface exploration companies, and similar organizations, including NAVFAC and USACE construction offices. Soil boring or well logs from the installation and aerial photographs showing pertinent geologic features are also valuable data sources.

2-3.1.4 Drainage and Groundwater Conditions.

Identify the natural drainage pattern and general surface-drainage system for the area from contour maps published by the U.S. Geological Survey, the National Oceanic and Atmospheric Administration, or the NGA. Collect detailed information concerning drainage at the airfield, including descriptions of any drainage structures and shoulder slopes, and whether excessive vegetation or soil along the pavement edges ponds water on the pavements. Determine the depth to groundwater table near the airfield and at the airfield perimeter and note the presence of any perched water tables in the airfield subgrade. Obtain groundwater data and the location of springs and seeps from well logs, cuts, or borings in the vicinity. Also, identify and evaluate subsurface drainage systems.

2-3.1.5 Climatic Data.

The Pavement-Transportation Computer Assisted Structural Engineering (PCASE) application has a world index database with the average daily maximum and minimum temperatures for each month, average annual rainfall, and the freezing index. This, as well as other information such as the average humidity and description of the prevailing winds for the period of record, can be found in routine National Weather Service publications, from records of the airfield weather station, or from the U.S. Air Force 14th Weather Squadron (formerly Combat Climatology Center [AFCCC]) Asheville, NC.

2-3.1.6 Construction/Work History.

Having an accurate construction history is essential to analyze the pavement surface condition deterioration and is used for structural analysis if field testing cannot be conducted. Information on other work performed, such as dates for overlays, surface treatments, joint seals, patches, and other repairs, enhances analysis capability. Obtain detailed information on the construction and maintenance performed on each facility from the installation engineer organization responsible for base maintenance. The construction office responsible for construction on the installation (e.g., NAVFAC or USACE) may also be able to provide this information.

2-3.1.7 Traffic Data.

Collect data from airfield management on the type, gross weight, and typical operating weight of each type of aircraft regularly using the airfield on a day-to-day basis. Specific traffic data (type, weight, passes) for all fixed or rotary wing aircraft using each runway, taxiway, and apron system will enhance the evaluation accuracy if available. These data will be used to define future expected traffic loading and pass levels. Specific traffic analysis procedures are discussed in detail in Chapter 4.

2-3.2 Mapping and Inventory.

Having a geospatially correct map linked to areas of pavement with similar characteristics provides organization for pavement testing, analysis, and reporting. Mapping and inventory standards and procedures are described in detail in UFC 3-270-08. The following is a process summary.

2-3.2.1 Pavement Inventory.

Pavement inventory is the term used to describe all the airfield pavement on an installation. The pavement is divided into a hierarchy consisting of a network, branches, and sections. A site typically has one airfield network but can have more than one in some situations. Branches are divided based on pavement use (e.g., runways, taxiways, and aprons) and sections are areas of pavement with similar physical characteristics. Each of these entities has an ID and the combination of the network, branch, and section IDs is the pavement ID (PID). The PID is associated with the pavement evaluation data in the database and its respective polygon on the map. See UFC 3-270-08 for more detail.

2-3.2.2 Creating and Updating Maps.

Use a Geographic Information System (GIS) application such as ArcMap or AutoCAD 3D Map to create or update mapping. There is also the option to use the GIS application to update inventory data and work history associated with section polygons. When implementing this option, the inventory and work history data structure must follow the PAVER standard. Export the map to a shape (.shp) file or table and import that file to PCASE or PAVER for use in either application.

2-3.2.3 Importing Maps to PCASE or PAVER Applications.

The PCASE and PAVER applications both use the same database. When you import the map in PCASE, the updated map is available in PAVER and vice versa. Details on importing GIS/tabular data are available in the PCASE and PAVER user guides. The process is the same for both.

2-3.2.4 Creating and Updating Inventory in PCASE or PAVER.

When the map imported from the GIS application does not include inventory or work history data, it is updated in PCASE or PAVER using the Define Inventory tool. The updated section data is then assigned to the section polygons using the GIS Assignment tool. When starting with an empty inventory, add a network to the inventory, then add branches to the network and add sections to the branches.

2-3.2.5 Linear Segmentation.

Linear segmentation is the process of linking the pavement inventory to the corresponding facilities in the Real Property data structure. This linkage is created between the branch and the facility using the Real Property Unique ID (RPUID) such that a pavement network can have one or many facilities and a facility can have one or many branches. The objective of creating this linkage is to be able to report pavement management data in Real Property terms (facility) for use at the Service and Office of Secretary of Defense (OSD) level. See UFC 3-270-08 for more detail.

2-3.3 Test Plan.

Using the mapping, inventory structure, and data gathered from previous reports and other sources, develop a test plan that defines the types and estimated number of tests required as outlined in paragraph 3-1 to accurately characterize the pavement structure of each section in the inventory. This historical data provides an indication of the uniformity of the pavement structure for each section. It is used to identify gaps in the data or the need to validate the historical data with testing. Note that even data captured twenty, thirty, or more years ago remains valuable. Once a soil reaches an equilibrium moisture content, strength and thickness may not change significantly over time. Where moisture varies seasonally or frost issues exist, address these seasonal variations with appropriate testing described in Chapter 8 and Appendix A. When performing testing such as coring or using a dynamic cone penetrometer (DCP), develop a map with the approximate locations of these tests. The map is helpful to communicate the test plan to the installation engineers and airfield management. Depending on the Service, installation, and type of testing, a work clearance request may be required before the start of field work.

2-3.4 Perform Field Testing.

Conduct field testing based on the test plan to determine the pavement characteristics and structure of each section in the inventory, using one or a combination of the procedures below. Note that additional testing is often required to supplement the test plan when test results deviate from previous evaluation, design, or construction data. When no previous evaluation or construction data are available and there is significant variability in the test plan testing results, conduct additional tests as required. Finally, access time on the airfield may limit the number of tests that can be performed. In these cases, prioritize the tests. Details on the procedures below are included in Chapter 3.

2-3.4.1 PCI Inspection.

Conduct a PCI survey to determine the PCI for each section or validate the results from a previous inspection.

2-3.4.2 Coring or Test Pits.

Coring is used to determine the pavement thickness, get asphalt or concrete samples, and provide access for DCP testing and collecting soil samples. Test pits are rarely used due to operational restrictions but provide the capability to collect more samples and do more robust material testing.

2-3.4.3 Dynamic Cone Penetrometer (DCP).

Use the DCP or automated DCP (ADCP) to determine soil strengths and layer thickness.

2-3.4.4 Falling Weight Deflectometer (FWD).

Provides deflection data used to backcalculate the moduli for the layered elastic analysis procedure.

2-3.4.5 Ground-Penetrating Radar (GPR).

Use GPR to determine pavement layer thicknesses for each material type and the presence of anomalies in a structure.

2-3.4.6 Portable Seismic Pavement Analyzer (PSPA).

Uses wave propagation and elastic theory to determine structural properties for the layered elastic analysis procedure.

2-3.4.7 MIRA Ultrasonic Tomography.

Used to estimate the average thickness of the section.

2-3.5 Perform Laboratory Testing.

Perform laboratory testing on asphalt, concrete, and soil samples taken during field work. This step in the process is used less frequently than in the past, but when performed, is typically done after the initial field work data compilation, modeling, and analysis. It is used to validate the initial results and improve the level of detail and overall quality of the report.

2-3.6 Compile Evaluation Data.

Select representative layer thickness, strength, and material types for the pavement surface, base course, subbase course, and subgrade of each section from available data and summarize the data in the physical property data (PPD) or construction history table of the report. These layer structures are used in the modeling and analysis process, so it is important to document any assumptions or limitations made in compiling the data. For example, if limited time did not permit additional testing or when data was taken from a previous report.

2-3.7 Modeling and Analysis.

There are two approaches to pavement modeling and analysis based on the performance models described in paragraph 2-2.2. The first is commonly known as airfield pavement evaluation (APE) analysis and the second is layered elastic analysis. Either or both models may be used, depending on the situation. While all of these procedures use different models to compute stresses, they all compute allowable passes, allowable load, the pavement classification number (PCN), and overlay requirements when required for each analyzed section.

2-3.7.1 APE Analysis.

APE analysis uses the CBR-Alpha-Beta Hybrid model for flexible pavement, the Westergaard model for rigid pavements, and the CBR-Alpha model for unpaved and mat airfields. These models are implemented in the PCASE APE module, which is typically used for contingency evaluations at forward operating locations or when layered elastic analysis does not yield reasonable results (e.g., on low strength pavements). APE inputs include the layer structure, thickness, and strength (CBR or k). Layers may be combined in some complex structures to facilitate analysis (e.g., a multi-layer composite pavement).

2-3.7.2 Layered Elastic Analysis.

Layered elastic analysis uses the YULEA model for both flexible and rigid pavement analysis. Layered Elastic analysis is implemented in the PCASE Layered Elastic Evaluation Program (LEEP). Layered elastic analysis is more commonly used to evaluate main operating installations but is also used at forward operating locations with an enduring mission. LEEP inputs include the layer structure, thickness, and properties (E and v). Similar layers are typically combined to simplify the structure being analyzed (e.g., combine the subbase and subgrade when they have similar material properties). Once the layer structure is defined, select FWD deflection (basin) data that define the pavement's response to loading and use it to determine the pavement layer moduli by matching the deflection basin with an elastic layer model. This process is known as backcalculation. Finally, select a representative model from the backcalculation procedure for layered elastic analysis.

2-3.8 Report Generation.

Report format and content varies by Service and mission (e.g., the report format and content for a contingency evaluation is different than that for a main operating installation). In general, a pavement evaluation report for a main operating installation has the report elements listed below. Contingency evaluations focus on tabular summaries of data collected in the field, PCI and structural analysis results, and any limitations to the proposed mission. More detailed information on report content is outlined in Chapter 10 of this UFC, UFC 3-270-08, and TSPWG M 3-260-03.02-19.

- Discuss construction changes that have occurred since the last evaluation
- Discuss changes in the installation mission regarding aircraft traffic mixes and define the critical aircraft and required overlays for deficient sections
- Discuss field data collection efforts and provide a tabular summary of the data structure for each section
- Tabular summary of PCI ratings
- Tabular summary of analysis results, including allowable aircraft loads, allowable aircraft passes, and PCN ratings
- Color maps for the inventory, PCI, and structural condition (e.g., PCN or Structural Index [ACN/PCN] ratios)
- Discuss structural capacity and functional condition deficiencies
- Recommend localized and global preventive maintenance and repair (M&R) requirements
- Recommend major M&R requirements and alternatives to address deficiencies

CHAPTER 3 DATA COLLECTION

3-1 GENERAL.

Selecting representative physical characteristics for a pavement section requires a thorough study of all existing information as well as field and, in some cases, laboratory testing. Previous evaluations, and when available, design and construction control data, provide a starting point for the evaluation test plan described in Chapter 2 that identifies test requirements for the evaluation. These tests fall into two general categories: nondestructive testing (NDT) and direct sampling.

3-1.1 Nondestructive Testing (NDT).

As the name implies, NDT does not require taking physical samples. This category includes methods such as the falling weight deflectometer (FWD), ground penetrating radar (GPR), and the MIRA ultrasonic tomography device.

3-1.2 Direct Sampling.

Direct sampling includes methods such as coring, DCP, split tensile, and soil classification as well as methods conducted in test pits such as in-place CBR, plate bearing, and soil density testing. More robust laboratory testing can be performed on asphalt, concrete, and soil samples collected from test pits. This chapter outlines data collection requirements and procedures. More detailed information on sampling and testing methods are discussed in Appendix A.

3-1.3 Determining Testing Methods.

There are a several factors that dictate the testing methods for an evaluation, including the purpose of the evaluation, logistics limitations, and site-specific testing limitations.

3-1.3.1 Purpose of the Evaluation.

Pavement evaluations fall into two general categories based on the nature of the mission: permanent and contingency. Contingency evaluations are further categorized as expedient or sustainment. A third general category is special purpose, in which the evaluation is focused on a specific issue. All require the same basic procedures as outlined in this chapter but differ in amount of data used in the evaluation and, in turn, the reliability of the results and the level of detail in the report. The evaluation classification is driven primarily by the purpose and time allotted for field work and analysis.

- Permanent: Managing pavement maintenance and repair (M&R) and long-term aircraft operations
- Contingency: Managing pavement and aircraft operations at forward locations
    - Expedient (100 passes or initial surge of mission aircraft)
    - Sustainment (5,000 passes or throughout anticipated operation)

- Special purpose: Address specific issues (e.g., void detection)

3-1.3.2 Logistics Limitations.

The ability to get test equipment to a site, time available for the evaluation, and access to the pavements are all limiting factors that determine the approach to pavement evaluation testing and analysis.

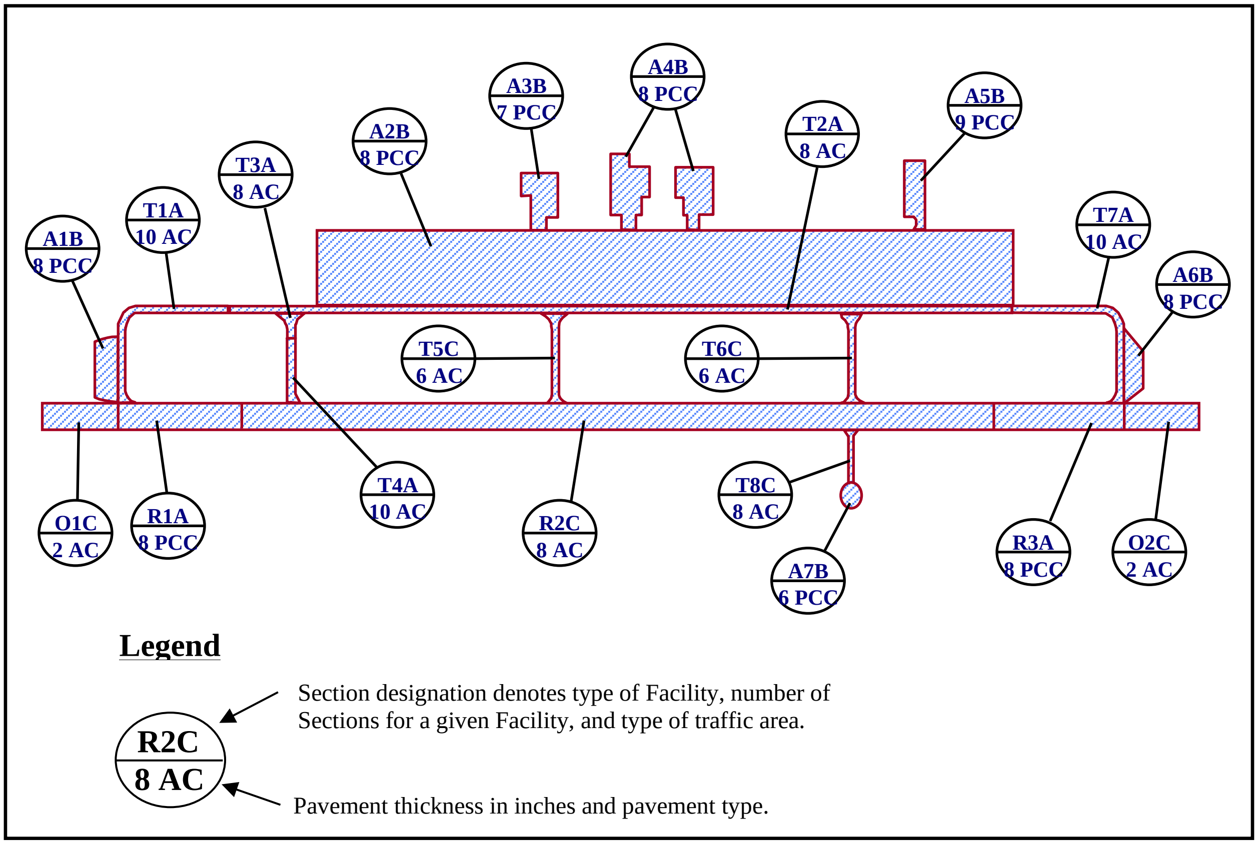
3-1.3.3 Site-Specific Testing Limitations.

The nature of the pavement or soils at the site can limit the reliability of the data. For example, FWD testing can provide unreliable results in certain soil types or when there is a high water table. DCP results can be unreliable in rocky soils. Research and understand the limitations of each test method to determine its suitability for the pavements or soils at each site. TSPWG 3-260-03.02-19, *Airfield Pavement Evaluation Standards and Procedures*, provides alternative testing procedures when site conditions limit the use of testing equipment.

3-2 MAPPING AND INVENTORY.

All testing described in this chapter is intended to determine representative physical characteristics at the pavement inventory section level as shown in Figure 3-1. It assumes that the mapping and inventory is established as outlined in paragraph 2-3.2, with specific details outlined in UFC 3-270-08. Note that Figure 3-1 is typical for a contingency evaluation. In an evaluation for a main installation, section IDs have a leading zero before the number (e.g., A01B and pavement thicknesses are typically rounded to the quarter inch, e.g., 8.25 AC).

Figure 3-1 Typical Airfield Section Map



3-3 PAVEMENT SURFACE CONDITION INSPECTION.

The Pavement Condition Index (PCI) is the standard measure of pavement surface condition used by DoD. PCI data are collected using the procedures outlined in UFC 3-260-16, which is the DoD equivalent of ASTM D5340, *Standard Test Method for Airport Pavement Condition Index Surveys*, with additional DoD-specific requirements. The PCI uses a scale from 0 to 100 to define the condition of the pavement as shown in Figure 3-2 and described in Table 3-1. Ideally a structural pavement evaluation includes a project-level PCI inspection (aka a PCI survey) but the situation may dictate a network-level inspection or even a cursory inspection, which is often the case in a contingency environment. The determining factors on the level of inspection are the intended use of the data and the time and manpower available.

Figure 3-2 PCI Rating Scale

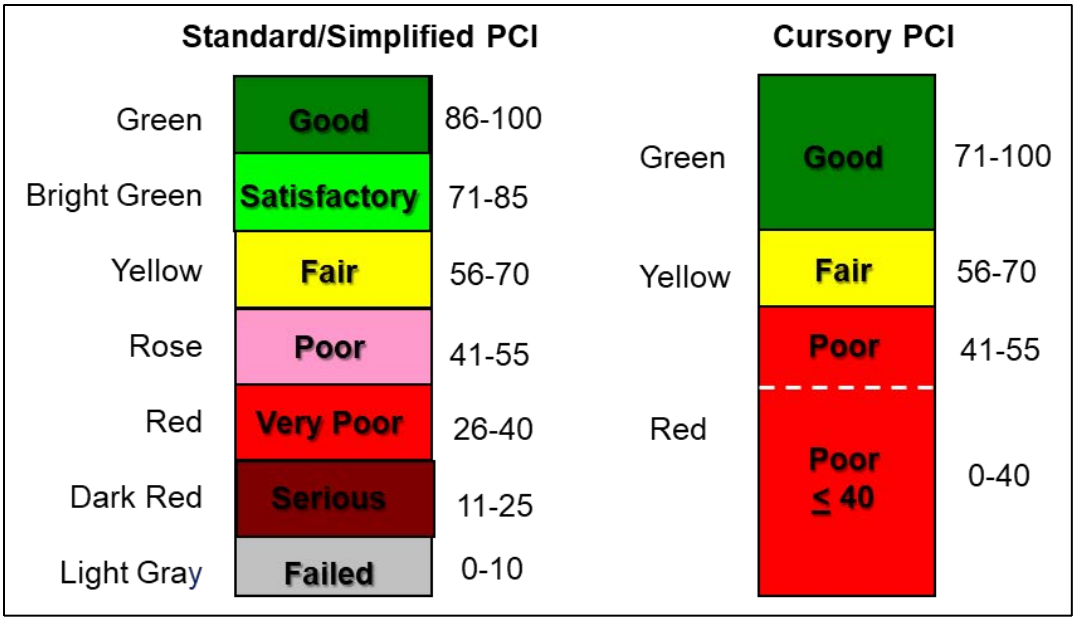


Table 3-1 PCI Rating Definitions

Rating	Definition
86–100	**GOOD:** Pavement has minor or no distresses and will require only routine maintenance.
71–85	**SATISFACTORY:** Pavement has scattered low-severity distresses, which should require routine maintenance.
56–70	**FAIR:** Pavement has a combination of generally low- and medium-severity distresses. Near-term maintenance and repair needs should be routine to major.
41–55	**POOR:** Pavement has low-, medium-, and high-severity distresses, which probably cause some operational problems. Near-term maintenance and repair needs should range from routine to reconstruction.
26–40	**VERY POOR:** Pavement has predominantly medium- and high-severity distresses causing considerable maintenance and operational problems. Near-term maintenance and repair needs will be intensive in nature.
11–25	**SERIOUS:** Pavement has mainly high-severity distresses, which cause operational restrictions; immediate repairs are needed.
0–10	**FAILED:** Pavement deterioration has progressed to the point that safe aircraft operations are no longer possible; complete reconstruction is required.

3-3.1 Project-Level PCI Inspection.

The project-level PCI is referred to as a standard PCI inspection in some contingency pavement evaluation material and in Figure 3-2 above. The PAVER pavement management application implements the inspection process outlined in UFC 3-260-16. It requires inspecting sufficient samples to achieve a 95 percent confidence level. Determine the samples to be inspected based on a systematic random sampling process. The formula for determining the number of samples is in UFC 3-260-16 but Table 3-2 provides a general idea of sampling requirements. Use the seven-tier PCI scale shown in Figure 3-2 and Table 3-1 when reporting results. Use project-level inspections when the data is used to develop project management plans for main installations or to meet a specific requirement for a higher confidence level. PAVER uses the same database structure as the Pavement-Transportation Computer Assisted Structural Engineering (PCASE) application, so PCI inspection data are also accessible in PCASE for use in structural analysis.

Table 3-2 Project-Level Sampling Requirements

PCC Sampling			
Total # of SU	Survey #	Total # of SU	Survey #
1-10	ALL	50-55	22
11-13	10	56-61	23
14-15	11	62-70	24
16-17	12	71-79	25
18-19	13	80-91	26
20-22	14	92-105	27
23-24	15	106-122	28
25-27	16	123-145	29
28-31	17	146-175	30
32-35	18	176-217	31
36-39	19	218-280	32
40-43	20	281-330	33
44-49	21	>= 331	10%

ACC Sampling	
Total # of SU	Survey #
1-7	ALL
8-11	7
12-15	8
16-19	9
20-24	10
25-32	11
33-44	12
45-64	13
65-104	14
105-150	15
≥151	10%

3-3.2 Network-Level PCI Inspection.

The network-level PCI is referred to as a simplified or contingency pavement condition survey in some contingency pavement evaluation references. It is also conducted in accordance with UFC 3-260-16 but requires a lower sample rate than a project-level PCI, as shown in Table 3-3. Another difference between the project and network-level PCI is that the network-level PCI requires representative rather than random samples. The inspector must determine the typical distress types in the section and inspect samples that are typical of the entire section. Place emphasis on structural or foreign object damage (FOD) -related distresses. Use the seven-tier PCI scale shown in Figure

3-2 and Table 3-1 when reporting results. The network-level inspection is typically used for contingency evaluations at forward or en-route operating locations but may also be used at sites such as auxiliary fields when there is not a specific requirement for a higher confidence level.

Table 3-3 Network-Level PCI Sampling Requirements

Section Size (Total Samples)	Sample Units to Survey
1 to 5	1
6 to 10	2
11 to 15	3
16 to 40	4
Greater than 40	10%

3-3.3 Cursory Pavement Condition Inspection.

In a cursory pavement condition inspection, the number of inspected sample units may be less than the minimum requirements for a network-level inspection. Use the same process outlined in UFC 3-260-16 when time permits or, when time is limited, conduct a visual assessment noting the primary distresses with a focus on distresses that cause limitations or mission impacts to aircraft. Mission-critical PCI values typically occur when the value is less than 40 or 25. In either case, report the results of a cursory survey as a qualitative assessment of the pavement surface condition using the Cursory three-color scale in Figure 3-2. When a cursory condition survey is conducted using the simplified evaluation procedures, the evaluation is considered "expedient" and valid for limited or immediate use only. Cursory inspections are typically used in contingency pavement evaluations.

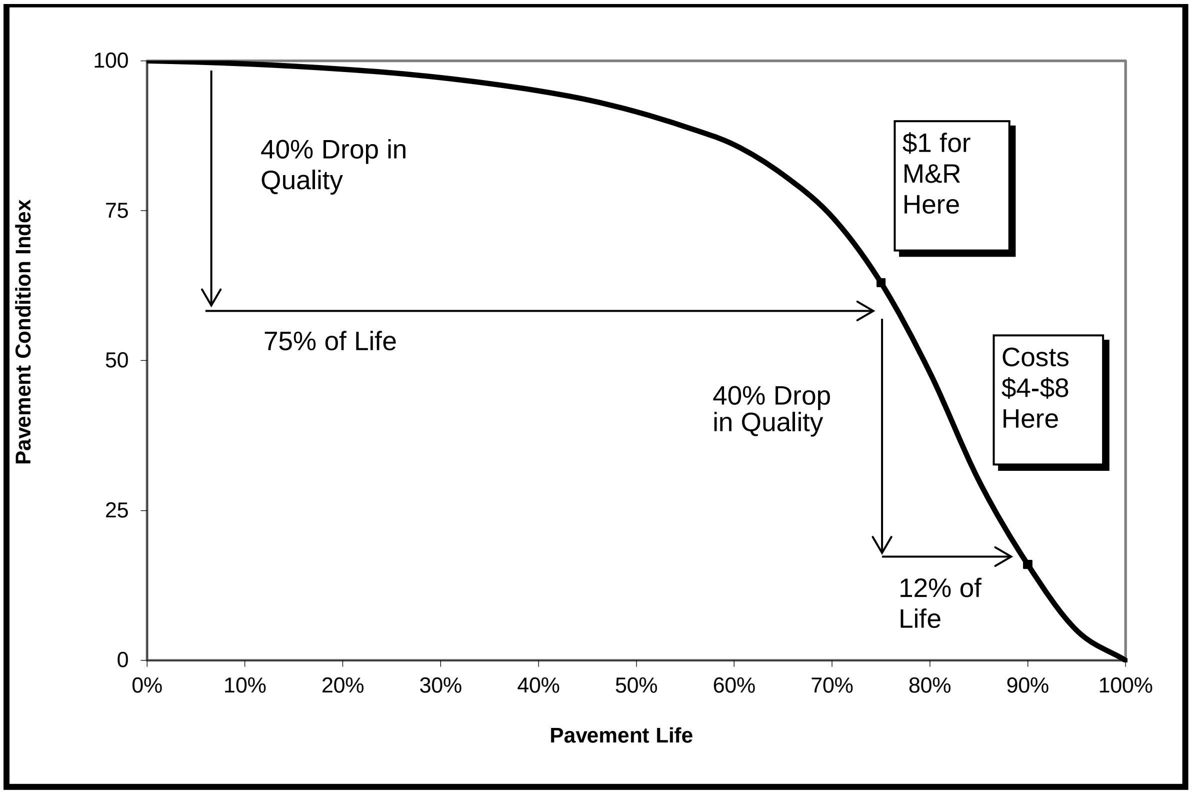
3-3.4 Using PCI Inspection Results.

The PCI of a pavement plays a critical role in determining localized and global preventive as well as major M&R requirements in pavement management plans. It is also used in all the structural evaluation pavement analysis procedures.

3-3.4.1 PCI Use in Pavement Management.

The PCI is used to determine the rate of deterioration of the surface condition and predict the future condition of the pavement. The predicted PCI is used to plan appropriate cost-effective M&R actions. When a pavement deteriorates to a condition where it is no longer cost-effective to do localized or global M&R (known as the critical PCI), major M&R is triggered to address issues before the pavement deteriorates to the point that reconstruction is required (see Figure 3-3). While each Service establishes PCI levels that trigger major M&R and reconstruction based on their respective missions, the general principles remain the same: invest in localized and global M&R to extend the service life of GOOD pavement and invest in major M&R at the appropriate time to delay the need for reconstruction.

Figure 3-3 Typical Pavement Life Cycle (APWA,1983)



3-3.4.2 PCI Use in Pavement Structural Analysis.

The pavement condition can adversely affect aircraft operations because some distresses generate foreign object debris (FOD) that poses a risk to aircraft operations. It can also help identify potential structural problems (e.g., structural distresses that indicate the pavement is overloaded or at the end of its service life). When the PCI is 40 or lower, reported allowable gross loads (AGL) are reduced by 25 percent. In addition, the PCI is used to compute the structural condition index (SCI). The SCI is like the PCI but only considers the load-related distresses. The SCI is used as the failure criteria for rigid pavement when doing layered elastic analysis and used to determine the condition factors Cb and Cr that determine the equivalent thickness of existing overlays on rigid pavements or new overlay requirements when an existing pavement is not capable of supporting the evaluation traffic.

3-3.5 Additional Contingency Evaluation Considerations.

The amount of time available to conduct PCI surveys impacts the number of sample units inspected. The evaluator’s most important task is to accurately identify the correct distress type and severity level as described in UFC 3-260-16. Acceptable errors in distress quantity will have less of an impact on the PCI value and FOD risk to mission aircraft. Typically, medium- and high-severity distresses create the highest FOD potential that may cause operational limitations or impacts to the mission aircraft. While the PCI value may provide an indirect measure of subsurface deficiencies, it is important to consider both the surface condition (e.g., PCI) from a function perspective and structural evaluation results. A pavement surface may rate GOOD (PCI 71 to 100) but have underlying pavement or soil conditions that could result in pavement failure under repeated aircraft operations. On the other hand, a pavement may be structurally sound, but the surface condition may be hazardous for aircraft traffic (e.g., FOD).

3-4 NONDESTRUCTIVE PAVEMENT TESTING.

Paragraph 3-1.1 describes three nondestructive pavement testing techniques currently in use, the FWD, GPR, and the MIRA device. Each is used to determine different pavement characteristics are used in conjunction with each other or in conjunction with direct sampling testing.

3-4.1 Falling Weight Deflectometer (FWD).

The falling or heavy-weight deflectometer (FWD/HWD) is an impulse loading device that measures the response of a pavement system to a falling dynamic load that simulates a moving vehicle or aircraft wheel. FWD is the generic term for the device, with the HWD capable of applying a heavier load than other FWDs, but the terms are used synonymously. The heavier load of the HWD is preferred on thick AC and PCC airfield pavement structures. The objective is to apply the maximum load possible to simulate aircraft loading without overloading the FWD sensors. ASTM D4694, *Standard Test Method for Deflections with a Falling-Weight-Type Impulse Load Device*, provides detailed guidance on the FWD and HWD test procedures.

3-4.1.1 FWD Description.

The load on the pavement (impulse force) from an FWD is created by dropping weights from different heights onto a rubber or spring buffer system. The standard loading plates used to transmit the applied force to the pavement are either 12 inches (300 millimeters) or 18 inches (450 millimeters) in diameter, with the 12-inch plate being most commonly used for AC or PCC pavement surfaces while the 18-inch load plate used for unbound aggregate layers and stabilized subgrades. The drop height is varied to produce an impact force up to 56,000 pounds (25,401 kilograms), depending on the HWD. Other FWD models are limited to lower loads more typical of road traffic.

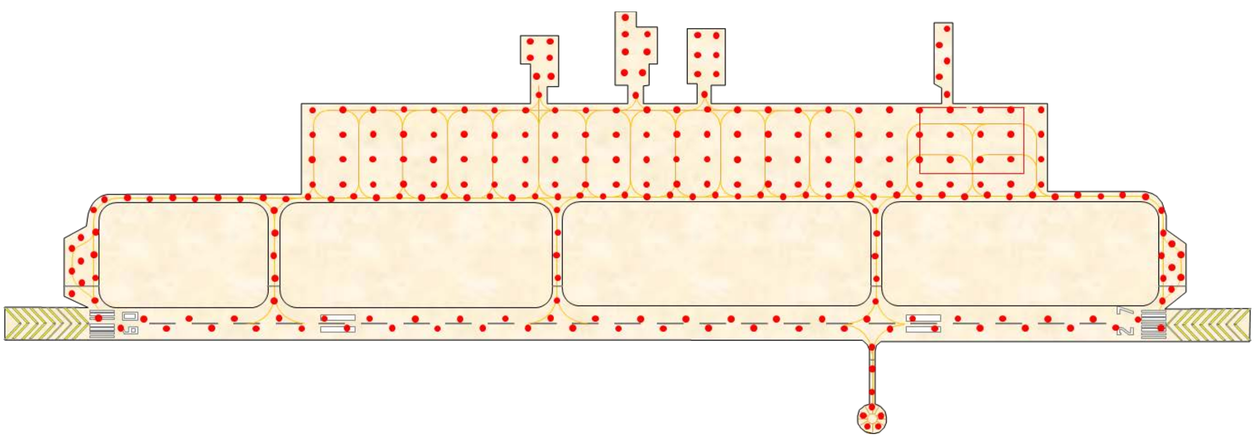
3-4.1.2 Measuring Pavement Response.

The FWDs currently in use by DoD use geophones, which are velocity transducers that convert ground movement (velocity) into voltage to measure the pavement response to the applied load. The load is measured by a load cell integral to the FWD load system and the pavement response is captured by the pavement deflection which is obtained by integrating the surface velocity measured by the velocity transducers. Other systems use seismometers but both are typically referred to as sensors. Seven sensors are preferred, with a sensor located at the center of the load plate and the remaining sensors at 12-inch (300-millimeter) intervals, with the outermost sensor (farthest from the falling weight load application) at 72 inches (1829 millimeters). There may be instances when fewer sensors are used but in no case should the outermost sensor be less than 48 inches (1219 millimeters) from the load.

3-4.1.3 Test Location and Density.

The time required to measure the deflection basin at each testing location is short (one to two minutes), allowing for many tests in a short period of time. Conduct FWD testing at 100-foot (30-meter) intervals on runways and taxiways. Alternate tests on either side of the centerline at an offset that is within the main gear wheel paths of aircraft that frequently use the airfield or are based at the site. The centerline offset is usually 10 to 12 feet (3 to 4 meters) for flexible pavements. Adjust this offset distance for rigid pavements as required to accommodate joint layouts and PCC slab size. Conduct FWD tests on apron areas in a grid pattern at 100- to 200-feet (30- to 61-meter) spacing. As seen in Figure 3-4, the procedure outlined above establishes longitudinal profiles along the runways, taxiways, and aprons to produce a test density that gives a comprehensive assessment of subgrade, base, and pavement structural condition. The uniformity of results will dictate whether test spacing can be increased or whether additional tests should be conducted when there are large variations in pavement response. When failed areas or areas of excessive pavement distress are encountered, locate enough FWD and other tests in the failed or distressed areas to determine the cause of the failure or distress. Conduct a minimum of five FWD tests on all pavement sections.

Figure 3-4 FWD Test Locations



3-4.1.4 Performing the FWD Test.

Position the FWD equipment at each test location and initiate the test sequence through the FWD application provided with the system. Test sequences require a minimum of three drops (loads) and use of the same drop heights (e.g., 2-4-4) throughout a given section. The first loading is at a lower drop height and is considered a seating load and results are not typically used in backcalculation. The second and third loadings are set to maximize the magnitude of the loading without exceeding the geophone limitations. They should produce similar results and are used for the analysis. If inconsistencies are observed in either of these test sequences (e.g., high errors or inconsistent basin shape), select the better of the two drop sequences for analysis. The load is applied for each drop in the sequence, the resulting surface deflections are determined at each geophone location, and the results are stored in a data file. There are several data file formats, but a formatted text file with a .fwd or .hwd file extension is typically used by DoD. Import the .fwd file (or other chosen format) into PCASE for analysis.

3-4.1.5 FWD Testing for Asphalt.

The modulus of bituminous concrete is temperature dependent. There are relationships between the temperature and the modulus used in backcalculation and analysis as described in Chapter 5. The relationship for backcalculation requires the mean pavement temperature at the time of testing. This datum can be captured by measuring the temperatures with thermometers installed 1 inch (25 millimeters) below the pavement surface, 1 inch (25 millimeters) above the bottom of the AC layer, and at mid-depth of the bituminous layer, but this procedure is seldom used. The standard approach is to collect data on the average (mean) air temperature for the five-day period prior to the day of testing and adding it to the measured pavement surface temperature, which is captured by the FWD at the time of the test to determine the mean pavement temperature using the relationship described in Chapter 5.

3-4.1.6 FWD Testing for Concrete.

Perform tests on rigid pavements near the center of the PCC slabs but at a minimum of 3 to 6 feet (1 to 2 meters) away from the joints and linear cracks that may exist within the slab. When a slab width or length is less than 20 feet (6 meters), center the entire sensor array on the slab, keeping the outer sensor at least 3 feet (1 meter) from the joint.

3-4.1.7 FWD Testing for Joint Load Transfer.

Rigid airfield pavements are commonly designed to transfer at least 25 percent of the load on a slab to adjacent slabs. FWD testing is used to verify that the load is being transferred across the joint. Figure 3-5 shows the test configuration with the plate (and sensor 1) on the loaded slab and the second sensor on the unloaded slab. The deflection ratio of the unloaded slab to the loaded slab is the deflection ratio used to determine the joint load reduction factor using the relationship shown in Figure 3-6 to define joint transfer efficiency. If the joint load transfer is poor, the load-carrying capacity of the PCC slabs is reduced, with a corresponding decrease in the pavement service life.

Joint testing policy varies. In some cases, joint testing is always done and in other cases it is only done when there are indications that there is poor load transfer such as longitudinal cracking in the wheel path on multiple slabs in a section. In either case, determine the number of center slab tests, take 20 percent of that number and perform joint tests on that number of slabs. Joint load transfer is temperature dependent; testing in the morning can yield different results in the afternoon as slabs heat up and expand. While not always feasible, it is best to perform NDT work in the spring or fall to avoid high temperatures in the summer and cold temperatures in the winter that may not represent typical load-transfer for a pavement system. If NDT work must be performed in the summer, consider early-morning testing when temperatures are typically cooler than in the afternoon. This is especially relevant if joint load transfer exists primarily from aggregate interlock because no dowel bars exist in the jointed PCC pavement. Reference point tests can establish a relationship between air temperature and the deflection ratio from NDT such that adjustments are made to test results collected over a wide range of temperatures. Select a reference slab within each section to be tested on a given day. Conduct joint tests on each reference slab at one- to two-hour intervals throughout the testing period, or at closer intervals if the testing period is less than four hours on a given section.

Figure 3-5 NDT Configuration for Determining PCC Joint Load Transfer

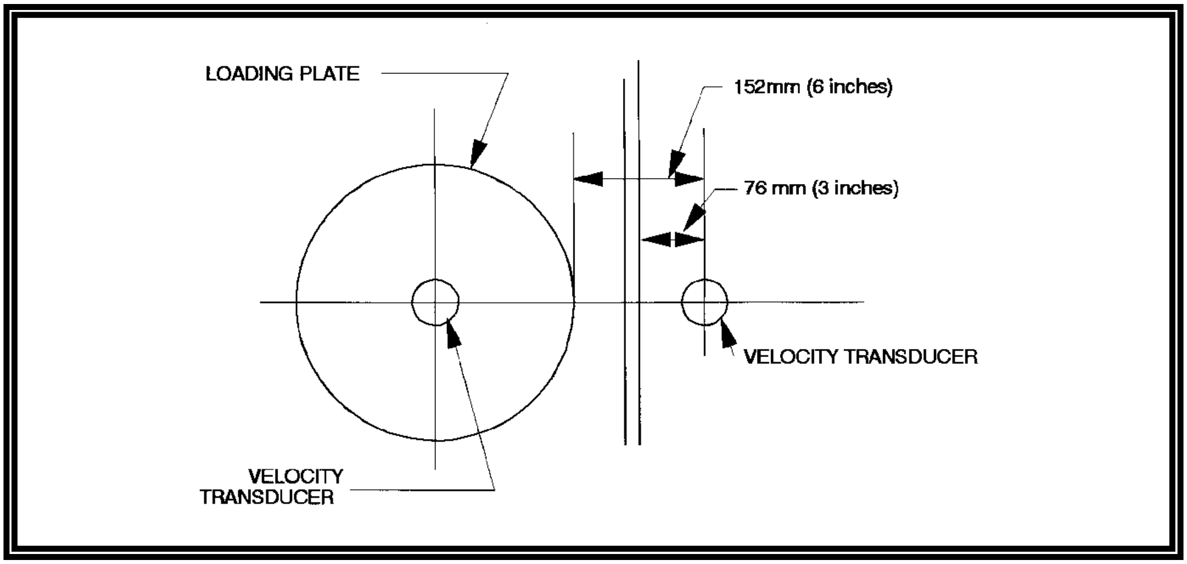
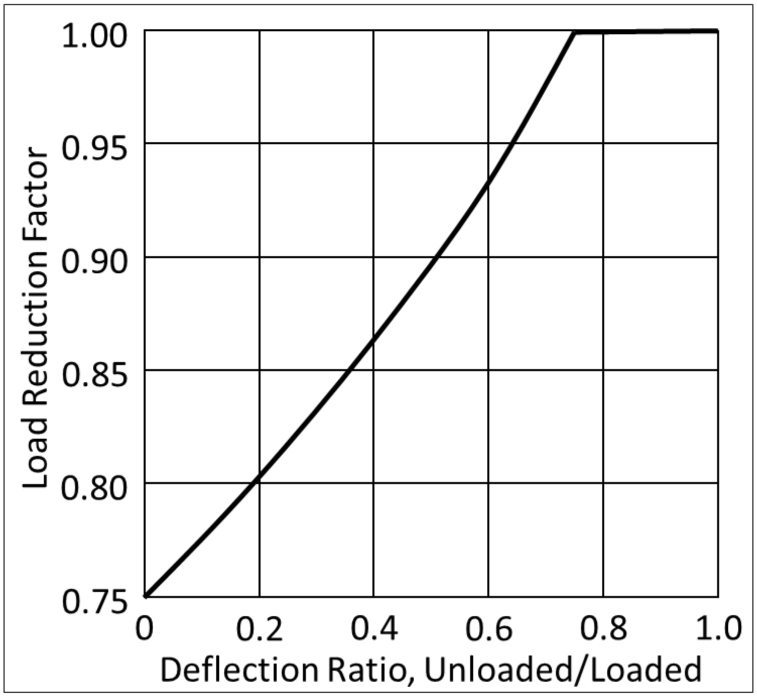


Figure 3-6 Joint Load Reduction Factor



3-4.2 Ground Penetrating Radar (GPR).

The primary benefit of GPR is that it can collect large amounts of detailed data in a short time. Use GPR to determine pavement layer thicknesses for each material type and the presence of anomalies in a structure. There are air-coupled and ground-coupled GPR variants that use electromagnetic radiation, usually in the range of 10 MHz to 2.6 GHz. Higher frequencies do not penetrate as far as lower frequency antennae but may provide better resolution. A GPR transmitter emits electromagnetic energy into the structure. When the energy encounters a buried object or a boundary between materials having different permittivity, it is reflected, refracted, or scattered back to the surface. The receiving antenna records the variations in the return signal.

GPR is sensitive to specific site conditions. The material types encountered will dictate the ability of the GPR to evaluate the layered structure. Dry, sandy soils or materials such as granite or limestone tend to be resistive rather than conductive and can penetrate up to 49 feet (15 meters). Moist or clay-laden soils and materials with high electrical conductivity can limit penetration to as little as a few inches. Materials with similar dielectric constants will limit the ability to discern layer changes. Before testing, calibrate the GPR system (see Figure 3-7) at each site using cores and a steel plate. Take measurements along FWD testing paths on each side of the centerline for taxiways and runways and along the FWD testing path on aprons. The data collection system records the voltage and time history of the signal and GPS location and camera images for use in post-processing. Post-process the data to determine layer thickness by comparing voltage peaks (amplitude) and the time between peaks to estimate the layer thickness and use these data to determine the average layer thicknesses for each section. Use the procedure outlined in Appendix B for void detection.

Figure 3-7 Air Coupled GPR

3-4.3 MIRA Ultrasonic Tomography.

The MIRA ultrasonic tomography device is used to determine concrete pavement thickness. The standard procedure is to take measurements near each FWD test location with the objective of achieving a 95 percent confidence level that the average value reported for each section is within 0.5 inch (13 millimeters) of the true value. Round the computed average value to the nearest 0.25 inch. While coring has the benefit of providing a sample that can be measured and tested for flexural strength, the MIRA can test more locations to determine an average thickness without the need to repair core holes. Figure 3-8 shows a MIRA device being used for testing.

Figure 3-8 MIRA Ultrasonic Tomography

3-5 DIRECT SAMPLING.

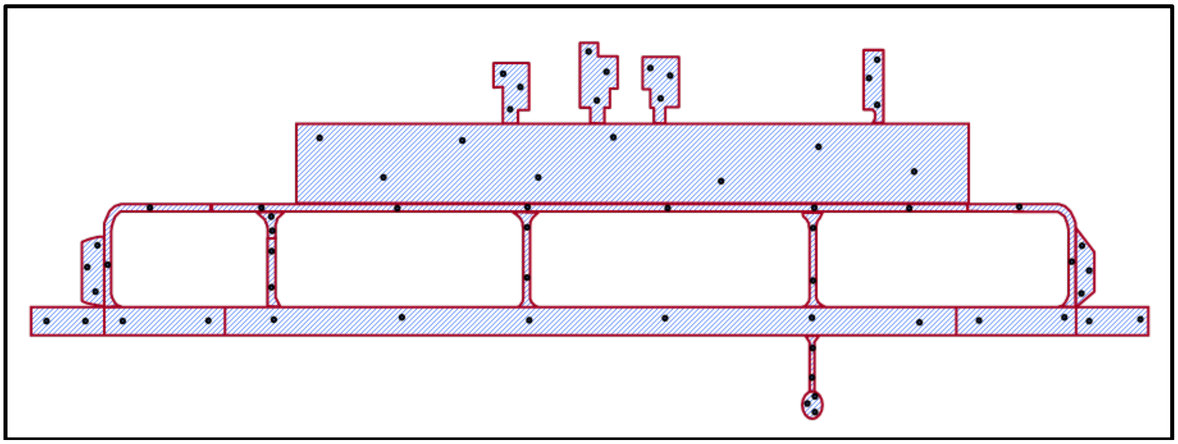
3-5.1 Pavement Coring and Drilling.

Pavement coring or drilling is used to collect pavement and soil samples, verify the pavement thickness, and provide access to the subsurface layers for DCP testing.

3-5.1.1 Coring or Drilling Locations.

When there were previous evaluations at a site, select locations that were not previously tested and use the data from both the previous and new evaluation to define the representative pavement structure. For rigid pavements, core in the center of the slabs to avoid thickened edges. Recording new location GPS coordinates can assist in preparing GIS maps. For contracted coring or drilling work, obtain GPS data for each location if the airfield owner allows GPS data collection. When coring or drilling is done in conjunction with FWD testing, use the FWD data to identify locations for additional testing where there are anomalies or changes in strength. The size and uniformity of the section dictates the number of tests required but test at least three locations for any new pavement not previously tested. Perform tests in the aircraft wheel paths on alternating sides of the centerline and in any weak areas. Conduct additional tests to verify the boundaries of these areas. When test time is limited, prioritize runway and taxiway tests. Figure 3-9 shows a typical test plan for coring or drilling.

Figure 3-9 Typical Coring/Drilling Test Plan



3-5.1.2 Pavement Coring.

Figure 3-10 shows a typical coring operation. The core drill uses 4- to 8-inch (102- to 203-millimeter) -diameter, diamond-tipped coring barrels (6-inch [152-millimeter] is the norm) to cut through asphalt or concrete pavements. This type of pavement coring system can cut through pavements to depths greater than 36 inches (914 millimeters) using a technique known as double dipping to remove the core in sections. Measure the cores to the nearest 0.25 inch and inspect them in the field for evidence of defects such as alkali-silica reaction (ASR).

Figure 3-10 Typical Coring Operation

3-5.1.3 Pavement Drilling.

Impact or rock drills are commonly used for contingency pavement evaluations because they have a smaller logistics footprint. Drill 1- to 1.25-inch (25- to 32-millimeter) -diameter holes through bound materials or any layers impenetrable by a DCP. Pavement thickness is measured to the nearest 0.25 inch in the drill hole.

3-5.2 Dynamic Cone Penetrometer (DCP).

The DCP is a device used to determine the thickness and strength of the soil layers in a pavement structure. There are manual, semi-automated, and automated DCP variants but all apply the same principles to measure the depth of penetration for a known applied load to determine a DCP index (in. or mm / blow). The DCP index is empirically correlated to CBR, k, or modulus.

3-5.2.1 DCP Description.

The four main components of the DCP are the 0.79-inch (20-millimeter) -diameter 60-degree cone, the rod, the anvil, and the 17.6-pound (7.98-kilogram) hammer, as described in ASTM D6951, *Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications*. The cone is driven into the ground by raising and dropping a hammer 22.6 inches (575 millimeters) against the anvil. The manual hand-held version shown in Figure 3-11 is portable, requires the hammer be lifted manually, and the depth of penetration measurements be taken manually using an incremented measuring stick. The correct number and length of extensions in the field must account for the thickness of all bound layers or materials that cannot be penetrated by the DCP. The semi-automated version requires lifting the hammer manually but the depth of penetration is measured automatically using a magnetic rule, string potentiometer, or similar device, and the blow count and depth of penetration are saved in a data file.

The automated DCP (ADCP) has a mechanism for lifting the hammer to the prescribed height and releasing it, then recording the blow count and depth of penetration, which are saved in a data file. Figure 3-12 shows an example of a system that has both a core drill and an ADCP.

Figure 3-11 Schematic of DCP

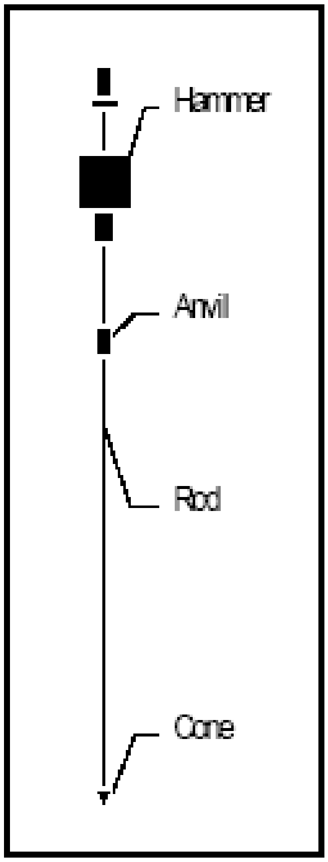


Figure 3-12 ADCP

3-5.2.2 DCP Test Procedure.

A 1-inch (25-millimeter) or 6-inch (152-millimeter) -diameter hole is drilled or cored through the pavement until the top of the base or subgrade is encountered. The rod with the cone attached is placed in the hole until it is in contact with the soil, then the hammer is raised and dropped and the depth of penetration recorded. The standard test is designed to penetrate soils to a depth of 48 inches (1219 millimeters) from the top of the pavement, although extension kits can go deeper, with a maximum recommended depth of 6.5 feet (2 meters). Testing is normally done to 36 inches (914 millimeters) in contingency evaluations. Once the DCP test is completed, the DCP is removed from the hole and soil samples for lab testing can be taken using a hand auger. Detailed test procedures and correlations for using the DCP and ADCP are provided in TM 3-34.48-2, *Theater of Operations: Roads, Airfields, and Heliports - Airfield and Heliport Design*.

3-5.3 Test Pits.

Test pits are seldom used for evaluations due to the number of tests required to characterize an entire airfield and the time it takes to open the pit and conduct testing, both of which typically have a significant impact on the mission. They are used more frequently for geotechnical work associated with a project or when doing forensic analysis to determine the cause of a pavement failure. Test pits provide greater opportunity to collect more pavement samples and larger soil samples for testing. An alternative to test pits is a minimum of three core holes up to 8 inches (203 millimeters) in diameter to permit in-place small aperture CBR tests and obtain samples for laboratory tests. The size of the test pits and some test procedures vary between flexible and rigid pavements. Following are descriptions for both pavement types.

3-5.3.1 Test Pits for Flexible Pavements.

Test pits for flexible pavements are approximately 4 feet (1 meter) wide by 5 feet (1.5 meters) long. Whether doing a full test pit or core holes for small aperture CBR testing, record the general condition of the pavement and a visual classification of materials from each test pit or core hole. Take several measurements around the perimeter of the test pit or core hole to determine the representative pavement thickness to the nearest 0.25 inch. For each test pit, perform CBR and field density tests on the base and collect disturbed and undisturbed soil samples of the base material for laboratory testing. Remove the remaining base material and measure the thickness of the base at several locations around the perimeter to determine the representative base thickness to the nearest 1 inch. Repeat this process for each subbase and the subgrade. Describe each soil course, noting color, in situ conditions, texture, and a visual classification. Sampling procedures, test descriptions, and testing references are included in Appendix A.

3-5.3.2 Test Pits for Rigid Pavements.

Test pits for rigid pavements are a minimum of 4 feet by 5 feet (1 meter by 1.5 meters), although the size of the test pits for rigid pavements depends, in part, on the thickness of the pavement because the length of the beams for flexural strength tests cut from the slab must be at least three times the pavement thickness, except when 6-inch by 6-inch (152-millimeter by 152-millimeter) beams are cut from the top and bottom of the slab for a three-point beam test. Record the general condition of the pavement and a visual classification of materials from each test pit. Take several measurements around the perimeter of the test pit to determine the representative pavement thickness to the nearest 0.25 inch. For each test pit, perform a plate bearing test, field density tests and, in some cases, CBR testing on the base. Collect disturbed and undisturbed soil samples of the base material for laboratory testing. Remove the remaining base material and measure the thickness of the base at several locations around the perimeter to determine the representative base thickness to the nearest 1 inch. Repeat this process (without the plate bearing test) for each subbase and the subgrade. Describe each soil course, noting color, in situ conditions, texture, and a visual classification. Sampling procedures, test descriptions, and testing references are included in Appendix A.

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CHAPTER 4 TRAFFIC

4-1 TRAFFIC DEFINITION.

A fundamental component of pavement evaluation is the traffic concept. Traffic is the mix of different aircraft types, loads, and number of passes used for the evaluation analysis. This group of aircraft defines the anticipated applied stress and number of stress repetitions the pavement will experience. Traffic is applied in the analysis procedures in different ways, depending on the Service and mission. Following is a summary of traffic terms and concepts and the various ways traffic is defined in an evaluation.

4-1.1 Traffic Pattern.

Traffic pattern is a term used to describe one or more aircraft or ground vehicles, with the weight and number of passes defined for each. The term traffic pattern is often used interchangeably with traffic mix and aircraft group when the loads and passes are defined for the aircraft in the group.

4-1.2 Traffic Mix.

Traffic mix is a term used to describe one or more aircraft or ground vehicles with the weight and number of passes defined for each. The term traffic mix is often used interchangeably with traffic pattern and for aircraft group when the loads and passes are defined for the aircraft in the group.

4-1.3 Aircraft Group.

An aircraft group is a collection of one or more aircraft organized by a specific criterion (e.g., pavement effect, gear type, or mission). When the load and passes are defined for each aircraft in the group, the term is synonymous with the term traffic pattern or traffic mix.

4-1.4 Representative Aircraft.

An aircraft in an aircraft group that is representative of the group based on a specified criterion such as gear configuration, weight, or a combination of these that defines the effect on the pavement for that group.

4-1.5 Controlling Aircraft.

The controlling aircraft is used in a mixed traffic analysis. In design, it is the aircraft in the traffic mix that requires the greatest pavement thickness. In evaluation, it is the aircraft with the fewest allowable passes.

4-2 AIRCRAFT PASSES.

Passes are defined as the number of aircraft movements across an imaginary transverse line placed within 500 feet (152 meters) of the end of the runway. Since touch-and-go aircraft operations will not pass this line, they are not counted. For taxiways and aprons, passes are determined by the number of aircraft movements across a line on the primary taxiway that connects the runway and the parking apron. At single-runway airfields with a parallel taxiway, the pass levels for the runway, taxiway, and apron could be the same, but passes can vary based on the airfield configuration as shown in Figures 4-1 through 4-4.

Figure 4-1 Takeoff and Land in Same Direction with No Back Taxiing

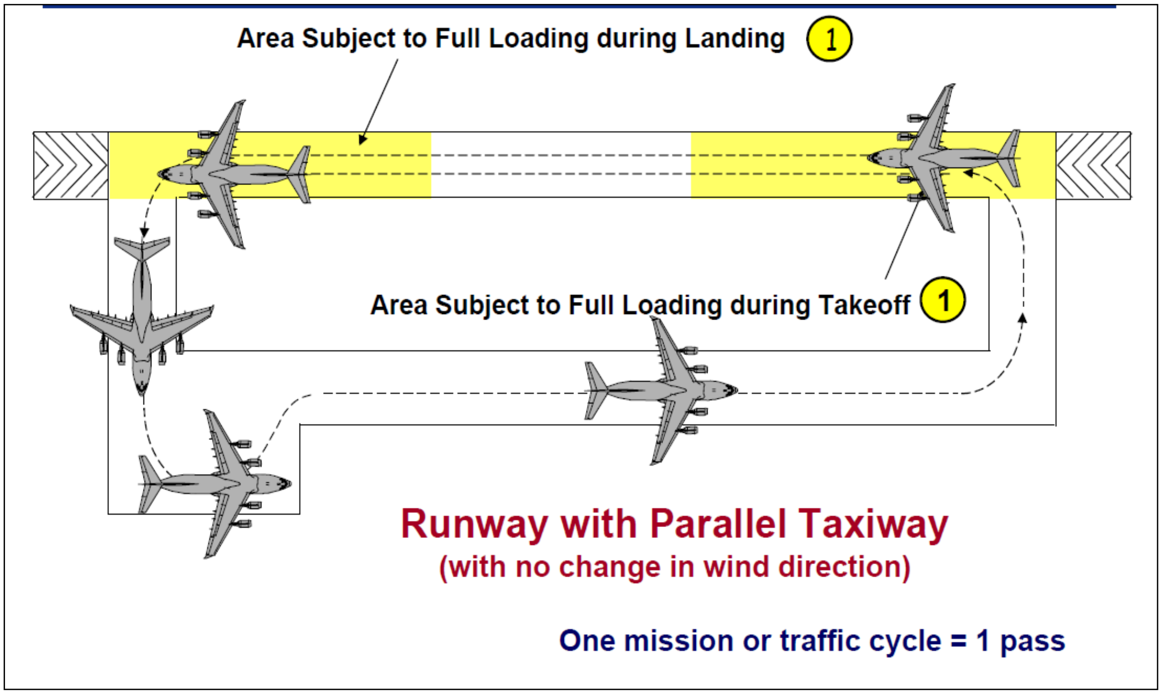


Figure 4-2 Takeoff and Land in Opposite Directions with No Back Taxiing

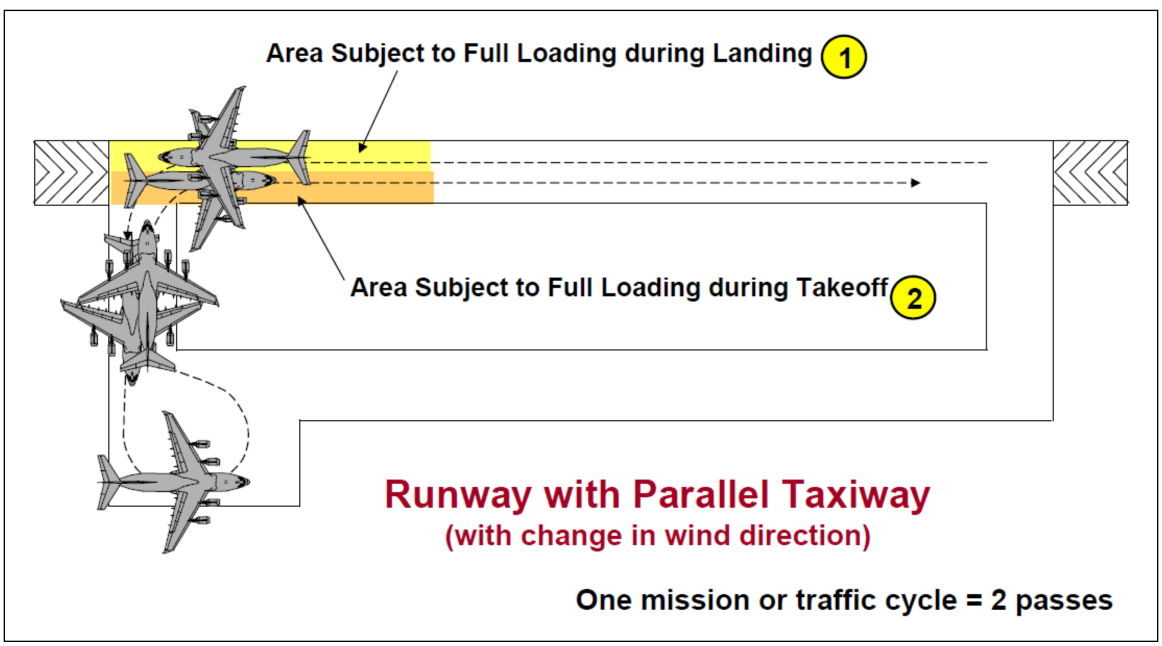


Figure 4-3 Takeoff and Land in Same Direction with Back-Taxiing

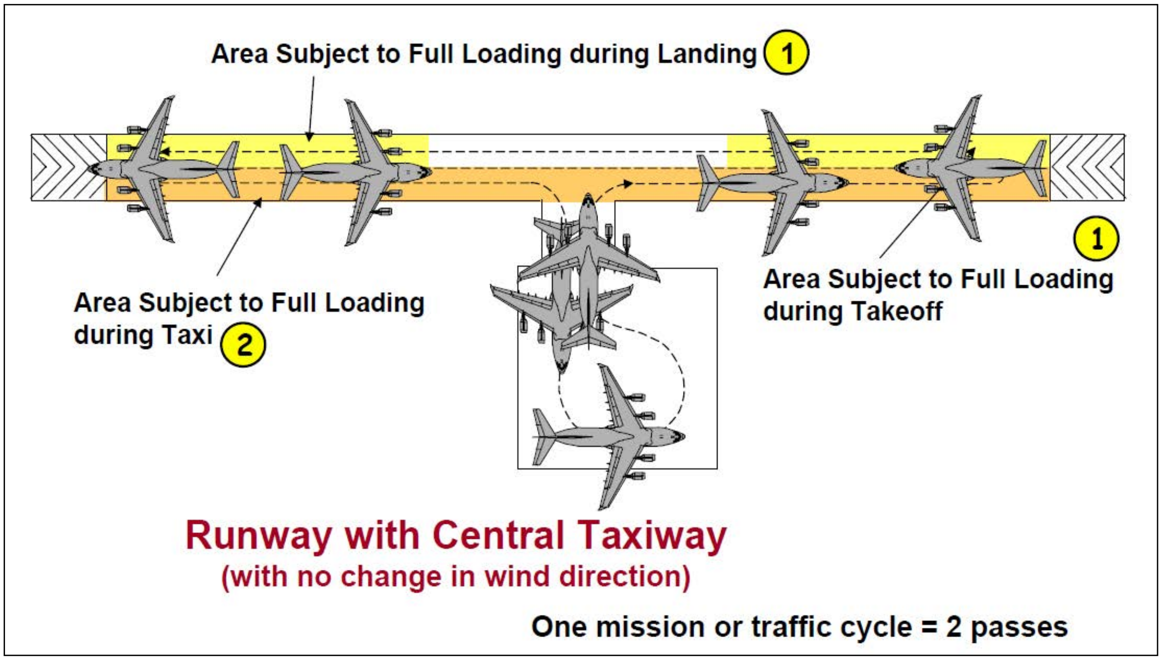
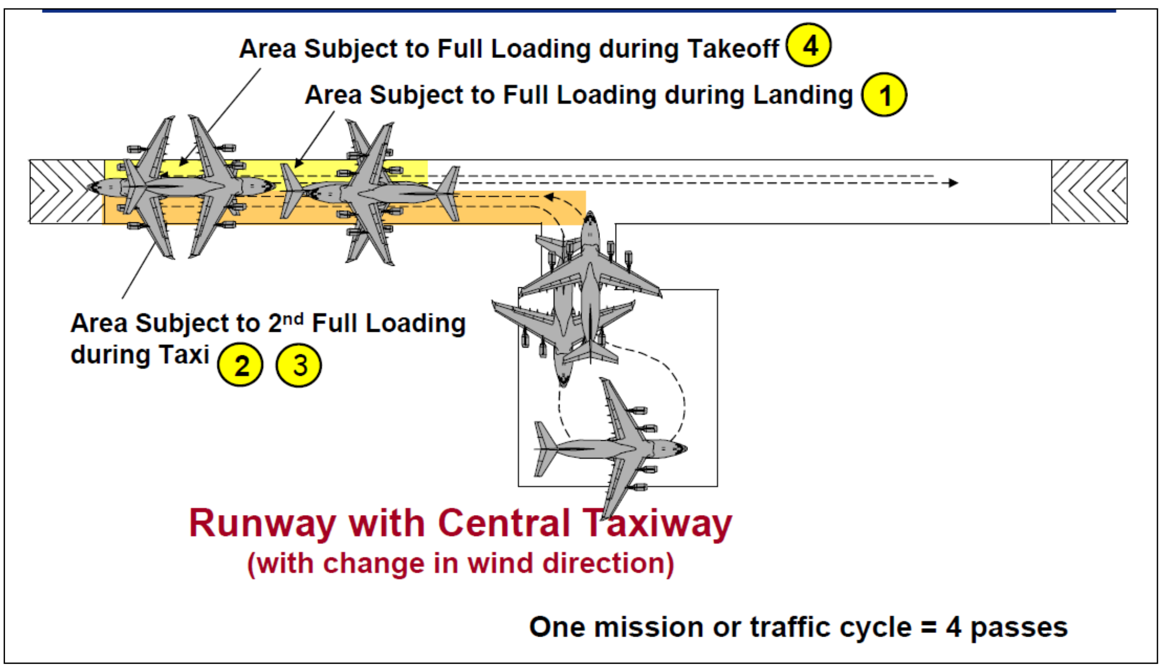


Figure 4-4 Takeoff and Land in Opposite Directions with Back-Taxiing



4-3 AIRCRAFT COVERAGES.

Passes are converted to coverages for analysis. Coverage is a term used to define the number of maximum stress repetitions that occur in a pavement due to aircraft operations. For flexible pavement, a coverage occurs when every point on the pavement surface within the traffic lane has been subjected to one application of maximum stress by operating aircraft. For rigid pavement, a coverage occurs when each point in the pavement within the limits of the traffic lane has been subjected to a maximum stress by operating aircraft. Maximum stress is the stress induced in the pavement by the aircraft wheels when the aircraft is operating at its maximum gross weight. An important point is that the surface criteria (AC and PCC) are based on coverages to failure, while the subgrade criteria are based on repetitions to failure. The lateral distribution of traffic has a greater effect on the number of maximum stress applications that occur at a point near the surface than for a point deep within the pavement structure (ERDC Miscellaneous Paper S-73-56, *Lateral Distribution of Aircraft Traffic*). A coverage is a function of gear configuration and tire width as well as the traffic area, so the pass/coverage (P/C) ratio varies for each aircraft and for each traffic area. The Pavement-Transportation Computer Assisted Structural Engineering (PCASE) application implements the P/C ratio concept for rigid and flexible pavement design and evaluation. These ratios are shown in TSPWG M 3-260-03.02-19.

4-4 TRAFFIC AREA.

The traffic area defines the wander width and load condition on specific portions of the airfield.

4-4.1 Wander Width.

Wander width is defined by whether aircraft traffic is close to the centerline of the runway or taxiway or whether they tend to deviate from the centerline. The first scenario is known as channelized traffic and is used when 75 percent of traffic occurs within ±35 inches (889 millimeters) from the center line for a runway or taxiway (a 70-inch [1778-millimeter] wander width). The second scenario is known as unchannelized traffic, which is used when 75 percent of traffic occurs within ±70 inches (1778 millimeters) from the centerline of a runway, taxiway, or apron (a 140-inch [3556-millimeter] wander width). The pass-to-coverage ratio for a given aircraft is lower for channelized traffic than for unchannelized traffic.

4-4.2 Load Condition.

An aircraft is typically fully loaded as it moves from the apron onto the taxiway and to the runway end. As the aircraft takes off, the wings provide lift and the interior portion of the runway is not typically experiencing the full aircraft weight. As an aircraft lands, the wings are still providing lift until the aircraft comes to taxi speed at the end of the runway, onto the taxiway and then to the apron. When the airfield configuration requires back-taxiing, as seen in Figures 4-3 and 4-4, the pavement will experience the full weight of the aircraft.

4-4.3 Traffic Area Designations.

Table 4-1 summarizes the wander width and load condition of the different traffic areas. Details are available in UFC 3-260-02, *Pavement Design for Airfields*.

Table 4-1 Traffic Area Summary

Traffic Area	Load Condition	Distribution	Usage
A	Full weight	Channelized	Runway ends and primary taxiways
B	Full weight	Unchannelized	Aprons
C	75% weight	Unchannelized	Runway interiors and secondary taxiways
D	75% weight	Unchannelized and 1% of passes	Overruns

4-5 STANDARD VERSUS MISSION AIRCRAFT TRAFFIC.

There are three approaches to defining the traffic mix used in an evaluation: standard aircraft traffic groups, mission aircraft traffic groups, and representative/mission aircraft groups. One or more of these approaches may be used for any given evaluation, depending on the Service and mission.

4-5.1 Standard Aircraft Groups.

In this approach, the Service defines a standard mix of aircraft types, weights, and passes for a standard aircraft traffic group based on its mission and operations. They are used for both design and evaluation, although these groups are different for each. Standard groups are used in design when the Service wants to address future uncertainty. For example, it is often difficult to predict future mission changes, aircraft loads and passes, and potential maintenance and repair (M&R) funding constraints over the design life of the pavement. Using a standard aircraft group reduces this risk. The same concept applies to evaluation and has the benefit of better evaluation results comparison between installations. Standard groups may be supplemented with specific aircraft for use in an area of operations or specific mission and often include the same aircraft at different loads.

4-5.1.1 Standard Aircraft Group by Aircraft Effect and Pass Level.

The standard 14-aircraft group in Table 4-2 has aircraft with a similar load effect on the pavement grouped together. This load effect is termed an index and each group has a designated controlling aircraft based on its gear configuration and load. Note that a given group can have more than one gear configuration as shown in Table 4-3. Each group has a minimum weight based on the unloaded weight of the lightest aircraft in the group and a maximum weight based on the fully loaded weight of the heaviest aircraft in the group. This standard aircraft group is used in an individual analysis procedure described in paragraph 4-6. Each of the 14 groups is analyzed at each pass intensity level. The primary benefit of this approach is that it can be used to consider the impact of a wide array of aircraft at different pass intensity levels and can be used to compare the capability of different installations for specific aircraft groups.

Table 4-2 14-Aircraft Group Index Table

Aircraft Group Index

Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Included Aircraft	C-12 C-21 C-23 C-38A C-41A HH-60 RC-26 RQ-4-Bk 10 T-1* T-6 T-7A T-37 UH-1H	A-10 AT-38 F-15* F-16 F-22 F-35 F-117 RQ-4-Bk 20+ T-38	CV-580* MH-53 MV-22 CV-22	C-130* C-27J C-295 CN-235	C-20* C-37	B-717* C-9 DC-9 T-43	A-319 A-320 A-321 B-727 B-737 C-22 C-40 MD-81 MD-82 MD-83 MD-87 MD-90 P-3* P-8A	A-300 A-310 B-2A B-707 B-720 B-757 C-32A* DC-8 E-3 E-8C KC-135 RC-135 VC-137	A-330 B-1 B-767 B-787 DC-10-10 KC-46A L-1011 MD-10 B-767 -400ER*	C-17* IL-76	C-5*	A-340 A-350 B-777 DC-10-30 DC-10-40 KC-10 MD-11*	A-380 AN-124 B-747 B-747-8 E-4 VC-25 B-747 -400*	B-52*

Note: * Denotes Controlling Landing Gear Configuration in Group

Pass Intensity Levels (in Passes)

Level	1	2	3	4	5	6	7	8	9	10	11	12	13	14
I		300,000						50,000						15,000
II		50,000						15,000						3,000
III		15,000						3,000						500
IV		3,000						500						100

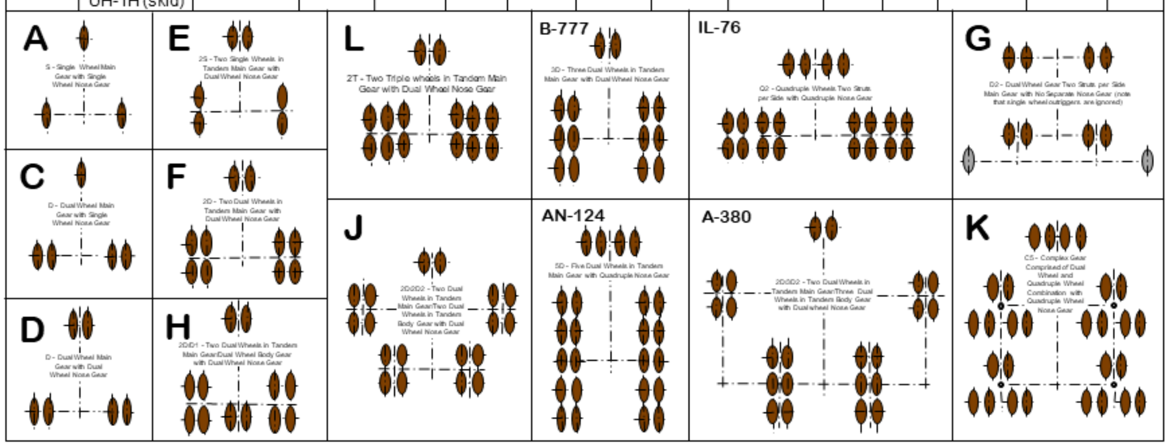
Gross Weight Ranges for Aircraft Groups (in KIPs)

Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Lowest Gross Weight	4	8	23	22	39	49	55	110	177	178	374	240	342	230
Highest Gross Weight	27	84	61	175	91	121	210	376	507	585	840	775	1,301	488

Table 4-3 14-Aircraft Group Gear Types

Aircraft Group Index: Gear Types

Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Included Aircraft	A C-23 C-41A HH-60 T-1* T-6 T-7A T-37 C C-12 RQ-4-Bk 10 D C-21 C-38A RC-26 UH-1H (skid)	A A-10 AT-38 F-15* F-16 F-22 F-35 F-117 RQ-4-Bk 20+ T-38	D CV-580* MH-53 MV-22 CV-22	E C-130* C-27J C-295 CN-235	D C-20* C-37	D B-717* C-9 DC-9 T-43	D A-319 A-320 A-321 B-727 B-737 C-22 C-40 MD-81 MD-82 MD-83 MD-87 MD-90 P-3* P-8A	F A-300 A-310 B-2A B-707 B-720 B-757 C-32A* DC-8 E-3 E-8C KC-135 RC-135 VC-137	F A-330 B-1 B-767 B-787 DC-10-10 KC-46A L-1011 MD-10 B-767 -400ER*	L C-17* IL-76	K C-5*	H A-340 A-350 DC-10-30 DC-10-40 KC-10 MD-11* B-777	J B-747 B-747-8 E-4 VC-25 B-747 -400* A-380 AN-124	G B-52*



4-5.1.2 Standard Aircraft Group for Contingency Evaluation.

Table 4-4 shows an example of a standard aircraft group with aircraft that might operate at a forward operating location or en-route airfield. Each Service will have their own pattern, dependent on the mission requirements. The primary objective of this approach is to determine the allowable passes for each aircraft at the defined load. Note that the C-17 at 585,000 pounds is evaluated for 50,000 passes. In this example standard aircraft group, the C-17 is evaluated for 50,000 passes and the resulting allowable gross load (AGL) is used to determine the PCN. This concept is further discussed in Chapter 9.

Table 4-4 Contingency Evaluation Traffic Group

Aircraft	Load (lb)	Passes
C-5	840,000	1,000
E-3A	325,000	1,000
F-15D	68,000	1,000
KC-10	590,000	1,000
KC-135R/T	322,500	1,000
MV-22	60,500	1,000
C-130J	135,000	1,000
C-130J	155,000	1,000
C-130J	175,000	1,000
C-17	450,000	1,000
C-17	500,000	1,000
C-17	585,000	50,000

4-5.1.3 Standard Aircraft Group by Gear Type.

Table 4-5 shows a standard aircraft group categorized by gear types, with a defined representative aircraft for each group. This standard traffic group assumes the maximum load for the aircraft in each group but differs from the previous groups in that there are no predefined pass levels. This group is typically used in conjunction with the mission aircraft group for a specific location using the procedure described in paragraph 4-5.3.

Table 4-5 Aircraft Gear Type Groups

Single Tricycle	Dual Tricycle	Single-Tandem Tricycle	Dual-Tandem Tricycle	Triple Tandem Tricycle
AV-8	C-9	C-130[1]	E-6B	C-17[1]
C-2	C-12		KC-135[1]	
E-2	C-20			
EA-6	C-26			
EA-18	C-37			
F-5	C-38			
F-16	C-40			
F-35B	EP-3			
F-35C[1]	H-3			
FA-18	H-53			

Single Tricycle	Dual Tricycle	Single-Tandem Tricycle	Dual-Tandem Tricycle	Triple Tandem Tricycle
H-60	H-92			
MQ-4C	KC-10			
MQ-25	P-3			
NU-1	P-8[1]			
T-6	V-22			
T-34				
T-38				
T-44				
U-6				
UC-35				
Note 1: Designated representative aircraft for each group.				

4-5.2 Mission Aircraft Groups.

Mission aircraft groups are used for both design and evaluation and are based on the anticipated aircraft traffic at the specific airfield over the design life of the pavement, which is currently 20 years as defined in UFC 3-260-02. Note that different sections on an airfield can have different mission aircraft groups depending on the aircraft that use that specific section. It is not unusual to have two or more mission aircraft groups for any given airfield as shown in the example from a specific airfield in Table 4-6. The primary benefit of a mission aircraft group is that it gives a higher level of fidelity for managing pavements at that specific location but does not serve as well as the standard group when trying to compare evaluation results between installations. Mission aircraft groups are typically used with a mixed traffic analysis.

Table 4-6 Mission Aircraft Group Example

Aircraft	Gross Weight (lb)	20-year Projected Aircraft Passes	20-Year Equivalent PCC Passes	20-Year Equivalent AC Passes
Fixed-Wing Pavements				
C-9A	108,000	600	49	1
C-12J	16,600	1,100	1	1
C-130H	155,000	10,000	42	52
C-17A	585,000	6,300	6,300	6,300
C-23	24,600	800	1	1
C-26	16,500	340	1	1
Equivalent C-17 Passes at 585,000 lb			9,436	6,356
Rotary-Wing Pavements				
UH-60	16,300	6,700	283	3,954
AH-64	18,000	4,720	160	1,929
CH-47	50,000	4,820	4,820	4,820
MH-60	16,300	1,340	57	791
Equivalent CH-47 Passes at 50,000 lb			5,321	11,494
Fixed-Wing and Rotary-Wing Pavements				
CH-47	50,000	9,600	1	1
C-17	585,000	2,000	2,000	2,000
AH-64	18,000	19,000	1	1
C-130H	155,000	800	5	9
Equivalent C-17 Passes at 585,000 lb			2,475	2,011

4-5.3 Mission/Representative Aircraft Group.

The goal of this traffic approach is to determine the equivalent passes of the mission aircraft group in terms of each of the five representative aircraft gear-type groups listed in Table 4-5. The first step in achieving this goal is defining the aircraft and pass levels in the mission aircraft group for the specific location using the procedure in paragraph 4-5.2, then append this traffic mix with each representative aircraft from Table 4-5 that is not already included in the mission aircraft group, with each aircraft at full load and one pass. The next step is to use a mixed traffic analysis to determine the controlling aircraft in the group. Next, manually set the first representative aircraft gear type as the controlling aircraft and determine the equivalent passes. Repeat the process for each representative aircraft shown in Table-4-5.

This approach results in equivalent passes for each of the five representative aircraft. The equivalent passes will vary by section depending on the pavement type, subgrade category, and traffic area as described in paragraph 4-6.2. The load and equivalent passes for each of these patterns are used in the structural analysis procedure for each section. The intent of this approach is to get the fidelity of the mission traffic approach while facilitating comparison between installations. There may be specific instances where aircraft not represented in Table 4-5 would also be presented this way and there may also be sections or sites whose missions support aircraft significantly lighter than the representative aircraft. In these instances, only add the appropriate representative aircraft (up to three) that do not overload the pavement.

4-6 INDIVIDUAL VERSUS MIXED TRAFFIC ANALYSIS.

Both standard and mission traffic patterns can be used in an individual or mixed traffic analysis although a mixed traffic analysis is typically used for a mission traffic pattern. Individual or mixed traffic analysis can be used for either a conventional (APE) or layered elastic (LEEP) analysis.

4-6.1 Individual Traffic Analysis.

In an individual traffic analysis, each aircraft in the group is analyzed individually. The allowable passes for the specified aircraft load and the allowable load for the specified evaluation passes are computed irrespective of the other aircraft.

4-6.2 Mixed Traffic Analysis

In a mixed traffic analysis, the controlling aircraft is determined based on the pavement type (rigid or flexible), traffic area (defined above), subgrade category (see Table 4-7), and number of passes. The equivalent passes of each aircraft in the mix are determined in terms of the controlling aircraft and the equivalent passes for all aircraft are added together. The result is a controlling aircraft at a specified weight and number of equivalent passes that is used in analysis.

Table 4-7 Subgrade Category

Subgrade Category	Rating	Flexible (CBR %)	Representative CBR	Rigid (k pci)	Representative k
A	High	CBR ≥ 13	15	k ≥ 442	452.6
B	Medium	8 < CBR < 13	10	221 < k < 442	294.7
C	Low	4 < CBR ≤ 8	6	92 < k ≤ 221	147.4
D	Ultra Low	CBR ≤ 4	3	k ≤ 92	73.7

4-7 GEAR CONFIGURATIONS.

Early aircraft were primarily supported on two main landing gear wheels, referred to as “single” wheels. With the large increases in aircraft gross weights, landing gear have changed to twin (two per strut) wheel loadings, to twin-tandem (four wheel) loadings, and to more complex (16 and 24 main-gear wheels, extra “belly” gear) wheel support systems. The two main wheels of single-wheel aircraft are generally spaced far enough apart that there is no significant overlap of the distributed loads for even very thick pavement structures protecting weak subgrades. For twin wheels, however, and closely spaced tandem wheels or complex wheel groups, the patterns of distributed surface loadings at and near the bottom of pavement structures overlap so the intensities (pressures or stresses) combine between adjacent wheels. This combining effect of load intensities is greater as the adjacent wheels become closer. The aircraft gear configurations and nomenclature used by the Services are shown in Appendix C.

4-8 TIRE PRESSURE.

The intensity of stress at a given point in a flexible pavement is affected by the tire contact pressure, which, for large aircraft tires, is roughly equivalent to the inflation pressure. The major difference in stress intensities caused by variation in tire pressure occurs near the surface; consequently, the pavement surface and upper base-course layers are most seriously affected by high tire pressures. Current evaluation criteria outlined in this UFC and implemented in PCASE are based on constant tire pressure. Previous versions of UFC 3-260-03 had criteria based on constant contact area. This difference does result in changes to evaluation results.

4-9 MANAGING AIRCAFT TRAFFIC.

The goal in defining the anticipated load and passes for the aircraft in a traffic mix is to determine whether each pavement section can structurally support the traffic to accomplish the mission, typically for a defined period. When the evaluation determines the pavement is not structurally capable, there are several options for managing the traffic:

- Reducing the departure weights of one or more aircraft in the traffic mix
- Reducing the number of daily operations of some aircraft in the mix
- Decreasing the pavement service life and programming repairs

The first two options typically focus on large, heavy aircraft that can generate unacceptable amounts of structural damage. Structural damage is often sensitive to changes (5 percent or less) in the aircraft gross loads for heavier aircraft, so it is often more advantageous to restrict the operations of one to three heavy aircraft that typically cause 90 percent of the pavement fatigue damage rather than limiting day-to-day operations. Whether the focus is on using up the service life and performing timely repairs for each inadequate section or managing the traffic as in the first two options, color-coded structural and condition maps convey this information. Chapter 10 describes these report products in more detail.

CHAPTER 5 LAYERED ELASTIC PAVEMENT EVALUATION

5-1 PERFORMANCE CRITERIA.

5-1.1 Flexible Pavement Performance Criteria.

The flexible pavement structural evaluation procedure considers two performance criteria: cracking in the asphalt surface course by limiting values of the tensile strain at the bottom of the AC layer and rutting due to deformation in the subgrade by limiting values of the vertical strain at the top of the subgrade. The limiting performance criterion is typically the vertical strain at the top of the subgrade. There are cases where the tensile strain controls the allowable number of passes or allowable gross load (AGL) for thin asphalt surfaces (e.g., less than 3 inches [76 millimeters]), but this scenario could also exist for thicker AC layers when there are no bases or subbases, or these layers are weak.

5-1.2 Rigid Pavements Performance Criteria.

Performance criteria for rigid pavements are based on limiting the tensile stress in the PCC slabs such that failure occurs only after the pavement with has sustained many load repetitions. Failure is based on a SCI of 50 or 0, as discussed in paragraphs 3-3.4.2 and 5-3.9.1.3.

5-2 PAVEMENT RESPONSE MODEL.

The YULEA linear elastic modeling subroutine computes the pavement responses that implement the performance criteria in the Pavement-Transportation Computer Assisted Structural Engineering (PCASE) Layered Elastic Evaluation Program (LEEP) module. The following assumptions apply in YULEA.

5-2.1 Pavement Structure.

Pavement is a multilayered structure, with each layer characterized by its thickness, modulus of elasticity, and Poisson’s ratio. Layers are assumed to be homogeneous, isotropic, and extend infinitely in the horizontal direction.

5-2.2 Layer Interface.

The interface between layers is continuous, meaning the friction resistance between layers is greater than the developed shear force.

5-2.3 Bedrock Layer.

The bedrock layer is located 20 feet (6 meters) from the surface and is of infinite thickness. When geotechnical information indicates the depth to the bedrock layer is less than 20 feet (6 meters), adjust the depth to bedrock to the known depth.

5-2.4 Loads.

All loads are static, circular, and uniform over the contact area.

5-3 LAYERED ELASTIC EVALUATION PROCEDURE.

The layered elastic evaluation procedure is based on a layered linear elastic model that characterizes multilayer pavement systems as outlined above. It applies to flexible, plain concrete, plain concrete overlays, and non-rigid overlays on plain concrete pavements. Layered elastic criteria are not currently available for reinforced or fibrous pavements. Refer to Chapter 7 for methods to evaluate reinforced pavements. It uses layer properties determined from in situ measurements (at the time fieldwork is conducted) to compute allowable loads for a selected number of aircraft passes, allowable passes at a specified load, and the Pavement Classification Number (PCN). When the pavement structure cannot support the defined pass level and aircraft load, PCASE can determine overlay requirements to strengthen the pavement. More detailed information on the following procedure is available in the PCASE User Manual.

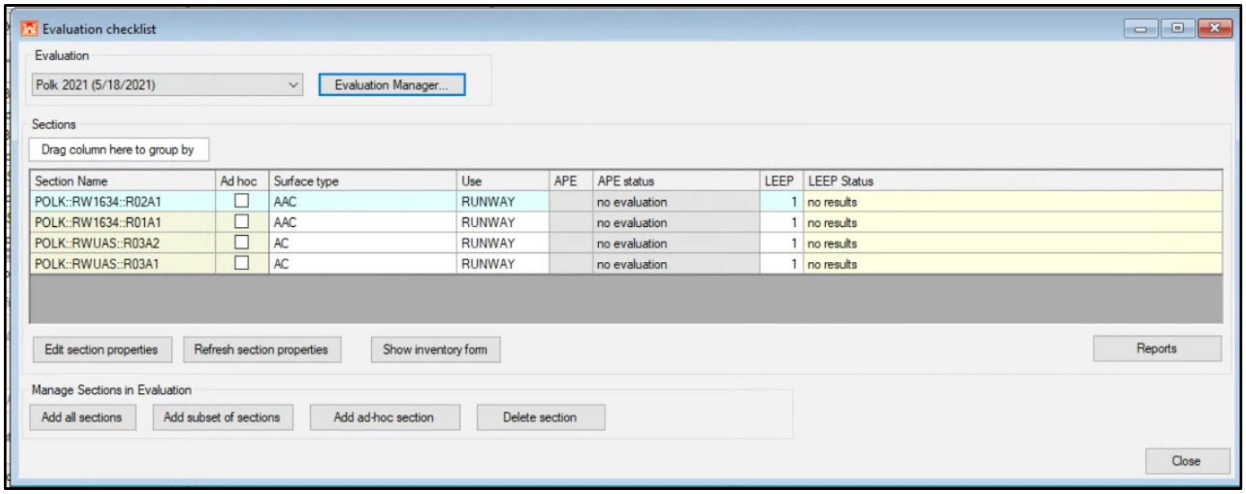
5-3.1 Layered Elastic Evaluation Using PCASE.

The Services use the PCASE application for design and evaluation of pavements (see Appendix E). Use the PCASE LEEP module to compute allowable loads, allowable passes, and PCNs using layered linear elastic evaluation criteria.

5-3.2 Step 1 – Create a New Evaluation.

Open the PCASE Evaluation Checklist to create a new evaluation using the Evaluation Manager. Define the Service, climate data, evaluation traffic, and rigid failure criteria for the evaluation, then assign the inventory sections to be included in the evaluation.

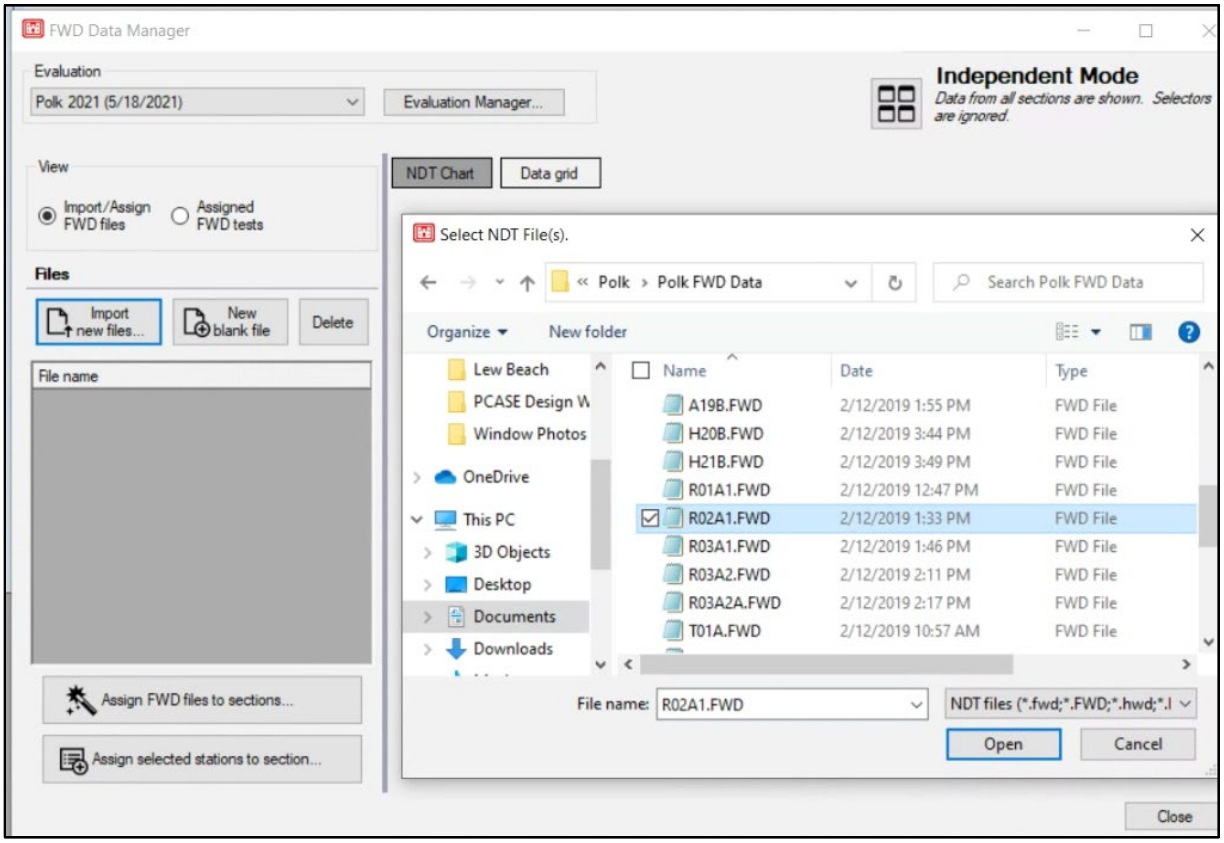
Figure 5-1 Evaluation Checklist



5-3.3 Step 2 – Import HWD Test Data.

Use the FWD Module to import the NDT files created during FWD testing (as described in Chapter 3) into PCASE.

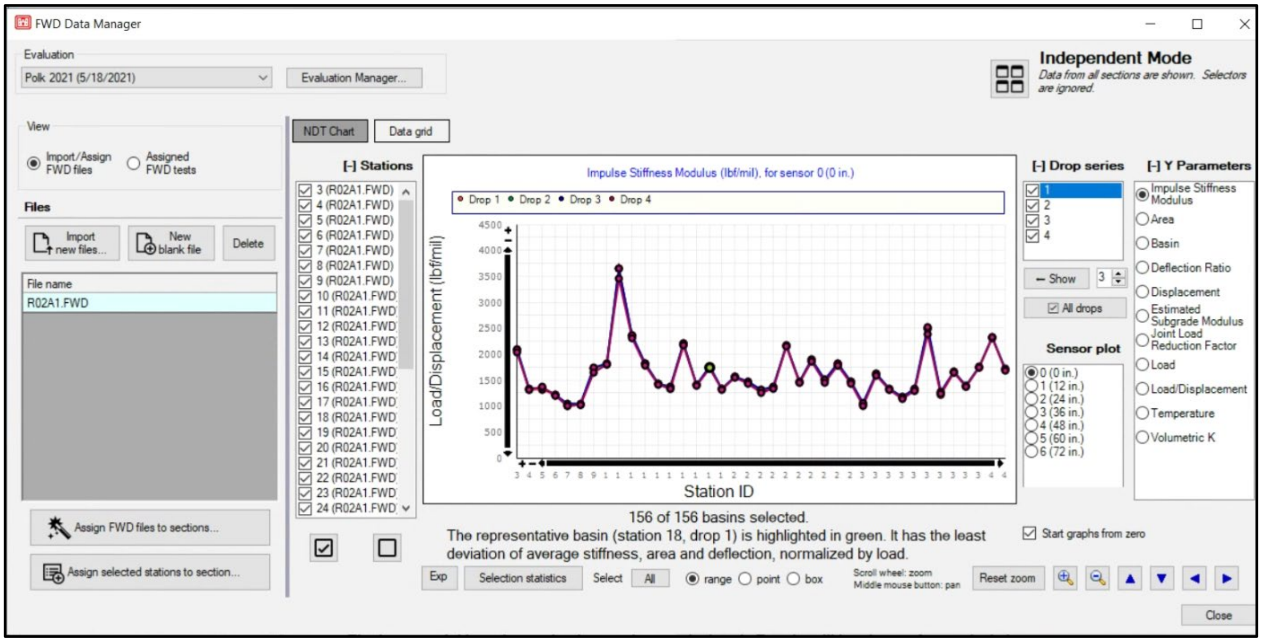
Figure 5-2 FWD Data Import



5-3.4 Step 3 - Assign Basins to Sections.

Each FWD test (each drop at each station) defines a deflection basin, which is viewed in PCASE as a two-dimensional plot, as shown in Figure 5-3. When the HWD file has data for an entire branch (e.g., an entire runway), use the FWD tool to “Assign selected stations to sections.” When all the stations in an HWD file were collected for a specific section, use the “Assign FWD files to sections” option.

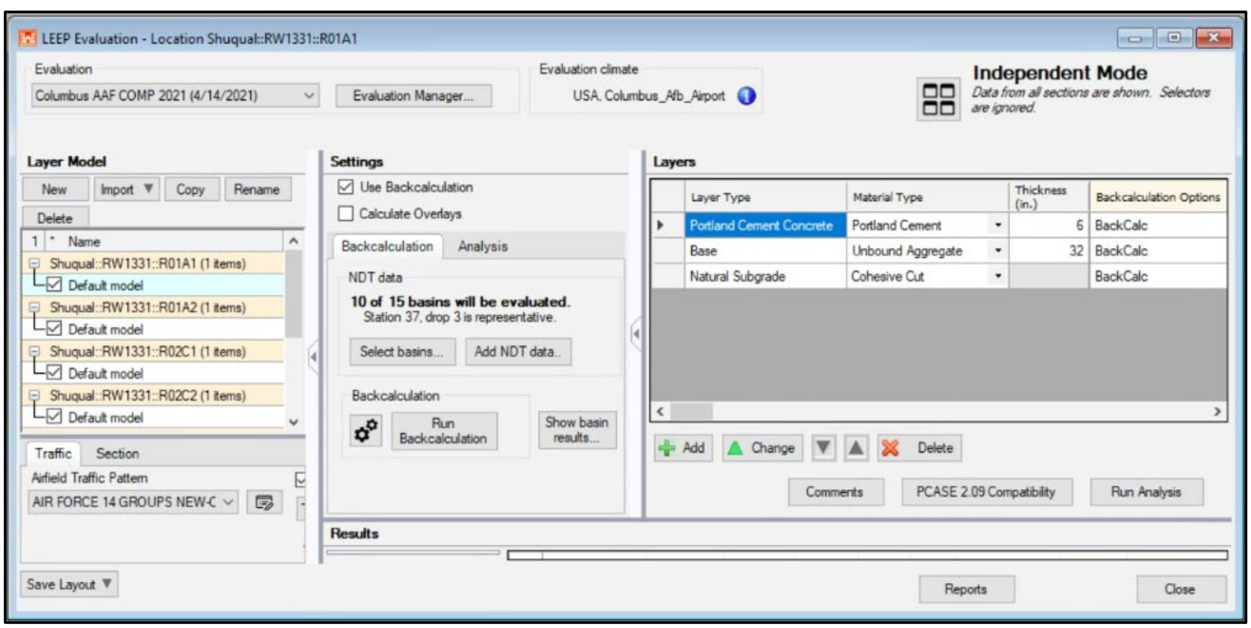
Figure 5-3 Assign FWD Files to Sections



5-3.5 Step 4 – Select Basins for Backcalculation.

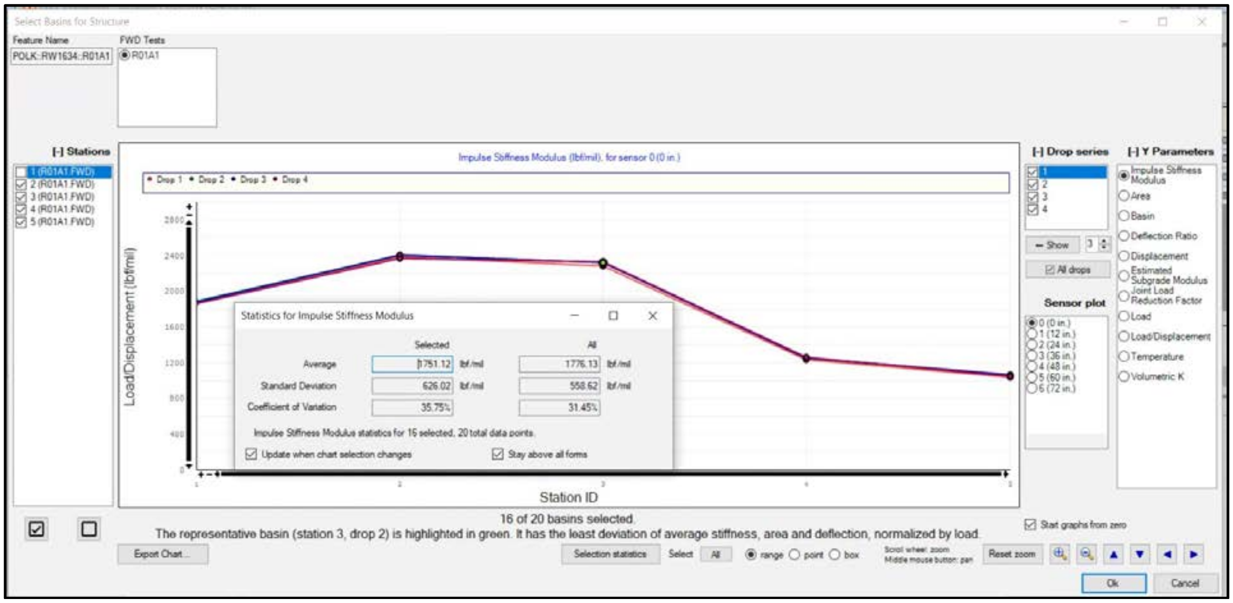
Open the LEEP module and use the Select Basins tool on the Settings tab to define the basins used in backcalculation.

Figure 5-4 Select Basins for Backcalculation



The Select Basins tool is like the NDT tool but only displays the basins for the section that is the current focus. Use the Selection Statistics tool to determine which basins to include or exclude from backcalculation. This tool displays statistics on the impulse stiffness modulus by default. Other views of the basin data are available including Area, Basin, Displacement, Estimated Subgrade Modulus, Load, Load Displacement, Temperature, and Volumetric K, Deflection Ratio, and Joint Load Reduction Factor (testing rigid pavement joints) as shown in Figure 5-5 and described in the following paragraphs.

Figure 5-5 FWD Analysis Parameters



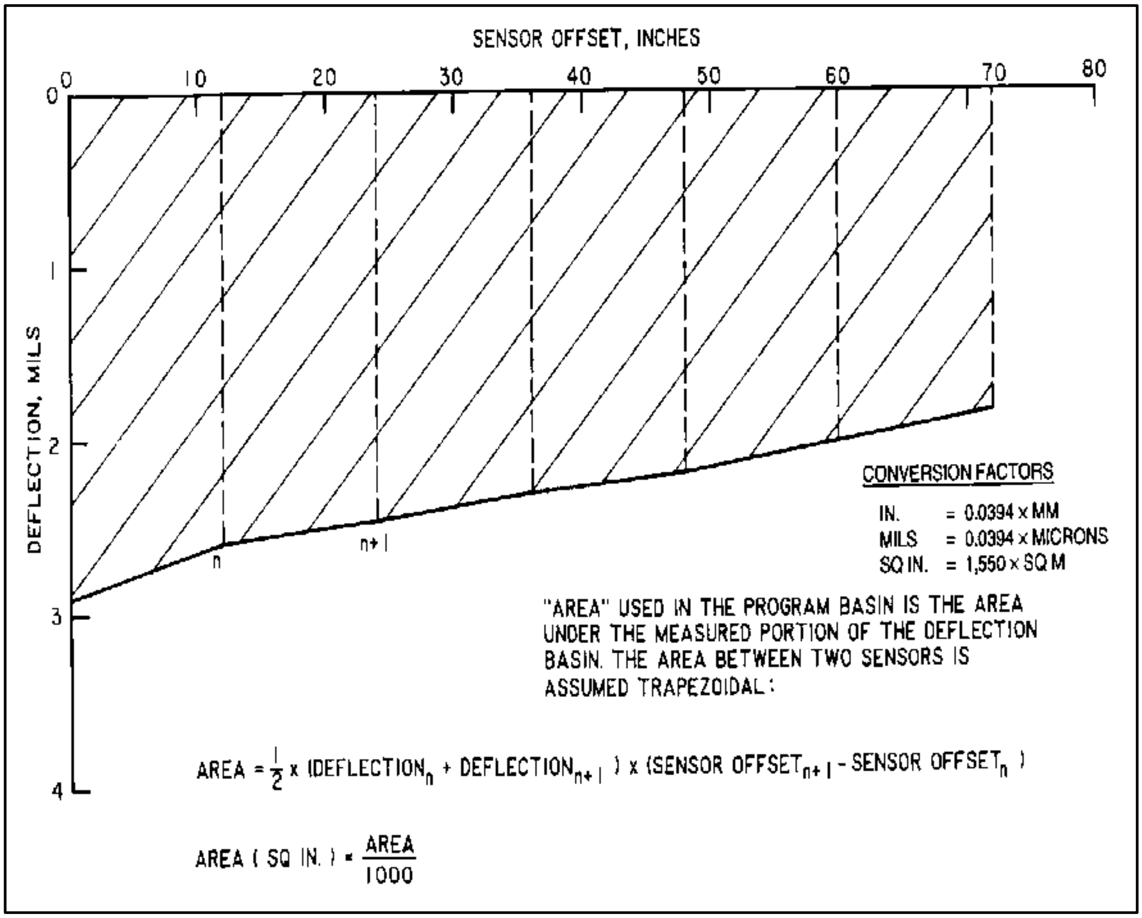
5-3.5.1 Impulse Stiffness Modulus.

The impulse stiffness modulus (ISM) is defined as the FWD force or load in kips divided by the deflection measured at the center of the load in inches. ISM values computed for the load-plate sensor (geophone) represent the overall strength of the pavement structure. These ISMs provide a quantitative stiffness comparison between test points and between pavement sections. The ISM values are plotted on the Y axis for each station (test point) in the section. This data is used to visually determine if a change in strength exists and define where sections change when the FWD file has basin data from multiple sections. Even when a pavement section has the same pavement type and construction, the ISMs measured in one area of the section can be statistically different from those in another area of the section. In this case, consider splitting the section. Ideally the Coefficient of Variation of the selected basins within a section should be less than 20 percent. PCASE also displays ISM values for the other sensors that can be used to compare the relative strength of the base, subbase, or subgrade at each NDT location.

5-3.5.2 Basin Area.

The AREA parameter displays the area of each deflection basin determined using the procedure illustrated in Figure 5-6. Only the hatched area (under the measured portion of the basin) is considered in this computation, and the area between two sensors is assumed trapezoidal. Selection Statistics for AREA displays the average deflection basin area for the section.

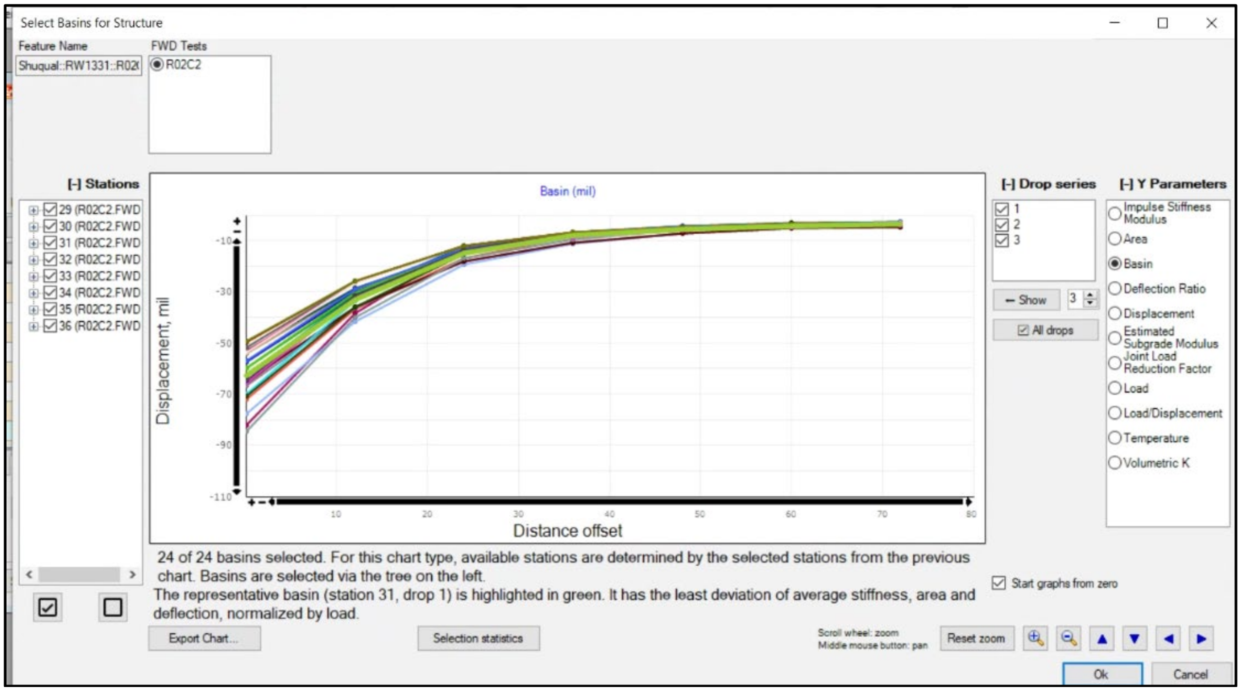
Figure 5-6 Determining AREA Beneath Deflection Basin



5-3.5.3 Basin.

The basin plot displays the deflection (in mils) on the Y axis for each sensor at its respective offset distance on the X axis. The plot provides a visual indication of the quality of the basin data. When the lines in the plot are well organized, as in the Figure 5-7 example, the data is likely good. When there are discontinuities in the data, such as varying basin shapes and crossing lines, the quality of the data is questionable.

Figure 5-7 Basins



5-3.5.4 Displacement.

Displacement plots show the sensor deflection (in mils) for each drop in the test series on the Y axis for each station on the X axis. Like the basin plot, this plot provides a visual indication of the quality of the data. Discontinuities such as lines crossing can indicate anomalies such as voids or delamination or indicate data quality issues.

5-3.5.5 Estimated Subgrade Modulus.

The estimated subgrade modulus is displayed on the Y axis for each drop in the series for each station in the section. The estimate is computed in Equation 5-1 using the deflection measured at the 72-inch (1829-millimeter) offset. These values are also used as the seed moduli for the subgrade layer in the backcalculation procedure.

Equation 5-1. Estimated Subgrade Modulus

$$E = 59{,}304.82\,(D72)^{-0.98737}$$

Where:

E = *subgrade modulus, psi*

D72 = *deflection measured at 72 inches (1829 millimeters) from the NDT load normalized to 25,000 pounds (11,340 kilograms)*

5-3.5.6 Load.

Load plots show the load (in lbf or kN/μm) for each drop in the test series on the Y axis for each station on the X axis. This plot provides a visual indication of the quality of the data. Discontinuities such as lines crossing can indicate data quality issues.

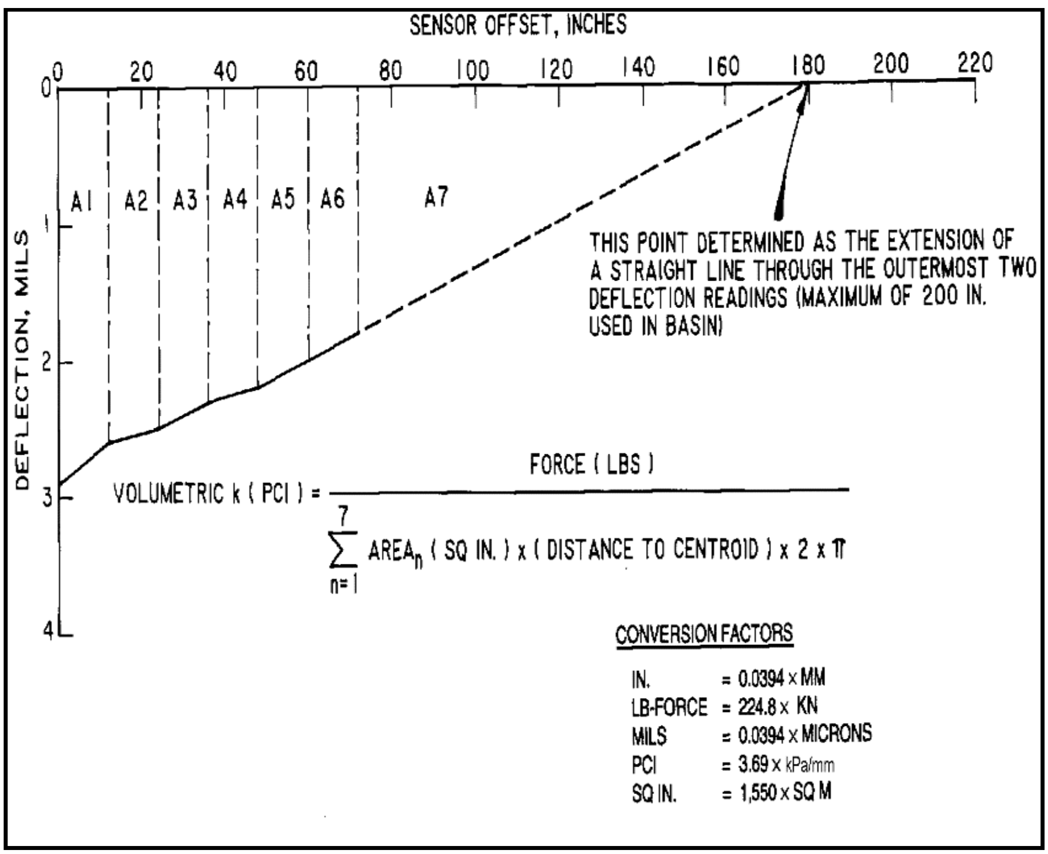
5-3.5.7 Temperature.

Temperature plots show the temperature (in °F or °C) on the Y axis for each drop in the test series for each station on the X axis. The air and the surface temperature are captured at the time of testing and the pavement temperature (at depth) is calculated.

5-3.5.8 Volumetric Estimation of k Value.

This procedure estimates the modulus of subgrade reaction, k, beneath rigid pavement, or rigid pavement with a flexible overlay. It computes the volume of the deflection bowl as illustrated in Figure 5-8. The k value obtained in this manner is only an approximate value that can be used for comparison with results from other test procedures such as plate bearing or dynamic cone penetrometer (DCP) tests used to determine k values. When no other test data to determine k is available, use the volumetric k in an airfield pavement evaluation (APE) analysis for comparison with the layered elastic analysis results. Note that volumetric k values are not typically sufficiently accurate to compute allowable aircraft loads and PCN values.

Figure 5-8 Determining Volumetric k (Estimate of Modulus of Subgrade Reaction)



5-3.5.9 Deflection Ratio.

The layered elastic rigid pavement analysis procedure assumes a 25 percent load transfer by default. Validate this assumption by testing joints with the FWD as described in more detail later in this chapter. The result of this test is used to compute the joint deflection ratio and, when results indicate, reduce the percent of load transfer. PCASE can also compute the deflection ratio between other sensors, but this capability is not typically used at this time.

5-3.5.10 Joint Load Reduction Factor.

The deflection ratio is used to determine and, when appropriate, adjust the load transfer percentage between slabs for the analysis. The Joint Load Reduction Factor is equal to one whenever the joint deflection ratio is greater than or equal to 0.76.

5-3.6 Step 5 – Layer Model and Backcalculation Options.

LEEP populates a default layer model for each section based on the pavement type, but the user must update the layer structure as shown in Figure 5-9 based on the data collected during fieldwork, including the type and thickness of each layer and the flexural strength (for PCC). In addition, the user can select different backcalculation options and edit the seed moduli used to initiate the backcalculation procedure as well as the lower (min) and upper (max) limits used in the procedure. Following are the backcalculation options for the various layer types.

Figure 5-9 Layer Model for Backcalculation

Layers

Layer Type	Material Type	Thickness (in.)	Backcalculation Options	Seed Modulus (psi)	Min Modulus (psi)	Max Modulus (psi)	Apply Limit
Portland Cement Concrete	Portland Cement	6	Flexural Strength	5,000,000	2,500,000	10,000,000	☑
Base	Unbound Aggregate	32	BackCalc	60,000	5,000	150,000	☑
Natural Subgrade	Cohesive Cut		BackCalc	9,132	4,132	14,132	☑

5-3.6.1 Backcalculation Option.

The Backcalculation option can be selected for any layer type. It uses estimated initial modulus values, a minimum, and a maximum modulus that are set for each layer but the number of backcalculated layers cannot exceed the number of measured deflections. Table 5-1 provides an example of typical default values used in PCASE that can be edited when test data is available. When the Apply Limit box is checked, the backcalculation routine keeps the solution within the limits and when it is unchecked, the backcalculation routine is not restricted by the limits for that layer.

Table 5-1 WESDEF Default Modulus Values (psi)

Material	Range		Initial Estimate	Poisson's Ratio
	Minimum	Maximum		
Asphalt concrete	100,000	2,500,000	350,000	0.35
Portland cement concrete	2,500,000	10,000,000	4,000,000	0.15
High-quality stabilized base	500,000	2,500,000	1,000,000	0.20
Base-subbase, stabilized	100,000	1,000,000	650,000	0.25
Base-subbase, unstabilized	5,000	150,000	61,000	0.35
Subgrade	1,000	75,000	15,000	0.40

5-3.6.2 Subgrade Seed Modulus.

The seed modulus for the subgrade is determined differently than other layer types. It is estimated using the deflection measured at the 72-inch (1829-millimeter) offset from the load using Equation 5-1. The maximum and minimum moduli are set to ±5,000 psi (34 MPa) respectively. This relationship is not valid when bedrock is present near the pavement surface (< 20 feet [6 meters]). In this case use the depth to bedrock estimation tool (for asphalt pavements) or other geotechnical information to adjust the depth to bedrock and determine a reasonable subgrade seed modulus.

5-3.6.3 Flexural Strength Option.

The Flexural Strength option uses Equations 5-2 and 5-3 to estimate the modulus value based on the flexural strength of the pavement.

Equation 5-2. Compressive Strength

$$C = 0.4036 * {M_R}^{1.4281}$$

Equation 5-3. PCC Layer Modulus

$$E = 57{,}000 * C^{0.5}$$

Where:

C = *Compressive strength, psi*

M_R = *Flexural strength, psi*

E = *Modulus of elasticity, psi*

5-3.6.4 Backcalculation Temperature Option.

This option adds the surface temperature at the time of testing to the previous five-day mean air temperature to determine the pavement temperature at depth as shown in Figure 5-10. Use this mean calculated mean pavement temperature to estimate the AC modulus using the relationship in Figure 5-11. The FWD or HWD device normally produces a load frequency at or near 20 Hz. The curves in Figure 5-11 are extrapolated from laboratory relationships for new AC mixes; therefore, predicted values may not always agree with actual field values.

Figure 5-10 Determining Mean Pavement Temperature

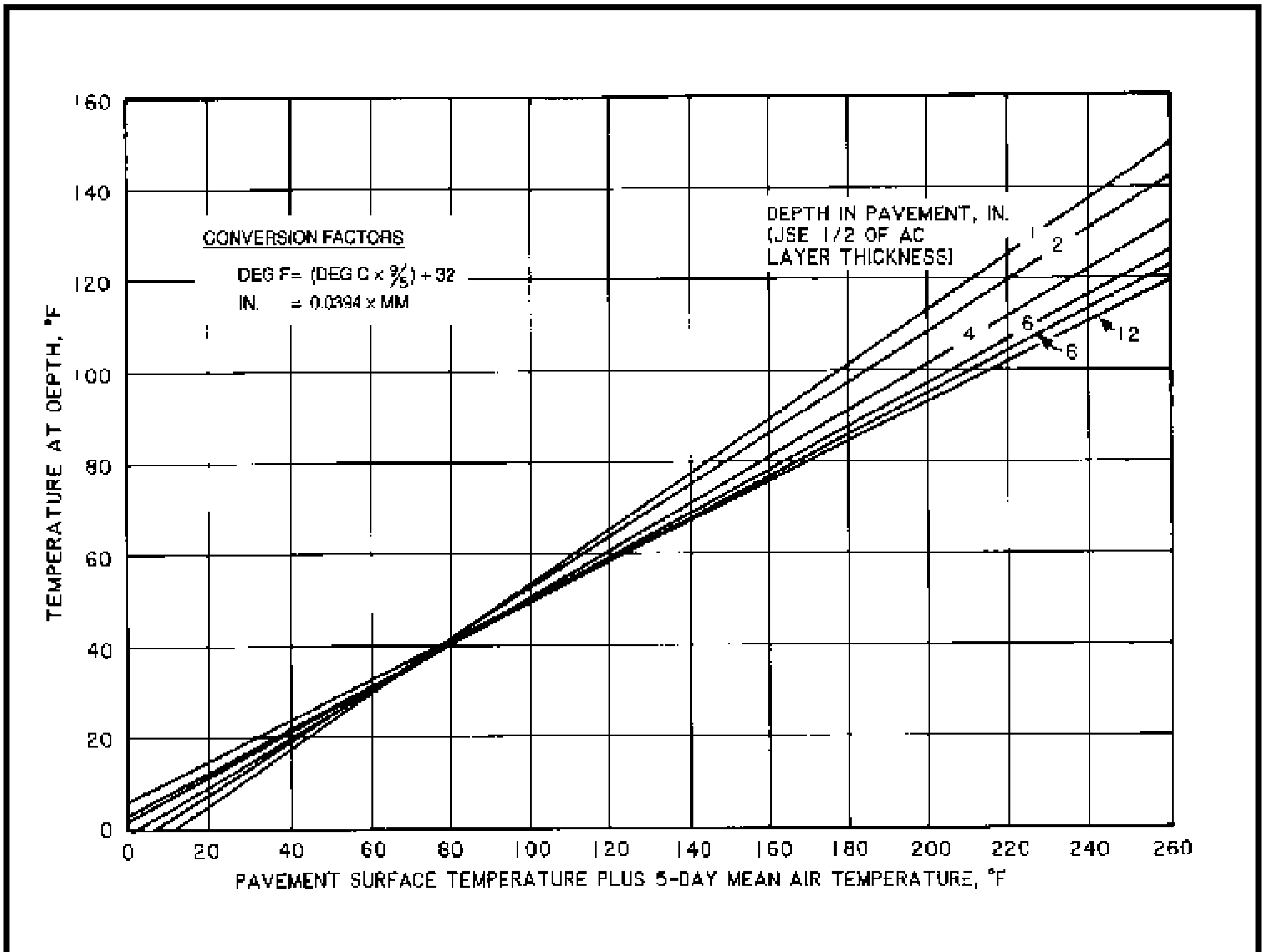
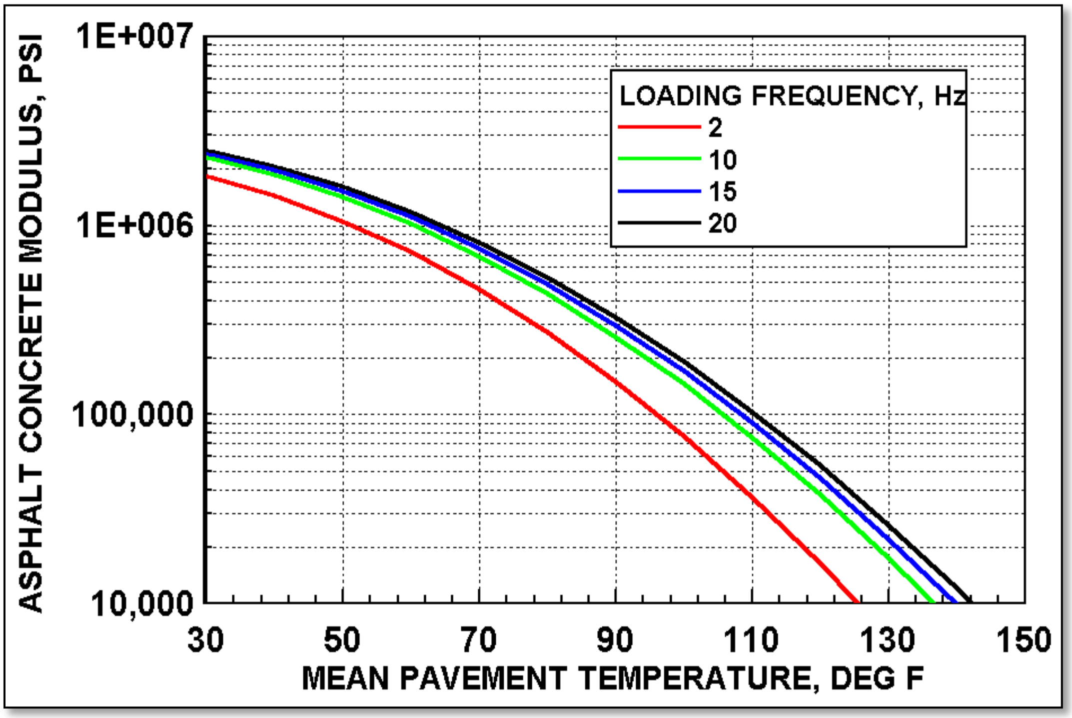


Figure 5-11 Predicting AC Modulus for Asphalt Layers



5-3.6.5 En+1 Option.

The E_{n+1} option uses the modulus of the layer below to estimate the base or subbase modulus using Equation 5-4 for base course and Equation 5-5 for subbase layers:

Equation 5-4. Base Course

$$E_{n+1} = E_n * (1.0 + 10.52 \log t - 2.1 \log E_n * \log t)$$

Where:

E_{n+1} = Modulus of base layer with a maximum value of 100,000 psi

E_n = Modulus of subbase or subgrade layer

t = Thickness of base layer

Equation 5-5. Subbase Layer

$$E_{n+1} = E_n * (1.0 + 7.18 \log t - 1.56 \log E_n * \log t)$$

Where:

E_{n+1} = Modulus of subbase layer with a maximum value of 40,000 psi

E_n = Modulus of subgrade layer

t = Thickness of subbase layer

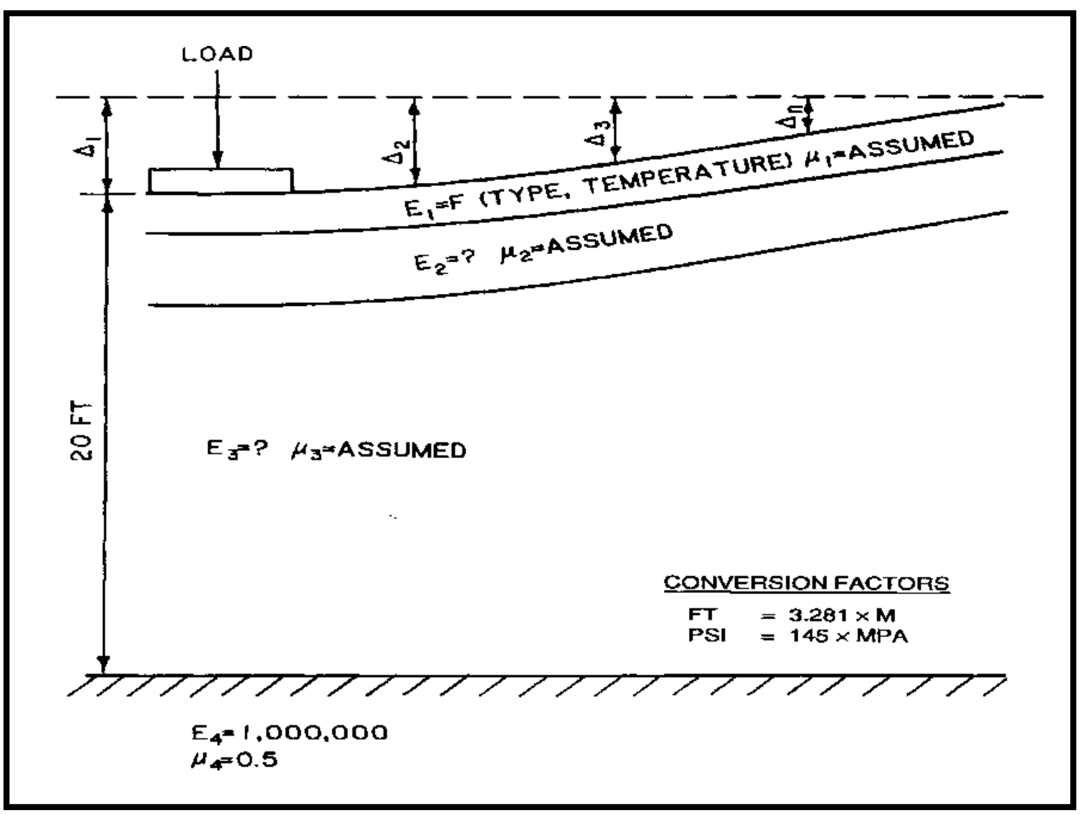
5-3.6.6 Manual Option.

Typically, the modulus of any layer can be backcalculated; however, when backcalculated results are erratic, assigning a modulus value to a base or subbase layer based on its material type or other tests (e.g., DCP) can resolve backcalculation issues. In general, use the backcalculation, flexural strength, or temperature options for surface layers. If the results are reasonable for all unbound layers but not surface layers, adjust the surface layer modulus in analysis rather than in backcalculation. Modulus values developed from the portable seismic pavement analyzer (PSPA) are also used for the surface layer modulus in analysis when this testing is performed.

5-3.7 Step 6 – Backcalculate Layer Modulus Values.

The deflection basin produced by applying a load to the pavement with an NDT device gives input parameters to the system analysis that are used to derive the relative strength parameters of the pavement layers. To determine modulus values, model the pavement structure as a layered system like that illustrated in Figure 5-12. PCASE uses the YULEA module to determine a set of modulus values that provides the best fit between a measured and a computed deflection basin when given an initial estimate of the elastic modulus values, a range of modulus values, and a set of measured deflections. The following paragraphs summarize the layered elastic modulus backcalculation routine.

Figure 5-12 Layered Pavement Structure



5-3.7.1 Backcalculation Objective.

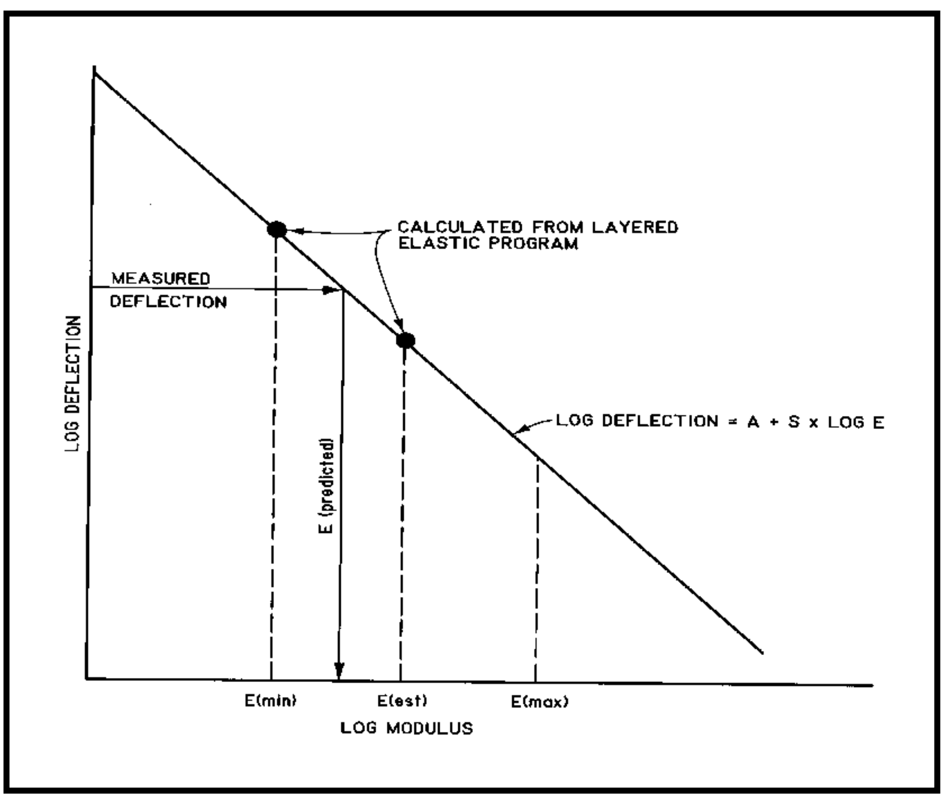
Consider the pavement system where:

- The modulus is unknown for a number of layers (NL).
- The deflection due to an NDT load is measured at a number of deflection sensors (ND).
- The number of deflection sensors (ND) is greater than the number of layers (NL).
- The objective is to determine the set of elastic moduli values that minimizes the error between the computed deflection (CD) and the measured deflection (MD).

5-3.7.2 Elastic Modulus Backcalculation from NDT Data.

Assume a set of E values and compute the deflection at the sensor location corresponding to the measured deflection. Vary each unknown E individually and compute a new set of deflections for each variation. Figure 5-13 presents a simplified description of how the deflection basins are matched. This illustration is for one deflection and one layer. For multiple deflections and layers, obtain the solution by developing a set of equations that defines the slope and intercept for each deflection and each unknown layer modulus using Equation 5-6.

Figure 5-13 Simplified Description of Matching Deflection Basins in YULEA (One Deflection and One Layer)



Equation 5-6. Backcalculated Layer Modulus

$$Deflection_j = A_{ji} + S_{ji}(\log E_i)$$

Where:
A = *intercept*
S = *slope*
j = *1 to the number of deflections*
i = *1 to the number of layers with unknown modulus values*

5-3.7.3 Depth to Bedrock Estimation.

PCASE assumes a stiff layer having a modulus of elasticity of 1,000,000 psi (6,895 MPa) and Poisson's ratio of 0.5 below the subgrade layer. This stiff layer defaults to a 20-foot (6-meter) depth and is infinitely thick. When modulus values for the subgrade seem excessively high for the material type, adjust the depth to bedrock using geotechnical information such as boring logs or the PCASE Depth to Bedrock tool for asphalt pavements that uses Equations 5-7 through 5-10 to estimate the depth of bedrock for each station and then uses equation 5-11 to determine the average depth to bedrock (see Report No. FHWA/TX-91/1123-3, *Modulus 4.0: Expansion and Validation of the Modulus Backcalculation System*)

Equation 5-7. Depth to Bedrock, Asphalt Thickness < 2 in.

$$\frac{1}{B} = 0.0362 - 0.3242r_0 + 10.2717r_0^2 - 23.6609r_0^3 - 0.0037BCI$$

Equation 5-8. Depth to Bedrock, Asphalt Thickness > 2, ≤ 4 in.

$$\frac{1}{B} = 0.065 + 0.1652r_0 + 5.42898r_0^2 - 11.0026r_0^3 - 0.0004BDI$$

Equation 5-9. Depth to Bedrock, Asphalt Thickness > 4, ≤ 6 in.

$$\frac{1}{B} = 0.0413 + 0.9929r_0 - 0.0012SCI + 20.0063BDI - 0.0778\log(BCI)$$

Equation 5-10. Depth to Bedrock, Asphalt Thickness > 6,

$$\frac{1}{B} = 0.0409 + 0.5669r_0 + 3.0137r_0^2 + 0.0033BDI - 0.0665\log(BCI)$$

Where:
$r_0 = {}^1\!/_r \ intercept\ by\ extrapolating\ the\ steepest\ section\ of\ the$
$\quad {}^1\!/_r\ vs.deflection\ curve\ \left({}^1\!/_{ft.}\ units\right)$
$SCI = D_0 - D_1\ (Surface\ Curvature\ Index)$
$BDI = D_1 - D_2\ (Base\ Damage\ Index)$
$BCI = D_2 - D_3\ (Base\ Curvature\ Index)$
$D_i = Surface\ deflection\ (inches\ 10^{-3})\ normalized\ to\ 9{,}000\ lb.load$
$\quad at\ an\ offset\ i\ in\ feet.$

Equation 5-11. Average Depth to Bedrock

$$D = \left[\frac{n}{\sum_{i=1}^{n} \frac{1}{B_i}}\right]$$

Where:

D = *Average depth to an apparent rigid layer in feet*
B_i = *Depth to the apparent rigid layer for the ith deflection bowl*
n = *Number of deflection bowls within one standard deviation of the mean 1/*B_i

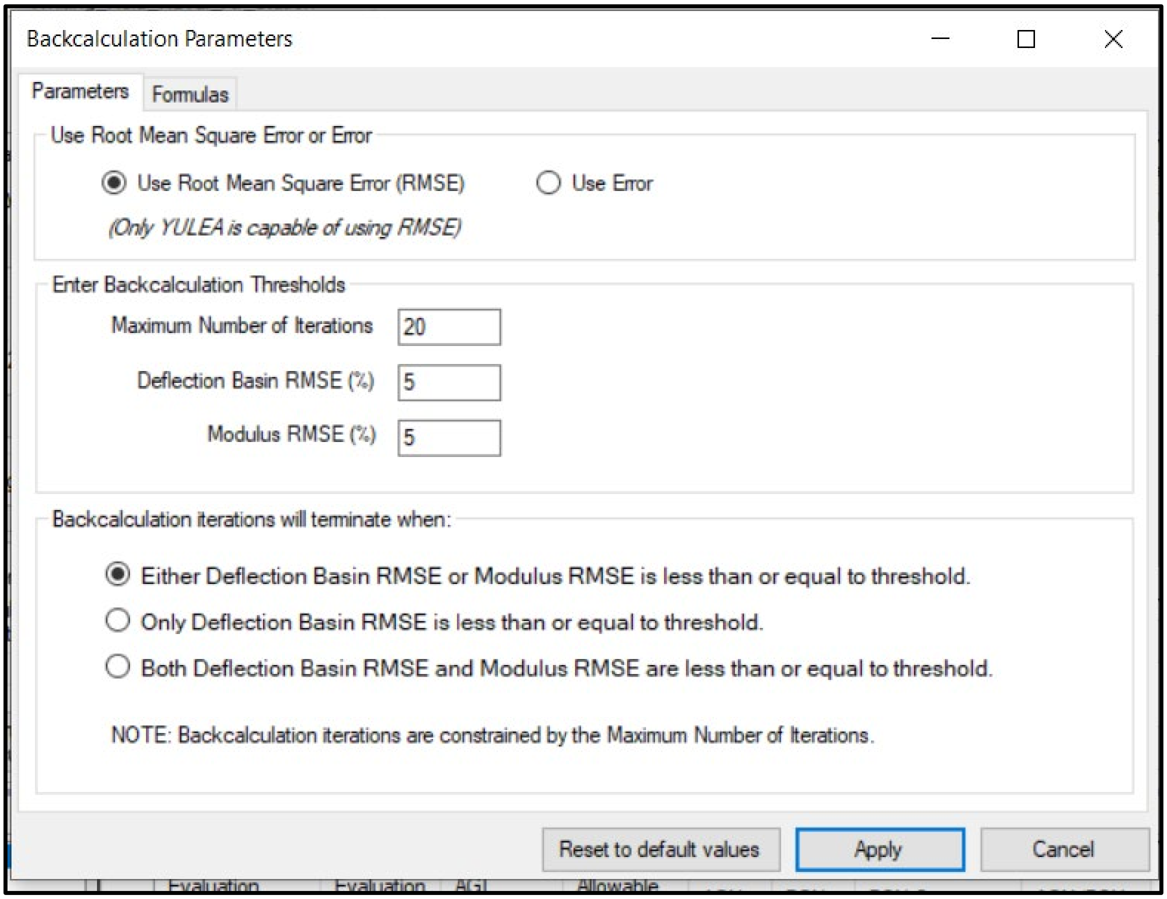
5-3.7.4 Layered Elastic Interface Conditions.

YULEA can accommodate multiple loads and variable interface conditions. For a given layer (n) and underlying layer (n + 1), set the interface value to "Fully Bonded" for complete adhesion between the layers or "Partially Bonded" for almost frictionless bond between the layers. The procedure assumes a partially bonded condition at the bottom of a PCC layer and a fully bonded interface condition for all other layers.

5-3.7.5 Backcalculation Procedure Closure.

PCASE allows the user to define the backcalculation procedure closure parameters. The user can choose whether the to use the Error (historically used by DoD) or Root Mean Square Error (RMSE) which is more commonly used in industry. The user can define the maximum number of iterations and the closure parameters, including the percent error (or RMSE) for the deflection basin (Equation 5-12) and the percent error (or RMSE) for the modulus (Equation 5-13). There are also options for defining the backcalculation termination parameters, including when both the basin and modulus error (or RMSE) are less than or equal to the thresholds, only the basin error (or RMSE) is less than or equal to the threshold, or either the basin or modulus error (or RMSE) is less than or equal to the threshold. The latter is the default setting. The maximum iterations defaults to 20, and both the basin and modulus error defaults to five percent as shown in Figure 5-14. When the backcalculation results meet the parameters for each basin, the procedure closes and presents the results. The targeted error for deflection basin and modulus is less than 3 percent after one or two iterations. Compare the results from the basin and modulus backcalculation methods to obtain optimum results with low standard deviations and low coefficients of variation. A coefficient of variation that is less than 15 percent is good but this statistic depends heavily on the variability of the pavement layer thicknesses, material types, and strength.

Figure 5-14 PCASE Backcalculation Closure Options



Equation 5-12. Basin RMSE

$$RMSE_{Deflection\ Basin} = 100 * \sqrt{\frac{\sum_i^n \left(\frac{D_{measured} - D_{computed}}{D_{measured}}\right)^2}{n}}$$

Where:

$RMSE_{Deflection\ Basin}$	= *Deflection basin root mean square error*
i	= *ith Sensor*
n	= *Total number of sensors*
$D_{measured}$	= *Measured deflection at sensor i*
$D_{computed}$	= *Computed deflection at sensor i*

Equation 5-13. Modulus RMSE

$$RMSE_{Modulus} = 100 * \sqrt{\frac{\sum_{i}^{n}\left(\frac{E_{i-1,j} - E_{i,j}}{D_{i-1,j}}\right)^{2}}{n}}$$

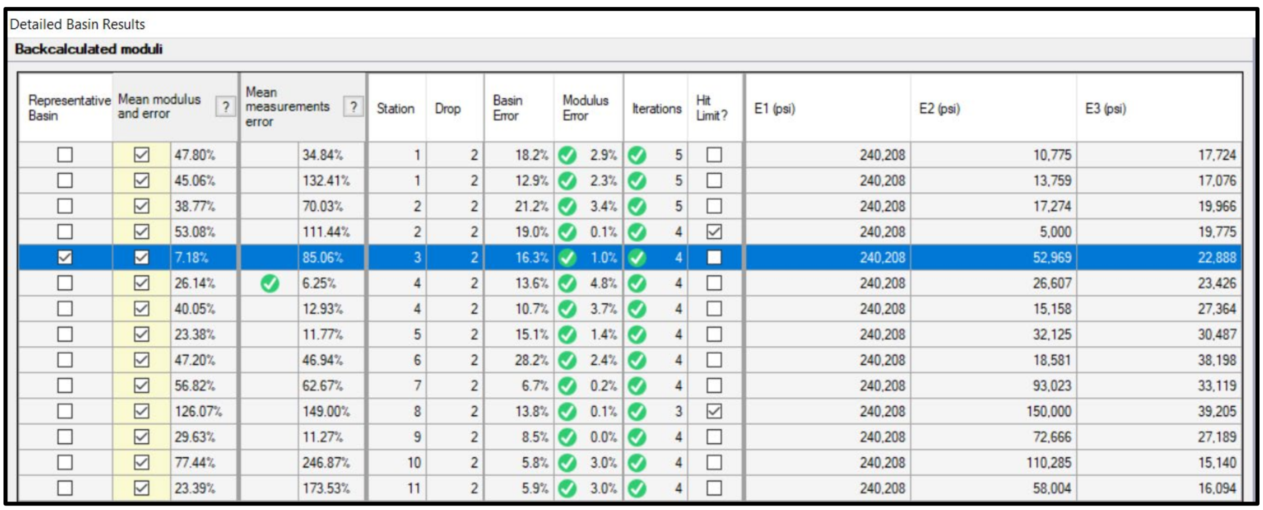
Where:

$RMSE_{Modulus}$ = *Modulus root mean square error*
i = *ith Iteration*
j = *jth Layer*
n = *Total number of layers*
$E_{i-1,j}$ = *Modulus from previous iteration for layer j*
$E_{i,j}$ = *Modulus for current iteration for layer j*
$D_{i-1,j}$ = *Deflection from previous iteration for layer j*

5-3.8 Step 7 – Select Layer Model for Analysis.

In addition to the basin and modulus error closure procedure described above and shown in Figure 5-15, PCASE provides several other statistics to aid in selecting a basin for layered elastic analysis. These include the representative basin (mean modulus error) (Equation 5-15) and the mean measurement error (Equation 5-16).

Figure 5-15 Detailed Basin Results


Detailed Basin Results
Backcalculated moduli

Representative Basin	Mean modulus and error ?		Mean measurements error ?		Station	Drop	Basin Error	Modulus Error		Iterations		Hit Limit?	E1 (psi)	E2 (psi)	E3 (psi)
☐	☑	47.80%		34.84%	1	2	18.2%	✓	2.9%	✓	5	☐	240,208	10,775	17,724
☐	☑	45.06%		132.41%	1	2	12.9%	✓	2.3%	✓	5	☐	240,208	13,759	17,076
☐	☑	38.77%		70.03%	2	2	21.2%	✓	3.4%	✓	5	☐	240,208	17,274	19,966
☐	☑	53.08%		111.44%	2	2	19.0%	✓	0.1%	✓	4	☑	240,208	5,000	19,775
☑	☑	7.18%		85.06%	3	2	16.3%	✓	1.0%	✓	4	☐	240,208	52,969	22,888
☐	☑	26.14%	✓	6.25%	4	2	13.6%	✓	4.8%	✓	4	☐	240,208	26,607	23,426
☐	☑	40.05%		12.93%	4	2	10.7%	✓	3.7%	✓	4	☐	240,208	15,158	27,364
☐	☑	23.38%		11.77%	5	2	15.1%	✓	1.4%	✓	4	☐	240,208	32,125	30,487
☐	☑	47.20%		46.94%	6	2	28.2%	✓	2.4%	✓	4	☐	240,208	18,581	38,198
☐	☑	56.82%		62.67%	7	2	6.7%	✓	0.2%	✓	4	☐	240,208	93,023	33,119
☐	☑	126.07%		149.00%	8	2	13.8%	✓	0.1%	✓	3	☑	240,208	150,000	39,205
☐	☑	29.63%		11.27%	9	2	8.5%	✓	0.0%	✓	4	☐	240,208	72,666	27,189
☐	☑	77.44%		246.87%	10	2	5.8%	✓	3.0%	✓	4	☐	240,208	110,285	15,140
☐	☑	23.39%		173.53%	11	2	5.9%	✓	3.0%	✓	4	☐	240,208	58,004	16,094

5-3.8.1 Representative Basin.

PCASE determines the representative basin using Equation 5-14. It highlights the row for the basin with the lowest mean modulus error, which is based solely on the backcalculation results. The basin with the lowest error is sent to LEEP for analysis unless the user selects another basin (e.g., the basin with the lowest mean measurement error).

Equation 5-14. Mean Modulus Error

$$Error_k = \sum_{i=1}^{NL} \left(\frac{\bar{E}_i - E_i}{\bar{E}_i} \right)^2$$

Where:

$\bar{E}_i$	*= Average of the modulus of the i-th layer among all the basins 1 to k*
k	*= basin number*
NL	*= number of layers*

5-3.8.2 Mean Measurement Error.

The mean measurement error is computed using Equation 5-15 and is based solely on the FWD data, not the backcalculation results. The basin with the lowest error is indicated by a green circle with a white checkmark in the mean measurements error column as shown in Figure 5-15.

Equation 5-15. Representative Basin

$$Error_k = \left(\frac{\overline{ISM} - ISM_k}{\overline{ISM}} \right)^2 + \sum_{1}^{ND} \left(\frac{\overline{DF} - DF_k}{\overline{DF}} \right)^2 + \left(\frac{\overline{AREA} - AREA_k}{\overline{AREA}} \right)^2$$

Where:

ISM	*= computed ISM*
DF	*= measured deflection*
AREA	*= computed area*
k	*= basin number*
ND	*= number of deflection sensors*
$\overline{\mathrm{ISM}}$	*= average ISM*
$\overline{\mathrm{DF}}$	*= average deflection*
$\overline{\mathrm{AREA}}$	*= average basin area*

5-3.8.3 Basin Selection for Analysis.

Ideally, we want the basin and modulus error of closure (paragraph 5-3.7.5) to be below five percent, but there can be situations when one or both values exceed this threshold. In addition, having low errors for any of the statistics outlined above does not guarantee modulus values for the layers are reasonable. When results are not reasonable, adjust the model or backcalculation parameters as outlined in the following paragraphs and run backcalculation again. Select a basin with reasonable results for the material type even if the error is higher. Simply taking the average of each deflection reading from each FWD sensor and computing engineering properties from an “average deflection basin” is not a best-practices procedure. Each FWD test within a section represents a unique pavement response (e.g., deflection basin) for a unique pavement cross-section.

5-3.8.4 Backcalculation Analysis Guidelines.

Contributing factors that affect the reasonableness of results include errors between measured and calculated values, compensating adjacent layer E-values, or assigning inappropriate E-values. To overcome these issues, first identify the cause of the issue and do not make random changes to the structure. The following backcalculation guidelines are helpful in determining layer moduli.

- If modulus values are against the limits, turn off the limits and backcalculate again or modify the limits to include the computed elastic modulus. Results can come back within the original boundary conditions.
- Fix the modulus of an AC or PCC surface layer using the Temp or Flex option or based on tests conducted with the PSPA or on material type and condition at the time of testing rather than computing the modulus.
- Combine base and subbase into one layer and compute a composite modulus or divide the base course into two layers.
- Fix the subgrade modulus based on results of a preliminary run or on the deflection of sensor #7. In some cases, subdividing the subgrade into two layers is warranted.
- When a rigid pavement has a base and/or subbase, best practice is to include them in the model. However, if results are not reasonable, use a two-layer model with a composite modulus for the combined base and subgrade. Note that this can impact the PCN subgrade category in analysis.
- Do not attempt to compute the modulus of layers less than 3 inches (76 millimeters) thick. Assign the modulus of a thin layer based on material type, temperature, etc., or combine a thin layer with an adjacent layer with similar material properties to determine a composite modulus.
- Exercise caution when using modulus values outside the default ranges. Because the ranges are quite broad, values outside these limits can be unrealistic.

5-3.9 Step 8 – Layered Elastic Analysis.

The PCASE LEEP module uses YULEA to compute load-carrying capabilities and required overlay thicknesses for the defined traffic pattern (e.g., aircraft gear configuration, load, pass intensity level) on an existing pavement structure using layer moduli obtained through backcalculation or assigned based on one of the other previously described options. YULEA computes stresses (rigid and non-rigid overlay on rigid pavement) and strains (flexible pavement) that occur in the pavement system. Next, it calculates the limiting stress or strain values from empirically developed layered elastic values. LEEP compares the predicted stress or strain to the limiting value and outputs the allowable load for the defined pass level and allowable passes for the defined traffic (aircraft) load. The specific criteria and methodology are outlined below.

5-3.9.1 Analysis Criteria.

Maximum stresses and strains within a pavement system are computed using the controlling wheels of the design aircraft. The location of the maximum stress and strain value is influenced by factors such as pavement structure, wheel load, and wheel spacing. For a single wheel aircraft, the maximum stress and strain always occurs directly underneath the wheel. For other more complicated gear configurations, compute stresses and strains at several positions to determine the critical values. The PCASE LEEP module uses YULEA to determine the limiting values of stress/strain for a particular pavement type using the following.

5-3.9.1.1 AC Pavement Analysis Criteria.

The horizontal tensile strain at the bottom of the AC layer and vertical subgrade strain at the top of the subgrade are considered when evaluating flexible pavements. The limiting AC strain criterion (shown graphically in Figure 5-16) is as follows:

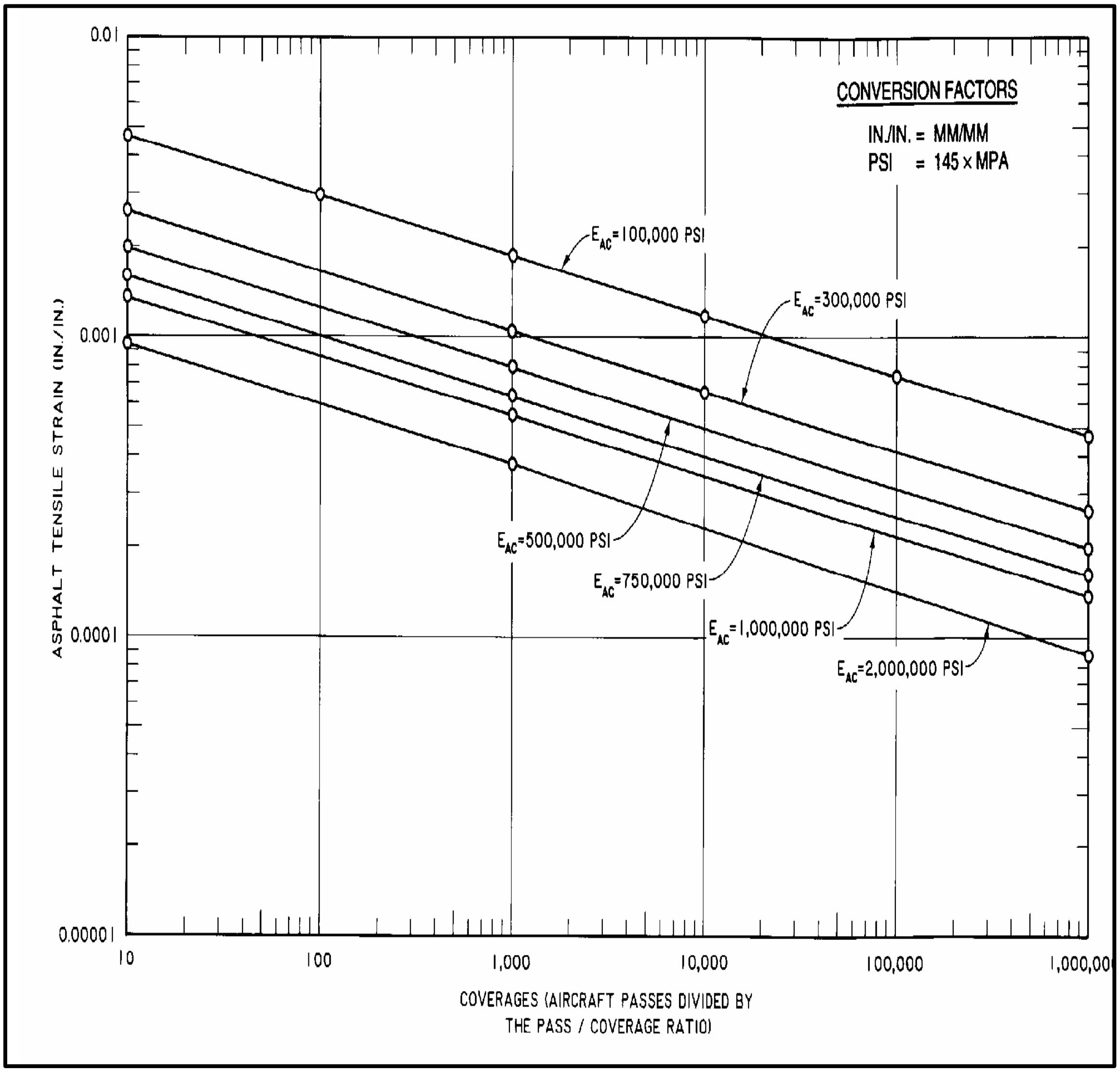
Equation 5-16. Allowable AC Strain

$$ALLOWABLE\ STRAIN_{AC} = 10^{-A}$$

Where:

ALLOWABLE STRAIN$_{AC}$ *= allowable tensile strain at the bottom of the asphalt layer, inches/inches*

Figure 5-16 Limiting Horizontal Tensile Strain Criteria for an AC Layer



The allowable subgrade strain criterion (shown graphically in Figure 5-17) is calculated using Equation 5-17.

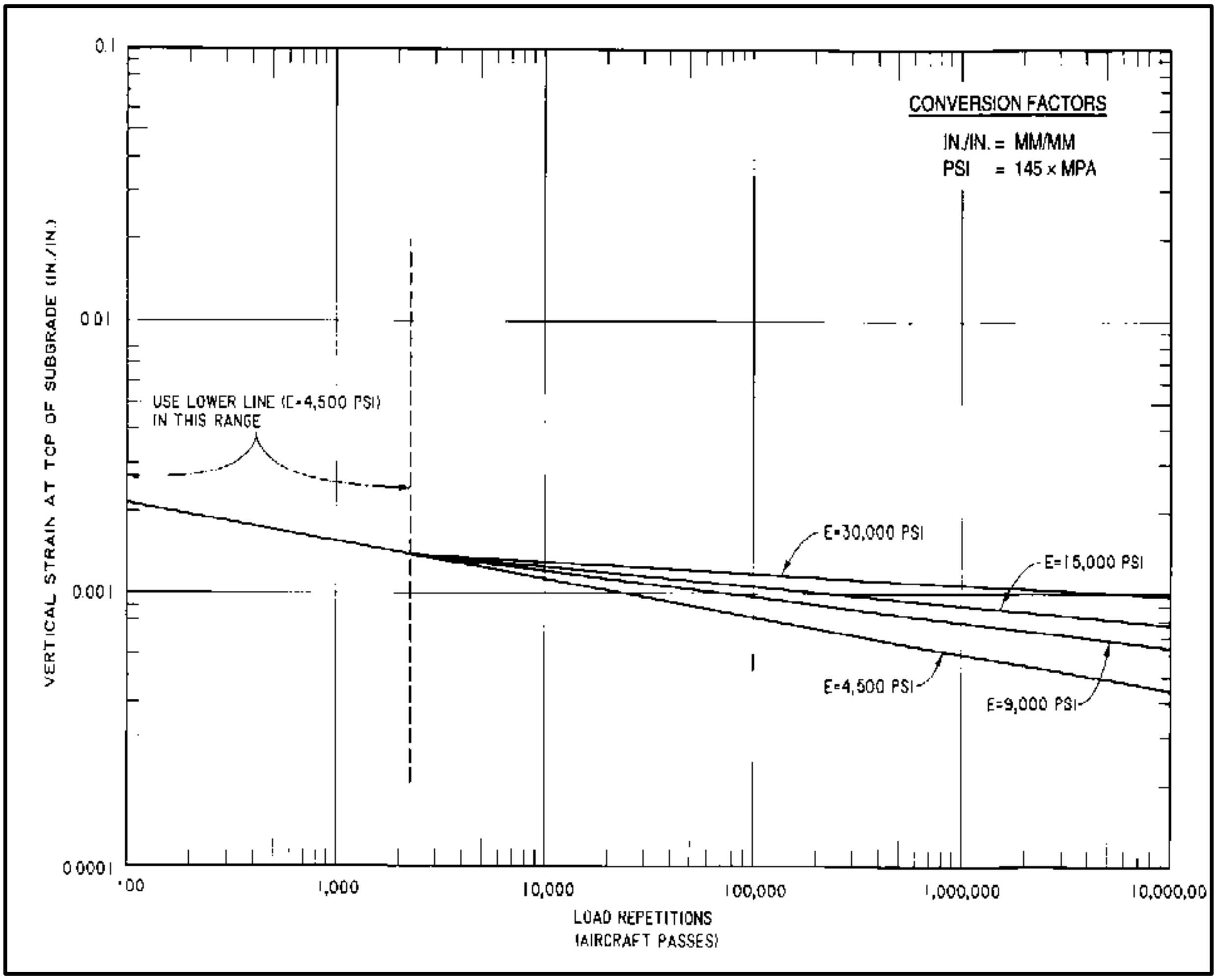
Equation 5-17. Allowable Subgrade Strain

$$ALLOWABLE\ STRAIN_{SG} = \left(\frac{10{,}000}{N}\right)^{1/B} A$$

Where:

ALLOWABLE STRAIN$_{SG}$	*= allowable vertical strain at the top of the subgrade, inches/inches*
N	*= aircraft repetitions (passes)*
A	*= 0.000247 + 0.000245 LOG(E_{SG})*
B	*= 0.0658 (E_{SG})$^{0.559}$*
E_{SG}	*= subgrade modulus, psi*

Figure 5-17 Limiting Vertical Subgrade Strain Criteria for Flexible Pavement



5-3.9.1.2 Asphalt Design Modulus.

While the backcalculation procedure uses the surface and five-day mean to determine a modulus, the analysis procedure uses the design air temperature that is the average of the hottest month's mean and maximum temperatures. The LEEP module pulls this data from the world index (climate) database to determine the design pavement temperature using the relationship in Figure 5-18. The design pavement temperature is then used in the relationship shown in Figure 5-19 to determine the asphalt modulus for the specific load frequency. Use the 10 Hz load frequency for runways and the 2 Hz load frequency for taxiways and aprons.

Figure 5-18 Design Pavement Temperature

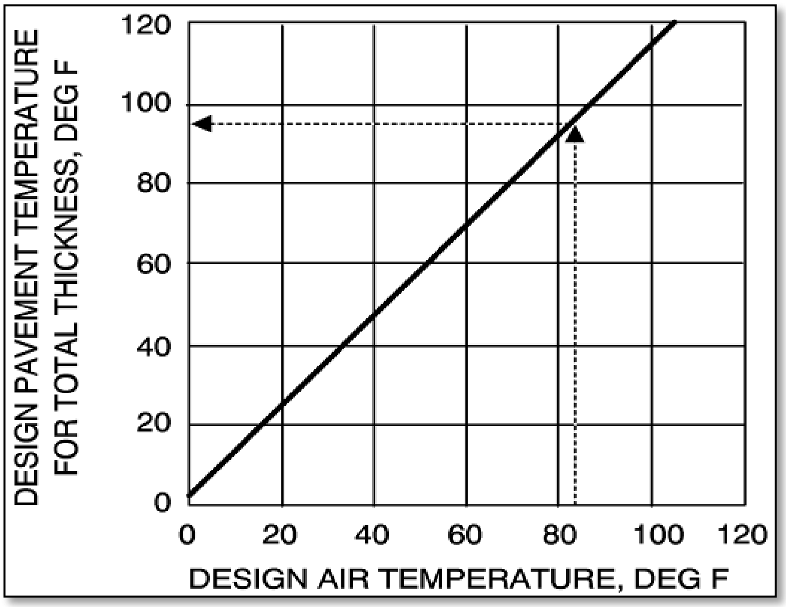
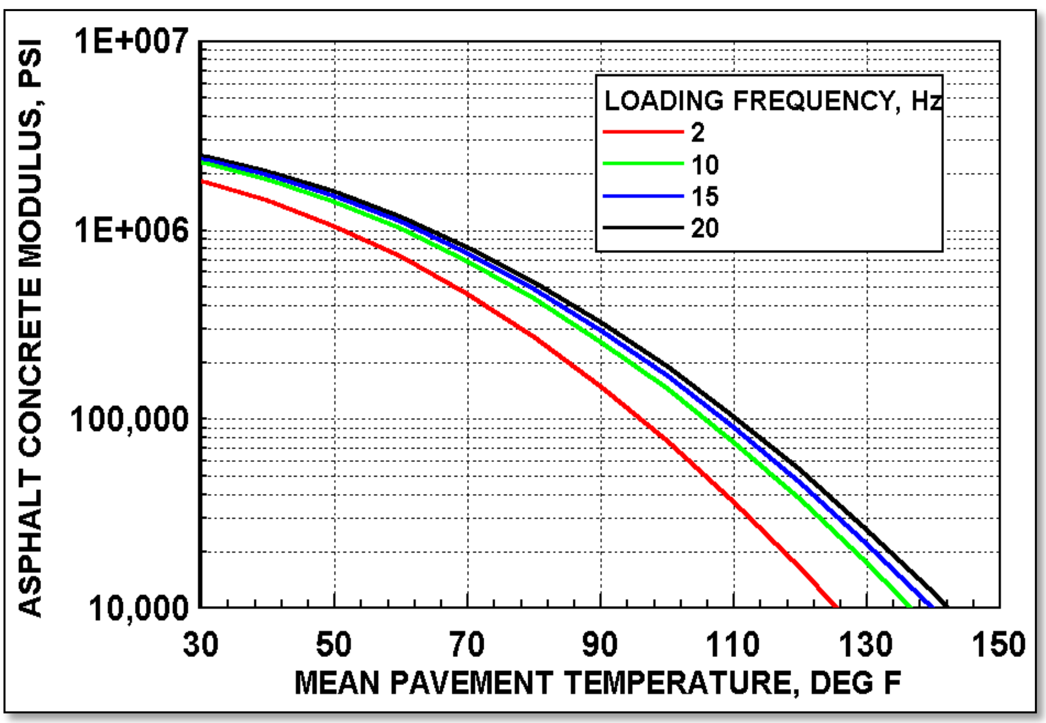


Figure 5-19 Asphalt Concrete Modulus



5-3.9.1.3 PCC Pavement Analysis Criteria.

LEEP assumes that an AC over PCC structure is a rigid pavement unless the backcalculated modulus of the PCC layer is less than 1,000,000 psi (6,895 MPa), then evaluate it as a flexible pavement. Rigid and non-rigid overlays of rigid pavements are evaluated based on the tensile stress at the bottom of the PCC slab and the predicted pavement deterioration in terms of the Structural Condition Index (SCI) as defined in Equation 5-18.

Equation 5-18. Structural Condition Index

$$SCI = 100 - A * (\,sum\ of\ structural\ deducts)$$

A is an adjustment factor based on the number of distress types with load-related PCI deduct values greater than five points as determined from the PCI survey procedure. The load-related PCI distresses are established and computed in the PAVER software program. These structural deducts are a function of distress types, severities, and densities associated with repeated aircraft and vehicle loads. The SCI prediction is based on a relationship between design factor and stress repetitions as related to crack formation in the PCC slabs due to load. An SCI of 50 corresponds well to the formation of one or more cracks per slab in 50 percent of the trafficked slabs (first crack failure criteria) and an SCI = 0 correlates approximately to a shattered-slab condition. The design factor, DF, is the concrete flexural strength divided by the flexural stress in a PCC slab.

Equation 5-19 shows the SCI-based equation for determining the DF. Using the PCC flexural strength, determine the allowable PCC slab flexural stress using Equation 5-20.

Equation 5-19. Design Factor

$$DF = A + B\ LOG\ \ C$$

Where:
DF = *design factor*
A = *0.2967 + 0.002267 (SCI)*
B = *0.3881 + 0.000039 (SCI)*
C = *coverage level at selected SCI*
SCI = *structural condition index*

Equation 5-20. Allowable PCC Slab Flexural Stress

$$ALLOWABLE\ STRESS_{PCC} = \frac{R}{DF}$$

Where:
$ALLOWABLE\ STRESS_{PCC}$ = *allowable tensile stress at the bottom of the slab, psi*
R = *PCC flexural strength, psi*

5-3.9.2 PCC Joint Load Transfer Efficiency Using NDT Tests.

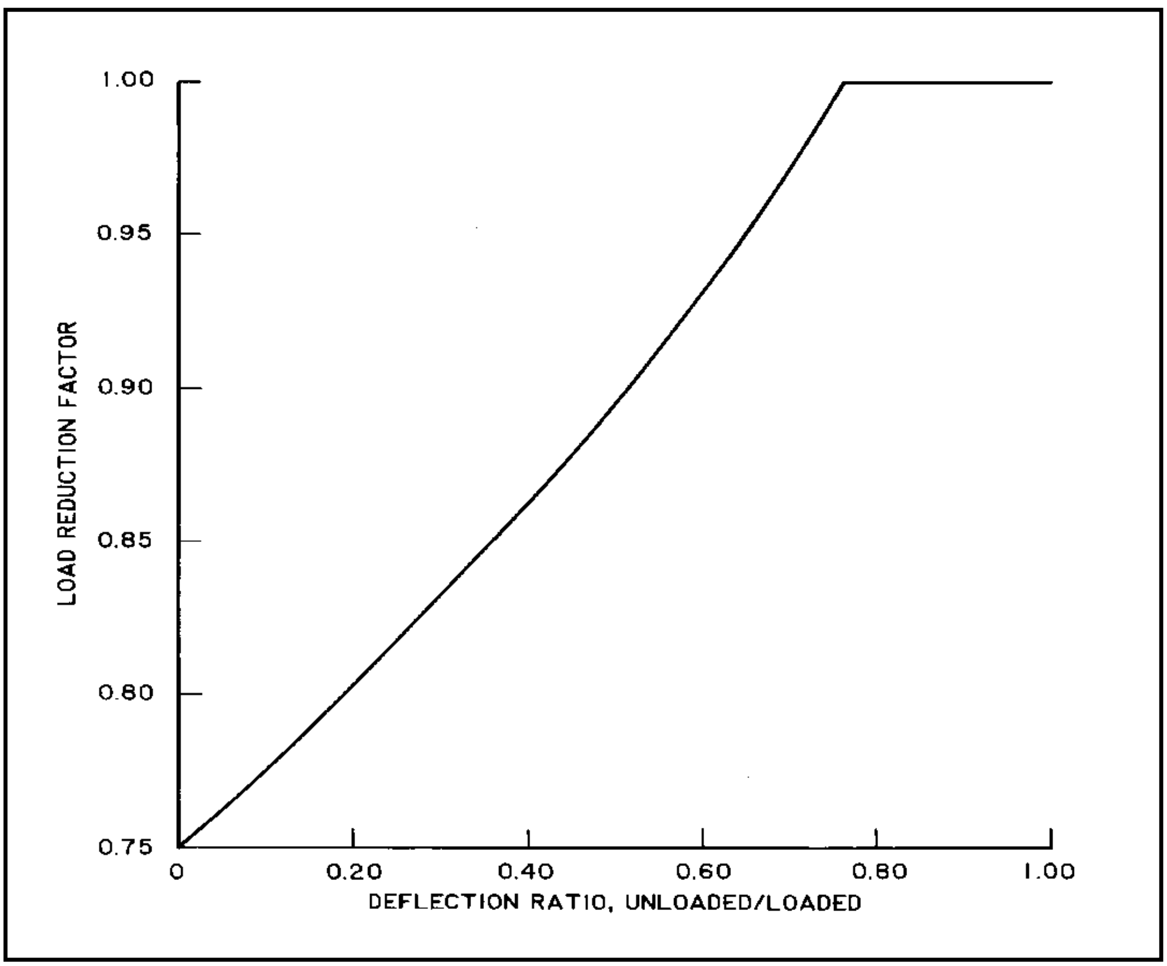
Rigid pavement analysis assumes 25 percent load transfer between slabs. The allowable loads determined at the slab centers can be reduced for poor joint transfer using load reduction factors shown in Figure 5-20. So, when there is evidence that there is a lack of load transfer (e.g., longitudinal cracking along the length of a section), test the joint load transfer as outlined in paragraph 3-4.1.7 and use the PCASE FWD module to compute the deflection ratio and load transfer efficiency as follows:

Equation 5-21. Deflection Ratio and Load Transfer Efficiency

$$DEFLECTION\ RATIO\ = \frac{DEFLECTION\ OF\ UNLOADED\ SLAB}{DEFLECTION\ OF\ LOADED\ SLAB}$$

The relationship in Figure 5-20 was developed using finite element programs to compute edge stresses for a range of pavement thicknesses and subgrade moduli and k values to relate the deflection ratio to the percent maximum edge stress. The maximum edge stress condition is a free edge with no load transfer. The edge stress is reduced as more load is transferred across a PCC joint from the loaded to the unloaded slab. For a load reduction factor of 1.0 (e.g., 100 percent of the aircraft design load), the deflection ratio is at least 76 percent as shown in Figure 5-20. As the deflection ratio falls below 76 percent, the load factor and corresponding design load decrease. The load reduction factor varies from 0.75 to 1.00, with a minimum load reduction factor of 75 percent when the deflection ratio is zero. This procedure is also used for both rigid and non-rigid overlays of rigid pavements.

Figure 5-20 Load Reduction Factors for Load-Transfer Analyses

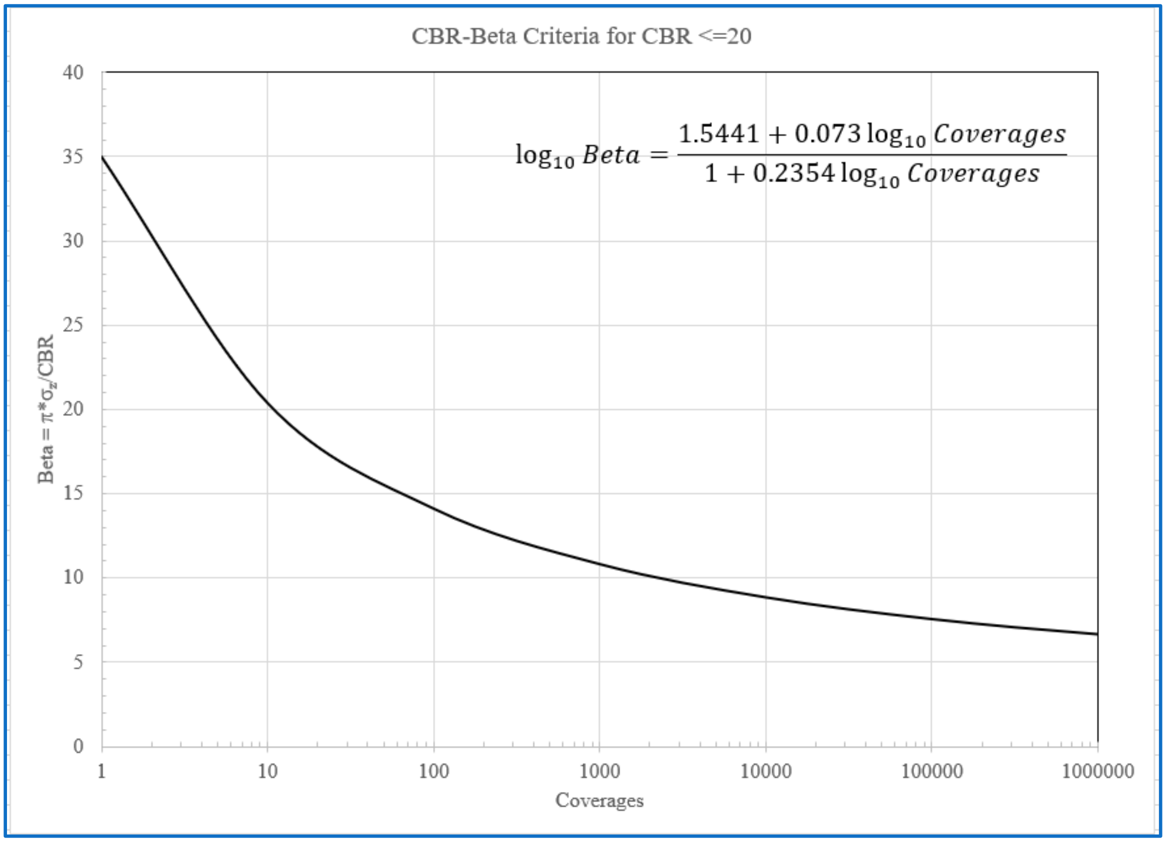


CHAPTER 6 FLEXIBLE PAVEMENT EVALUATION – CBR PROCEDURE

6-1 PERFORMANCE CRITERIA.

This flexible pavement structural evaluation procedure is a mechanistic-empirical approach known as the Alpha-Beta hybrid procedure which uses the California Bearing Ratio (CBR) as a measure of strength to analyze the vertical stress at the top of each layer and determine the allowable load and passes for an existing structure. Figure 6-1 shows the CBR Beta Performance model, which is based on the test points gathered in multiple full-scale test sections. The CBR Beta model is used when the CBR of a layer is less than or equal to 20. When the CBR of a layer is greater than or equal to 30, the CBR Alpha model is used for analysis, and when the CBR is greater than 20 and less than 30, the Alpha-Beta Hybrid model is used for analysis. The term CBR procedure is commonly used to describe the alpha-beta hybrid procedure. The details of this procedure are outlined in Appendix D and ERDC/GL TR-12-16, *Reformulation of the CBR Procedure*.

Figure 6-1 CBR-Beta Performance Criteria



6-2 FACTORS LIMITING LOAD-CARRYING CAPABILITY.

Structural failure criterion for a flexible pavement is based on a 1-inch (25-millimeter) rut. The load-carrying capability of a flexible pavement is limited by its critical or controlling layer, either the pavement surface, base, subbase, or subgrade.

6-2.1 Controlling Layer.

The ability of a given subsurface layer to withstand the loads imposed on it depends on the thickness and strength of material above it and its strength in its weakest condition. The critical or controlling layer is the layer that will support the least allowable load. To be realistic, an evaluation must consider possible future changes in moisture content and density as well as the effects of freezing and thawing.

6-2.2 Surface Condition.

A flexible pavement is assumed to have lost some structural capability when the PCI is less than or equal to 40 (VERY POOR, SERIOUS, or FAILED). When this occurs, a 25 percent load reduction is imposed on the section.

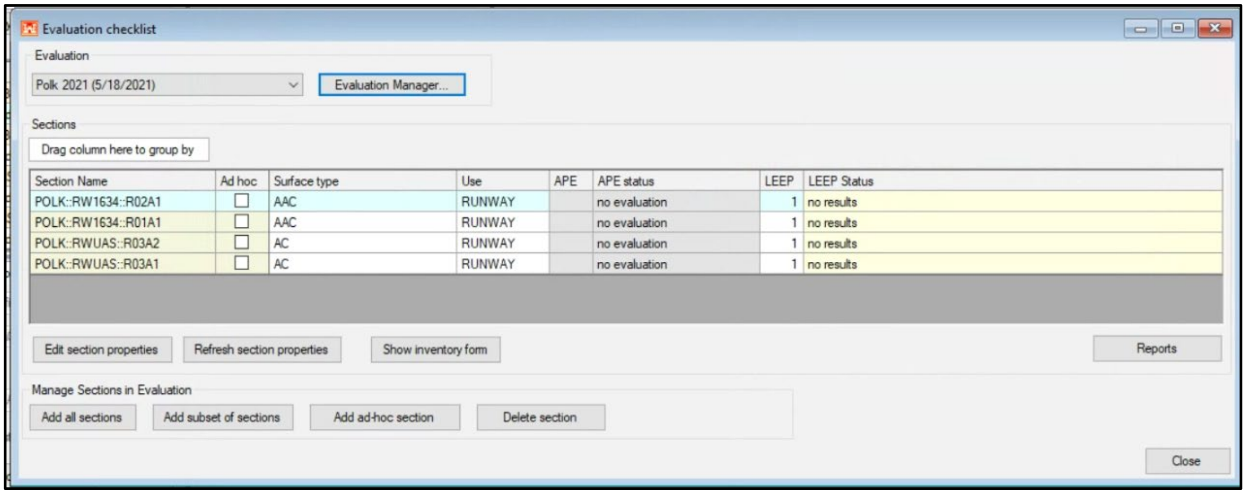
6-3 FLEXIBLE PAVEMENT (CBR) EVALUATION PROCEDURE.

The CBR evaluation procedure applies to flexible pavements. It analyzes the shear stress at the top of each layer using the CBR as a measure of the shear strength. It uses layer properties determined from in situ measurements to compute allowable loads for a selected number of aircraft passes, allowable passes at a specified load, and the Pavement Classification Number (PCN). When the pavement structure cannot support the defined pass level and aircraft load, determine overlay requirements to strengthen the pavement when desired. Following is a step-by-step procedure for evaluating a pavement section. Repeat Steps 2 through 4 of this process for each section being evaluated. The Pavement-Transportation Computer Assisted Structural Engineering (PCASE) Airfield Pavement Evaluation (APE) module implements the CBR criteria. More detailed information on using PCASE is available in the PCASE *User Manual*.

6-3.1 Step 1 – Create a New Evaluation.

Open the PCASE Evaluation Checklist to create a new evaluation using the Evaluation Manager. Define the Service, climate data, evaluation traffic, and rigid failure criteria for the evaluation, then assign the inventory sections to be included in the evaluation.

Figure 6-2 Evaluation Checklist



6-3.2 Step 2 - Input Pavement Layers and Thickness.

Open the APE module, edit the default layer structure, and enter the pavement thickness for each section. Determine the in-place thicknesses of asphaltic concrete to the nearest 0.25 inch and underlying unbound layers to the nearest inch by testing or from construction data when testing is not possible. Layer thickness testing can include measurements from coring, DCP, soil boring, GPR, or a combination of these tests. The number of tests required will vary based on the area and use of the pavement as well as the uniformity of the structure. When the layer thicknesses vary for a given section, evaluate the section using different models that replicate what was seen in the field, but only report the controlling evaluation for the facility.

6-3.2.1 Equivalency Factors.

When the measured thickness of a layer exceeds the required minimum thickness as defined in UFC 3-260-02, the excess measured thickness is converted to an equivalent thickness of base course and added to the existing base thickness. Then, any excess base-course thickness is converted to an equivalent thickness of subbase and added to the subbase thickness. This adjusted section is then used for evaluation. The equivalency factors for converting asphalt to base and subbase are 1.15 and 2.3 respectively, and for converting base course to subbase is 2.0, as shown in Table 6-1. This means that 1 inch (25.4 millimeter) of asphalt is equal to 1.15 inches (29 millimeters) of base and 2.3 inches (58 millimeters) of subbase, and 1 inch (25.4 millimeter) of base course is equal to 2 inches (51 millimeters) of subbase. The following example illustrates the use of equivalency factors.

Table 6-1 Equivalency Factors

Material	Base Equivalency Factor	Subbase Equivalency Factor
Unbound crushed stone	1.00	2.00
Unbound subbase*	-	1.00
Asphalt-stabilized and all-bituminous concrete	1.15	2.30
GW, GP, GM, GC	1.00	2.00
(SW, SP, SM, SC)*	-	1.50
Cement-stabilized		
GW, GP, SW, SP	1.15	2.30
GC, GM	1.00	2.00
(ML, MH, CL, CH)*	-	1.70
(SC, SM)*	-	1.50
Lime-stabilized		
(ML, MH, CL, CH)*	-	1.00
(SC, SM, GC, GM)*	-	1.10
Lime-, cement-, fly ash-stabilized		
(ML, MH, CL, CH)*	-	1.30
(SC, SM, GC, GM)*	-	1.40

*** Note:** Material is not to be used as a base layer.

6-3.2.2 Equivalent Thickness Example.

Evaluate a runway touchdown section for C-130 operations. The measured thickness of the pavement section and the equivalent thickness used to evaluate the pavement are shown in Table 6-2. The C-130 requires a minimum surface thickness of 4 inches (102 millimeters) and a minimum base thickness of 6 inches (152 millimeters). The base is unbound crushed stone.

Table 6-2 Equivalent Thicknesses

Layer	Measured Thickness (in.)	Equivalent Thickness of Base (in.)	Equivalent Thickness of Subbase (in.)	Evaluation Thickness (in)
Asphalt surface	5	5" - 4" min = 1" excess	-	4
Base	7	8.15 = 7.0 +1 x 1.15)	8.15" – 6" min = 2.15" excess	6
Subbase	10	-	14.30 = 10 + 2.15 x 2	14.3
Subgrade	-	-	-	-

6-3.2.3 Stabilized Layer Equivalent Thickness.

Stabilized layers are incorporated in the design of pavement sections to make use of locally available materials that cannot otherwise meet the criteria for base or subbase courses. Materials must meet the requirements in UFC 3-250-11, *Soil Stabilization and Modification for Pavements*. In design, the equivalency factors shown in Table 6-1 are assigned to the stabilized material and result in a thickness reduction as compared with an unbound base course or subbase course. These same equivalency factors result in an increase in thickness of the layer in evaluation. If no information is available on the condition and strength of the stabilized layer, it should be treated as a high-quality granular layer. If DCP results indicate the layer is well stabilized (refusal for DCP), then consider the layer for the equivalency factors.

6-3.2.4 Stabilized Layer Equivalent Thickness Example.

Assume that an Air Force pavement structure consists of a 4-inch (102-millimeter) asphaltic concrete, an 8-inch (203-millimeter) bituminous concrete base, and an 8-inch (203-millimeter) cement-stabilized gravelly clay subbase with an unconfined compressive strength of 700 psi (4.83 MPa). From Table 6-1, the 8-inch (203-millimeter) bituminous concrete base equivalency factor is 1.15, which increases the thickness of the stabilized base for evaluation to 9.2 inches (234 millimeters). Table 6-1 shows that the 8-inch (203-millimeter) cement-stabilized subbase has an equivalency factor of 2.0, which increases the thickness of the stabilized subbase for evaluation to 16 inches (406 millimeters).

6-3.3 Step 3 - Soil Layer Strength Values.

Enter the CBR for the subgrade and overlying subbase and base courses. Both in-field and laboratory CBR tests are described in CRD-C654, *Standard Test Method for Determining the California Bearing Ratio of Soils*. Field DCP tests are described in Appendix A and TM 3-34.48-2, Appendix G. Use construction data in conjunction with testing or when testing is not possible. The CBR test results from an individual test pit or from multiple DCP tests are seldom uniform. Therefore, analyze the data carefully as described in Chapter 3 to determine reasonable CBR values to use for an evaluation.

6-3.3.1 Base Course CBR.

Base course CBR or DCP testing can produce inaccurate CBR values when performing in-place tests or for laboratory tests due to inherent difficulties in processing samples. For example, DCP test results may show a 100 CBR for a Poorly Graded Gravel however, it is likely the DCP encountered large aggregates that skewed the test results. In this case, assign CBR values based on the material's typical behavior, as shown in Table 6-3.

Table 6-3 Assigned CBR values for Base Course Materials

Aggregate Base Course	Assigned CBR
Graded crushed aggregate	100
Aggregate	80
Limerock	80
Coral	80
Shell Rock	80

6-3.4 Step 4 – Flexible Pavement Analysis.

6-3.4.1 Alpha-Beta Hybrid (CBR) Evaluation Procedure.

Once the thickness and CBR values are selected for each of the layers, use these values to determine the shear stress at the top of each layer based on the stress-based CBR Alpha-Beta hybrid procedure assuming constant tire pressure. The objective of the analysis is to determine the allowable load and allowable passes for the structure. Note that results using the current criteria will differ from the CBR Alpha criteria and constant contact area assumption used in past versions of this UFC. PCASE automates the analysis procedure outlined in this chapter and in Appendix D. The procedure for generating aircraft curves using the current criteria is included in TSPWG M 3-260-03.02-19.

6-3.4.2 Procedure for Determining Allowable Gross Load (AGL).

The inputs for this analysis are the traffic mix with the load and number of passes for each vehicle in the mix defined, the pavement structure, and the traffic area. Determine the controlling/representative vehicle and equivalent passes based on one of the traffic analysis procedures outlined in Chapter 4. Perform the allowable coverages calculation using the Alpha-Beta Hybrid procedure in which limiting (vertical) stress is calculated for each layer in the pavement structure based on load of the controlling/representative vehicle load. Compute the cumulative damage factor (CDF). If the CDF is less than 1, increase the gross load and repeat the analysis procedure. If the CDF is greater than 1, decrease the load and repeat the analysis procedure. When CDF equals 1, use that value for the AGL. See Appendix D for details on this procedure.

6-3.4.3 Procedure for Determining Allowable Passes.

The inputs for this analysis are the traffic mix with the load and number of passes for each vehicle in the mix defined, the pavement structure, and the traffic area. Determine the controlling/representative vehicle and equivalent passes based on one of the traffic analysis procedures outlined in Chapter 4. Perform the allowable coverages calculation using the Alpha-Beta Hybrid procedure in which limiting (vertical) stress is calculated for each layer in the pavement structure based on load of the controlling/representative vehicle load. See Appendix D for details on this procedure.

6-3.4.4 Load, Tire Pressure, and Contact Area Relationship.

Typically, the relationship between weight on a tire, tire pressure, and contact area is:

Tire Contact Area = Load on Tire/Constant Tire Pressure

This relationship is good for AGLs up to approximately the maximum aircraft load. At that point, contact area begins increasing to unrealistic values to the extent that the limiting stress is not reached. Therefore, a solution for allowable load is not achievable. To resolve this issue, the following relationship is used for the allowable loads above the maximum aircraft loads.

Equation 6-1. Tire Pressure Relationship

$$T_p = T_{pml} + \frac{D}{T_{ca}\left[1 + \left(\frac{AGL}{D}\right)^3\right]}$$

where

$T_p = Tire\ pressure\ used\ for\ calculations$

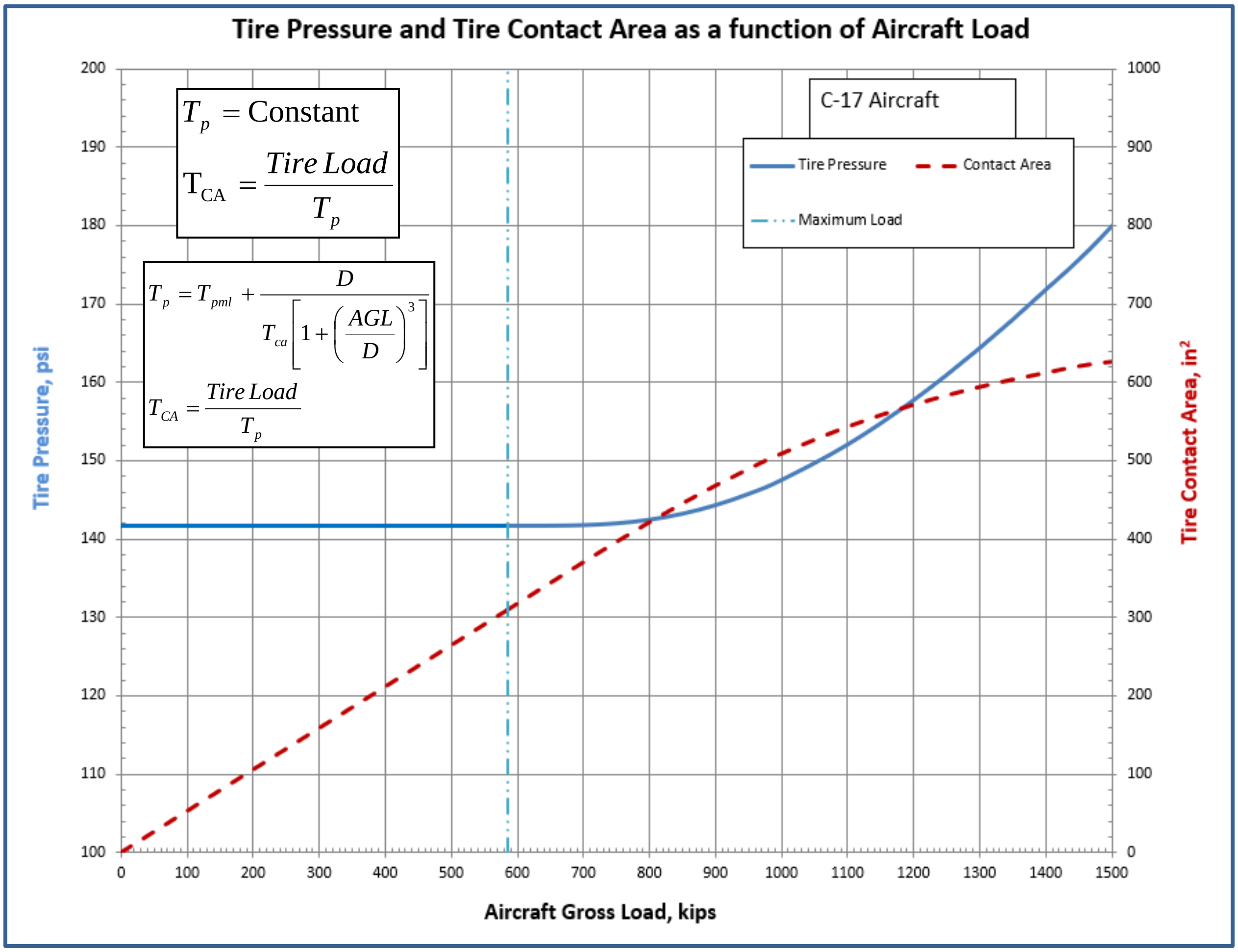
$T_{ca} = Tire\ contact\ area\ at\ MaxLoad$

$T_{pml} = Tire\ pressure\ at\ MaxLoad$

$D = AGL - MaxLoad$

An example of this relationship for the C-17 is shown in Figure 6-3.

Figure 6-3 Tire Pressure/Contact Area vs. AGL



6-3.5 Pavement Classification Number (PCN).

The process described above is used to calculate the allowable load which is then used to compute the PCN. Comparing the aircraft classification number (ACN) to the PCN of a pavement section is an expedient way to determine if it can support a particular aircraft. Chapter 9 presents the PCN procedure.

6-4 OTHER FLEXIBLE PAVEMENT EVALUATION CONSIDERATIONS.

The structural analysis procedure above assumes the quality of the materials and construction procedures used to construct a flexible pavement meet the criteria outlined in UFC 3-260-02 and the various Unified Facility Guide Specifications (UFGS). When field and laboratory testing indicate that this assumption is not valid, adjust evaluation inputs or at least fully document any anomalies in the report. The following paragraphs discuss evaluation issues that should be considered.

6-4.1 Ability to Support Traffic.

The type and gradation of the aggregate, the amount of bitumen in the mix, and the compaction of the mix all affect the ability of a mix to support traffic of a given load. Mixes with rounded aggregates are less stable than those with crushed-face aggregates. Mixes with aggregates of irregular grading are less stable than those with well-graded aggregates. A bitumen deficiency produces a pavement that may ravel, but too much bitumen produces a pavement that may rut and shove. Compare the test data from the laboratory recompacted core sample specimens taken during the evaluation with the design criteria in UFC 3-260-02. The condition of surface or binder course pavement at the time of sampling can be an indication of future behavior under additional traffic. Table 6-4 shows the prediction of behavior from tests on cores and on laboratory recompacted surface course specimens. Assume the thickness and aggregate gradation are satisfactory.

Table 6-4 Example Test Data

Tests	Field Cores	Recompacted Sample - 50 Blows*	Recompacted Sample - 75 Blows
Unit weight (density), pcf	144.2	149.7	150.9
Unit weight, percent of 50-blow laboratory compaction	96	-	-
Unit weight, percent of 75-blow laboratory compaction	95	-	-
Stability (pounds)	1,883	2,929	3,276
Flow (1/100 inch)	15	16	16
Voids total mix, percent	8.5	4.5	3.7
Voids filled, percent	57.2	72.1	75.8

***Note:** For shoulders and overruns

The test data from recompacted specimens shown above indicates the current density (field cores) is relatively low, the flow is approaching the upper limit, and the void relations are outside the acceptable ranges, but the stability is satisfactory. This means that additional compaction from traffic will likely increase the stability but also cause some rutting of the pavement. Therefore, the pavement should be able to withstand heavier loads than it sustained in the past and is satisfactory under traffic having up to 200 psi (1.4 MPa) tire pressure. At 75 blow laboratory compaction, the voids total mix value is below the midpoint of the acceptable range and the flow is at the upper limit, indicating a mix slightly rich of optimum. However, no danger from flushing is expected.

6-4.2 Ability to Withstand Fuel Spillage.

Fuel dripping on a given area at frequent intervals or a pervious pavement mix that allows considerable penetration of the fuel will cause pavement distresses because asphaltic cements are readily soluble in fuels. The voids in the total mix control the rate at which penetration occurs. Fuel will penetrate very little into pavements with 3 percent voids but will rapidly penetrate pavements with high (over 7 percent) voids. Therefore, an AC layer with higher density will typically increase the pavement's resistance to jet fuel penetration and weathering. Pavements about one year or older usually perform better in this respect than new pavements. Evaluate the surface course characteristics for resistance to jet fuel. Table 6-5 serves as a guide for evaluating asphalt pavements regarding fuel spillage for use in different areas of the airfield.

Table 6-5 Surface Course Fuel Resistance

Pavement Type	Texture	Satisfactory for
Asphaltic concrete	Dense	Runway interiors and areas of taxiways where aircraft do not warm up or stop frequently
Asphaltic concrete	Open	Runway interiors or any high-speed areas

6-4.3 Ability to Withstand Jet Blast.

Tests have shown that about 300 °F (149 °C) is the critical temperature for asphaltic concrete. Field tests simulating pre-takeoff checks at the ends of runways indicate that the maximum temperatures induced in the pavements when afterburners are not used are less than 300 °F (149 °C). Maximum temperatures induced in pavement tests simulating maintenance checkups are 315 °F (157 °C). When afterburners are turned on after the aircraft has begun the takeoff run, little or no damage occurs.

Thin-surface courses, not well-bonded to the underlying layers, are subject to erosion (e.g., weathering, raveling, jet blast) by a high-velocity blast, even though the binder is not melted. All jet aircraft currently in use are believed to produce blasts of sufficiently high velocity to flay such courses. Setback distances for running-up engines are established and included in UFC 3-260-01, *Airfield and Heliport Planning and Design*. Surface layers less than 1 inch (25.4 millimeters) thick and poorly bonded are considered unsatisfactory for parking areas and the 1,000-foot (304.8-meter) ends of runways and are so reported in the narrative portion of the evaluation report for all aircraft. DoD aircraft inventories now include aircraft with thrust vectors that potentially negatively impact airfield pavements, depending on operational usage. When these aircraft are present, the evaluation should consider the expected decrease in performance due to thrust vector forces.

6-4.4 Effects of Traffic Compaction on Paving Mixes.

Traffic tends to densify flexible pavements, depending on the gear loads applied and the characteristics of the mix. Densification is limited where traffic is widely distributed and is greatest where traffic is channelized. High tire pressures produce greater densification than low tire pressures. The probability of densification under a given loading decreases somewhat with pavement age because of hardening of the asphalt. A comparison of the in-place density and void relations of the pavement with the results of comparable tests on specimens recompacted in the laboratory gives an indication of future behavior. If the pavement is constructed so the voids fall near the lower limit of the specified allowable range, it is probable that aircraft with relatively high-pressure tires will produce sufficient densification to appreciably reduce the voids in the total mix. The pavement is considered unstable and may rut when the voids fall below the specified minimum (see UFC 3-260-02). These conditions cannot be translated into numerical evaluations, but they should be discussed in the evaluation report and summarized so engineers will have the information available.

6-4.5 Effects of Traffic Compaction on Base Course and Subgrade.

6-4.5.1 Degree of Compaction for CBR Values.

Definite degrees of compaction are specified for the subgrade and base course in airfield pavement construction to prevent excessive densification under traffic, the consequent development of surface roughness “birdbaths,” and loss of grade. The design CBR values are based on assumed degrees of compaction outlined in the specifications.

6-4.5.2 Density Requirements.

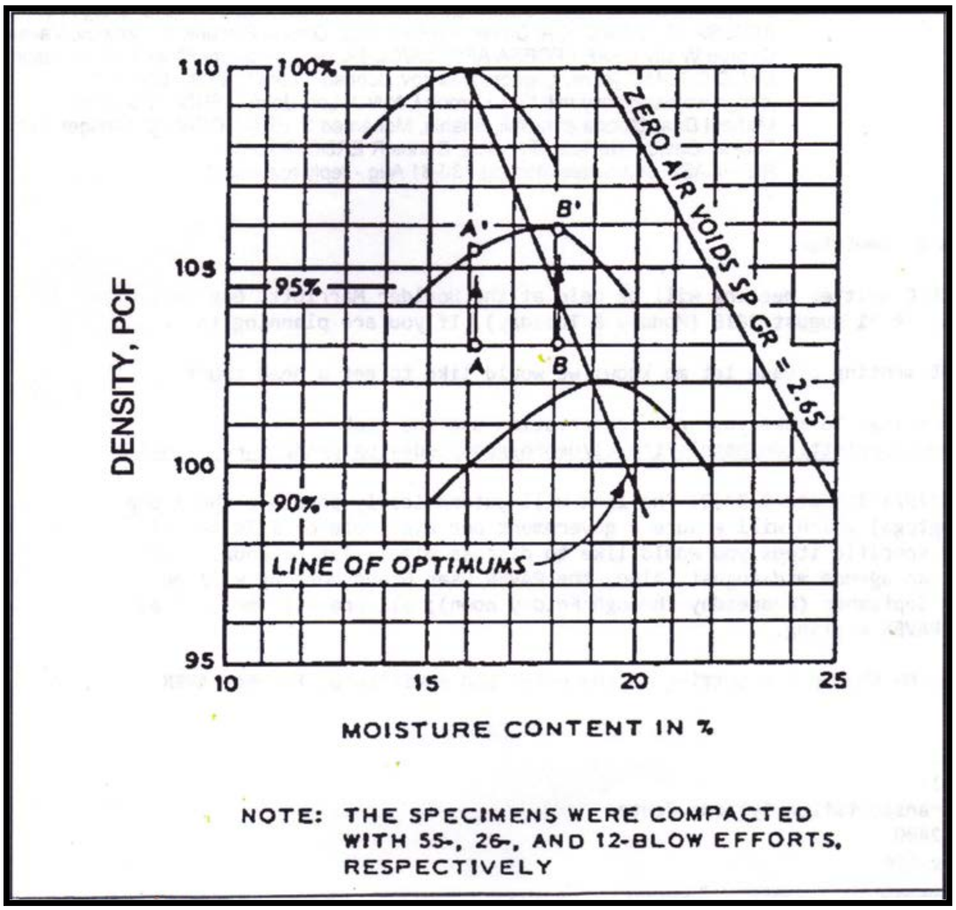
Compare the in-place densities, as a percentage of ASTM D1557, *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 [2,700 kN-m/m^3])*, maximum density, with the design requirements for the various loads and gear configurations that the pavement is expected to support to evaluate the base, subbase, and subgrade from the standpoint of future compaction. When the in-place density of a layer is appreciably lower than that required, assume that traffic will densify the layer in time. Density requirements at various depths are discussed in UFC 3-260-02.

6-4.5.3 Selection of Evaluation CBR Value.

Consider the effect of further compaction on strength of base and subgrade. Some cohesive soils, when highly saturated, potentially develop pore pressures under traffic of heavy wheel loads and show serious loss of strength. Compare the in-place density and moisture contents with those of the laboratory compaction tests made at three compaction efforts to determine if there is potential for strength loss. These data are used to determine the line of optimums illustrated in Figure 6-4 by a line drawn through the three optimum moisture contents. Pore pressure seldom develops unless the moisture and density results fall to the right of the line of optimums. When this occurs, it is likely that future compaction will produce pore pressures. For example, consider point

A plotted in Figure 6-4 at a moisture content of 16 percent and a density of 103 pounds per cubic foot (1,651 kilograms per cubic meter). Assume this represents a subgrade that has 95 percent of ASTM D1557 maximum density. If further compaction occurs, the density will increase to approximately 105 pounds per cubic foot (1,682 kilograms per cubic meter) (point A' on the curve for 26 blow effort). Since this is to the left of the line of optimums, no pore pressures will develop. If the subgrade had a moisture content of 18 percent (point B), the increased compaction would cause the density to be plotted to the right of the line of optimums (B') and pore pressures would result. The CBR that would develop under this condition could be estimated from laboratory CBR tests in which the material was compacted to the same density and moisture content.

Figure 6-4 Line of Optimums



It is not necessary to lower the load-carrying capacity of the facility below that derived based on thickness and CBR because compaction does not meet specifications. However, if the measured densities are considerably less than those specified, the deterioration of the pavement may be high, resulting in a decrease in service life. Note that materials of low density combined with low moisture content may not densify under traffic, but subsequent increases in moisture content will permit densification. There may be possible settlement due to densification in the evaluation of pavements being subjected to channelized and heavy wheel-load traffic. In the case of cohesive materials that may develop pore pressures and a loss in strength, consider a lower CBR when evaluating allowable aircraft loads.

6-5 EVALUATIONS IN ARID REGIONS.

The danger of saturation beneath flexible pavements is reduced when the annual rainfall is less than 15 inches (381 millimeters), the water table (including perched water table) is at least 15 feet (5 meters) below the surface, and the water content of the subgrade will not increase above the optimum as determined by the ASTM D1557 compaction test. Under such conditions, the total design thickness of the pavement, when based on a soaked CBR, can be reduced 20 percent. This reduction is subtracted from the thickness of the select material or the subbase course having the lowest design CBR value. Therefore, when flexible pavements are evaluated using a soaked CBR value, the total thickness above the subgrade is increased 25 percent before entering the evaluation curves. This increase in thickness is added to the select material, or the subbase course having the lowest CBR, or to the same layer in which the reduction was made in the design analysis. This increase in thickness does not apply for evaluations using in-place data.

6-6 EVALUATION FOR FROST CONDITIONS.

If the existing soil, water, and temperature conditions are conducive to detrimental frost effects in the base-course, subbase, or subgrade materials, then the pavement evaluation is based on criteria for frost areas as given in Chapter 8.

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CHAPTER 7 RIGID PAVEMENT EVALUATION USING THE K PROCEDURE

7-1 PERFORMANCE CRITERIA.

This chapter presents criteria for evaluating rigid pavements using the Westergaard solution that uses medium-thick plate theory and treats the combined support of the base, subbase, and subgrade as a bed of independent springs (Winkler's Foundation) represented by the Modulus of Subgrade Reaction (k). Chapter 3 outlines how to use plate bearing tests or dynamic cone penetrometer (DCP) test data to determine the k value.

7-2 FACTORS LIMITING LOAD-CARRYING CAPACITY.

Jointed, plain PCC pavements are evaluated using stresses due to edge loading of a slab. Either first crack or shattered slab failure criteria are used for rigid pavements as described below. The Service dictates which criterion it uses in its evaluations.

7-2.1 Standard Evaluation Failure Criterion.

First crack failure (sometimes referred to as initial failure or standard failure) means that 50 percent of the slabs in a sample or section are cracked into two or three pieces.

7-2.2 Shattered Slab Failure Criterion.

Shattered slab failure (sometimes referred to as extended life failure) means that 50 percent of the slabs in a sample or section are cracked into approximately six pieces or when 50 percent of slabs are cracked into four pieces and cracks are medium or high severity.

7-2.3 Basis of Load-carrying Capability.

The load-carrying capability of rigid pavements depends on the thickness and flexural strength of the PCC surface layer and the support in terms of the modulus of subgrade reaction (k) value provided by the base, subbase, and subgrade. Long-term rigid pavement system performance depends on many elements, including PCC and stabilized base material durability, unbound material and subgrade gradations, moisture content and density, and regional climatic effects such as freezing and thawing.

7-2.4 Surface Condition

Assume a rigid pavement has lost some structural capability when the PCI is less than or equal to 40 (VERY POOR, SERIOUS, or FAILED). When this occurs, reduce the load on the section by 25 percent.

7-2.5 Load Transfer.

The rigid pavement analysis procedure assumes a 25 percent load transfer across joints from aggregate interlock in sawn joints or by dowels. When testing (by FWD) indicates inadequate joint load transfer, change the percent load transfer. This change recalculates the joint deflection ratio and increases the maximum edge stress to a maximum of 100 percent. The effect of this change is an allowable load reduction to 25 percent.

7-2.6 Combined Load Reduction.

Any allowable aircraft load reduction is based on engineering judgment, but there is typically no combined load reduction for both PCI and load transfer. The engineer must investigate all possible sources of pavement engineering data to ensure that site conditions, including field and laboratory test results, are consistent with proposed reductions in allowable loads.

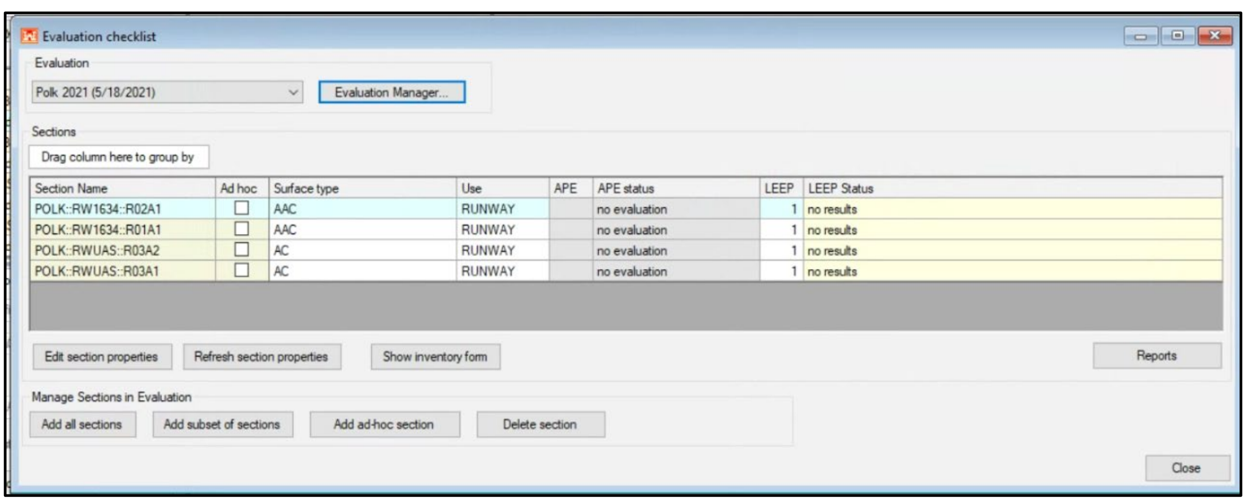
7-3 RIGID PAVEMENT (K) EVALUATION PROCEDURE.

The Westergaard (k) evaluation procedure applies to rigid pavements. It analyzes the critical tensile stresses produced within the slab by the vehicle loading. It uses layer properties determined from in situ measurements to compute allowable loads for a selected number of aircraft passes, allowable passes at a specified load, and the Pavement Classification Number (PCN). When the pavement structure cannot support the defined pass level and aircraft load, determine overlay requirements to strengthen the pavement when desired. The following paragraphs present a step-by-step procedure for evaluating a pavement section using the Pavement-Transportation Computer Assisted Structural Engineering (PCASE) Airfield Pavement Evaluation (APE) module that implements the CBR criteria. Repeat Steps 2 through 5 of this process for each section evaluated. More detailed information on PCASE is available in the PCASE *User Manual*.

7-3.1 Step 1 – Create a New Evaluation.

Open the PCASE Evaluation Checklist to create a new evaluation using the Evaluation Manager. Define the Service, climate data, evaluation traffic, and rigid failure criteria for the evaluation, then assign the inventory sections included in the evaluation.

Figure 7-1 Evaluation Checklist



7-3.2 Step 2 - Input Pavement Layers and Thickness.

Open the APE module, edit the default layer structure, and enter the pavement thickness. Determine the in-place thicknesses of PCC pavement to the nearest 0.25 inch and underlying unbound layers to the nearest inch by testing or from construction data when testing is not possible. Layer thickness testing can include measurements from coring, DCP, soil boring, GPR, or a combination of these tests. The number of tests required varies based on the area and use of the pavement as well as the uniformity of the structure. When the layer thicknesses vary for a given section, evaluate the section using different models that replicate field observations, but only report the controlling evaluation for the facility. Repeat this process for each section.

7-3.2.1 Stabilized Base Equivalent Thickness

When a pavement structure contains a stabilized base layer, determine the modulus of elasticity and thickness of the stabilized layer. The modulus of elasticity of the stabilized layer is more difficult to determine than the PCC layer. If the stabilized layer is a high-quality lean concrete or cement-stabilized layer, assign it a modulus value of 1,200,000 psi (8274 MPa). If the stabilized layer is lower quality, such as a lime or asphalt stabilized layer, assign it a modulus value of 500,000 psi (3447 MPa). Use the following equation to determine the equivalent thickness of the combined PCC and stabilized layers. Use this equivalent thickness value (h_e) with the PCC flexural strength and the modulus of subgrade reaction, k, of the material below the stabilized base layer in the analysis. PCASE automates this procedure.

Equation 7-1. Equivalent Thickness

$$h_e = 1.4\sqrt{(h_c)^{1.4} + \left(3\sqrt{\left(\frac{E_s}{E_c}\right)}\,h_s\right)^{1.4}}$$

Where:

h_e = *thickness of plain PCC equivalent to the combined PCC and stabilized base layer thicknesses, inches*

h_c = *thickness of PCC pavement, inches*

h_s = *thickness of stabilized base layer, inches*

E_c = *modulus of elasticity of PCC. The modulus values that are used in PCASE can be modified, based on engineering judgment. However, the UFC and PCASE should be consistent unless there is evidence to suggest otherwise.*

E_s = *modulus of elasticity of the stabilized base layer, psi. Estimate from Table 7-1 or calculate using deflections resulting from ASTM D1635.*

Table 7-1 E Values for Pavement Materials (Guide When E is not Available)

Material	Range (psi)	Typical Modulus (psi)
Portland cement concrete	3,000,000 – 6,000,000	4,000,000
Cement-treated bases	1,000,000 – 3,000,000	2,000,000
Soil cement materials	50,000 – 2,000,000	1,000,000
Lime-fly ash materials	500,000 – 2,500,000	1,000,000
Granular bases	40,000 – 100,000	60,000
Stiff clay	7,600 – 17,000	12,000
Medium clay	4,700 – 12,300	8,000
Soft clay	1,800 – 7,700	5,000
Very soft clay	1,000 – 5,700	3,000

7-3.2.2 Poisson's Ratios of Pavement Materials

Table 7-2 shows typical values for Poisson's ratios for different pavement materials.

Table 7-2 Poisson's Ratios for Pavement Materials

Material	Range	Typical Value
Hot mix asphalt	0.30 – 0.40	0.35
Portland cement concrete	0.15 – 0.20	0.15
Untreated granular base	0.30 – 0.40	0.35
Cement-treated granular base	0.10 – 0.20	0.15
Cement-treated fine soils	0.15 – 0.35	0.25
Lime-stabilized materials	0.10 – 0.25	0.20
Lime-fly ash mixtures	0.10 – 0.15	0.15
Loose sand or silty sand	0.20 – 0.40	0.30
Dense sand	0.30 – 0.45	0.35
Fine-grained soils	0.30 – 0.50	0.40
Saturated soft clays	0.40 – 0.50	0.45

7-3.3 Step 3 – Input the PCC Flexural Strength.

Enter the flexural strength for each PCC layer using the guidance below. Repeat the process for each section

7-3.3.1 PCC Flexural Strength, M_R Based on Testing.

Determine the representative M_R value using the results of split tensile tests or by conducting flexural strength beam tests. The M_R value used for each section in the evaluation is the arithmetical mean of all M_R values as described in Appendix A. Do not discard high or low results unless it is established that results were erroneous because the sample was defective or due to incorrect test procedures. In special instances the evaluating engineer may use a slightly lower or higher value that is more representative of existing conditions. Round the flexural strength to the nearest 5 psi (0.03 MPa), limit the maximum flexural strength for individual tests to 850 psi (5.9 MPa), and the average flexural strength to 800 psi (5.5 MPa) when reporting physical property data (PPD) and modeling.

7-3.3.2 PCC Flexural Strength, M_R Based on Construction Data.

For evaluations based on design or construction data, the representative M_R value is the arithmetical mean of the M_R values obtained in the construction-control beam tests. Disregard small changes in mix design necessary during construction to obtain the design strength when selecting representative M_R values. However, if there is a design strength change that necessitated a change in mix design, consider this change and a representative M_R value obtained for each facility for which the design strength was changed.

7-3.3.3 PCC Flexural Strength, M_R When No Data is Available.

When there is no test, design, or construction data available for an evaluation, assume a 650-psi (4.5-MPa) flexural strength when probability of construction quality control is high and 600 psi (4.1 MPa) when it is not.

7-3.4 Step 4 – Input Soil Layer Strength (k) Values.

Determine the subgrade and overlying subbase and base courses strengths by means of plate bearing tests described in CRD-C655, *Standard Test Method for Determining the Modulus of Soil Reaction*, and ASTM D1196, *Standard Test Method for Nonrepetitive Static Plate Tests of Soils and Flexible Pavement Components for Use in Evaluation and Design of Airport and Highway Pavements*, or DCP tests described in TM 3-34.48-2, Appendix G. Use construction data in conjunction with testing or when testing is not possible. The test results from an individual test pit or from multiple DCP test are seldom uniform; therefore, analyze the data carefully as described in Chapter 3 to determine reasonable k values to use for the evaluation.

7-3.4.1 Determining Representative k Values.

Compute an average k value for each pavement section, limiting the maximum k value to 500 psi/inch (13,840 grams per cubic centimeter) for evaluations. When the average k value exceeds 200 psi/inch (5,536 grams per cubic centimeter), round down to the nearest 25 psi/inch (692 grams per cubic centimeter). When it is less than 200 psi/inch (5,536 grams per cubic centimeter), round down to the nearest 10 psi/inch (277 grams per cubic centimeter). When test results are considerably higher or lower than the average of most values, conduct a thorough study of foundation conditions to determine whether the test was erroneous or whether the foundation is non-uniform. If the test is erroneous, discard the unusually high or low value. If the foundation is non-uniform, conduct more testing to select a representative k value. Do not make a saturation correction for k values since the material has likely reached an equilibrium moisture content.

7-3.4.2 Determining k Values with Plate Bearing Tests.

The plate bearing test procedures as described in CRD-C 655 and ASTM D1196 are the preferred methods to determine k values. However, existing pavement must be removed to create a test pit to conduct a plate bearing test. Operational considerations typically limit the ability to do a plate bearing test during an evaluation but will be used when the geotechnical work is for a specific project design.

7-3.4.3 Estimating k Values with DCP Tests.

When operational limitations prevent performing a plate bearing test for an evaluation, use the DCP test discussed in Chapter 3. The CBR is correlated to the k value for each layer using Figure 7-2 (based on Equations 7-2 through 7-4) and these values are used to determine the effective k at the bottom of the slab as described in the effective k procedure below. When performing DCP testing in conjunction with HWD testing, the volumetric k from HWD testing can be compared with the effective k derived from the DCP test as a checkpoint to determine the reasonableness of the k value. Note that k values derived from either of these procedures should be used with caution since CBR, volumetric k, and k values derived from plate bearing testing are fundamentally different soil engineering properties with poor correlations for many real-world cases.

Equation 7-2. CBR to k Coarse Grained Non-Plastic Subgrade Material

$$k = 129.58076 * CBR^{0.5} - 5.49306 * CBR - 242.93236$$

Equation 7-3. CBR to k Fine Grained Subgrade Material with LL < 50

$$k = 60.2282 * CBR^{0.5} + 2.1854046 * CBR - 11.245482$$

Equation 7-4. CBR to k Fine Grained Subgrade Material with LL > 50

$$k = 20 * CBR$$

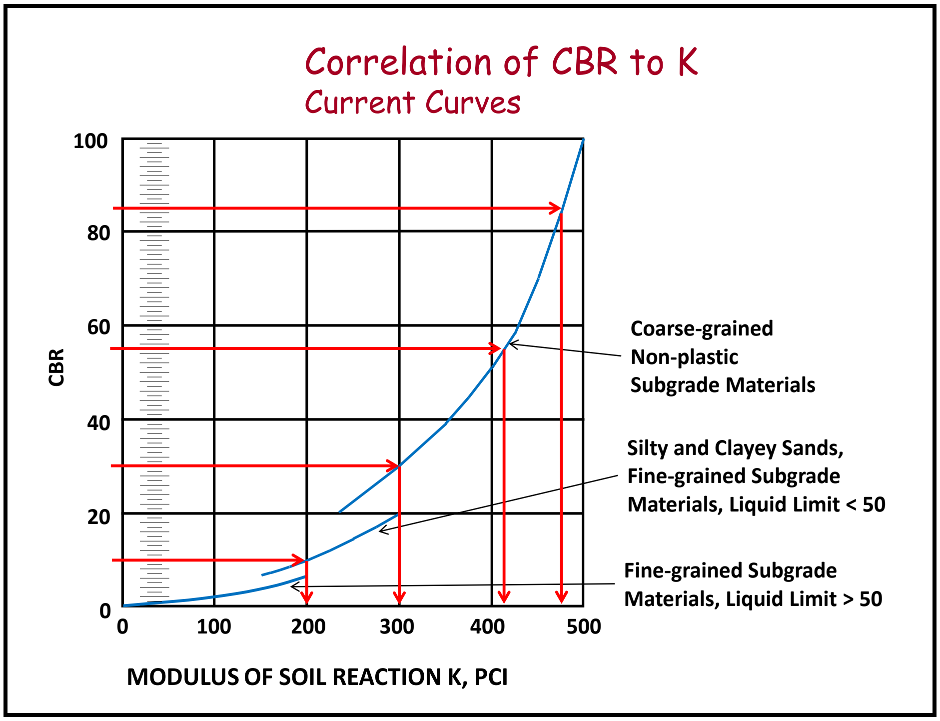
Where:
k = *Modulus of Subgrade Reaction*
CBR = *California Bearing Ratio*

Source: ERDC/GSL TR-12-20

7-3.4.4 Procedure to Determine Effective k Values.

Determine the k value for each layer in the pavement structure by inputting the CBR results from the DCP test into Equation 7-2, 7-3, or 7-4, depending on the material type. Figure 7-2 is derived from these equations. Determine the effective k for each layer using Figures 7-2 through 7-8. Compare the effective k for each layer to the k for each layer determined by Figure 7-2 and use the lower value for computing the effective k of the next layer. This process is automated in the PCASE APE module.

Figure 7-2 Estimation of K values from CBR



7-3.4.5 Determine Layer Structure and CBR Values from DCP Test.

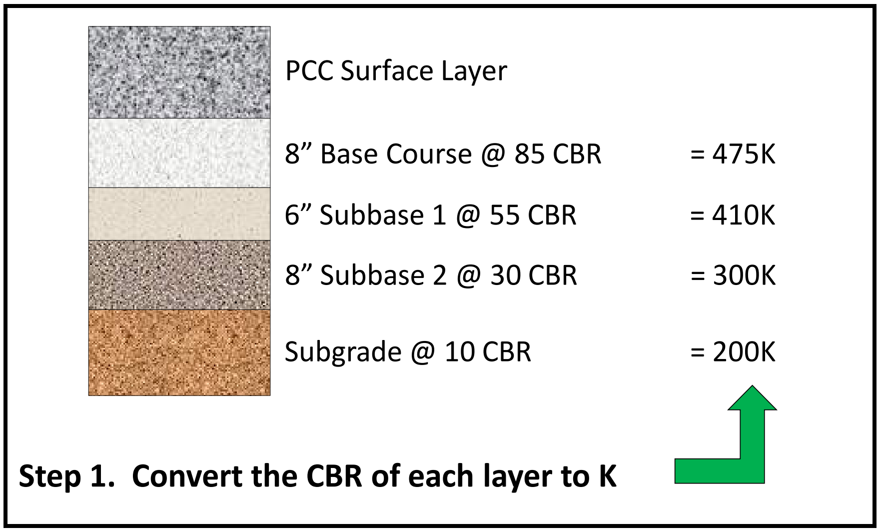
Using the following layer structure, determine k and effective k values.

- Base course is 8 inches (203 millimeters) thick with a CBR = 85
- Subbase 1 is 6 inches (152 millimeters) thick with a CBR = 55
- Subbase 2 is 8 inches (203 millimeters) thick with a CBR = 30
- Subgrade CBR = 10

7-3.4.5.1 Step 1 - Determine k Value for Each Layer Using Figure 7-2.

Use Figure 7-2 to determine the k values for the subgrade, subbase 1, subbase 2, and base course to compare with tentative k values at the top of each of these layers as shown in Figure 7-3.

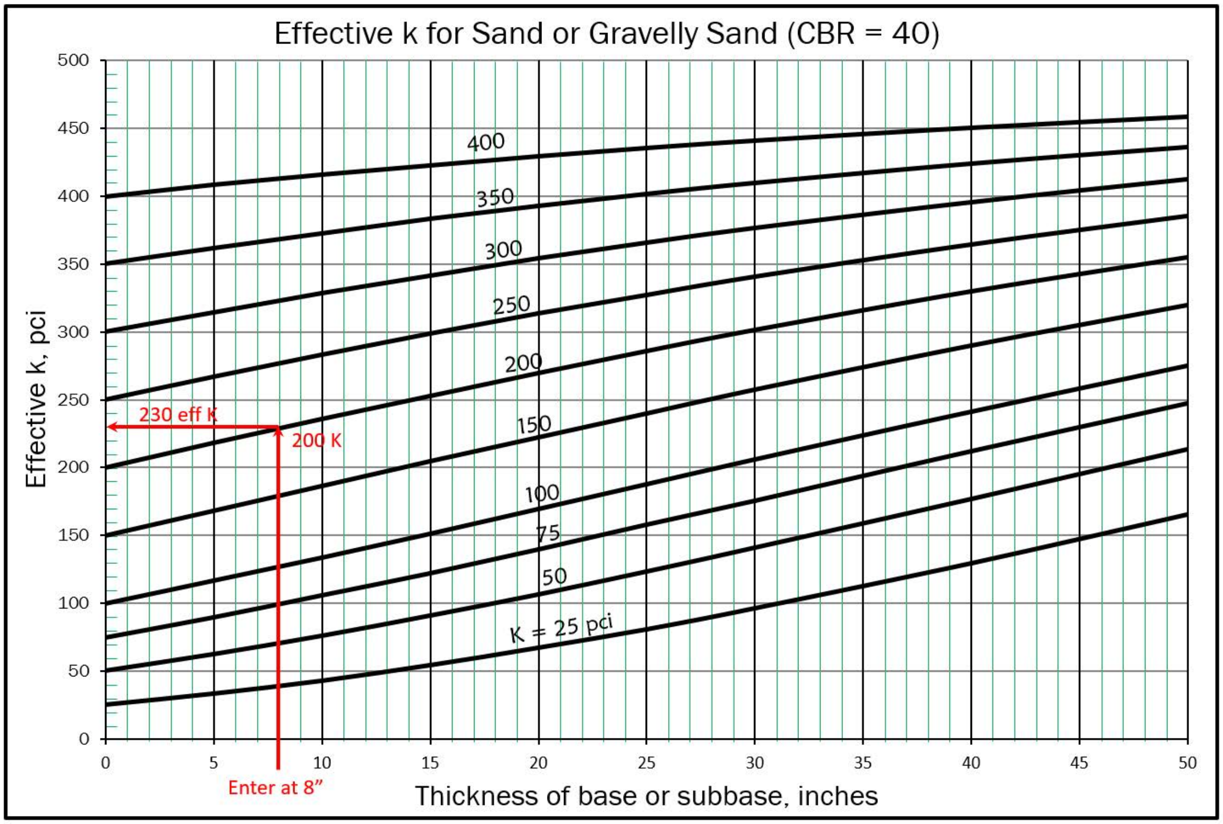
Figure 7-3 CBR to k Conversion Profile



7-3.4.5.2 Step 2 - Determine Effective k for Subbase 2.

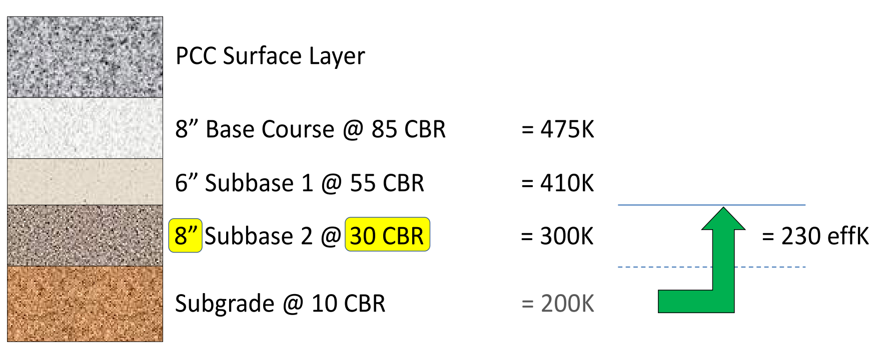
Use Figure 7-4 to determine effective k for layers with CBR values < 50. Results for this step are show in Figure 7-5.

Figure 7-4 Determine Effective k for Subbase 2



For base or subbase layers with CBR < 50 / (K < 399)

Figure 7-5 Effective k Subbase 2 Profile



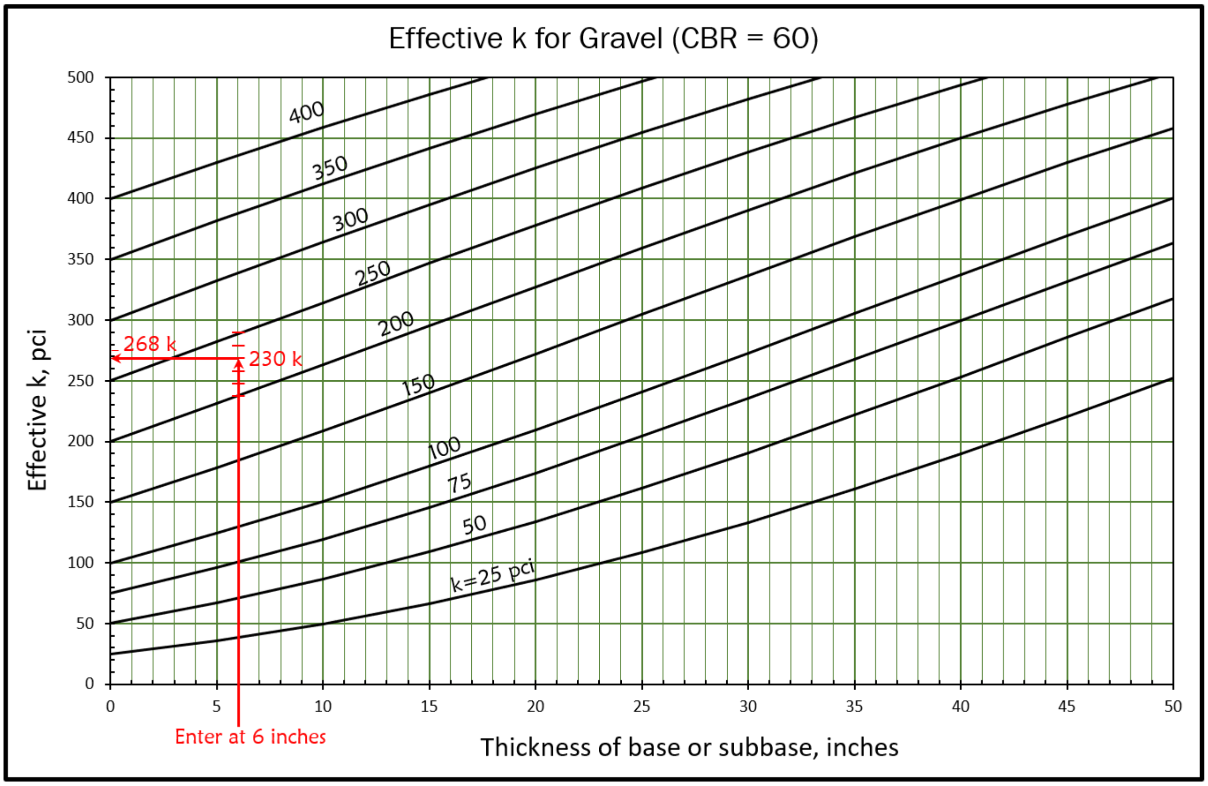
Step 2. Start with bottom layer:

Determine the effective K (230) of this layer (SG) based upon the strength and thickness (8") of the layer (SB 2) immediately above it

7-3.4.5.3 Steps 3 & 4 - Determine Effective k for Subbase 1.

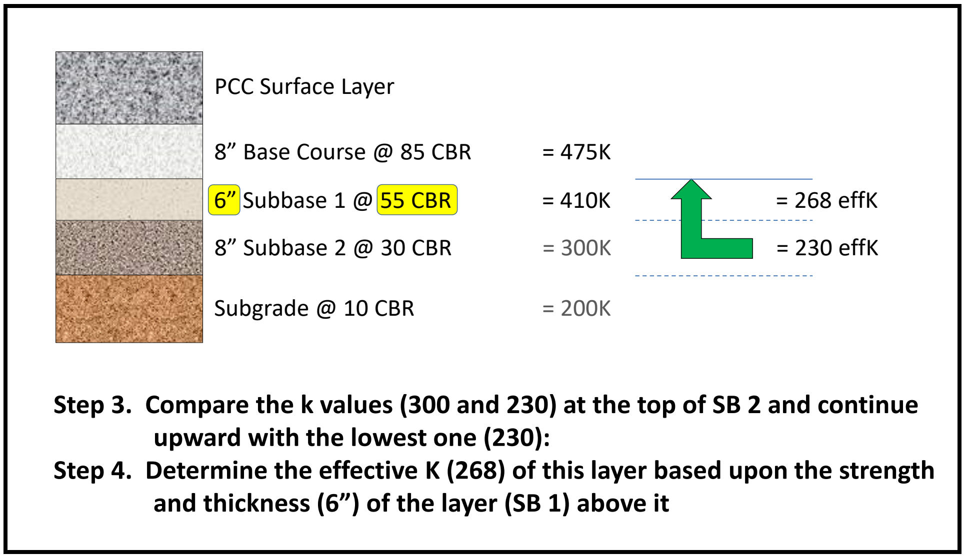
Use Figure 7-6 to determine effective k for layers with CBR values 50 ≤ CBR < 70. Results for this step are show in Figure 7-7.

Figure 7-6 Determine Effective k for Subbase 1



For base or subbase layers with 50 ≤ CBR < 70 / (399 ≤ k < 457 pci)

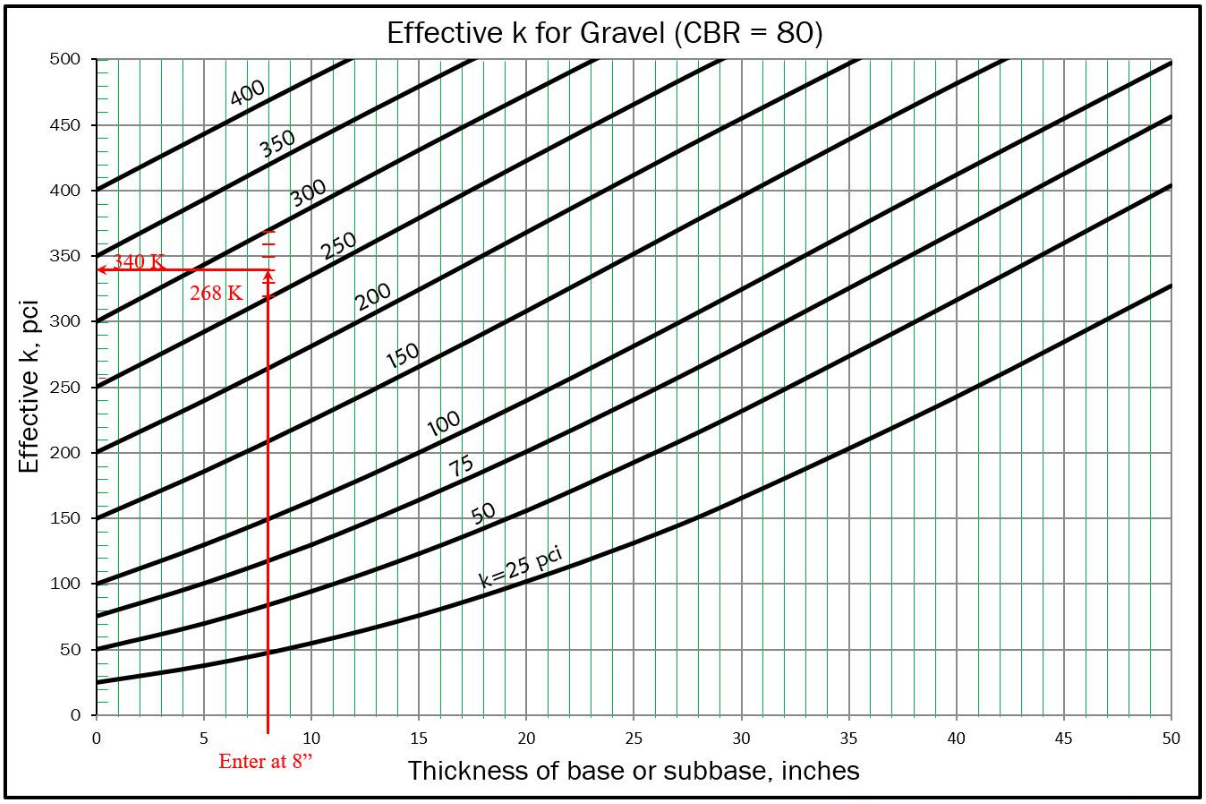
Figure 7-7 Effective k Subbase 1 Profile



7-3.4.5.4 Steps 5 & 7 - Determine Effective k for Base Course.

Use Figure 7-8 to determine effective k for layers with CBR values 70 ≤ CBR <90. Results for this step are shown in Figure 7-9. Use the lower of the measured k or computed effective k. In this case, use 435 pci to evaluate the structure.

Figure 7-8 Effective k Base Course Determination



For base or subbase layers with 70 ≤ CBR < 90 (457 ≤ K < 490)

Figure 7-9 Effective k Base Course Profile

Step 5. Compare the K values (410 and 268) at the top of SB 1 and continue upward with the lowest one (268):

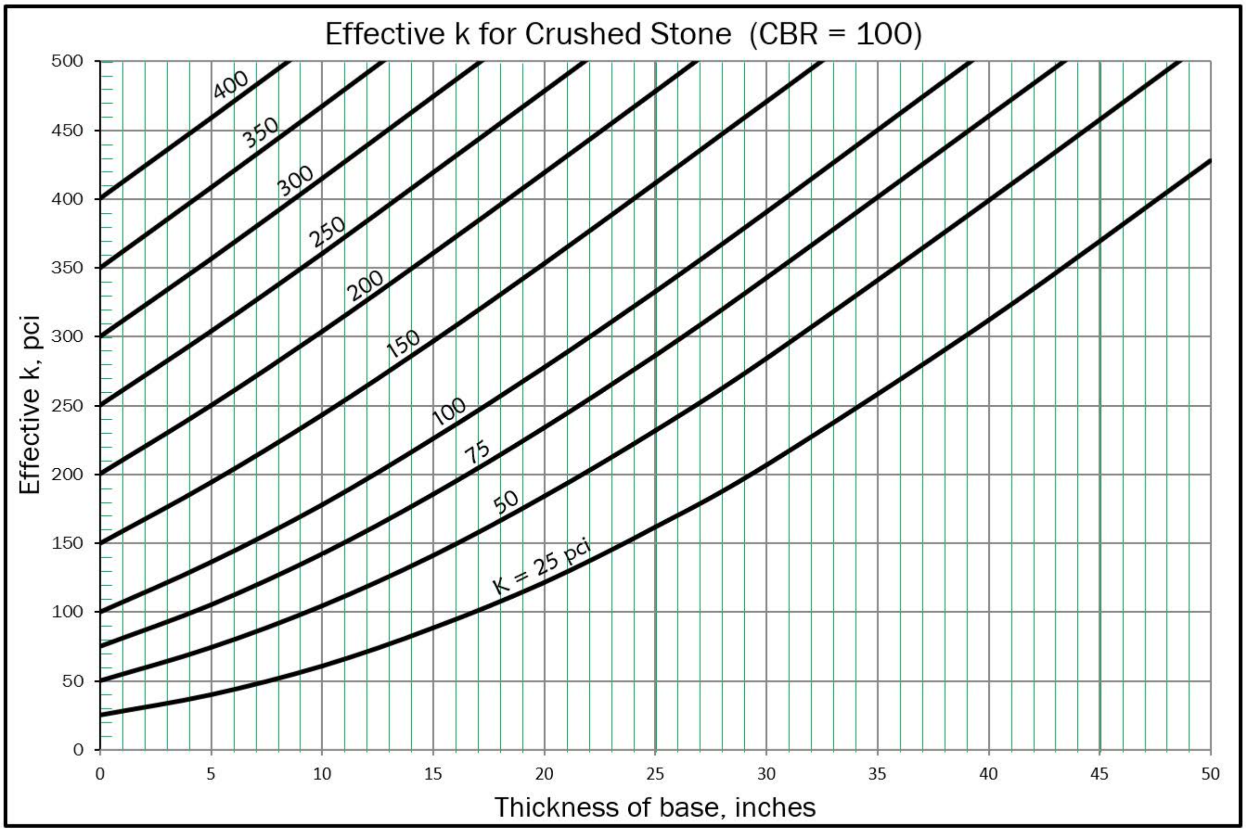
Step 6. Determine the effective K (340) of this layer based upon the strength and thickness (8”) of the layer (BC) above it

Step 7. Compare the eff K values of the layers immediately beneath the PCC (in this case 475 and 340) and use the lowest eff K (340) to evaluate the PCC

7-3.4.5.5 Effective k Crushed Stone Base Course.

While not used in the example problem, the set of curves in Figure 7-10 are used to determine the effective k when the material is crushed stone (CBR 100).

Figure 7-10 Effective k Crushed Stone Base Course Determination



For base layers with CBR $\geq$ 90 / (K $\geq$ 490)

7-3.5 Rigid Pavement Analysis.

7-3.5.1 Westergaard (k) Evaluation Procedure.

Once the thickness, flexural strength, and k values are selected for the respective layers, use these values to determine the critical tensile stresses produced within the slab by the vehicle loading based on the Westergaard procedure and assuming constant tire pressure. Note that results using the current criteria will differ from earlier criteria given that the procedure now assumes constant pressure rather than constant contact area used in past versions of this UFC. The objective of the analysis is to determine the allowable load and allowable passes for the structure. PCASE automates the analysis procedure outlined in this chapter and in Appendix D. The procedure for generating aircraft curves using the current criteria is in TSPWG M 3-260-03.02-19.

7-3.5.2 Procedure for Determining Allowable Gross Load (AGL).

The inputs for this analysis are the traffic mix with the load and number of passes for each vehicle in the mix defined, the pavement structure, and the traffic area. Determine the controlling/representative vehicle and equivalent passes based on one of the traffic analysis procedures outlined in Chapter 4. Compute the design factor based on the flexural strength and load transfer. Perform the allowable coverages calculation using the Westergaard (k) procedure to determine the free edge bending stress for the pavement structure. The bending stress is based on the controlling/representative vehicle load and the design factor. Then use the allowable coverages to compute the cumulative damage factor (CDF). If the CDF is less than 1, increase the Gross load and repeat the analysis procedure. If the CDF is greater than 1, decrease the load and repeat the analysis procedure. When CDF equals 1, use that value for the AGL. See Appendix D for details on this procedure.

7-3.5.3 Procedure for Determining Allowable Passes.

The inputs for this analysis are the traffic mix with the load and number of passes for each vehicle in the mix defined, the pavement structure, and the traffic area. Determine the controlling/representative vehicle and equivalent passes based on one of the traffic analysis procedures outlined in Chapter 4. Perform the allowable coverages calculation using the Westergaard (k) procedure with the free edge bending stress calculated for the pavement structure based on the controlling/representative vehicle load and the design factor that is computed based on the flexural strength and load transfer. See Appendix D for details on this procedure.

7-4 REINFORCED CONCRETE PAVEMENTS.

The process and data required to evaluate reinforced concrete pavements is essentially the same as those for plain concrete pavements, except the percent steel is also required.

7-4.1 Reinforcing Steel.

The reinforcing steel in a reinforced concrete pavement is normally located at or above the neutral axis of the pavement section. If the steel is below the neutral axis, it affects the determination of the flexural strength and the static modulus of elasticity in flexure. Therefore, when the reinforcing steel falls below the neutral axis in a test beam, turn the beam over and test it with the reinforcing steel above the neutral axis. The split tensile test cannot be performed on a core with reinforcing steel although it may be possible to obtain a core to test with no reinforcing steel. If the pavement is thick enough, saw the core just below the reinforcing steel and perform the split tensile test on the lower, non-reinforced portion.

7-4.2 Reinforced PCC Evaluation Procedure.

Determine the percentage of steel reinforcement S per foot of pavement cross-sectional area using Equation 7-5 then use Figure 7-11 to convert the existing reinforced pavement thickness (h_r) to an equivalent thickness (h_E) of plain concrete pavement and calculate the load-bearing capability using plain concrete equivalent thickness.

Equation 7-5. Steel Reinforcement Required

$$S = \frac{A_s}{A_p} * 100$$

Where:

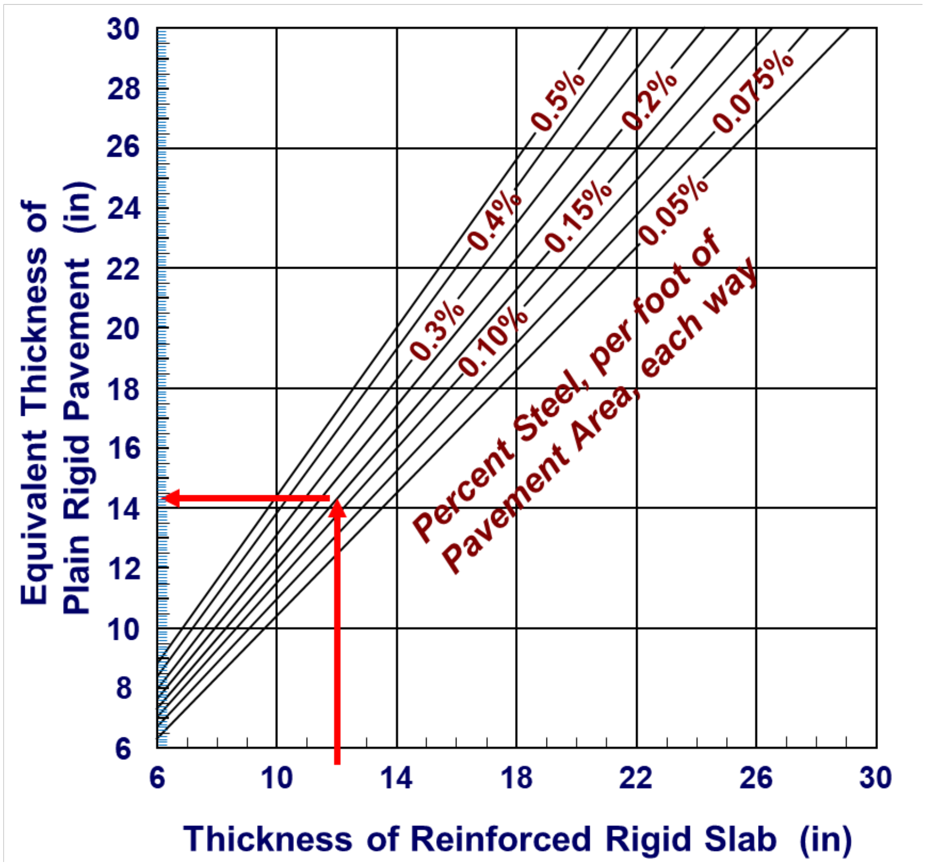
A_s = *cross-sectional area of the reinforcing steel per foot of pavement width or length, square inches*

A_p = *cross-sectional area of pavement per foot of pavement width or length, square inches*

7-4.2.1 Determine Equivalent Plain PCC Thickness of Reinforced PCC.

Compute the percent steel in both the longitudinal and transverse directions. Typically, it will be the same in both directions, but if there is a difference, use the smaller value. Next, enter Figure 7-11 with the known value of h_r, thickness of reinforced PCC pavement. Make a vertical projection and extend it until it intersects the diagonal line representing the computed value of S. Then make a horizontal projection to the left until it intersects the scale line representing the value for h_E, thickness of plain PCC equivalent that would have the same load-carrying capacity as the reinforced concrete pavement. When S is less than 0.05, h_E will equal h_r. When S is greater than 0.5, use the diagonal line representing S = 0.5 percent to determine h_E.

Figure 7-11 Reinforced to Plain PCC, Equivalent Thickness



7-4.2.2 Evaluating Reinforced PCC Overlay or with Stabilized Base.

Determining the equivalent thickness of a reinforced PCC overlay is a two-step process. First, determine the equivalent plain PCC thickness, then determine the equivalent thickness using the fully, partially, or unbonded overlay equivalent thickness calculation described in paragraph 7-4. When a reinforced concrete pavement is placed over a stabilized layer, determine the equivalent thickness of plain concrete pavement as described above using Figure 7-11, then determine the equivalent thickness h_E of the PCC and stabilized layer using Equation 7-1. See reinforced PCC equivalent thickness calculation examples in the PCASE Getting Started module and *User Guide*.

7-5 RIGID OVERLAY ON RIGID PAVEMENT.

The first step in rigid pavement structure with rigid overlay(s) is determining the equivalent thickness of the combined pavement structure. The equivalent thickness is defined as a single thickness of plain concrete pavement with the same load-carrying capacity as the combined thickness of the rigid overlay(s) and the rigid base pavement. Overlay equivalent thickness calculation examples are provided in the PCASE Getting Started module and *User Guide*.

7-5.1 Determining Equivalent PCC Thickness of a Rigid Overlay.

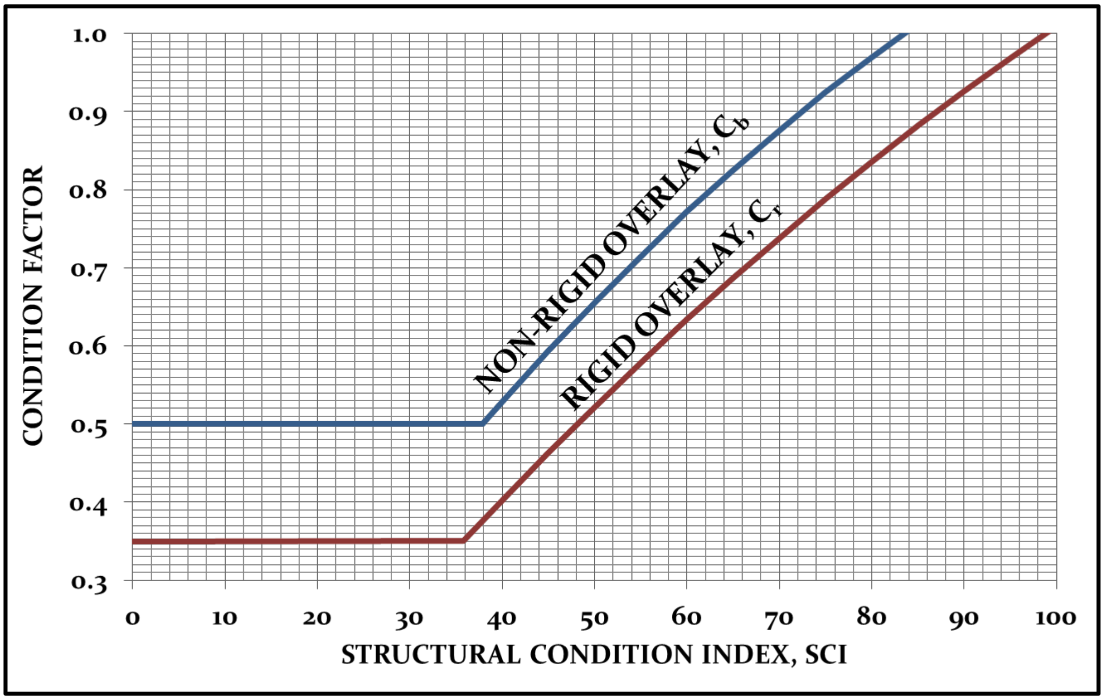
The condition of the base pavement is a key input in determining the equivalent thickness. Structural distresses in the base slab will migrate through the overlay so if the overlay pavement only has minimal structural defects (e.g., reflected longitudinal and transverse cracking as opposed to joint reflective cracking), it is an indication the base pavement is still in good condition. FWD testing or evaluation data from prior to the overlay can also help discern the condition of the base slab and strength of underlying surface layers. Start at the bottom of the structure and determine the equivalent thickness of the base pavement and overlay using the appropriate equation for the overlay type. If there is more than one overlay, use that equivalent thickness and the next overlay to determine the combined equivalent thickness. Continue this procedure with any remaining overlays. When there is variability in the base slab and overlay thicknesses across a section, use the average thickness of each layer in the section to determine the equivalent thickness.

7-5.1.1 PCC Overlay Condition Factors.

Estimate the rigid overlay condition factor (Cr) based on the current surface condition (PCI) and percent of load-related distresses that are used to compute the structural condition index (SCI). PCASE computes the Cr value, but if PCI data is not available, use the recommended Cr values below. In addition, use the values below when it is not possible to visually determine the condition of the existing base PCC slab. The relationship between the SCI and Cr is shown in Figure 7-12. An SCI of 100 indicates good condition and an SCI of 0 indicates poor condition.

- Cr = 1.00 for base PCC in very good condition. There are no structural or reflective cracks in the rigid overlay. If the condition of the base pavement cannot be determined or is unknown, do not use this value.
- Cr = 0.75 for base PCC in good condition. There are a few initial cracks in the surface PCC due to loading or reflective cracks from the base PC slabs, but no progressive cracks.
- Cr = 0.35 for badly cracked base PCC layer. Approximately 60 percent of the slabs in the overlay contain medium- or high-severity cracking or 50 percent of the slabs contain high-severity cracks.

Figure 7-12 SCI – Condition Factor Relationship



7-5.1.2 Partially Bonded PCC Overlays.

If the overlay slab was cast directly on the base slab and no effort was made to break the bond between the overlay and the base pavement by means of a tack coat, sand, paper, bituminous concrete, or other materials placed between the overlay and the base pavement, treat it as a partially bonded overlay. Compute the equivalent thickness h_E of the combined partially bonded overlay and base pavement using Equation 7-6.

Equation 7-6. Equivalent Thickness for Partially Bonded PCC Overlays

$$h_E = \sqrt[1.4]{(h_o)^{1.4} + Cr\,(h_b)^{1.4}}$$

Where:

h_o = thickness of rigid overlay pavement, inches
C_r = coefficient representing condition of rigid base PCC layer
h_b = thickness of rigid base pavement, inches

7-5.1.3 Unbonded PCC Overlays.

If a bond-breaker layer was used between the rigid overlay and the rigid base pavement, treat it as an unbonded overlay. Compute the equivalent thickness h_E of the combined unbonded overlay and base pavement using Equation 7-7. Do not give any thickness credit to the bond breaker layer if it is less than 4 inches (102 millimeters). If the thickness of the bond breaker is greater than 4 inches (102 millimeters), evaluate it as a composite pavement.

Equation 7-7. Equivalent Thickness for Unbonded PCC Overlays

$$h_E = \sqrt{(h_o)^2 + Cr(h_b)^2}$$

7-5.2 Structural Analysis Using the h_E Value.

After determining the h_E value using Equation 7-6 or 7-7, determine the weighted average flexural strength (R) of the overlay and base pavement using Equation 7-8 and use these values to determine the load capability the same as a plain PCC pavement.

Equation 7-8. Weighted Average Flexural Strength

$$R = \frac{h_o(R_o) + h_b(R_b)}{h_o + h_b}$$

Where:
h_o = *thickness of overlay*
R_o = *flexural strength of overlay*
h_b = *thickness of base slab*
R_b = *flexural strength of base slab*

7-6 FLEXIBLE OVERLAY ON RIGID PAVEMENT.

First determine if the flexible (e.g., asphalt) overlay meets the structural design (minimum thickness) requirements in UFC 3-260-02. Thin overlays used to correct surface defects are not given structural credit. When the overlay meets minimum thickness requirements, the procedures outlined below recommend evaluating the pavement as both a rigid and flexible structure and using the method that yields the higher AGL. Use the procedures in Chapter 6 and treat the base slab as a base course for the flexible analysis. For the rigid pavement analysis, determine the equivalent thickness h_E of the combined pavement structure. The equivalent thickness is defined as a single thickness of plain concrete pavement with the same load-carrying capacity as the combined thickness of the flexible overlay(s) and the rigid base pavement. Overlay equivalent thickness calculation examples are provided in the PCASE Getting Started module and *User Guide*.

7-6.1 Determining Equivalent PCC Thickness of a Flexible Overlay.

Just as with a rigid overlay, the condition of the base pavement is a key input in determining the equivalent thickness. In addition, the degree of cracking allowed in the base slab is also required for the equivalent thickness computation. Start at the bottom of the structure and determine the equivalent thickness of the base pavement and overlay using the appropriate equation for the overlay type. If there is more than one overlay, use that equivalent thickness and the next overlay to determine the combined equivalent thickness. Continue this procedure with any remaining overlays. When there is variability in the base slab and overlay thicknesses across a section, use the average thickness of each layer in the section to determine the equivalent thickness.

7-6.1.1 Flexible Overlay Condition Factor.

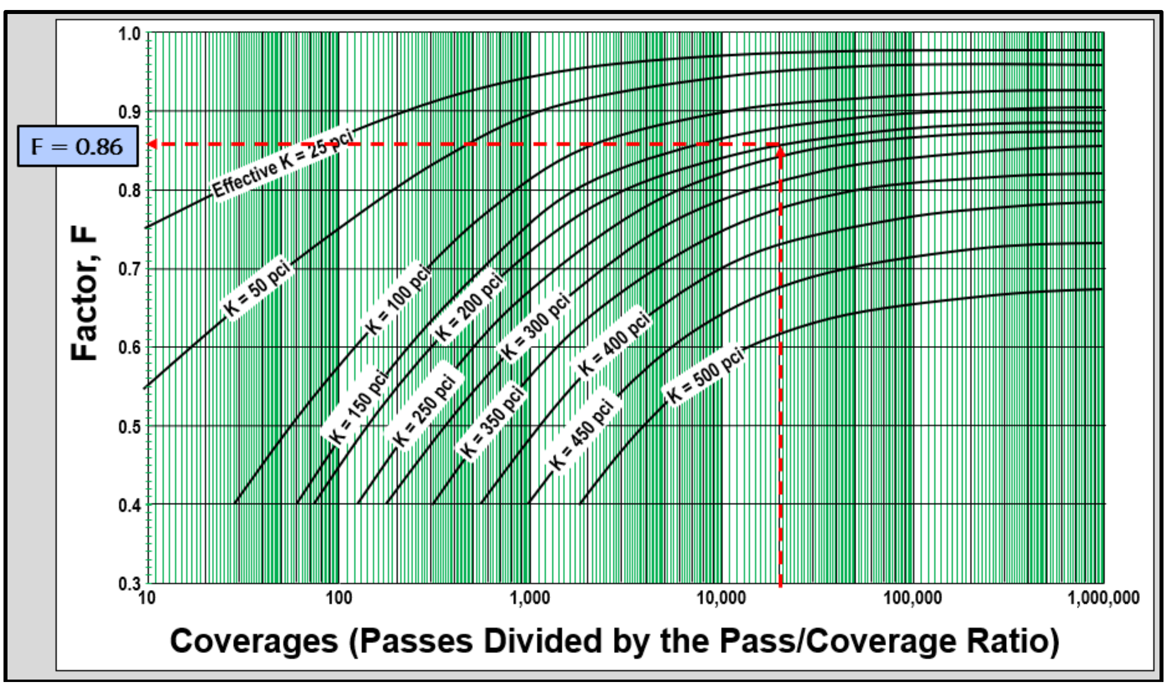
Estimate the flexible overlay condition factor (C_b) based on the current surface condition (PCI) and percent of load-related distresses, which are used to compute the SCI. PCASE will compute the Cb value, but if PCI data is not available or if it is not possible to visually determine the condition of the existing base PCC slab, use the recommended Cb values below. The relationship between the SCI and Cb is shown in Figure 7-11. An SCI of 100 indicates good condition and an SCI of 0 indicates poor condition:

- C_b = 1.0 Use if there are no reflective distresses on the asphalt surface and it is positive that the base pavement is in good condition.
- C_b = 0.8 Use if there are only joint reflective distresses on the asphalt surface.
- C_b = 0.5 Use if there are reflective cracks in addition to reflective joints.

7-6.1.2 Controlled Cracking with F Factor.

The F factor in the equivalent thickness Equation 7-9 defines the degree of cracking allowed in the rigid base pavement during the life of the pavement. It is dependent on the modulus of subgrade reaction k (measured or computed directly under the pavement) and traffic intensity in terms of coverages (passes/pass to coverage ratio of the critical aircraft). PCASE computes the F factor based on the relationship shown in Figure 7-13. The maximum k value used to compute the h_E value is 500 pci. The equivalent thickness equation can yield h_E values greater than the combined thickness of h_b + t for some F factors. If this occurs, use the h_b + t value for h_E.

Figure 7-13 SCI – Condition Factor Relationship



7-6.1.3 Flexible Overlay on Rigid Pavement – Rigid Analysis.

Use the measured pavement thicknesses for the base slab and overlay and the Cb and F values described above to calculate the equivalent thickness h_E in Equation 7-9. The equivalent thickness, h_E, is defined as the thickness of a plain concrete pavement having the same load-carrying capacity as the combined overlay section. Use h_E and the flexural strength of the base slab to determine the load capability using the same procedure as a plain PCC pavement.

Equation 7-9. Equivalent Thickness for Flexible Overlay

$$h_E = \frac{1}{F}(0.33\,t + C_b\,h_b)$$

Where:

t = *thickness of non-rigid overlay pavement, inches*
h_b = *thickness of rigid base pavement, inches*
C_b = *coefficient representing the condition of the rigid base*
F = *a factor which controls the degree of cracking in the rigid base pavement (Several F Factor curves are included in TSPWG M 3-260-03.02-19.)*

7-6.2 Flexible Overlay on Rigid Pavement – Flexible Analysis.

The flexible pavement evaluation method uses the procedures in Chapter 6 and considers the flexible overlay on rigid pavement as a flexible pavement, with the rigid base pavement assumed to be a high-quality base course with a CBR of 100 and the subbase and subgrade characterized by their respective CBR values.

7-6.3 Other Considerations.

7-6.3.1 PCC Material Property Limitations.

When conditions indicate PCC or soil properties are not typical, modify the evaluation accordingly. Consider the possible factors that are influencing the material properties such as those outlined below. Discuss the effect that any of the following factors may have on the evaluation of the pavement in the narrative portion of an evaluation report.

- High moisture absorption and shrinkage of the PCC
- High variations in daily ambient air temperature
- Wide variation in the flexural strength within a given pavement section
- Heterogeneous subgrade, base, or moisture conditions resulting in wide variations in modulus of subgrade reaction values
- Non-rigid overlays (bituminous concrete and flexible overlay) that do not meet design requirements for flexible pavements
- Poor PCC joint load transfer (e.g., NDT deflection ratios)

7-6.3.2 Joint Load Transfer.

As stated previously (see paragraph 5-3.9.2), rigid pavement criteria assume 25 percent joint load transfer. If test data indicate this assumption is not valid, adjust the percent load transfer to reflect what was measured.

7-6.3.3 Asphalt Overlay Quality.

The evaluation procedure outlined above assumes the asphalt concrete meets UFC 3-260-02 design requirements. Determine whether surface cracking is the result of inadequate strength in the overlay or reflective cracking from joints and structural defects in the rigid base pavement. When the surface condition indicates the quality assumption is not valid, it may be necessary to conduct additional tests on the asphalt overlay as outlined in Chapter 3 to determine whether it meets design requirements. Construction records may also be used to determine the quality of the overlay materials. When the asphalt concrete does not meet design requirements, discuss the consequences, such as rutting and raveling, in the narrative portion of the evaluation report. Raveling can be a sign of a poor mix design or construction issues. Rutting or surface cracking can be signs of inadequate strength or asphalt compaction.

7-6.3.4 Comparing the Rigid and Flexible Analysis Procedure.

Typically, the rigid overlay evaluation method yields higher allowable gross weights than the flexible procedure and will be used for reporting purposes. However, when the flexural strength of the rigid base pavement is less than 400 psi (2.8 MPa) or the k value of the foundation is greater than 200 pci, the flexible pavement evaluation method can yield the higher allowable gross weight at a selected pass level. Therefore, especially when the test results indicate that the flexural strength of the rigid base pavement is less than 400 psi (2.8 MPa) or the k value is greater than 200 pci, evaluate the flexible overlay on rigid pavement by both methods to determine which yields the higher allowable gross weight for a selected pass level.

7-6.4 Asphalt Additional Overlay Thickness.

Use Equation 7-10 to determine the additional asphalt overlay thickness required to support aircraft operations.

Equation 7-10. Additional Overlay Thickness Calculation

$$t_{ao} = 3 \cdot [F \cdot h_d - h_E]$$

Where:

t_{ao} = *additional overlay required, inches*
h_d = *new pavement PCC layer design thickness, inches*
h_E = *equivalent thickness of existing PCC base and overlay, inches*
F = *a factor which controls the degree of cracking in the rigid base pavement, see paragraphs 7-6.1.2 and 7-6.1.3.*

7-7 RIGID OVERLAY ON FLEXIBLE PAVEMENT.

The flexible pavement layer (e.g., asphalt concrete) in a rigid overlay on flexible pavement structure is treated as a base course for the rigid overlay. Determine the k value on the surface of the flexible pavement with the plate-bearing test subject to the limitations described in paragraph A-5.9 or using the effective k procedure described in paragraph 7-3, but in no case use a k value greater than 500 pci.

7-7.1 Rigid Overlay on Flexible Pavement Analysis.

Select representative thickness values for the rigid overlay and other layers in the structure, determine the flexural strength of the rigid overlay, and modulus of subgrade reaction (k) on the surface of the existing flexible pavement as described in paragraph A-5.9.2. Evaluate the rigid overlay on flexible pavement using the same procedures used for plain PCC pavement on a base course.

7-8 COMPOSITE PAVEMENT.

A composite pavement consists of three or more pavement layers. This section specifically addresses the situation in which there is a rigid layer over asphalt over a rigid base slab. The analysis procedure depends on whether the asphalt layer is less than or greater than 4 inches (102 millimeters).

7-8.1 Asphalt Layer Less than 4 Inches (102 Millimeters).

When the thickness of the asphalt layer is less than 4 inches (102 millimeters), treat the rigid surface as an unbonded overlay, with the thickness of the asphalt layer assumed to be a bond-breaking layer. Determine the layer thicknesses of each layer in the structure, the equivalent thickness of the asphalt and base pavement, the flexural strength of the rigid overlay and base pavement, and the k value of the foundation materials beneath the rigid base pavement. Estimate the condition of the base slab as described in paragraph 7-5.1.1 and use Equation 7-7 for an unbonded overlay to determine h_E.

7-8.2 Asphalt Layer Greater than or Equal to 4 Inches (102 Millimeters).

When the thickness of the asphalt between the rigid pavements is greater than or equal to 4 inches (102 millimeters), treat the surface layer as rigid pavement on a base. Determine thickness of each layer in the structure, the flexural strength of the rigid overlay, and the k value on the surface of the asphalt layer beneath the rigid surface layer. Use the procedure described in paragraph 7-7.1 for a rigid overlay on a flexible pavement to determine the effective k.

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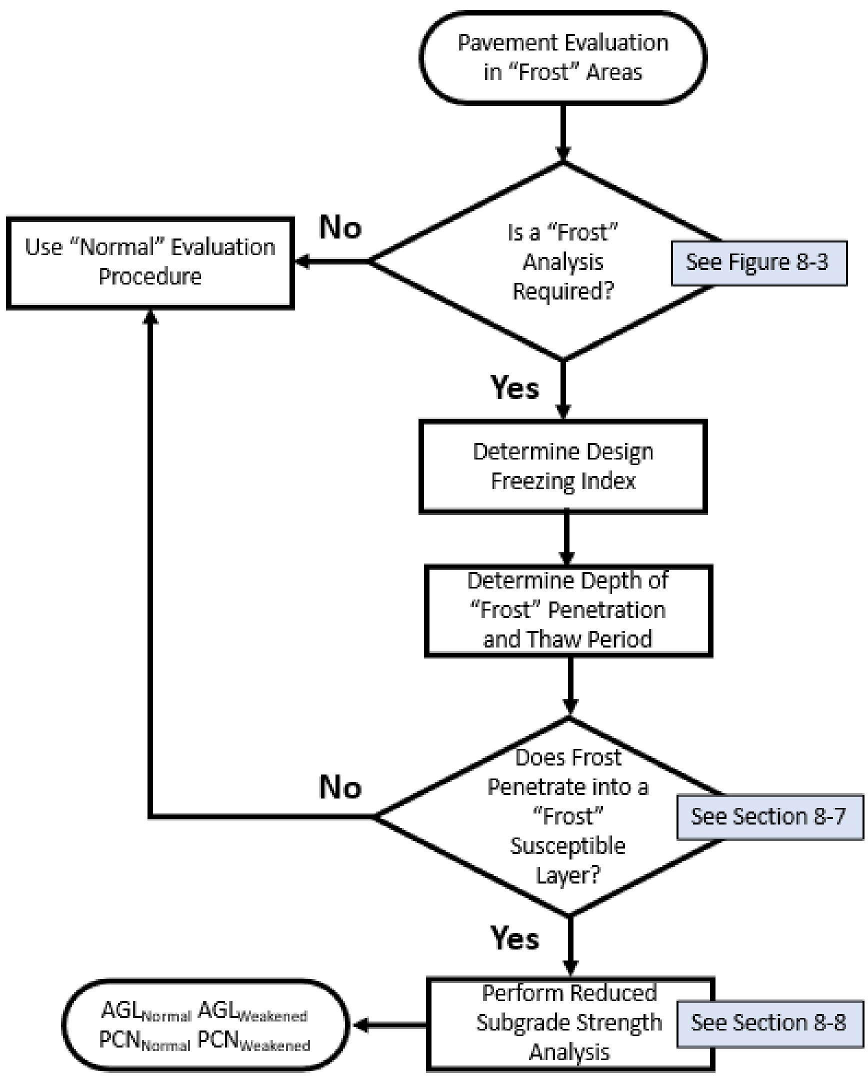
CHAPTER 8 PAVEMENT FROST EVALUATION

8-1 PAVEMENT FROST EVALUATION PROCESS.

The term frost evaluation is used to describe the process of determining if a pavement is susceptible to the detrimental effects of frost action and, if so, analyzing the pavement structure to determine the impact of these effects on the load-carrying capacity of the pavement during the thaw period. Figure 8-1 describes the overall process. The first step is to determine if a frost analysis is warranted. If it is, compute the design freezing index (DFI) using climate data from the WorldIndex database, then determine the depth of frost penetration and start and duration of the freezing season. If the depth of frost penetration does not penetrate into a layer of frost-susceptible material, use the normal evaluation procedure. If it does, then use the reduced subgrade strength procedure. Terms used in this chapter that are not explained in the text are defined in the glossary in Appendix F.

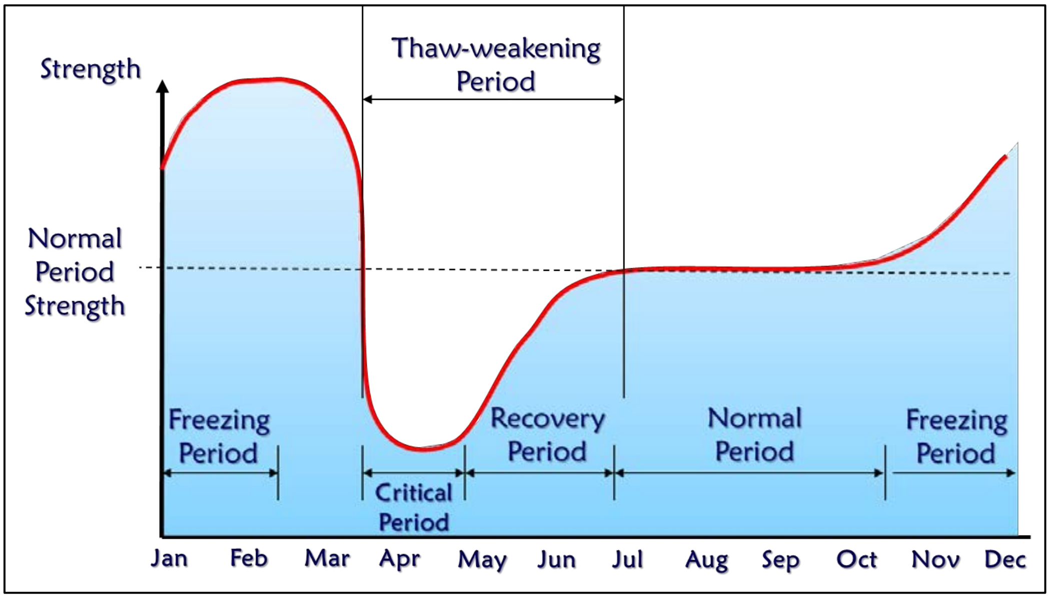
Figure 8-1 Pavement Frost Evaluation Process



8-2 FROST ACTION.

Frost action is a general term for freezing and thawing of moisture in materials and the resultant effects on these materials, the overall structure, and adjacent structures. Detrimental effects can occur when a pavement structure is exposed to freezing temperatures, has frost-susceptible soils, and has a source of water near the freezing front. When these conditions exist, water is drawn upward to the freezing front, creating ice lenses, which can result in pavement frost heave that increases the roughness of the pavement surface. As the ice melts, water does not readily drain or redistribute itself, saturating and thus weakening the soil and reducing the pavement structure's load-bearing capacity during the thaw period. The weakened pavement transitions back to a normal state as the soil drains, pore water pressure dissipates, and soil reconsolidates. Figure 8-2 provides a conceptual graphic of the freeze-thaw cycle.

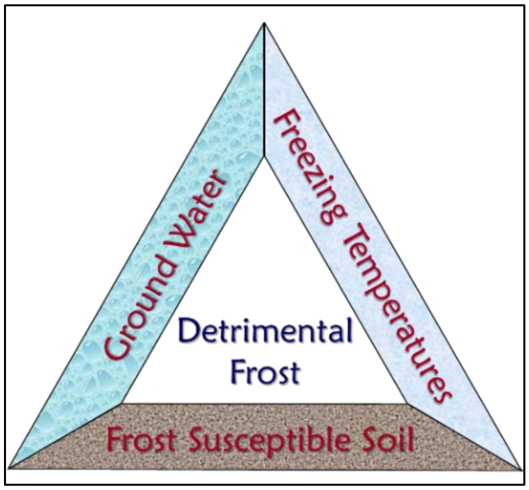
Figure 8-2 Freeze-thaw Cycle



8-3 WHEN TO PERFORM A FROST EVALUATION.

A frost evaluation is not warranted unless all the elements that increase the risk of detrimental frost action exist as shown in Figure 8-3. Additional soil sampling and laboratory testing is required to determine the moisture content, dry density, and frost susceptibility of the soil. This information is used to determine the depth of frost penetration and potential loss of load-carrying capability.

Figure 8-3 Detrimental Frost Action



8-3.2 Temperature.

The average daily air temperature at the location must remain below freezing for sufficient time for the freezing front to extend into frost-susceptible soil layers. If it does not, frost analysis is not warranted.

8-3.3 Frost-Susceptible Soil.

The frost susceptibility of soil is defined by the percent of soil finer than a #200 (.075 mm) sieve by weight and the percent finer than 0.02 mm by weight. This determines the frost group of the soil, which is described in more detail in paragraph 8-6.1.2. Non-frost-susceptible soils have a minimal risk of detrimental frost action.

8-3.4 Ground Water.

Generally, if the water table is below 10 feet (3 meters), detrimental frost action is not a problem.

8-3.5 Evidence of Detrimental Frost Effects.

Even when it appears all the elements shown in Figure 8-3 and described above exist, check for evidence of damage due to detrimental frost action. If the conditions described below do not exist, frost analysis may not be required.

- Pavement heave and cracking
  - Differential heave caused by swelling of materials in subgrade and base due to frost action
  - Differential settlement caused by soil reconsolidation after heave
- Excessive cracking of rigid pavement
  - Pumping along cracks and joints
  - Durability (D) cracking

   - Excessive joint and crack spalling
   - Longitudinal cracking or other load-related distresses in non-traffic areas
- Accelerated cracking of flexible pavement
   - Alligator cracking or other load-related distresses
   - Distresses located in non-traffic areas
   - Accelerated deterioration along cracks

8-3.5.1 Detrimental Frost Effects.

Detrimental frost effects include frost heave and thaw weakening. Frost heave occurs when the pavement surface is raised. It is directly associated with ice segregation and is visible evidence on the surface that ice lenses have formed in the subgrade, subbase, or base layer materials. When ice segregation occurs in a frost-susceptible soil, the soil is subsequently weakened during prolonged thaw periods that can occur during winter partial thaws and early in the spring. When the segregated ice melts, it leads to excess water in the base, subbase, or subgrade that cannot drain through the still-frozen underlying soil. Drainage could also be restricted laterally at this time of the year; thus, the period of severe weakening may last several weeks. When the pavement structure has a drainage layer, this period of severe thaw-weakening can decrease.

8-3.5.2 Frost Heave.

Pavements constructed over F4 subgrade soils, and in some instances over F3 soils, as described in Table 8-1, may experience heave. Heave can be uniform or non-uniform, depending on variations in exposure to solar radiation, the character of the soil, and groundwater conditions underlying the pavement. Non-uniform heave results in unevenness or abrupt changes in grade at the pavement surface. This surface roughness may be objectionable for aircraft with high landing and takeoff speeds. If experience indicates this is the case, the report should include the locations and descriptions of the objectionable roughness. Obtain surface elevations at least once a month during the following winter to determine the magnitude of the detrimental heave.

8-3.5.3 Thaw Weakening.

The load-bearing capacity of both flexible and rigid pavements can be severely reduced during critical weakening periods; however, the reduction is less critical for rigid than for flexible pavements. Rigid pavements experience a smaller reduction because the subgrade has less influence on the supporting capacity of rigid pavements than on that of flexible pavements. Subgrade soils under rigid pavements are subjected to less shearing deformation and remolding during critical weakening periods.

Soils, such as clays, which often show no frost heave, may significantly lose supporting capacity during thawing periods. Frost-susceptible granular unbound base materials may also weaken significantly during frost-melting periods because of increased saturation and associated decrease of moisture tension, combined with reduced density that is derived from expansion in the previously frozen state. As the percent of fines in granular material increases, so does its potential for thaw weakening during frost-melting periods due to reduction of its permeability.

Traffic loads may cause excess hydrostatic pressures within the pores of the frost-affected soil during thaw-weakening periods, resulting in further reduction in strength or even failure. The degree to which a soil loses strength during a frost-melting period and the duration of the period of thaw weakening depend on the soil type, temperature conditions during freezing and thawing, the amount and type of traffic during frost melting, the availability of water during freezing and thawing, and drainage conditions.

8-3.5.4 Visible Surface Effects.

Visible surface effects associated with frost action include random cracking and roughness due to differential frost heave as described above. Noticeable cracking and weakening or deflection can also occur in flexible pavements during the thaw period but may not become visible in rigid pavements during thaw until subsurface damage accumulates and leads to visible surface cracking. As a result, thaw weakening may not always be recognized as the dominant factor causing accelerated deterioration. In either case damage due to thaw weakening may be more severe than cracks caused by frost heave or low-temperature contraction because it leads to destruction of the pavement, requiring reconstruction.

Cracks in flexible pavements may be the result of contraction of the pavement during periods of extremely low temperatures. Flexible pavements that experience accelerated deterioration because of thaw weakening can show alligator cracking or other load-associated cracking at an early age. Rigid pavements can exhibit slab cracking or pumping at cracks and joints. Studies of rigid pavements have shown that cracks may develop more rapidly during and immediately following the spring frost-melting period due to differential thaw than during the period of active heave. D cracking is also a common indication of freeze-thaw damage to PCC pavements but is primarily associated with aggregates of poor quality in the concrete mixture. These are closely spaced crescent-shaped cracks that occur adjacent to longitudinal and transverse joints or free edges.

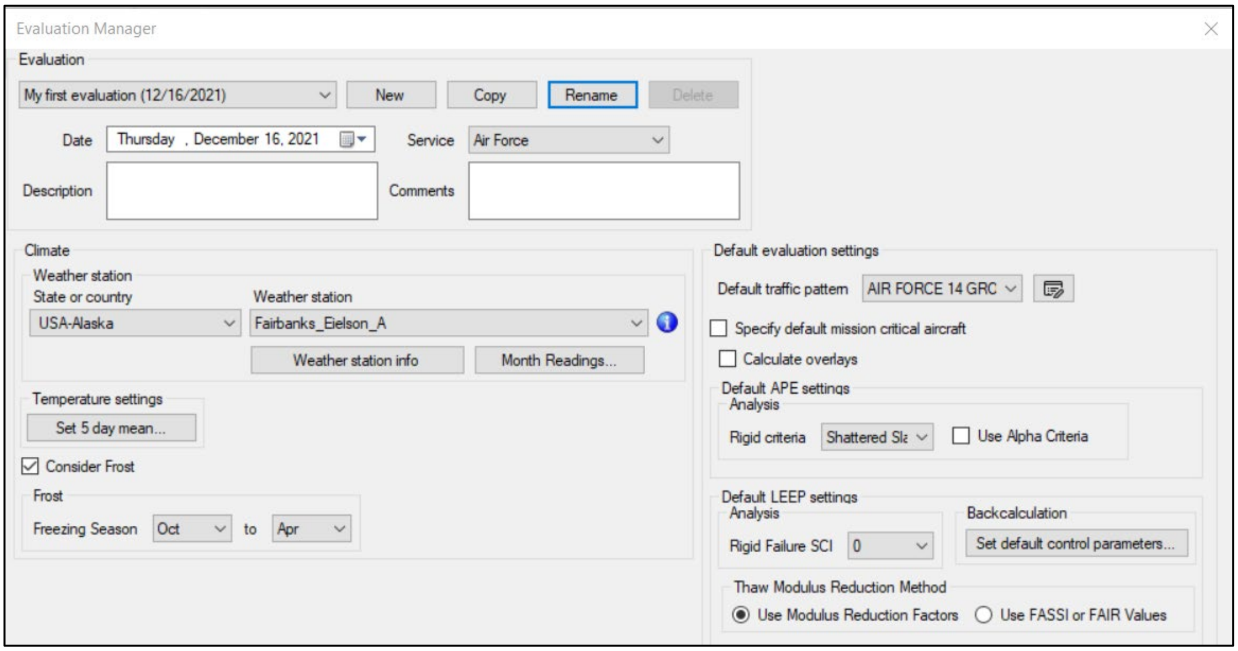
8-3.5.5 Field Inspection and Previous Records.

During pavement inspections, note any cracking, faulting, or pumping. Give particular attention to locations of transitions between cuts and fills and at any boundaries of subgrade soils of varying frost susceptibility. HWD testing can help determine where these transitions take place. Note all spalling at the edges of open cracks which can be an indication of “working cracks” caused by frost action. Construction maintenance and previous evaluation records may help in confirming whether frost-susceptible conditions exist. Records of highway performance in the vicinity of the airfield that have similar subgrade conditions may provide a clue as to whether weakening occurs because of frost melting. In the analysis of highway performance records, the evaluator should carefully note and assess the many local influences that may affect frost action, such as variations in ground-water level, soil conditions, type of pavement surface, degree of shading, north versus south slope, frequency of snow plowing, position of underlying bedrock, etc.

8-4 SETTING UP PCASE FOR FROST ANALYSIS.

When a frost analysis is required, in the Pavement-Transportation Computer Assisted Structural Engineering (PCASE) application the user must check the “Consider Frost” box on the Evaluation Manager form as shown in Figure 8-4, then select the state/country and station for the evaluation location. If there is no station for the specific location, select the station closest to the location at a similar elevation and with similar climatic conditions. This process identifies the climate data from the WorldIndex database to be used for the evaluation. Selecting the “Consider Frost” checkbox also activates additional fields on the airfield pavement evaluation (APE) and Layered Elastic Evaluation Program (LEEP) forms for use in frost analysis.

Figure 8-4 “Consider Frost” Checkbox and Select Station



8-5 DESIGN FREEZING INDEX (DFI).

The DFI is based on climate data from the WorldIndex database for the selected station. The DFI is a description of the length and severity of the winter for a given location. It is used to determine the surface freezing index which, in turn, is used to determine the depth of frost penetration. While the term “design” is used, the DFI is equally applicable to evaluation.

Historically, the DFI was defined as the average air freezing index (AFI) of the three coldest winters in the latest 30 years of record. If 30 years of record were not available, the AFI for the coldest winter in the latest ten-year period was used. This climate data was presented in maps showing the distribution of design AFI values or mean air freezing index values as described in paragraphs 8-5.5 and 8-5.6. The WorldIndex database provides a numerical solution for determining the DFI. The USACE Cold Regions Research and Engineering Laboratory (CRREL) created the WorldIndex database to aggregate climate data from the National Oceanic and Atmospheric Administration (NOAA).

8-5.1 WorldIndex Database.

The WorldIndex database is available through the PCASE program. The current version of the database was published in 2018 and uses historical surface air-temperature observations from 1980 to 2017 (37 years) at over 16,000 locations around the globe. Each station has a minimum of five years of continuous data available. The WorldIndex database is updated every five years. It aggregates data from the Global Surface Summary of Day (GSOD) database (version 7) and the Global Historical Climatology Network (GHCN) Cooperative Observer Program database, which are published by NOAA's National Centers for Environmental Information (NCEI) and the National Weather Service, respectively.

The database contains 80 air-temperature-based parameters determined for each station, including the parameters PCASE uses to determine the depth of frost penetration, the start and duration of the thaw season, and temperature data used to determine asphalt design/evaluation modulus values. All data is stored in Celsius units. Note that the WorldIndex database uses the term freezing degree-days (FDD) rather than the terms AFI or DFI. More details on the structure and content of the WorldIndex database are available in the ERDC/CRREL Technical Report TR-19-13, *WorldIndex Database Update 2018*.

8-5.2 Degree Days.

The number of degree-days for any given day is the difference between the average daily air temperature and 32 °F. The degree-days are negative when the average daily temperature is below 32 °F (freezing degree-days) and positive when above (thawing degree-days) although in both cases, the sign is typically omitted when presenting the data. Air temperatures are measured approximately 4.5 feet (1 meter) above the ground. Degree days may be computed in either Fahrenheit or Celsius units.

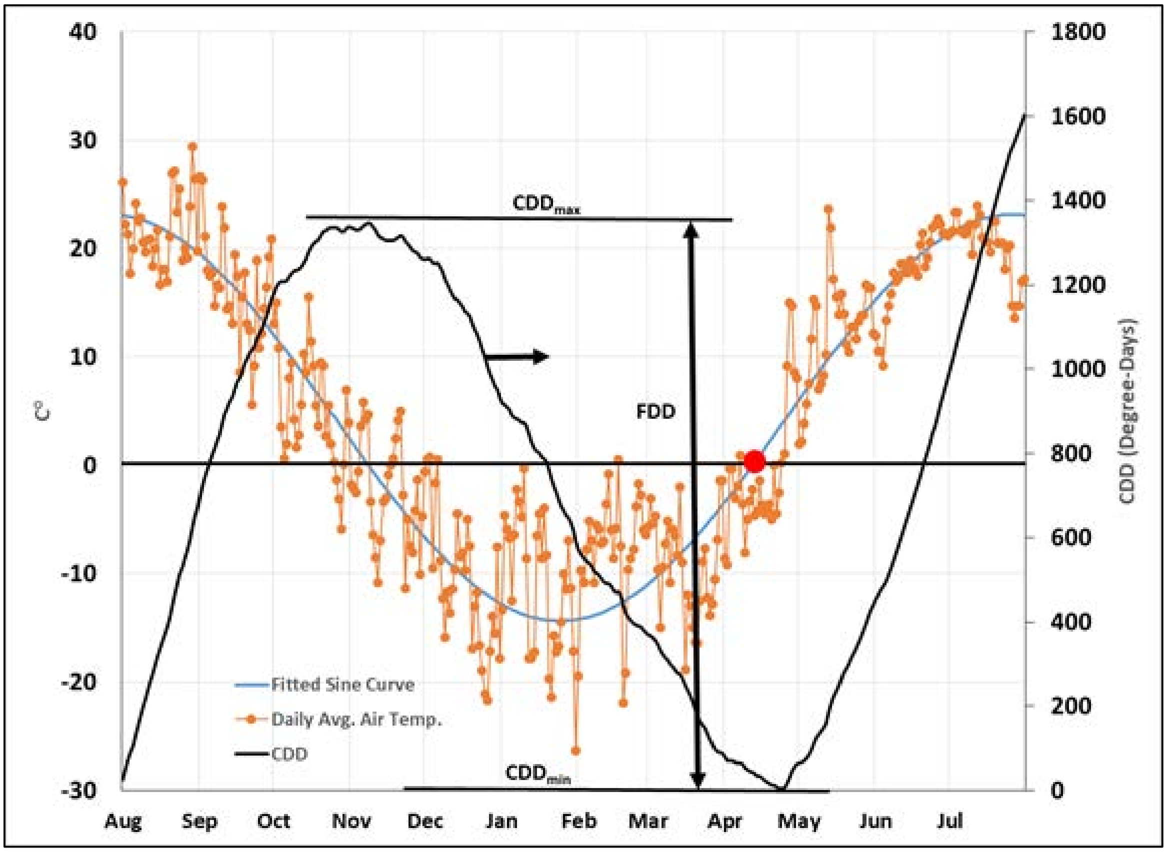
8-5.3 Cumulative Degree Days (CDD).

CDD are the arithmetic sum of FDD over time (typically a year). When CDD are plotted versus time, it generates a curve used to determine the AFI, as shown in Figure 8-5.

8-5.4 Air Freezing Index (AFI).

The AFI is the number of FDD between the highest (CDD_{max}) and lowest points (CDD_{min}) on a CDD curve versus time for a single freezing season. It is also called the annual AFI and is used as a measure of the combined duration and magnitude of below-freezing temperatures occurring during any given freezing season. Note that the AFI is shown as FDD in Figure 8-5 to reflect the terminology used in the WorldIndex database.

Figure 8-5 Air Freezing Index



8-5.5 Average Annual Air Freezing Index (AFI).

The average AFI is the average of all the annual AFIs over the period of record. As noted above, the period of record for the data in the WorldIndex database is 37 years rather than 30 years as described in past criteria documents. The WorldIndex database uses the term “average annual maximum cumulative freezing degree days (YRLY_AVG_FDD).” This value and the standard deviation of the average annual maximum cumulative FDD (YRLY_STDEV_FDD) are passed to PCASE to compute the DFI.

8-5.6 Computing the Design Freezing Index (DFI).

Past criteria defined the DFI as the average AFI of the three coldest winters in the latest 30 years of record. The current procedure uses the average annual AFI and its standard deviation to define the DFI as shown in Equation 8-1. This approach represents the 91st percentile of the freezing indices for the period of record for a given location assuming a normal distribution (Reference: Cortez, E.R., M.A. Kestler, and R.L. Berg. 2000, *Computer-Assisted Calculations of the Depth of Frost Penetration in Pavement-Soil Structures*).

Equation 8-1. DFI Computation

$$\text{DFI (°F days)} = 1.8 * \left(\overline{AFI_{Ann}} + (1.5 * \sigma_{AFI})\right)$$

Where:

$1.8 = constant\ to\ convert\ \text{°C}\ days\ to\ \text{°F}\ days$

$\overline{AFI_{Ann}} = Average\ AFI = YRLY\_AVG\_FDD\ (\text{°C}\ days)$

$\sigma_{AFI} = standard\ deviation\ of\ the\ average\ AFI = YRLY\_STDEV\_FDD\ (\text{°C}\ days)$

For example, if the average annual AFI is 990 ℃ days and the standard deviation is 310 ℃ days, the DFI is 2619 °F days.

$$1.8 * \left(990\ \text{°C}\ Days + (1.5 * 310\ \text{°C}\ days)\right) = 2619\ \text{°F}\ days$$

Figure 8-6 is taken from the previous version of this UFC based on data prior to 1987. It graphically depicts DFI distribution in North America and is presented here as a general guide. Note that the current release of the WorldIndex database identified overall decreases in global annual AFI values from previous data.

8-5.7 Alternate DFI Procedure.

In cases where climate data for a location is not available in the WorldIndex database but the mean freezing index is available from other data sources, the DFI can be roughly estimated using the equations below and used to manually compute the depth of frost penetration for use in PCASE. It is important to note the period of record for the available data. At a minimum, it should cover the latest 10 years and preferably at least 30 years. Special considerations will be necessary to compensate for local topographic conditions that will cause deviations from general freezing index values. Note that the mean freezing value must be multiplied by 13.33 to convert from degrees F days to degrees C hours in the second equation.

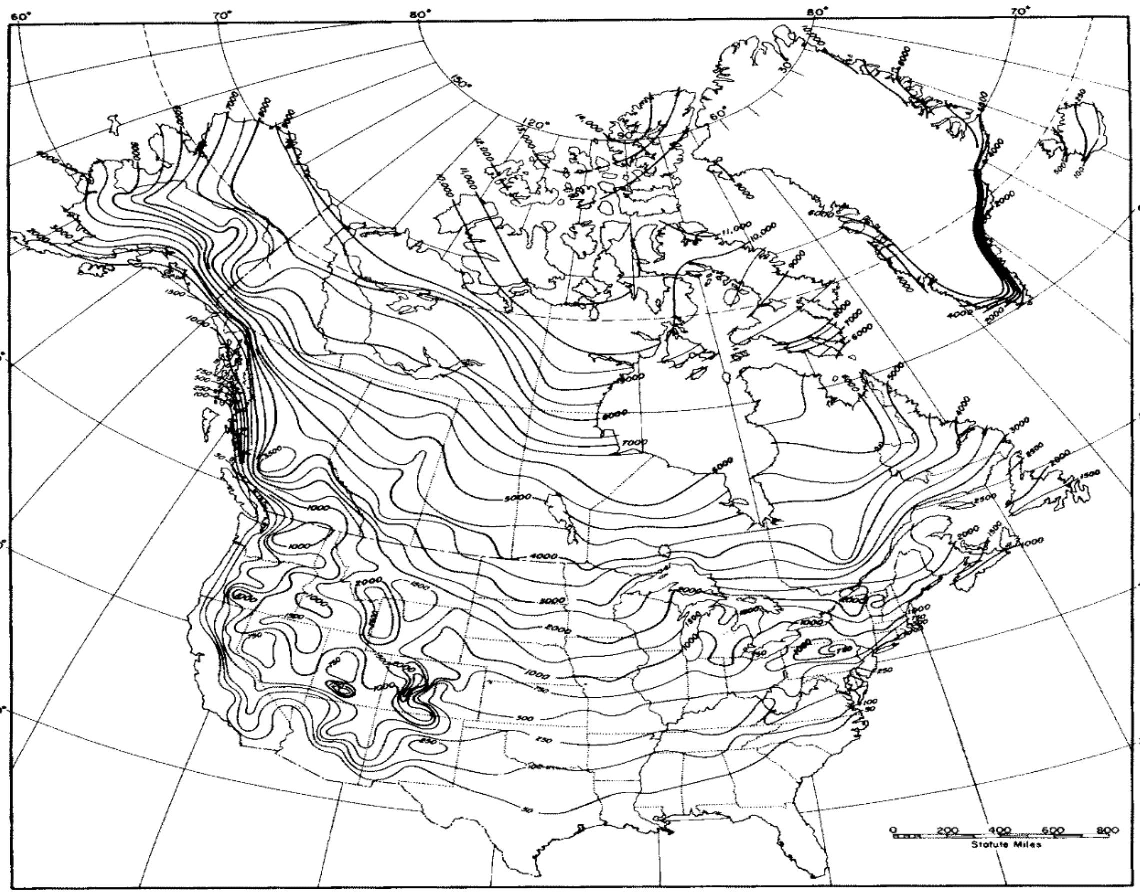
<u>*English Units*</u>

$$(DFI) = 429 + 1.143 \times mean\ freezing\ (^{o}\ F\ days)$$

<u>*SI Units*</u>

$$(DFI) = 5{,}718 + 1.143 \times mean\ freezing\ index\ (^{o}\ C\ hours)$$

Figure 8-6 Distribution of Design Air Freezing Indices in North America



CONVERSION FACTOR
DEG F DAYS = 0.075 × DEG C HOURS

8-6 DETERMNE DEPTH OF FROST PENETRATION AND THAW PERIOD.

The general process to determine the depth of frost penetration and the start and duration of the thaw period for a given pavement structure is outlined below. It focuses on the numerical procedure used in PCASE, but both the depth of frost penetration and length of the thaw period can be entered in PCASE based on manual calculations or experience at the location.

- Define the pavement layer structure
  - o Pavement type and thickness
  - o Soil layer type classifications and thicknesses
    - ▪ Soil frost group
    - ▪ Moisture content
    - ▪ Dry unit weight
- Compute the surface freezing index

- Determine the start and length of the thaw season

8-6.1 Define the Pavement Layer Structure.

Chapter 3 outlines field procedures for testing to determine the pavement layer structure. Chapters 5, 6, and 7 outline the procedure for entering the layer structure data for layered elastic and conventional (CBR and k) structural analysis. Frost analysis requires a frost code (soil frost group), gravimetric moisture content, and dry unit weight for each layer in addition to entering the pavement and soil layer types and thicknesses.

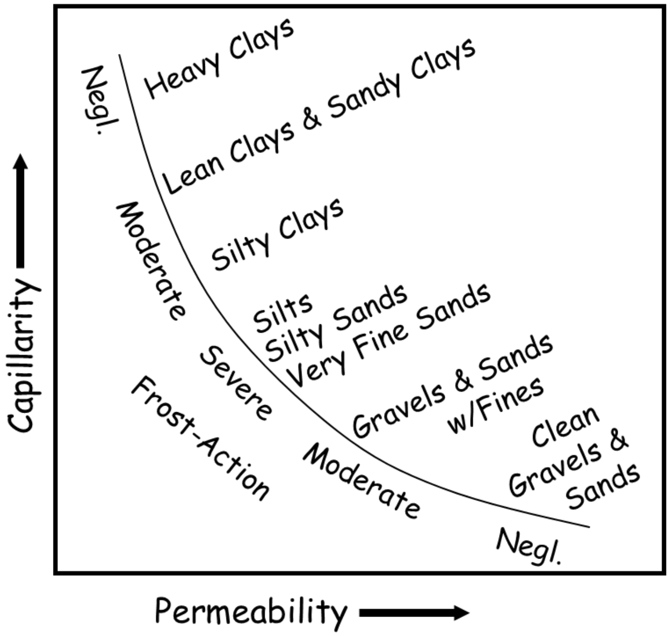
8-6.1.1 Supplementary Soil Testing for Frost Analysis.

When a frost analysis is warranted based on the criteria in paragraph 8-3, conduct testing on the base, subbase, and subgrade material to determine its frost susceptibility. Even if the materials were not frost-susceptible at construction, base and subbase materials can degrade due to freeze-thaw cycles and traffic loads over time. This degradation may introduce additional fines, increasing its thaw-weakening potential.

8-6.1.2 Frost Susceptibility of Base, Subbase, and Subgrade.

Use sieve and Atterberg limits testing to classify base, subbase, and subgrade soils according to the Unified Soil Classification System (USCS) (ASTM D2487, *Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)*). The frost susceptibility of soil is defined by the percent of soil finer than a #200 (.075 mm) sieve by weight and the percent finer than 0.02 mm by weight. Additional testing is required to characterize the percent finer than 0.02 mm by weight using methods described in ASTM D1140, *Standard Test Methods for Determining the Amount of Material Finer than 75-µm (No. 200) Sieve in Soils by Washing*, and ASTM D7928, *Standard Test Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis*. Table 8-1 identifies the frost susceptibility by soil type and percent fines. They are listed in approximate order of increasing frost susceptibility and decreasing bearing capacity during periods of thaw. The percent of fines defines the potential for capillary action and the permeability of soil, which both effect the potential for detrimental frost action as shown in Figure 8-7. Note that while clay materials may not show frost heave, they can still have significant loss of bearing capacity during thawing periods.

Figure 8-7 Frost Action Severity Based on Soil Type



Most cohesive soils have high capillarity but low permeability, water moves too slowly for growth of thick ice lenses.

Low-plasticity soils with high percentage of silt-sized particles, have pore sizes small enough to develop capillary potential, but large enough to permit travel of water to the frozen zone.

Coarser soils have higher rates of flow, but do not have the capillary potential to lift enough moisture for heaving.

Table 8-1 Frost Susceptibility Soil Classification

Frost Group	Soil Type	% Finer than 0.02 mm by Weight	% Finer than #200 Sieve by Weight[1]	Typical Soil Types (Unified Soil Classification System)
NFS[2]	(a) Gravel, crushed stone, crushed rock	0 - 1.5	0 - 3	GW, GP
	(b) Sands	0 – 3	0 - 7	SW, SP
PFS[3]	(a) Gravel, crushed stone, crushed rock	1.5 - 3	3 - 7	GW, GP
	(b) Sands	3 – 10		SW, SP
S1	Gravelly soils	3 - 6	7 - 15	GW, GP, GW-GM. GP-GM
S2	Sandy soils	3 - 6	7 - 15	SW, SP. SW-SM, SP-SM
F1	Gravelly soils	6-10		GM, GW-GM, GP-GM
F2	(a) Gravelly soils	10-20		GM, GW-GM, GP-GM
	(b) Sands	6-15		SM, SW-SM, SP-SM
F3	(a) Gravelly soils	Over 20		GM, GC
	(b) Sands, except very fine silty sands	Over 15		SM, SC
	(c) Clays, PI > 12	--		CL, CH
F4	(a) Silts	--		ML, MH
	(b) Very fine silty sands	Over 15		SM
	(c) Clays, PI < 12	--		CL, CL-ML
	(d) Varved clays and other fine-grained, banded sediments	--		CL, ML, and SM, CL, CH, and ML, CL, CH, ML, and SM

Notes: 1. These are rough estimates. If there are surface indications of frost action, then frost-susceptibility tests should be conducted.
2. Nonfrost susceptible.
3. Possibly frost susceptible; requires lab test to determine frost soil classification.

8-6.1.3 Moisture Content.

The moisture content and dry unit weight of the soil in each layer are required inputs that PCASE uses to compute the frozen and unfrozen soil thermal properties of each layer. Optimally, these values are determined based on field and laboratory testing such as ASTM D6938, *Standard Test Methods for In-Place Density and Water Content of*

Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth), or ASTM D2216, *Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass*. These values are used to estimate average moisture contents in the base subbase and subgrade at the start of the freezing period. When testing is not possible, average estimated values can be used based on pit data from previous pavement evaluations or data from construction projects.

PCASE assigns default moisture contents as shown in Table 8-2 based on the layer types. Use these conservative defaults when no other data is available. Note that the depth of frost penetration is sensitive to the moisture content. In general, for a given dry density, frost penetration increases with decreasing moisture content. For example, as shown in Figure 8-8, for a soil with a dry density of 115 pcf and an AFI of 2,000 ˚F Days, frost is able to penetrate 70 inches at 15 percent moisture content but penetrates to 80 inches at 5 percent moisture content.

Figure 8-8 Effect of Moisture on Frost Penetration

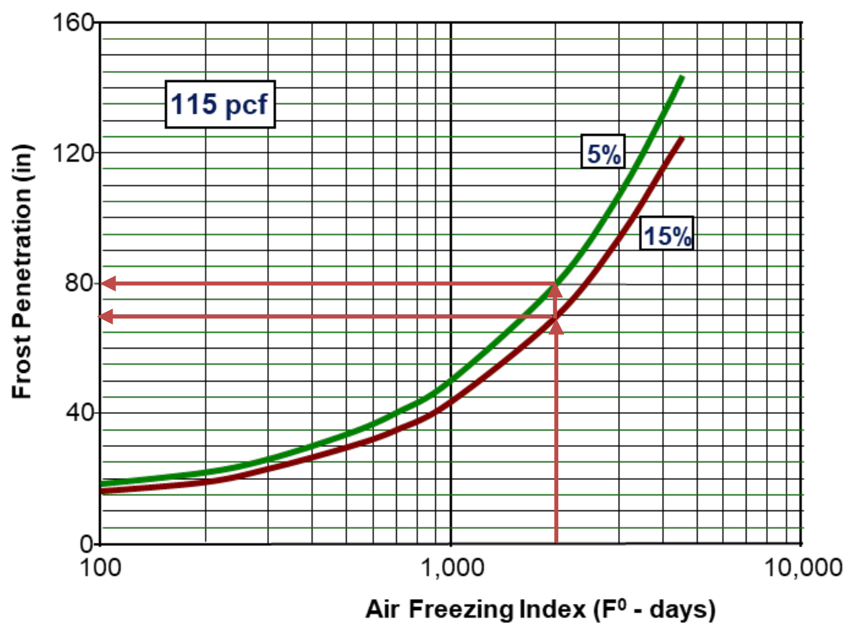


Table 8-2 Default Moisture Contents and Dry Densities

Layer Type	Moisture Content (%)	Dry Unit Weight (pcf)
Asphalt	0	140
Concrete	0	145
Stabilized base AC / PCC	5 / 0	140
Base	5	135
Drainage layer	5	135
Separation layer	5	135
Subbase	5	135
Stabilized subbase AC / PCC	5 / 0	130 / 140
Select fill	5	135
Stabilized subgrade PCC / Lime	0 / 10	130 / 110
Modified subgrade cohesive / cohesionless	18 / 10	100 / 120
Compacted subgrade	18 / 10	100 / 120
Natural subgrade cohesive / cohesionless	18 / 10	100 / 120

8-6.1.4 Dry Unit Weight.

The dry unit weight of a soil is determined based on field and laboratory testing using a nuclear gauge, sand cone, or compaction testing. Table 8-2 has the default dry unit weight values assigned in PCASE and Figure 8-9 provides estimated ranges of dry unit weight for various soil types. Note that in general, the depth of frost penetration will be greater for a soil with a higher dry unit weight at a given moisture content. For example, given a 12-inch rigid pavement overlying a homogeneous material at an infinite depth, at an AFI of 2,000 ˚F Days with 5 percent moisture content, the depth of frost penetration would be 100 inches for a soil with a density of 150 pcf, 80 inches at 115 pcf, and 70 inches at 100 pcf.

Figure 8-9 Soil Density Chart

Soil Types		Symbol		Drainage Characteristics	Unit Dry Weight Lb. per Cu Ft	Field CBR	Subgrade Modulus K Lb per Cu In
Coarse-grained Soils	Gravels and Gravelly Sands	GW		Excellent	125 - 140	60 - 80	300 or more
		GP		Excellent	110 - 130	25 - 60	300 or more
		GM	d	Fair to poor	130 - 145	40 - 80	300 or more
			u	Poor to impervious	120 - 140	20 - 40	200 to 300
		GC		Poor to impervious	120 - 140	20 - 40	200 to 300
	Sands and Sandy Gravels	SW		Excellent	110 - 130	20 - 40	200 to 300
		SP		Excellent	100 - 120	10 - 25	200 to 300
		SM	d	Fair to poor	120 - 135	20 - 40	200 to 300
			u	Poor to impervious	105 - 130	10 - 20	200 to 300
		SC		Poor to impervious	105 - 130	10 - 20	200 to 300
Fine-grained Soils	Silts and Clays LL <50	ML		Fair to poor	100 - 125	5 - 15	100 to 200
		CL		Impervious	100 - 125	5 - 15	100 to 200
		OL		Poor	90 - 105	4 - 8	100 to 200
	Silts and Clays LL >50	MH		Fair to poor	80 - 100	4 - 8	100 to 200
		CH		Impervious	90 - 110	3 - 5	50 to 100
		OH		Impervious	80 - 105	3 - 5	50 to 100
Highly Organic Soils		Pt		Fair to poor	-----	-----	-----

GM and SM groups are divided into subdivisions d and u for roads and airfields
Suffix d is used when LL $\leq$ 28 and PI $\leq$ 6 Suffix u is used when LL > 28

8-6.2 Surface Freezing Index.

As noted earlier, the DFI is based on the average annual AFI and standard deviation but this index is determined for air temperatures at 4.5 feet (1 meter) above the ground. We use the AFI because the data is more readily available than surface temperatures. The DFI and the n-Factor (Figure 8-10) are used in Equation 8-2 to estimate the surface freezing index, which is the temperature immediately below the pavement surface. PCASE determines the n-Factor based on the surface type of the layer model being analyzed (see Figure 8-10).

Equation 8-2. Surface Freezing Index

$$\text{Surface Freezing Index} = \text{n Factor} * \text{DFI}$$

Figure 8-10 n-Factors

Surface Type[1]	n-Factor for Freezing Conditions	n-Factor for Thawing Conditions
Snow Surface	1.00	-
Portland Cement Concrete	0.75	1.50
Bituminous Pavement	0.70	1.60 - 2.00[2]
Bare Soil	0.70	1.40 - 2.00[2]
Shaded Surface	0.90	1.00
Turf	0.50	0.80
Tree-Covered	0.30[3]	0.40

1. Surface exposed directly to sun or air without any overlying dust, soil, snow or ice, except as noted otherwise and with no building heat involved.
2. Use lowest value except in extremely high latitudes or at high elevations where a major portion of summer heating is from solar radiation.
3. Data from Fairbanks, Alaska, for single season with snow cover permitted to accumulate naturally.

8-6.3 Determine Start and Length of Thaw Season.

8-6.3.1 Thaw-weakened Period.

As shown in Figure 8-11, thaw-weakened periods are intervals of the year when the base, subbase, or subgrade strength are below normal summer values. These intervals correspond to frost melting periods. The period ends when the material is either refrozen or when the subgrade strength has returned to the normal summer value at the end of the spring thaw-weakening period.

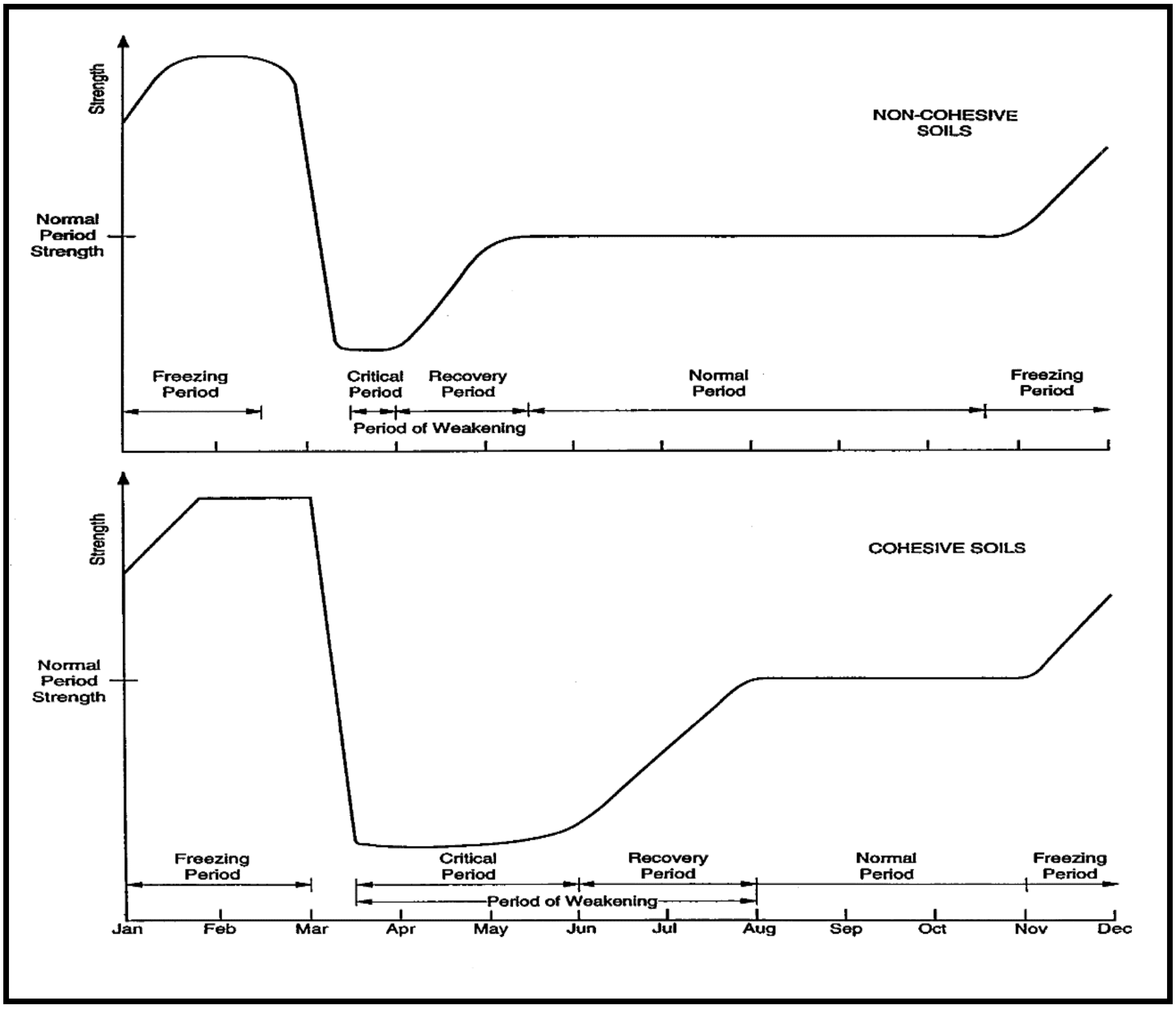
8-6.3.2 Critical Weakening Period.

The critical weakening period is the time interval during the thaw-weakened period when the base, subbase, or subgrade are at their lowest strength. As shown in Figure 8-11, the critical weakening period comes during the early stages of frost-melting and may occur intermittently during the winter when the segregated ice in the base, subbase, or subgrade is melting. This critical period can last from a week to several months, depending on the soil type and environmental conditions. The likely duration of the critical period can be estimated based on the performance of highways with a comparable subgrade in the vicinity of the airfield. However, since airfield pavements are wider and drainage paths longer, the thaw-weakened period is likely to be longer.

8-6.3.3 Recovery Period.

As the soil drains and reconsolidates, the pavement gradually regains full normal-period bearing capacity. The length of the recovery period varies from a few weeks to several months, depending on the intensity of ice segregation, depth of frost penetration, rate of thawing, permeability of the soil, drainage conditions, precipitation, and atmospheric humidity.

Figure 8-11 Illustration of Thaw-Weakening Period



8-6.3.4 Estimating Thaw Weakened Period Start and Duration.

Several frost-melting periods may occur during a typical winter period. The procedure outlined below is used to estimate the start and total period of weakening, including frost-melting periods during the winter. The length of the thaw-weakened period can be changed based on local experience. Principal factors affecting the recovery time are depth of frost penetration, type of frost-susceptible material, and subsurface drainage. Normally, the time for recovery will be from several weeks to several months.

The end of the freezing period defines the start of the thaw period. The thaw-weakened periods for different frost-susceptible soils are presented in Table 8-3. These values are adjusted based on whether the DFI ≤ 1,000-degree F-days or DFI > 1000 degree F-days as shown in Table 8-4. Note that the general soil type (cohesive or cohesionless) is used to determine the period adjustment for soils in the F3 and F4 frost groups.

Table 8-3 Length of End-of-Winter Thaw-Weakened Period

Frost Group	Thaw-Weakened Period (Months)
F1	1
F2	1
F3 and F4 (Cohesionless)	2
F3 and F4 (Cohesive)	3

Table 8-4 Thaw-Weakened Period Adjustment

Frost Group	Soil Type	DFI	Adjusted Thaw-weakened Period (Months)
F1, F2	N/A	< = 1,000 deg F days	1
F1, F2	N/A	> 1,000 deg F days	2
F3, F4	Cohesionless	< = 1,000 deg F days	2
F3, F4	Cohesionless	> 1,000 deg F days	3
F3, F4	Cohesive	< = 1,000 deg F days	3
F3, F4	Cohesive	> 1,000 deg F days	4

8-7 DETERMINE DEPTH OF FROST PENETRATION.

The objective of this step is to determine whether the freezing front penetrates a frost-susceptible layer. If not, use the normal evaluation procedure. Once the layer type and thickness, frost code, dry unit weight, and moisture content are entered for each layer and the analysis is run, PCASE will display the allowable passes, AGL, and Pavement Classification Number (PCN) for the thaw weakened period if the freezing front penetrates a frost-susceptible layer or will report only the normal values if it does not. Instructions for computing the depth of frost using PCASE are included in the PCASE *User Manual*.

This step can be performed manually by determining the surface thickness of the pavement (p), the total pavement (surface, base, and subbase) thickness (x) and estimate the depth of frost penetration (d) and following the criteria below:

- If ($x \geq d$) use the normal evaluation procedure.

- If ($x < d$), the pavement structure is inadequate for complete frost protection. If there are indications of frost action, evaluate the pavement structure with the reduced subgrade strength approach.
- If ($x - p \geq 60$ inches) or the base, subbase, and/or subgrade is classified as NFS, S1, or S2 and there are no surface indications of frost action, use the normal evaluation procedure.
- If ($x - p \geq 60$ inches) or the base, subbase, and/or subgrade is classified as NFS, S1, or S2 and there are indications of frost action, evaluate pavement structure with the reduced subgrade strength approach.

8-8 EVALUATE PAVEMENT FOR REDUCED SUBGRADE STRENGTH.

Both conventional and layered elastic reduced subgrade strength (RSS) evaluation procedures are based on the application of the fatigue damage concept (Miner's Hypothesis). The conventional evaluation procedure substitutes frost area soil support indices (FASSI) values for California Bearing Ratio (CBR) values in flexible pavement analysis and Frost Area Index of Reaction (FAIR) values for modulus of subgrade reaction values (k) in rigid analysis. In layered elastic evaluation, either the FASSI/FAIR procedure or the reduced modulus procedure can be used.

8-8.1 Frost Area Soil Support Indices (FASSI).

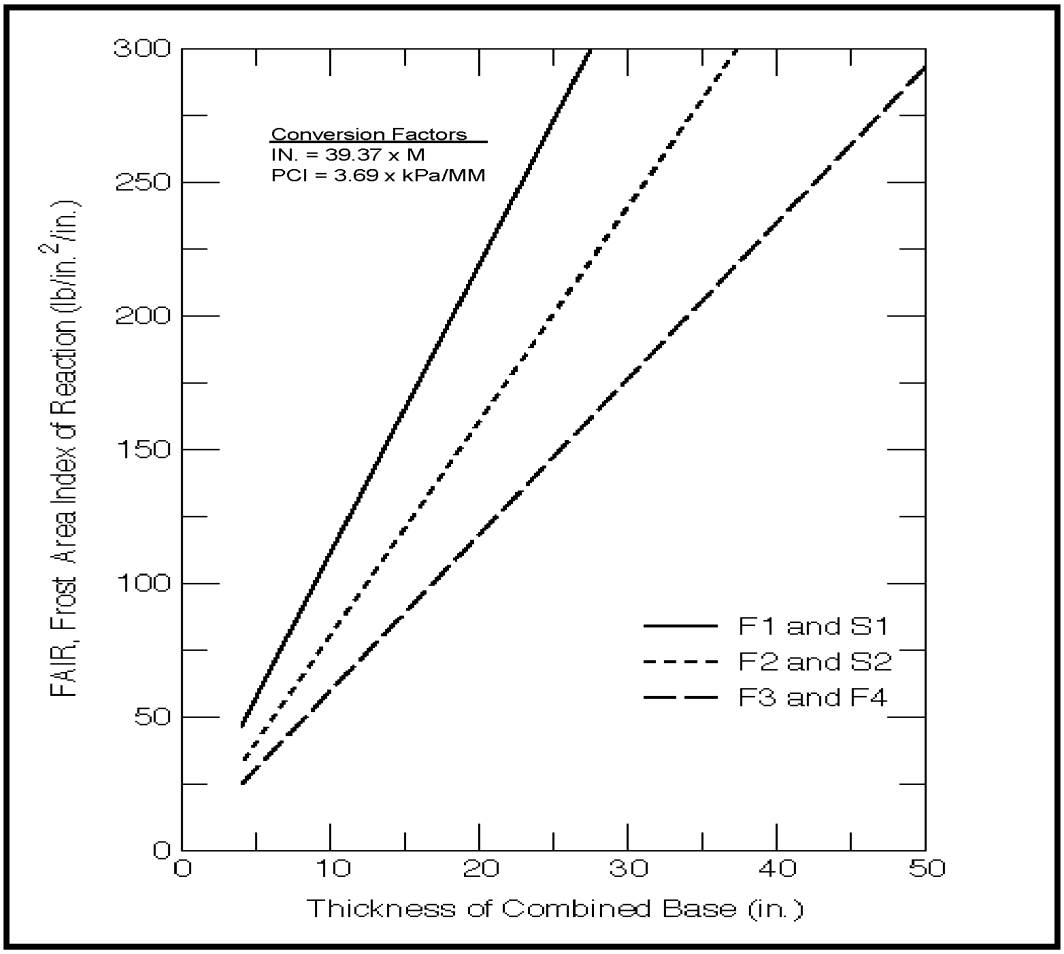
The FASSI values are used as if they were CBR values. The term CBR is not applied to them, however, because they are weighted average values for the annual cycle and their values cannot be determined by CBR tests. FASSI values are assigned based on the soil layer's frost group. Ideally, base and subbase layers are not frost susceptible but this is not always the case, so, for any layer with a frost code assigned (other than NFS), PCASE will replace the CBR with a FASSI value when the depth of frost penetrates that layer. If the depth of frost does not penetrate the layer, PCASE uses the assigned CBR. FASSI values for the respective frost codes are listed below.

- F1 and S1 soils = 9.0 FASSI
- F2 and S2 soils = 6.5 FASSI
- F3 and F4 soils = 3.5 FASSI

8-8.2 Frost Area Index of Reaction (FAIR).

FAIR values are used as if they were modulus of subgrade reaction values, k, and have the same units. However, the term modulus of subgrade reaction is not applied to them because the FAIR values are weighted average values for an annual cycle and cannot be determined by a plate-bearing test. Figure 8-12 shows the equivalent weighted average FAIR values for an annual cycle that includes a thaw-weakening period in relation to the combined thickness of the base and subbase. This figure is based on the FAIR value Equations 8-3, 8-4, and 8-5. If the depth of frost does not penetrate the layer, PCASE uses the assigned k value, or when the modulus of subgrade reaction k, determined from tests on the equivalent base course and subgrade for the normal period, is less than the FAIR value obtained from the equations, use the test value for the analysis.

Figure 8-12 Determination of FAIR Value



Equation 8-3. FAIR Value for F1 or S1 Material

$$FAIR\ ((psi/in.) = 4.2 + 10.8 \times \text{Combined } Base\ Course\ Thickness\ (inches)$$

Equation 8-4. FAIR Value for F2 or S2 Material

$$FAIR\ ((psi/in.) = 1.3 + 8.0 \times \text{Combined } Base\ Course\ Thickness\ (inches)$$

Equation 8-5. FAIR Value for F3 or F4 Material

$$FAIR\ ((psi/in.) = 1.6 + 5.9 \times \text{Combined } Base\ Course\ Thickness\ (inches)$$

8-9 MODULUS REDUCTION FACTORS.

There are two alternatives for reduced subgrade strength analysis using layered elastic procedures. In the first, the FASSI or FAIR values determined using the procedures above are correlated to modulus values and used for the RSS analysis. In the second approach, the modulus values of the respective layers during the normal period are reduced using the reduction factors shown in Table 8-5. The modulus for the normal period is multiplied by the reduction factor for the given frost group and this reduced modulus is used for the analysis. If the depth of frost does not penetrate the layer, PCASE uses the normal period modulus value. If modulus values were determined during the thaw period, then use those values in the thaw period analysis. In this case, the modulus for the normal period can be estimated by dividing the thaw period modulus value by the modulus reduction factor.

Table 8-5 Modulus Reduction Factors for Seasonal Frost Areas

Frost Group	Modulus Reduction Factors
NFS	1.00
PFS	0.90
S1	0.75
S2	0.70
F1	0.60
F2	0.50
F3/F4	0.30

8-10 EVALUATION USING DAMAGE CONCEPTS.

The fatigue damage concept (Miner's Hypothesis) is used to evaluate pavement structures when frost is a consideration. Damage is defined as the ratio of applied load repetitions to the allowable load repetitions to a failure and is expressed as:

Equation 8-6. Damage Definition

$$d = \frac{n}{N}$$

Where:
n = applied load repetitions
N = allowable load repetitions

When the applied load repetitions equal the allowable number of load repetitions, the damage ratio is equal to 1.0. This means that 100 percent of the pavement life has been consumed. The goal is to determine the allowable load or the allowable passes such that the damage ratio is equal to one (d = 1.0) for an analysis period.

8-10.1 Cumulative Damage Factor (CDF).

The damage concept can be extended to multiple aircraft and multiple seasons. A CDF can be expressed as the sum of individual damage contributions from different aircraft and different seasons or evaluation periods. The general equation for CDF, where the aircraft load and passes result in the maximum utilization of pavement life, is defined as:

Equation 8-7. General Cumulative Damage Factor

$$CDF = \sum_{i=1}^{nac} \sum_{j=1}^{ns} d_{ij} = 1.0$$

Where:

$d_{i,j}$ = damage for aircraft i and season *j*
nac = number of aircraft in mix
ns = number of seasons or analysis period

In pavement evaluation, the analysis is performed for only a single aircraft (*nac* = 1) and two seasons (*ns* = 2). The two evaluation seasons considered are the normal and thaw-weakened periods. The cumulative damage factor represented by Equation 8-7 can now be reduced to Equations 8-8 and 8-9.

Equation 8-8. Reduced Cumulative Damage Equation

$$CDF = d_{normal} + d_{thaw} = 1.0$$

Equation 8-9. Expanded Cumulative Damage Equation

$$CDF = \frac{n_{normal}}{N_{normal}} + \frac{n_{thaw}}{N_{thaw}} = 1.0$$

Where:
n_{normal}, N_{normal} are the applied and allowable number of coverages (or passes) during the normal period
n_{thaw}, N_{thaw} are the applied and allowable number of coverages (or passes) during the thaw-weakened period

8-10.2 Prorating Passes for Normal and Thaw Periods.

When evaluating pavement structures, the aircraft AGL is analyzed for a life expectancy expressed as the evaluation passes, *n*. Since *n* is the total number of passes applied throughout the whole year, a fraction of *n* is applied during the normal period and a fraction of *n* is applied during the thaw-weakened period. Each of these fractions will contribute to the total accumulated damage during a year. These fractions of *n* are determined as the prorated number of passes during the normal months and thaw-weakened months. For example, if evaluating the subgrade of a pavement structure for *n* = 50,000 passes and one month of the year is in a thaw-weakened condition, then Equations 8-10 and 8-11 represent the contribution of the total number of passes *n* in each season.

Equation 8-10. Prorated Evaluation Passes during the Normal Period

$$n_{normal} = n\left(\frac{11}{12}\right) = 50{,}000\left(\frac{11}{12}\right) = 45{,}833\ Passes$$

Equation 8-11. Prorated Evaluation Passes during the Thaw-weakened Period

$$n_{thaw} = n\left(\frac{1}{12}\right) = 50{,}000\left(\frac{1}{12}\right) = 4{,}167\ Passes$$

8-10.3 Damage in Conventional Flexible and Rigid Pavement Evaluation (APE)

The airfield pavement evaluation (APE) CBR / k models were not developed with the cumulative damage concept in mind. Therefore, the damage concept cannot be applied directly because the analysis is based on a single evaluation period and the APE analysis will only return the allowable number of coverages (or passes) for the entire pavement life, *N*. Equation 8-9 is solved in APE by allowing a predetermined amount of damage to occur during the thaw-weakened period as shown in Figure 8-11. The predetermined damage is assumed to be 25 percent during the thaw period (d_{thaw} = 0.25) and 75 percent during the normal period (d_{normal} = 0.75), as shown in Equations 8-12 and 8-13:

Equation 8-12. Damage Allowed during the Thaw Period

$$d_{thaw} = 0.25 = \frac{n_{thaw}}{N_{thaw}}$$

Equation 8-13. Damage Allowed during the Normal Period

$$d_{normal} = 0.75 = \frac{n_{normal}}{N_{normal}}$$

Both N_{thaw} and N_{normal} are the allowable number of coverages for the respective analysis periods or seasons. If we define N'_{thaw} as the allowable number of coverages (or passes) at failure when d'_{thaw} = 1.0, then 100 percent of the life will be consumed. Therefore, we must adjust N'_{thaw} by a factor of 0.25 as shown in Equation 8-14, because only one-quarter of its life is allowed be consumed during this analysis period.

Equation 8-14. Pavement Life Adjustment during the Thaw-weakened Period

$$N_{thaw} = 0.25\ N'_{thaw}$$

This leads to the equation of damage during the thaw-weakened period (Equation 8-15), that is interpreted as an adjustment to the allowable coverages (or passes), N'_{thaw} or as an adjustment to the evaluation coverages (or passes) n_{thaw}.

Equation 8-15. Adjustment to Evaluation Passes during the Thaw-weakened Period

$$d_{thaw} = \frac{n_{thaw}}{N_{thaw}} = \frac{n_{thaw}}{0.25\, N'_{thaw}} = \frac{4\, n_{thaw}}{N'_{thaw}}$$

Similarly, make an adjustment during the normal period using Equation 8-16, because only three-quarters of its life is consumed during the normal period.

Equation 8-16. Pavement Life Adjustment during Normal Period

$$N_{normal} = 0.75\, N'_{normal}$$

The damage during the normal period can then be estimated using Equation 8-17.

Equation 8-17. Damage Allowed during the Normal Period

$$d_{normal} = \frac{n_{normal}}{N_{normal}} = \frac{n_{normal}}{0.75\, N'_{normal}} = \frac{\frac{4}{3}\, n_{normal}}{N'_{normal}} = \frac{1.33\, n_{normal}}{N'_{normal}}$$

Aircraft AGL for the normal and thaw-weakened periods satisfying Equations 8-15 and 8-17 are individually calculated by an iteration process. In APE, the AGL is determined by evaluating for the following adjusted number of passes:

$$Thaw\ period = 4\ times\ prorated\ passes = 4\, n_{thaw}$$
$$Normal\ period = \frac{4}{3}\ times\ prorated\ passes = \frac{4}{3} n_{normal}$$

For our example in Equations 8-10 and 8-11, the cumulative damage factor becomes:

Equation 8-18. Example Cumulative Damage Factor for Two Analysis Periods

$$CDF = \frac{\frac{4}{3}(45{,}833)}{N'_{normal}} + \frac{4(4{,}167)}{N'_{thaw}} = 1.0$$

Equation 8-18 is solved iteratively by assuming an AGL for each season (AGL_{normal}, AGL_{frost}) and calculating the allowable number of passes (N'_{normal}, N'_{thaw}) until the *CDF* = 1.0 within an acceptable tolerance value. Here, N'_{normal} is a function of the subgrade strength during the normal period and N'_{thaw} is a function of the subgrade strength during the thaw-weakened period. In summary, in APE the AGL is determined by evaluating for the following equivalent number of passes:

$$Thaw\ period = 4\ times\ prorated\ passes = 4\, n_{thaw}$$
$$Normal\ period = \frac{4}{3}\ times\ prorated\ passes = \frac{4}{3} n_{normal}$$

8-11 DEFINING DAMAGE IN LAYERED ELASTIC EVALUATION PROGRAM (LEEP).

When designing flexible pavements using the layered elastic method, load repetitions are equated to coverages and both the limiting asphalt horizontal strain and the subgrade vertical strain criteria are checked in terms of coverages. However, when evaluating flexible pavements, the subgrade strain criterion is only checked in terms of passes. This simplification was adopted during the early stages of development of the evaluation criteria because passes at the subgrade level are approximately equal to coverages. Equation 8-19 defines damage in terms of the subgrade criterion for layered elastic evaluation of flexible pavements and Equation 8-20 defines the damage in terms of the asphalt criterion.

Equation 8-19. Subgrade Damage in Terms of Passes

$$d = \frac{applied\ passes}{allowable\ passes}$$

Equation 8-20. Asphalt Damage in Terms of Coverages

$$d = \frac{applied\ coverages}{allowable\ coverages}$$

When evaluating rigid pavements, the bending stress criterion at the bottom of the concrete layer is checked against the bending stress criterion in terms of coverages as shown by Equation 8-21.

Equation 8-21. Concrete Damage in Terms of Coverages

$$d = \frac{applied\ coverages}{allowable\ coverages}$$

Even though the layered elastic method permits the calculations of the damage for normal and thaw-weakened periods directly without having to assume d_{thaw} = 0.25 and d_{normal} = 0.75, the same procedure outlined here for APE is also applied with layered elastic analysis. In theory, the damage distribution between analysis periods could be changed to any another value if the field conditions warrant a different damage distribution between the two analysis periods.

8-11.2 LEEP (WESPAVE) Frost Analysis.

Earlier PCASE versions used the WESPAVE layered elastic model for LEEP analysis. The current PCASE version allows the user to set the WESPAVE option to replicate previous pavement evaluation results. When the WESPAVE option is on, the AGLs for the normal and thaw-weakened periods are determined by evaluating for the following adjusted number of passes:

$$Thaw\ period = \ 4\ times\ prorated\ passes = 4\ n_{thaw}$$
$$Normal\ period = \frac{4}{3}\ times\ prorated\ passes = \frac{4}{3}n_{normal}$$

8-11.3 LEEP (YULEA) Frost Analysis.

The current PCASE version (7.x and later) uses the YULEA layered elastic model in LEEP. When using YULEA, the AGLs for the normal and thaw-weakened periods are determined by setting the target damages during the two analysis periods directly as follows:

$$Thaw\ period - Set\ d_{thaw} = 0.25$$
$$Normal\ period - Set\ d_{normal} = 0.75$$

8-12 EVALUATING PAVEMENTS ON PERMAFROST.

Typically, pavements on permafrost are in their weakest condition during the summer. The permafrost thaws from the top down and provides excess water that cannot drain because of the underlying frozen permafrost. Pavement evaluations are performed during the weakened state, which may only last a few months. This is essentially the opposite of the evaluation procedures previously discussed in this chapter.

In this case, the pavement evaluation is conducted during the summer with a heavy weight deflectometer (HWD) when the pavement is in a weakened condition. Modulus values are established for each layer, including the saturated thawed layers and the frozen permafrost. This establishes the basis for the AGLs and PCNs published for the summer period. For the winter period, assume that the previously thawed layers (base, subbase, and subgrade) would have the same modulus values when frozen as those established for the frozen permafrost during the summer evaluation. Alternatively, apply the factors in Table 8-5 using the procedure in paragraph 8-9 to determine a conservative estimate of the modulus during the winter period. Assume that modulus values for the asphalt surface would be the same as established during the summer. These modulus values are used to determine the AGLs and PCNs during the winter period.

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CHAPTER 9 STANDARDIZED METHOD FOR REPORTING AIRFIELD PAVEMENT STRENGTH

9-1 BACKGROUND.

The Aircraft Classification Number (ACN) - Pavement Classification Number (PCN) method was adopted by the International Civil Aviation Organization (ICAO) as an effective, simple, and readily comprehensible means for reporting the aircraft weight-bearing capability of runways. As a cooperating member of the ICAO, the United States report airfield weight-bearing limits by this method as outlined in Doc 9157-AN/901, *Aerodrome Design Manual*, and Amendment 35 to *International Standards and Recommended Practices, Aerodromes (*Annex 14, Volume I to the Convention on International Civil Aviation). These weight-bearing limits are included in evaluation reports and reported in flight information pamphlets (FLIP).

9-2 ACN DEFINITION.

The ACN is a number that expresses the relative structural effect of an aircraft at a given weight on different pavement types (flexible or rigid) for four specified standard subgrade strengths in terms of a standard single-wheel load. ACN values are determined by the aircraft manufacturers. These same numbers can be calculated using computer programs such as Pavement-Transportation Computer Assisted Structural Engineering (PCASE) as outlined below.

9-2.1 Computing the ACN.

Computing the ACN requires detailed information on the operational characteristics of the airplane, such as maximum aft center of gravity, maximum weight, wheel spacing, tire pressure, and other factors. ACN values are available from aircraft manufacturers, Technical Report TSC 13-2, *Aircraft Characteristics for Airfield Pavement Design and Evaluation - Air Force and Army Aircraft*, and Technical Report TSC 13-3, *Aircraft Characteristics for Airfield Pavement Design and Evaluation - Commercial Aircraft*, or are computed by PCASE.

9-2.2 Subgrade Category.

The ACN-PCN method adopts four standard levels of subgrade strength for rigid pavements and four standard levels of subgrade strength for flexible pavements. These standard support conditions are used to represent a range of subgrade conditions as shown in Tables 9-1 and 9-2. Modulus values (E) for use in layered elastic analysis are shown in Tables 9-3 and 9-4. E values in Table 9-3 were obtained using k=.07906(E^0.7788). E values in Table 9-4 were obtained using E = 1500*CBR.

Table 9-1 Rigid Pavement k Subgrade Categories

Subgrade Strength Category	k-Value (pci)	Represents (pci)	Code Designation
High	552.6	K ≥ 442	A
Medium	294.7	221 < k <442	B
Low	147.4	92 < k ≤221	C
Ultra-low	73.7	k ≤ 92	D

Table 9-2 Flexible Pavement CBR Subgrade Categories

Subgrade Strength Category	CBR Value	Represents	Code Designation
High	15	CBR ≥ 13	A
Medium	10	8 < CBR <13	B
Low	6	4 < CBR ≤ 8	C
Ultra-low	3	CBR ≤4	D

Table 9-3 Rigid Pavement Modulus Subgrade Categories

Subgrade Strength Category	E Value (psi)	Represents (psi)	Code Designation
High	86,374	E≥ 64,840	A
Medium	38,530	22,627 <E< 64,840	B
Low	15,829	8,642 <E≤ 22,627	C
Ultra-low	6,500	E ≤ 8,642	D

Table 9-4 Flexible Pavement Modulus Subgrade Categories

Subgrade Strength Category	E Value	Represents	Code Designation
High	22,500	E≥ 19,500	A
Medium	15000	12,000 <E< 19,500	B
Low	9000	6,000 <E≤ 12,000	C
Ultra-low	4,500	E ≤ 6,000	D

9-2.3 Rigid Pavement ACN.

The aircraft landing gear flotation requirements for rigid pavements are determined by the Westergaard solution for a loaded elastic plate on a Winkler foundation (interior load case) for each subgrade category, assuming a concrete working stress of 399 psi (2.8 MPa).

9-2.4 Flexible Pavement ACN.

The airplane landing gear flotation requirements for flexible pavements are determined by the California Bearing Ratio (CBR) method for each subgrade support category. The CBR method uses a Boussinesq solution for stresses and displacements in a homogeneous, isotropic elastic half-space. To standardize the ACN calculation and to remove operational frequency from the relative rating scale, ACN values are determined for 10,000 coverages.

9-2.5 ACN Calculation.

A mathematically derived single-wheel load is calculated to define the landing gear/pavement interaction using the parameters defined for each type of pavement. The derived single-wheel load implies equal stress to the pavement structure and eliminates the need to specify pavement thickness for comparative purposes. This is achieved by equating the thickness derived for a given airplane landing gear to the thickness derived for a single wheel load at a standard tire pressure of 181 psi (1.2 MPa). The ACN is defined as two times the derived single wheel load (expressed in thousands of kilograms). The procedure for determining ACN is outlined in ICAO Doc 9157-AN/901, *Aerodrome Design Manual, Part 3 - Pavements*.

9-2.6 Variables Involved in Determining ACN Values.

Because airplanes can be operated at various weight and center of gravity combinations, ICAO adopted standard operating conditions for determining ACN values. The ACN is determined at the weight and center of gravity combination that creates the maximum ACN value. Tire pressures are assumed to be those recommended by the manufacturer for the noted conditions. Airplane manufacturers publish maximum weight and center of gravity information in their Airplane Characteristics for Airport Planning (ACAP) manuals.

9-2.7 PCASE ACN Example.

Figure 9-1 is from the PCASE ACN calculator. It shows the ACN information for the P-8 Poseidon aircraft operating at a weight of 188.2 kips on a flexible pavement. The ACN values for each subgrade category are displays as well as an ACN curve plot. Table 9-5 shows a summary of the ACNs for this aircraft on each subgrade category, assuming unlimited tire pressure as indicated by the “W” tire-pressure category.

Figure 9-1 Rigid and Flexible ACN Values for P-8 Poseidon Aircraft

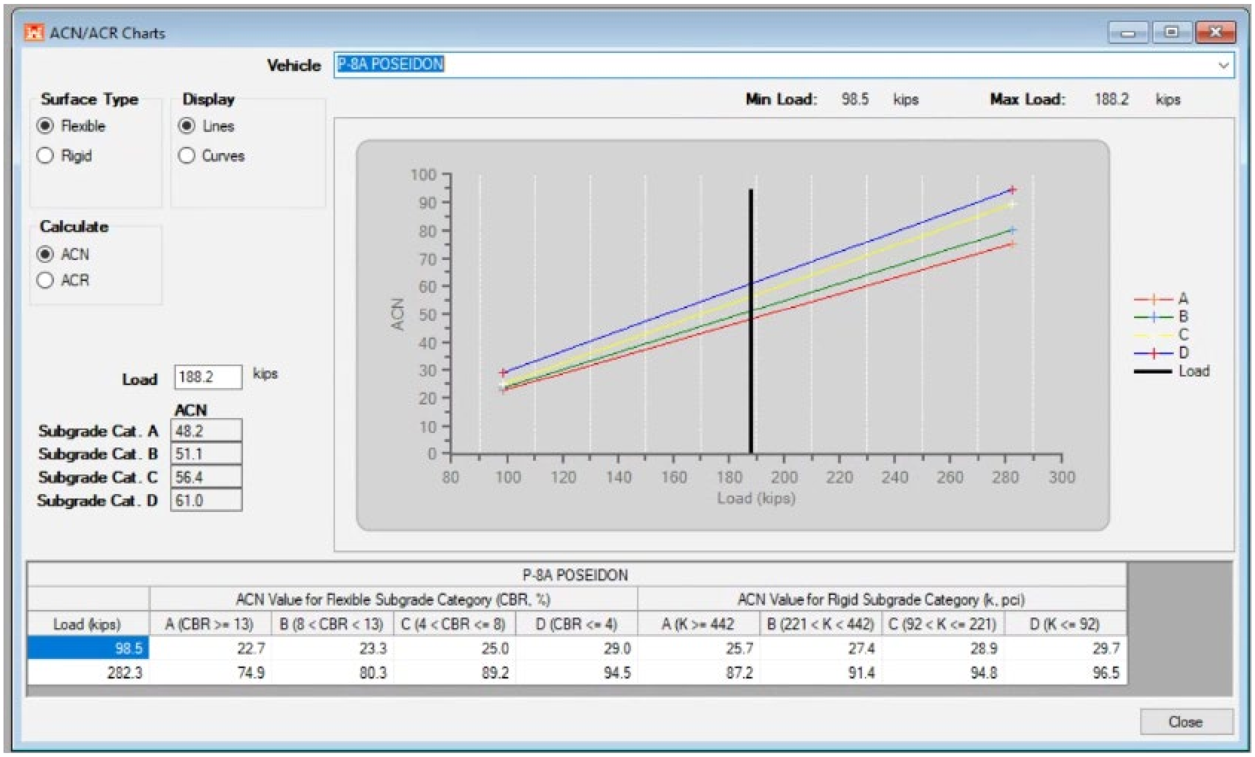


Table 9-5 ACN Ratings for P-8 Operating at 188.2 Kips

Rigid	Flexible
56/R/A	48/F/A
59/R/B	51/F/B
61/R/C	56/F/C
62/R/D	61/F/D

9-2.8 Adjusted ACN Due to Increase/Decrease in Tire Pressure.

Tire pressure is a secondary factor in determining an ACN; however, ICAO procedures can determine the increase or decrease in ACN if the aircraft is operating at a tire pressure different from the one used to determine the ACN. The adjusted ACN can be used if conditions, such as a thin asphalt surface or a weak upper pavement layer, exist. Figures 9-2 and 9-3 are used to adjust the ACN for flexible pavements and Figure 9-4 is used for rigid pavements. On flexible pavements, it is assumed that adjustments will only be one category. Figures 9-2 and 9-3 were developed by ERDC based on the equation in FAA Advisory Circular 150/5335-5D, *Standardized Method of Reporting Airport Pavement Strength – PCR*.

Figure 9-2 Adjusting Flexible Pavement ACN Due to an Increase or Decrease in Tire Pressure (Z to Y or Y to Z)

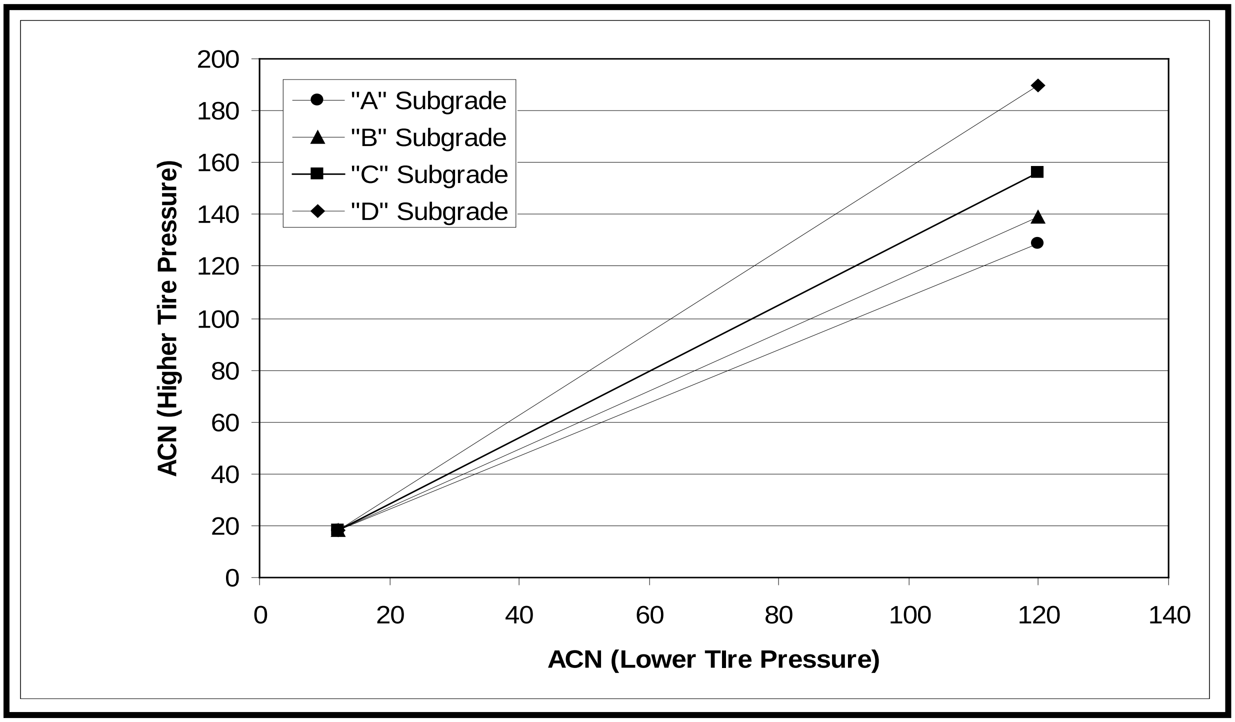


Figure 9-3 Adjusting Flexible Pavement ACN Due to an Increase or Decrease in Tire Pressure (Y to X, X to Y, X to W, W to X)

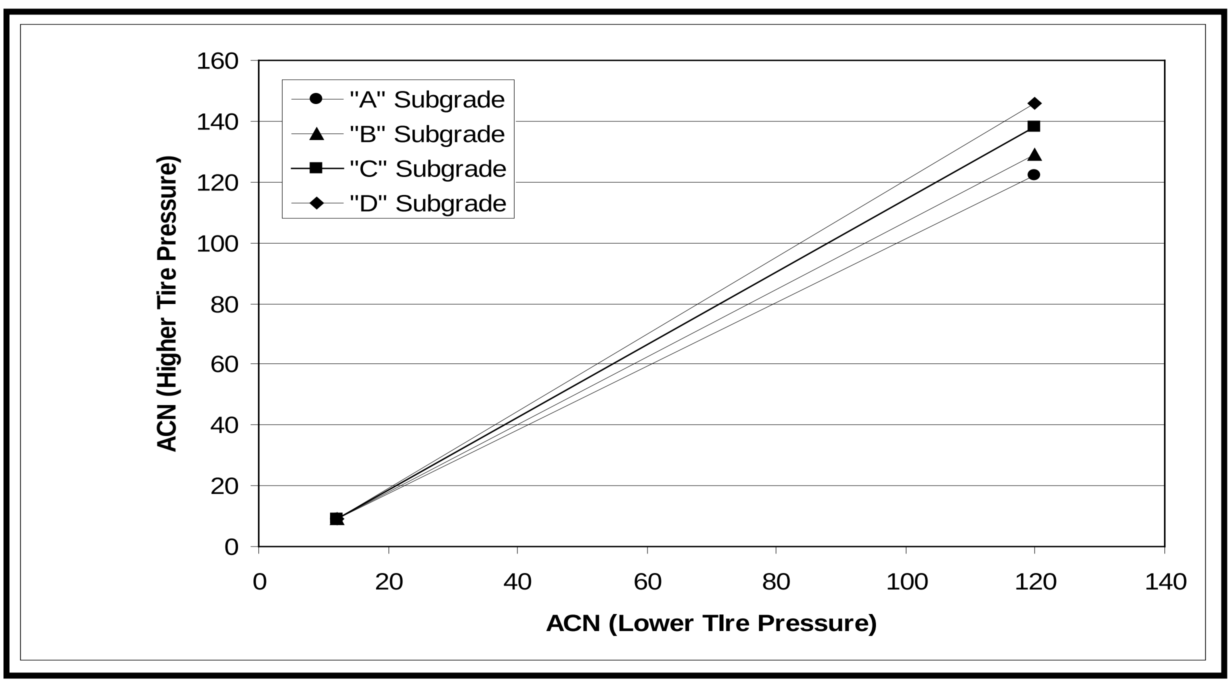
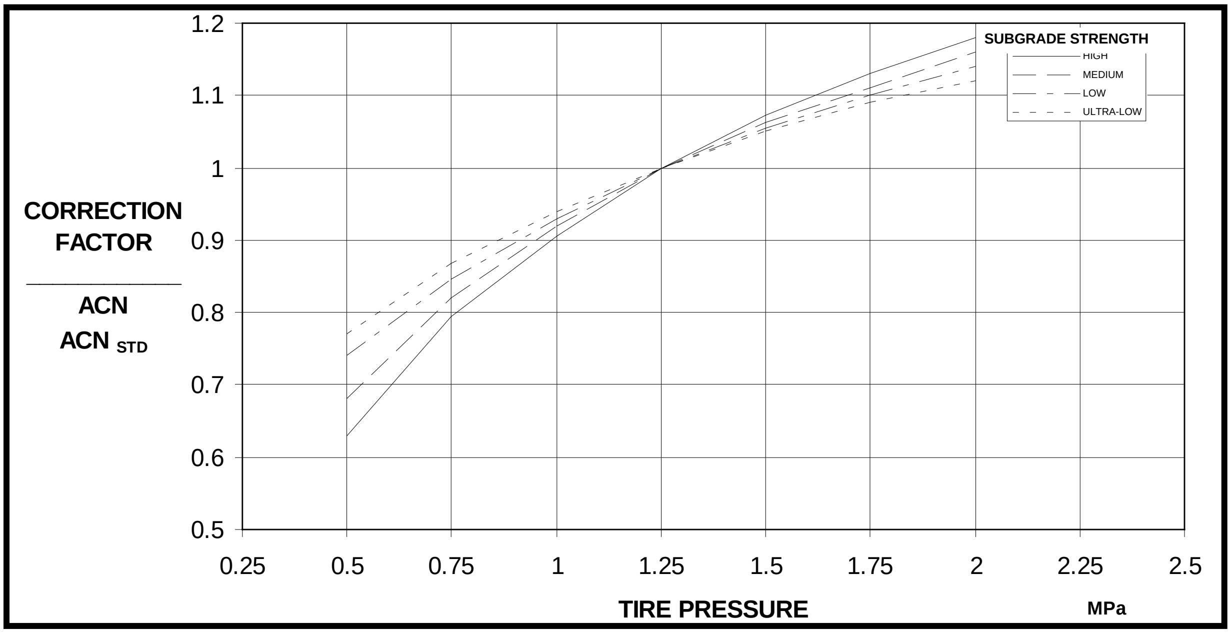


Figure 9-4 Adjusting Rigid Pavement ACN for Changes in Tire Pressure



9-2.8.2 Flexible Pavement ACN Adjustment Due to Tire Pressure.

The ACN for an aircraft was determined to be 60/F/D using a tire pressure of 160 psi (1.1 MPa). Using Figure 9-3, the ACN will be 55/F/D if the tire pressure is reduced to 140 psi (1.0 MPa).

9-2.8.3 Rigid Pavement ACN Adjustment Due to Tire Pressure.

An aircraft operating at a tire pressure of 180 psi (1.2 MPa) on a medium-strength subgrade has an ACN of 50/R/B. The ACN will be 53/R/B if the tire pressure is increased to 215 psi (1.5 MPa). (Enter Figure 9-4 with a tire pressure of 1.5 MPa and proceed vertically until the medium subgrade is intercepted. Proceed horizontally and read the correction factor of 1.06. (50 x 1.06 = 53).

9-3 PCN DEFINITION.

The PCN is a number that expresses the bearing strength (load-carrying capability) of a pavement based on a specified aircraft in terms of a standard single-wheel load at a specified number of passes. The aircraft and number of passes are determined based on the traffic approach as defined in Chapter 4 that is used in the evaluation. This can be a set number of passes of a specific aircraft (e.g., 50,000 passes of the C-17), the equivalent passes of the controlling aircraft over the next 20 years as defined in the mission aircraft group approach, or equivalent passes for representative groups as defined in the mission/representative aircraft group approach. The PCN value is for reporting pavement strength only. The PCN value expresses the results of pavement evaluation in relative terms and cannot be used for pavement design or as a substitute for a structural evaluation.

9-3.1 Computing the PCN.

The numerical PCN value is simply the ACN value of the specified aircraft at the specified number of passes as defined in paragraph 9-3. The entire PCN is a five-part code made up of the numerical portion of the PCN as well as a four-letter code that defines the pavement type, the subgrade category, and the tire pressure described below, as well as the procedure used to determine the numerical PCN value, the using aircraft method, or the technical evaluation method. ICAO procedures permit member states to determine how PCN values will be determined based upon internally developed pavement evaluation procedures. DoD PCN values are based on the technical evaluation method whenever possible.

9-3.1.1 Using Aircraft Method.

The using aircraft method is a simple procedure where ACN values for all aircraft currently permitted to use the pavement facility are determined and the largest ACN value is reported as the PCN. An underlying assumption is that the pavement structure has the structural capacity to accommodate all aircraft in the traffic mix and that each aircraft can operate on the pavement structure without restriction. Using an excessively damaging aircraft that uses the pavement on a very infrequent basis to determine the PCN can result in significant over-estimation of the pavement capacity. This procedure can also result in significant under-estimation of the pavement capacity, preventing acceptable traffic from operating. Use of the using aircraft method is discouraged due to these concerns.

9-3.1.2 Technical Evaluation Method.

The accuracy of a technical evaluation is better than the using aircraft method but requires more time and resources. Pavement evaluation may require a combination of on-site testing and engineering judgment. Numerical PCN values for DoD are determined from an allowable load determined by a technical pavement evaluation conducted in accordance with this UFC.

9-3.1.3 Numerical PCN Value.

Report the numerical PCN value in whole numbers, rounding off any fractional parts to the nearest whole number. For pavements of diverse strengths, the weakest section PCN value normally controls the reported numerical PCN value. Engineering judgment is required if the weakest section is not in the most heavily used part of the runway. In this case, consider another representative section as the basis for the reported PCN.

9-3.1.4 Pavement Type.

Pavement types are either flexible or rigid structures. Table 9-6 lists the pavement codes for purposes of reporting PCN.

Table 9-6 Pavement Codes for Reporting PCN

Pavement Type	Pavement Code
Flexible	F
Rigid	R

9-3.1.4.1 Flexible Pavement.

Flexible pavements support loads through bearing rather than flexural action. They are normally composed of several layers of selected materials designed to gradually distribute loads from the surface to the layers beneath. For a CBR evaluation, each layer in the pavement structure is evaluated to determine structural capacity. The layer that produces the lowest allowable gross load (AGL) is the controlling layer. For a Layered Elastic Evaluation Program (LEEP) evaluation, the tensile strain in the AC surface layer and the vertical strain in the subgrade are used to determine the structural capacity. For the two location points in a LEEP evaluation, the location that produces the lowest allowable load controls the AGL. For LEEP evaluations, the default locations are the bottom of the AC surface layer and the top of the subgrade.

9-3.1.4.2 Rigid Pavement.

Rigid pavements employ a single structural layer, which is very stiff or rigid, to support the pavement loads. The rigidity of the structural layer and resulting beam action enable a rigid pavement to distribute loads over a large area of the subgrade. The load-carrying capacity of a rigid structure is highly dependent upon the strength of the structural layer, which relies on uniform support from the layers beneath.

9-3.1.4.3 Composite Pavement.

Various combinations of pavement types and stabilized layers can result in complex pavements that could be classified as either rigid or flexible. A pavement section may comprise multiple structural elements representative of both rigid and flexible pavements. Composite pavements are most often the result of pavement surface overlays applied at various stages in the life of the pavement structure. If a pavement is of composite construction, the pavement type should be reported as the type which provides the highest allowable load.

9-3.1.5 Subgrade Strength Category.

As discussed in paragraph 9-2.2, there are four standard subgrade strengths identified for calculating and reporting ACN or PCN values. The standard values for rigid and flexible pavements are shown in the section on ACNs in Tables 9-1 through 9-4.

9-3.1.6 Allowable Tire Pressure.

Table 9-7 lists the allowable tire pressure categories used in the ACN-PCN system. The tire pressure codes apply equally to rigid or flexible pavement sections; however, the application of the allowable tire pressure differs substantially for rigid and flexible pavements.

Table 9-7 Tire Pressure Codes for Reporting PCN

Category	Code	Tire Pressure Range
Unlimited	W	No pressure limit
High	X	Pressure ≤ 254 psi
Medium	Y	Pressure ≤ 181 psi
Low	Z	Pressure ≤ 73 psi

9-3.1.6.2 Tire Pressures on Rigid Pavements.

Tire pressure has little effect on pavements with PCC surfaces. Rigid pavements are inherently strong enough to resist high tire pressures and can usually be rated as code W. However, when the rigid layer is very thin (less than 4 inches [102 millimeters]) or is thoroughly shattered (PCI ≤ 25, with pieces less than about 3 feet [1 meter] wide), the tire pressure code is reduced to X.

9-3.1.6.3 Tire Pressures on Flexible Pavements.

Tire pressures may be restricted on asphaltic concrete, depending upon the quality of the asphalt mixture, climatic conditions, or thickness and condition of the surface. Tire pressure effects on an asphalt layer relate to the stability of the mix to resist shearing or densification. A poorly constructed asphalt pavement can be subject to rutting due to consolidation under load. A properly prepared and placed mixture that conforms to DoD specifications can withstand tire pressures more than 254 psi (1.8 MPa) and be rated as tire pressure code W. A flexible pavement that has a PCI > 25 and is ≥ 4 inches (102 millimeters) thick but less than the minimum required thickness per UFC 3-260-02 is assigned code X. Pavement that has a PCI > 25 but is < 4 inches (102 millimeters) thick is assigned code Y. Pavement with a PCI ≤ 25 (aged or severely cracked pavements) is assigned code Y.

9-3.1.6.4 Method Used to Determine PCN.

As discussed in paragraph 9-3.1, two pavement evaluation methods are recognized in the PCN system. If the evaluation represents the results of a technical study, the evaluation method should be coded T. If the evaluation is based on “using airplane” experience, the evaluation method should be coded U. Technical evaluation implies that some form of technical study and computation were involved in the determination of the PCN. Using airplane evaluation means the PCN was determined by selecting the highest ACN among the airplanes currently using the facility.

9-3.2 Critical PCN for a Runway.

When selecting the critical PCN rating for a runway with multiple sections, it is important to examine the entire rating, not just the numerical value. A PCN rating that includes the lowest numerical value may not be the critical PCN rating. It depends on the subgrade category. Examine the AGL when PCN values with different subgrade categories are similar and then use the PCN rating with the lower AGL. Typically, this critical PCN selection for multiple-section runways will occur either within the 75-foot keel or the full-width ends in the first 1,000 feet of the runway.

9-3.3 Example PCN Reporting.

An example of a PCN code is 80/R/B/W/T, with 80 expressing the PCN numerical value, R for rigid pavement, B for medium-strength subgrade, W for high allowable tire pressure, and T for a PCN value obtained by a technical evaluation.

9-3.4 Reporting the PCN Value.

The Service determines the traffic analysis approach used to determine the allowable load for critical/representative aircraft and passes used in the PCN numerical computation for each section. The standard aircraft approach (e.g., the C-17 at a pavement life of 50,000 passes) facilitates PCN comparison between installations. The mission group approach looks at the critical mission aircraft and equivalent passes for a specific installation for a 20-year period. This provides more value to the installation but does not allow for a comparison of load-carrying capacity between multiple installations. The mission/representative approach bases the PCN on the mission aircraft group in terms of a representative aircraft for each gear type group. This last approach provides fidelity for managing pavements at the installation level while facilitating comparison between installations. Note that the PCN and the ACN/PCN procedure described in the following paragraphs provides the first look for managing aircraft traffic at an installation. Ultimately, the allowable loads and allowable passes should be used to manage operations when questions arise. Once a PCN value and the coded entries are determined, the PCN code should be reported to:

National Geospatial-Intelligence Agency (NGA)
Attn: Air Information Library, L27
3838 Vogel Rd.
Arnold MO, 63010

9-4 AIRCRAFT/PAVEMENT (ACN/PCN) CLASSIFICATION NUMBERS.

The ACN/PCN method is a weight-bearing capability reporting tool and is not an evaluation procedure. The NGA publishes PCNs from the Services in their FLIPs for civil and international use. The FLIPs are used to determine weight-bearing limits in terms of the ACN/PCN ratio. The intent is to avoid either overloading pavement facilities or refused landing permission by providing planning information for individual flights or multi-flight missions.

9-4.1 ACN/PCN Concept.

The pavement PCN for a pavement structure is simply the ACN for the selected or most critical aircraft. Under these conditions, any aircraft with an ACN equal to or less than the reported PCN value can safely operate on the pavement, subject to limitations on tire pressure.

9-4.2 Limitations of the ACN/PCN System.

The ACN/PCN system is only intended as a method of reporting relative pavement strength so airport operators can evaluate acceptable operations of airplanes. It is not intended as a pavement design or pavement evaluation procedure, nor does it restrict the methodology used to design or evaluate a pavement structure. Operators should use the allowable loads or allowable passes contained in each Service's pavement evaluation reports to manage day-to-day operations. The use of the standardized method of reporting pavement strength applies only to pavements with bearing strengths of 12,500 pounds (5,700 kg) or greater.

9-5 PAVEMENT OVERLOAD.

Pavement overloading can result from aircraft loads that are too high, a substantial increase in operations rate, or both. Loads larger than the defined design or evaluation load shorten the design life, while smaller loads extend it. Except for massive overloading, pavements are not subject to a particular limiting load above which they suddenly or catastrophically fail. The structural behavior of pavements is such that a pavement can sustain a definable load for an expected number of repetitions during its design life. As a result, occasional overloading is acceptable, when expedient, with only a limited loss in pavement life expectancy and a relatively small acceleration of the pavement deterioration rate. Examples of situations where operators may decide that it is acceptable to overload a pavement are emergency landings, short-term contingencies, exercises, and air shows.

9-5.1 Structural Index (ACN/PCN Ratio) Standards.

9-5.1.1 Structural Index (ACN/PCN) ≤ 1.1.

Structural index (SI) values less than or equal to 1.1 have minimal impact on pavement life.

9-5.1.2 1.1 ≤ Structural Index (ACN/PCN) ≤ 1.4.

When the SI value is greater than 1.1 and less than or equal to 1.4, limit aircraft operations to ten passes and inspect the pavement after each operation, or consult the AGL and Pass-Level tables, or request a pavement engineer evaluate the structural capacity of the pavement to support the required mission. Ensure the airfield surface meets aircraft and mission requirements such as FOD and smoothness.

9-5.1.3 Structural Index (ACN/PCN) ≥ 1.4.

When the SI value is greater than 1.4, do not allow aircraft operations except for emergencies, or request a pavement engineer evaluate the structural capacity of the pavement to support the required mission.

9-5.2 Aircraft Movements.

The annual number of movements by aircraft exceeding an ACN/PCN ratio of 1.0 should not exceed 5 percent of the total annual aircraft movements.

9-5.2.1 Aircraft Movements During a Thaw Period.

Movements by aircraft exceeding an ACN/PCN ratio of 1.0 are normally not permitted on pavements exhibiting substantial signs of distress or failure. If the pavement must be used for operations, perform an analysis using the PCN criteria in Chapter 8 during any periods of thaw-weakening following frost penetration or when the strength of the pavement or its subgrade could be weakened by the presence of water.

9-5.2.2 AGL/Pass Level Methodology.

The AGL/pass level methodology must be used to determine airfield structural capability when the ACN/PCN ratios exceeds a value of 1.1.

CHAPTER 10 REPORTING EVALUATION RESULTS

10-1 OVERVIEW.

Evaluation results are reported using maps, tables, and figures compiled in an evaluation report. The content of the report varies based on the scope and intended use of the evaluation by each Service, such as a contingency evaluation versus an evaluation at a main operating installation where the report is used to generate pavement management plans. In either case, the report always describes and discusses the type and number of tests performed, the analytical process used to determine thickness and strength values, and any limitations or assumptions.

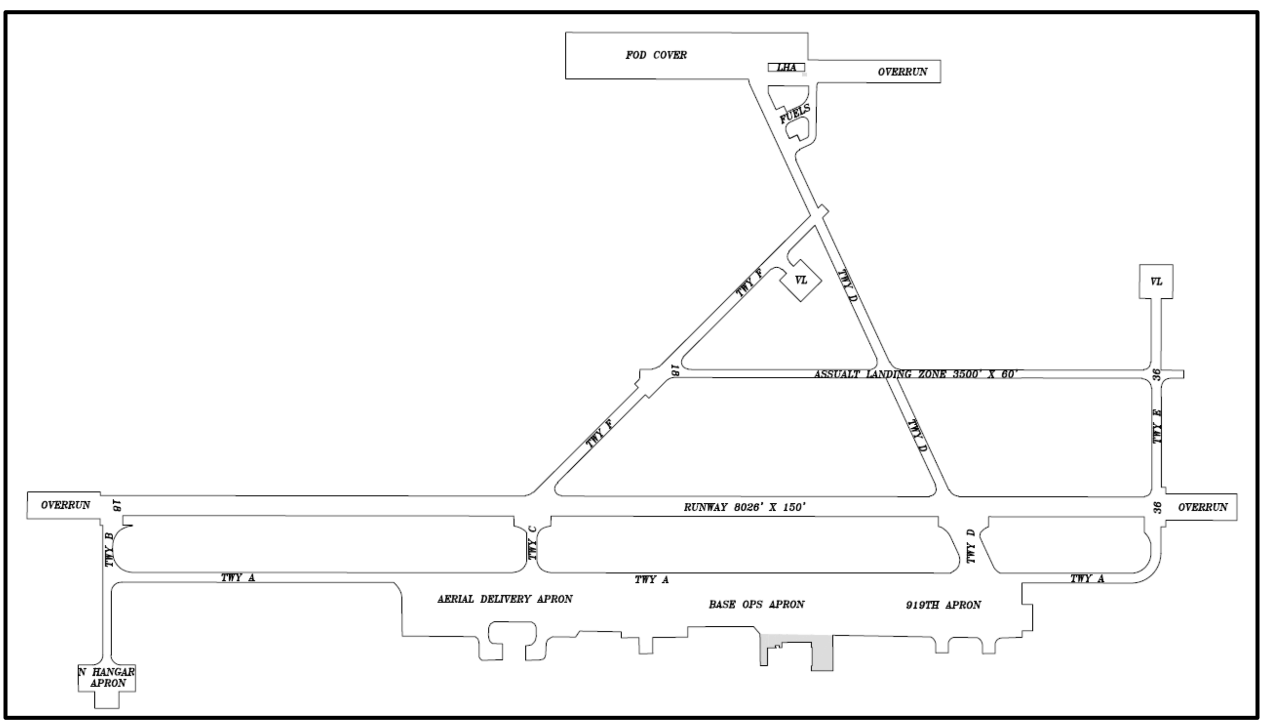
10-2 INVENTORY.

The pavement network, branch, and section inventory structure defines each pavement area for testing, analysis, and reporting. Tabular reports are sorted by branch and section or just by section, depending on the information presented and Service preferences. Maps also use branch and section IDs to organize and present inventory and analysis results. The following paragraphs present examples of inventory maps and tables.

10-2.1 Branch Maps.

Branch maps show the location of each branch on the airfield as shown in Figure 10-1. Variations of this basic map show both branches and sections or are color-coded to show condition data as shown in other examples in this chapter.

Figure 10-1 Branch Map Example



10-2.2 Section Maps.

Section maps show the location of each section on the airfield. They can include the pavement type and thickness as shown in Figure 10-2 or show only the section ID or branch and section ID as shown in Figure 10-3. Variations of these basic maps are color-coded to indicate condition data as shown in other examples in this chapter.

Figure 10-2 Section Map Example 1

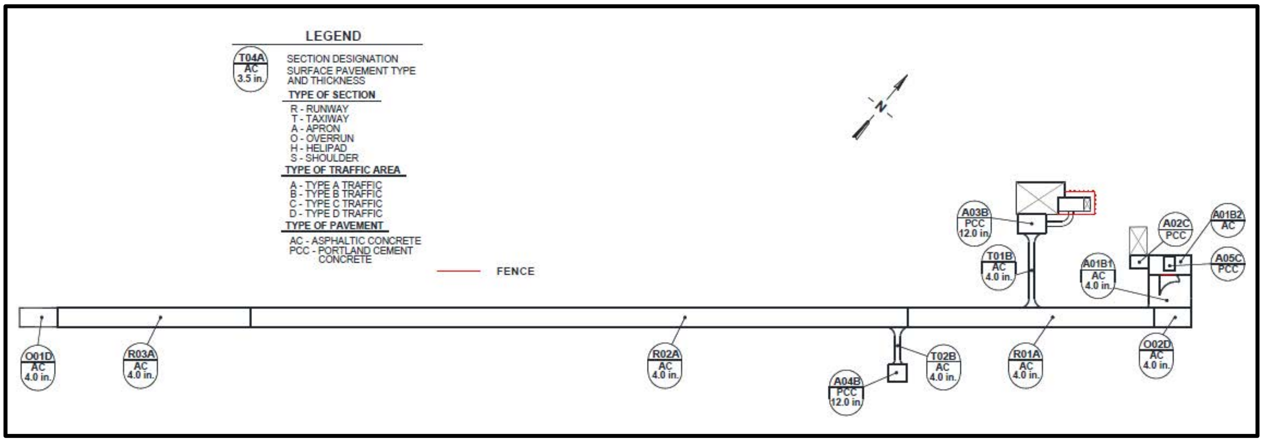
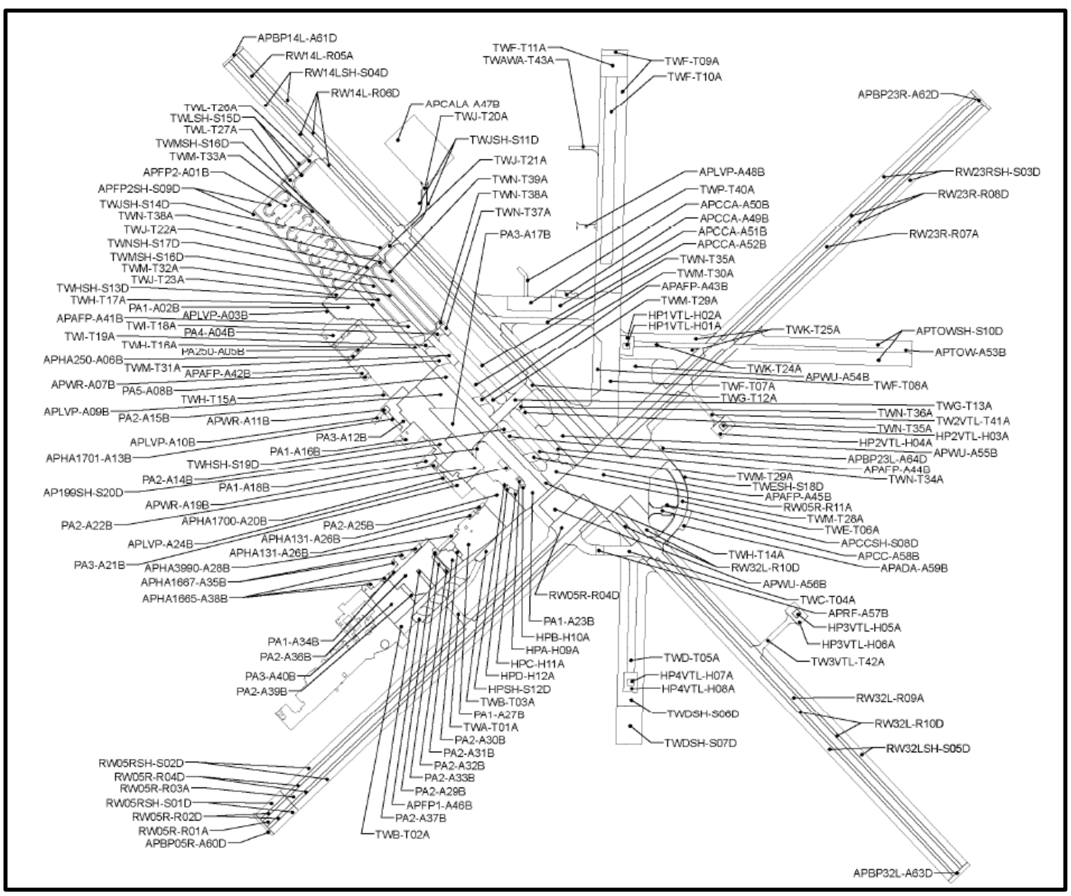


Figure 10-3 Section Map Example 2



10-2.3 Construction History.

Construction history, also known as work history, is integral to developing deterioration models and maintenance and repair (M&R) strategies. Typically, construction history is presented in tables and, while there are variations, construction history tables always have the section ID, the pavement type and thickness, and the construction date. Figure 10-4 is an example of a report generated by the PAVER application and Figure 10-5 is an example of a report generated in a spreadsheet. Variations of the report include information on subsurface layers or surface treatments.

Figure 10-4 Construction History Report Example 1

6/24/2021 **Work History Report** Page 1 of 3

Pavement Database: Mettie AS 2020_data_withGIS

Network: Mettie Airstrip, Yaki **Branch:** APNWTURN NW TURNAROU **Section:** A02B **Surface:**AC

L.C.D. 1/1/2019 **Use:** APRON **Rank:** P **Length:** 239.00 (Ft) **Width:** 114.00 (Ft) **True Area:** 27246.00000 (SqFt

Work Date	Work Code	Work Description	Cost	Thickness (in)	Major M&R	Comments
1/1/2019	NC-AC	New Construction - AC	0.00	0.00	☑	
1/1/2019	BA-AG	Base Course - Aggregate	0.00	0.00	☐	
1/1/2019	SG-CO	Subgrade - Compacted	0.00	0.00	☐	SILTY SAND (SP-SM)

Network: Mettie Airstrip, Yaki **Branch:** APSETURN SE TURNAROUN **Section:** A01B **Surface:**AC

L.C.D. 1/1/2019 **Use:** APRON **Rank:** P **Length:** 240.00 (Ft) **Width:** 112.00 (Ft) **True Area:** 26880.00000 (SqFt

Work Date	Work Code	Work Description	Cost	Thickness (in)	Major M&R	Comments
1/1/2019	NC-AC	New Construction - AC	0.00	0.00	☑	
1/1/2019	BA-AG	Base Course - Aggregate	0.00	0.00	☐	
1/1/2019	SG-CO	Subgrade - Compacted	0.00	0.00	☐	SILTY SAND (SP-SM)

Figure 10-5 Construction History Report Example 2

Pavement Section	Surface Pavement		Construction Date	Agency[a]
	Thicknesses in.	Type		
Runway 04-22				
R01A	24.0 20.0	PCC PCC	1957-1958 2021	IE CE
R02C	19.0[d]	PCC	1958-1959	CE
R03C	12.0[b] 2.0[c] 3.0[c] 17.0	AC AC AC PCC	1955-1956 1959 Unknown 2021	CE CE CE
R04A	16.0 21.5[d] 20.0	PCC PCC PCC	1956-1957 1996-2000 2019	CE CE CE

10-3 TRAFFIC.

An evaluation report typically includes a table that outlines the traffic used in the analysis. This may be one of the standard traffic patterns shown in Chapter 4 or the mission traffic as shown in Figure 10-6. In all cases, traffic tables include the aircraft used in the analysis, the load, the number of passes and, for a mixed traffic analysis, the controlling vehicle(s) and equivalent passes.

Figure 10-6 Mission Traffic Example

Aircraft from Table A-5	Aircraft Used for Evaluation in PCASE	Gross Weight lb	20-year Projected Aircraft Passes	20-year Equivalent C-17 Passes
Main Pattern PCC and AC Pavements[a]				
C-17	C-17A	585,000	50,000	50,000
20-year Total Equivalent C-17 passes @ 585,000 lb = 50,000				
Fixed-Wing Aircraft	Aircraft Used for Evaluation in PCASE	Gross Weight lb	20-year Projected Aircraft Passes	20-year Equivalent C-130 Passes
Limited Pattern PCC Pavements[a]				
A-10	A-10	50,000	360	31
A6E	A-6 Intruder	60,421	20	115
H64D	AH-64	18,000	52,140	1
BE20/C12	C-12J Huron	16,600	20,780	1
C-130J-30	C-130J-30 Hercules	164,000	1,560	1,560
D0328/C146	C-146 Wolfhound	30,843	60	1

10-4 ACN CHARTS AND TABLES.

The report uses charts, tables, or both to present ACN data. In all cases, the information includes the aircraft, pavement type, load, subgrade category, and the ACN.

10-4.1 ACN Table Example.

Figure 10-7 contains ACN values for the representative aircraft in Table 4-5 at various evaluation loads and Figure 10-8 shows an example at a single load. Figure 10-9 shows the ACN values for a single aircraft at varying operational loads.

Figure 10-7 ACN Values for Representative Aircraft

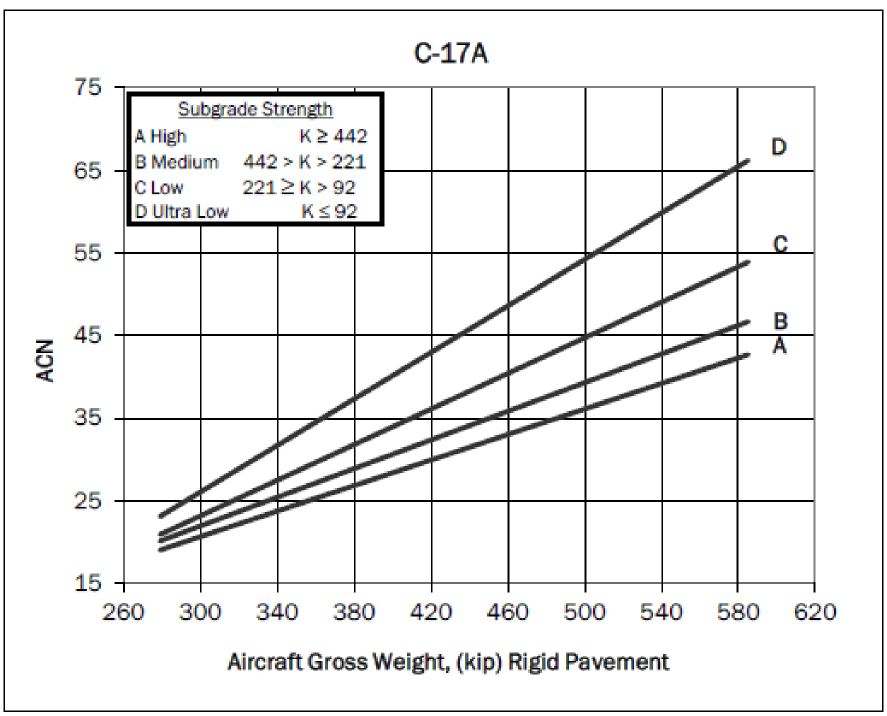
AIRCRAFT CLASSIFICATION NUMBERS										
AIRCRAFT	LOAD	MAX TAKE OFF WEIGHT (LBS)	RIGID PAVEMENT				FLEXIBLE PAVEMENTS			
			A	B	C	D	A	B	C	D
			K > 442	K < 442 K > 221	K < 221 K > 92	K < 92	CBR>13	CBR<13 CBR>8	CBR<8 CBR>4	CBR<4
			E>64,822	E<64,822 E>26,618	E<26,618 E>8,640	E<8,640	E>19,500	E<19,500 E>12,000	E<12,000 E>6,000	E<6,000
F-35C LIGHTNING II	FULL	70,400	30.1	30.1	30.1	30.1	28.2	28.2	28.2	28.2
	HALF	52,787	22.5	22.5	22.5	22.5	21.2	21.2	21.2	21.2
	EMPTY	35,174	14.9	14.9	14.9	14.9	14.1	14.1	14.1	14.1

AIRCRAFT	LOAD	MAX TAKE OFF WEIGHT (LBS)	RIGID PAVEMENT				FLEXIBLE PAVEMENTS			
			A	B	C	D	A	B	C	D
			K > 442	K < 442 K > 221	K < 221 K > 92	K < 92	CBR>13	CBR<13 CBR>8	CBR<8 CBR>4	CBR<4
			E>64,822	E<64,822 E>26,618	E<26,618 E>8,640	E<8,640	E>19,500	E<19,500 E>12,000	E<12,000 E>6,000	E<6,000
P-8A POSEIDON	FULL	188,200	55.7	58.7	61.1	62.3	48.2	51.1	56.4	61.0
	HALF	143,348	40.7	43.1	45.0	46.0	35.5	37.2	40.7	45.0
	EMPTY	98,495	25.7	27.4	28.9	29.7	22.7	23.3	25.0	29.0
C-130H HERCULES	FULL	175,000	30.9	34.1	37.3	39.7	27.4	32.0	34.8	40.6
	HALF	122,000	21.2	23.1	25.1	26.7	18.7	21.8	23.6	27.2
	EMPTY	69,000	11.4	12.1	12.9	13.7	9.9	11.5	12.3	13.7
C-17A GLOBE-MASTER III	FULL	585,000	42.7	46.7	53.9	66.3	50.5	57.0	68.5	90.2
	HALF	432,000	30.9	33.4	37.4	44.7	35.0	38.9	46.3	60.6
	EMPTY	279,000	19.0	20.1	20.9	23.1	19.5	20.7	24.0	31.0
KC-135 STRATO-TANKER	FULL	323,000	35.0	42.8	51.2	58.0	36.7	40.8	49.4	63.8
	HALF	213,650	22.1	26.3	31.2	35.4	23.0	25.2	30.0	38.3
	EMPTY	104,300	9.1	9.8	11.1	12.7	9.3	9.6	10.5	12.7
MV-22 OSPREY	FULL	60,500	10.6	11.7	13.6	15.4	12.2	13.2	14.1	14.6
	HALF	47,016	8.0	8.8	10.0	11.6	9.1	9.9	10.6	11.0
	EMPTY	33,531	5.3	5.9	6.4	7.7	6.0	6.5	7.0	7.4

Figure 10-8 ACN Values for Controlling Aircraft

Design Aircraft	Weight, lb	Subgrade Category[a]	ACN or Required PCN
PCC Pavements			
C-17A	585,000	A	43
		B	47
		C	54
		D	66
C-130-J	164,000	A	34
		B	37
		C	39
		D	42
AC Pavements			
C-17A	585,000	A	40
		B	45
		C	53
		D	70
C-130-J	164,000	A	31
		B	34
		C	36
		D	42

Figure 10-9 ACN Chart Example



10-5 REPORTING TEST RESULTS.

As discussed in Chapter 3, testing typically includes a mix of one or more of the following: coring or drilling, GPR, or MIRA testing to determine pavement thickness; GPR testing to determine subsurface layer structure; DCP testing to determine subsurface layer structure and strength; and FWD/HWD testing to determine the modulus of the layers in the pavement structure. Although not used as frequently as in the past, test pits are an option. The scope and intended use of the evaluation typically defines testing requirements. A comprehensive report includes test results to ensure readers have the necessary information to make decisions and provides a foundation for future evaluations.

10-5.1 Surface Condition.

The PCI provides an objective measure of the surface condition that is used in most instances. Use a cursory inspection with a direct rating of GOOD, FAIR, or POOR for contingency evaluations when a full PCI inspection is not performed. In either case, report the surface condition in either a table or a map.

10-5.1.1 Surface Condition Maps.

Surface condition maps vary depending on the scope and intended use of the evaluation. Maps show either the standard seven-tier PCI rating scale for a full PCI as shown in Figure 10-10 or a three-color condition map as shown in Figure 10-11. If a full PCI is not performed or when Service standards dictate, use three-color maps. Figure 10-10 includes the section information with the pavement types. At a minimum, the map includes either a branch or section ID.

Figure 10-10 Seven-Color PCI Map Example

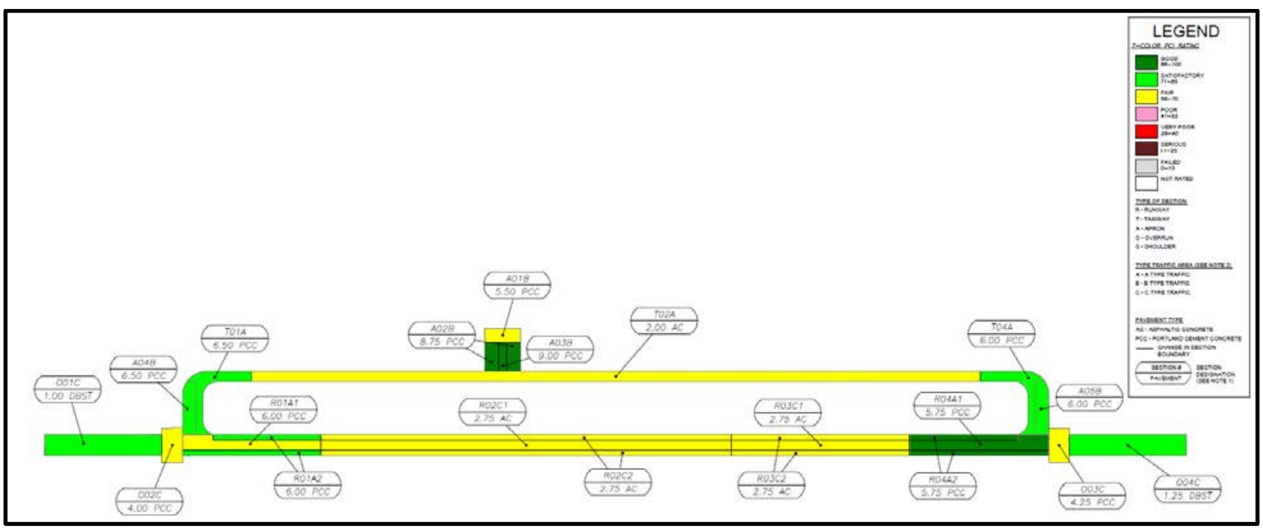
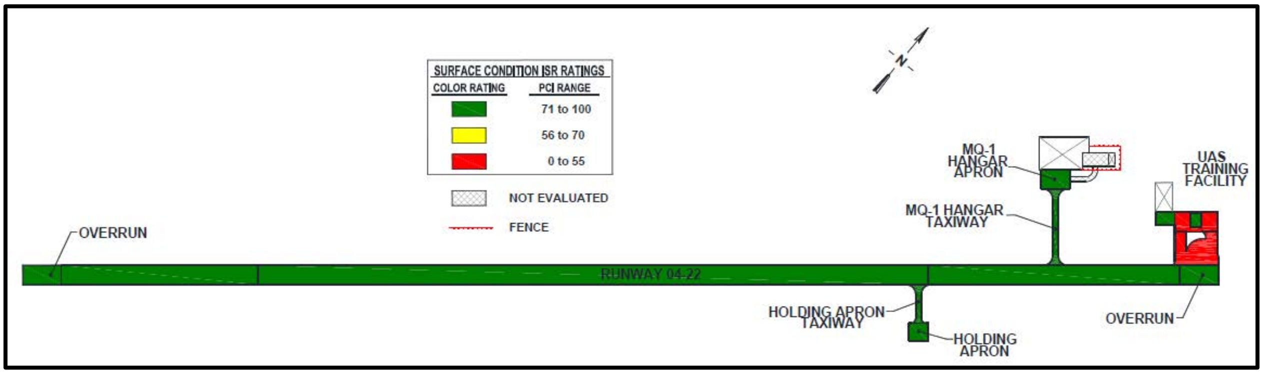


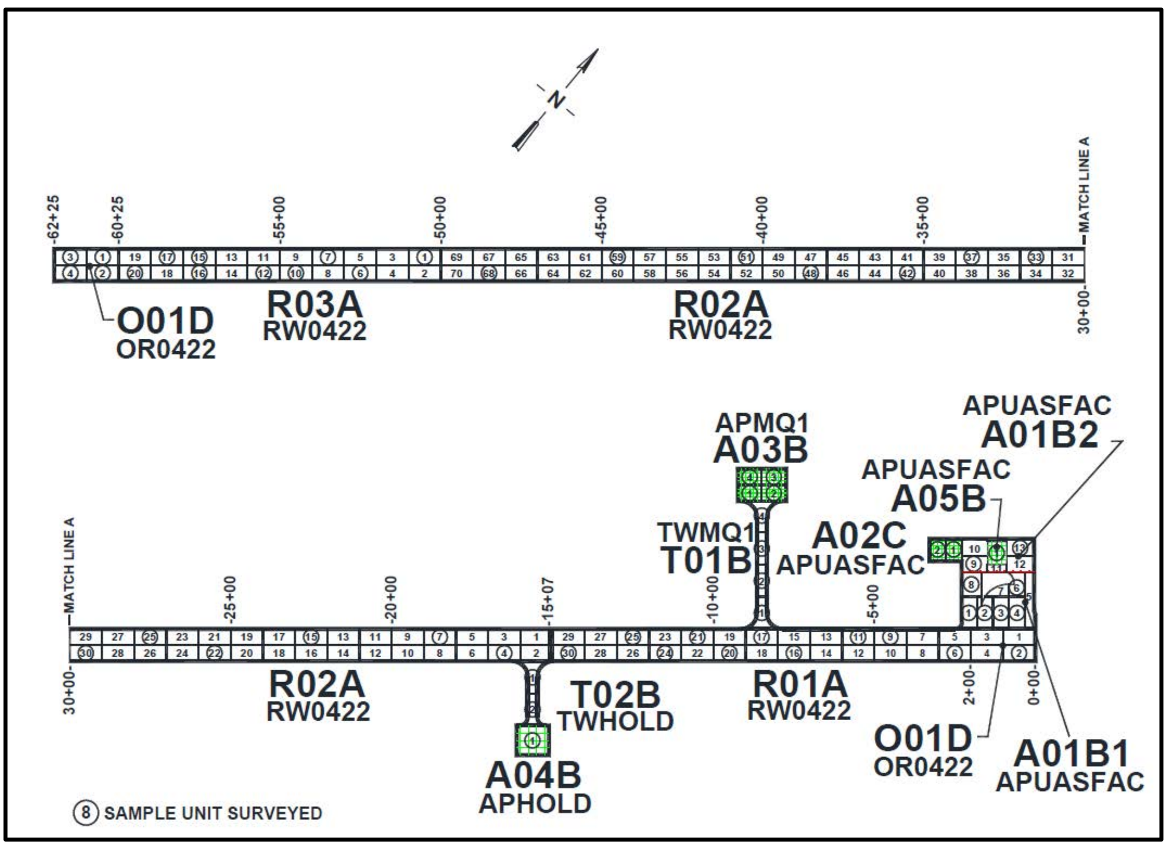
Figure 10-11 Three-Color PCI Map Example



10-5.1.2 Sample Unit Maps.

Sample unit maps define the location of each sample unit in an inspection. Sample unit maps show the section delineation and identification and include each sample unit with its number. In addition, sample unit maps for rigid pavements include the slab layout. All sample units are numbered and inspected samples have a circle around the number.

Figure 10-12 Sample Unit Map Example



10-5.1.3 Surface Condition Table.

The PCI is often included in other tables such as the physical property data (PPD) or M&R summary tables to provide context. When the PCI is the primary focus, summarize the data at the branch level as shown in Figure 10-13 or at the section level as shown in Figure 10-14, depending on the intended use. In either case, at a minimum, a surface condition table shows the branch and/or section ID, the condition, and last inspection date. Tables typically include other inventory information as well as the deterioration rate and predicted PCI.

Figure 10-13 Branch Condition Report Table

6/24/2021 **Branch Condition Report** Page 1 of 2

Pavement Database: Mettie AS 2020_data_withGIS

Branch ID	Number of Sections	Sum Section Length (Ft)	Avg Section Width (Ft)	True Area (SqFt)	Use	Average PCI	Standard Deviation PCI	Weighted Average PCI
APNWTUR	1	239.00	114.00	27,246.00	APRON	100.00	0.00	100.00
APSETURN	1	240.00	112.00	26,880.00	APRON	100.00	0.00	100.00
APUAS	1	40.00	40.00	1,600.00	APRON	55.00	0.00	55.00
RW1230	3	5,200.00	100.00	520,000.00	RUNWAY	100.00	0.00	100.00
TW1	1	1,082.00	80.00	87,594.00	TAXIWAY	100.00	0.00	100.00
TW2	1	2,664.00	60.00	185,435.00	TAXIWAY	100.00	0.00	100.00
TWUAS	3	182.00	15.00	2,735.00	TAXIWAY	77.00	24.54	83.93

Figure 10-14 Section Condition Report Table

Branch ID	Section ID	Surface	Use	Rank	Length (ft)	Width (ft)	Slabs	Slab Dimensions (ft)		Joint Length (ft)	True Area (sqft)	True Area (sy)	Last Inspection Date	Age at Time of Inspection (yrs)	Last Major Work Date	SCI	PCI Pct Load	PCI	Predicted PCIs	
								Width	Length							2018		2018	2021	2024
AP199SH	S20D	AC	SHOULDER-AF	T	331	40					11,601	1,289	11/8/18	8	01/06/11	93	0	32	6	0
APADA	A59B	PCC	APRON	P	326	74	131	12	15	3,138	24,508	2,723	11/8/18	43	06/15/76	100	0	85	84	83
APAFP	A41B	PCC	APRON	P	200	255	271	12	15	7,018	50,848	5,650	11/8/18	43	06/01/76	100	7	85	84	83
APAFP	A42B	PCC	APRON	P	200	130	140	12	15	3,473	26,290	2,921	11/8/18	43	06/01/76	91	41	87	86	85
APAFP	A43B	PCC	APRON	P	154	130	110	12	15	2,659	20,532	2,281	11/8/18	43	06/01/76	96	23	85	84	83
APAFP	A44B	PCC	APRON	P	200	130	140	12	15	3,480	26,189	2,910	11/8/18	43	06/01/76	94	30	84	83	82
APAFP	A45B	PCC	APRON	P	200	130	137	12	15	3,480	25,745	2,861	11/8/18	43	06/01/76	100	0	98	98	98
APBP05R	A60D	AAC	APRON	S	37	400					14,533	1,615	11/8/18	38	01/01/81	88	0	24	18	12
APBP14L	A61D	AAC	APRON	S	35	400					14,000	1,556	11/8/18	38	01/01/81	63	0	32	27	21
APBP23L	A64D	PCC	APRON	S	70	50	12	17	17	291	3,500	389	11/8/18	8	01/01/11	100	0	93	90	88
APBP23R	A62D	AAC	APRON	S	40	397					15,197	1,689	11/8/18	38	01/01/81	73	0	46	42	37
APBP32L	A63D	AAC	APRON	S	55	394					21,865	2,429	11/8/18	38	01/01/81	100	0	11	4	0
APCALA	A47B	PCC	APRON	P	881	611	2,867	12	15	77,457	537,491	59,721	11/8/18	34	06/15/85	100	0	94	93	93
APCC	A58B	PCC	APRON	S	420	119	235	13	15	6,791	44,005	4,889	11/8/18	43	06/15/76	100	0	95	95	94

10-5.2 Dynamic Cone Penetrometer (DCP) Report.

DCP reports include the location of the evaluation as well as the date and location or number of the test. Include the blow and penetration data as well as a data plot. This is typically a CBR plot, but a plot of k or other values may be presented as well. Identify the hammer correlation and soil correlation used to determine the CBR values. The layer structure used to populate the PPD table may also be included on the graph, in tabular form, or both. See Figure 10-15.

Figure 10-15 DCP Test Report

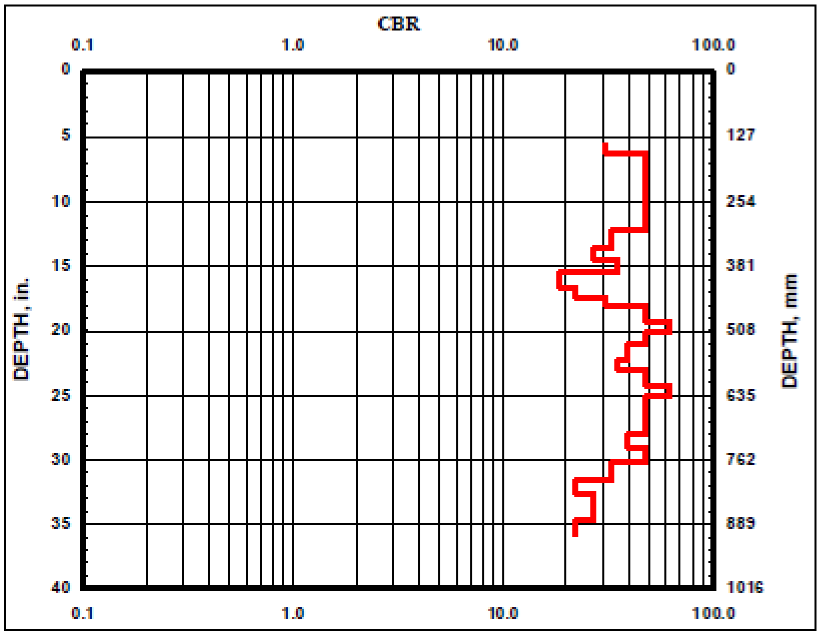
DCP TEST DATA

Project: *Stallion AAF*
Location: R01A-Sta 0+65, 20' W of CL
Date: 3-Oct-09
Soil Type(s):

Hammer
- ○ 10.1 lbs.
- ◉ 17.6 lbs.
- ○ Both hammers used

Soil Type
- ○ CH
- ○ CL
- ◉ All other soils

No. of Blows	Accumulative Penetration (mm)	Type of Hammer
0	145	1
2	160	1
5	185	1
5	210	1
5	235	1
5	260	1
5	285	1
5	310	1
5	345	1
3	370	1
3	390	1
3	425	1
2	445	1
2	460	1
2	470	1
4	490	1
5	510	1
5	535	1
5	565	1
3	585	1



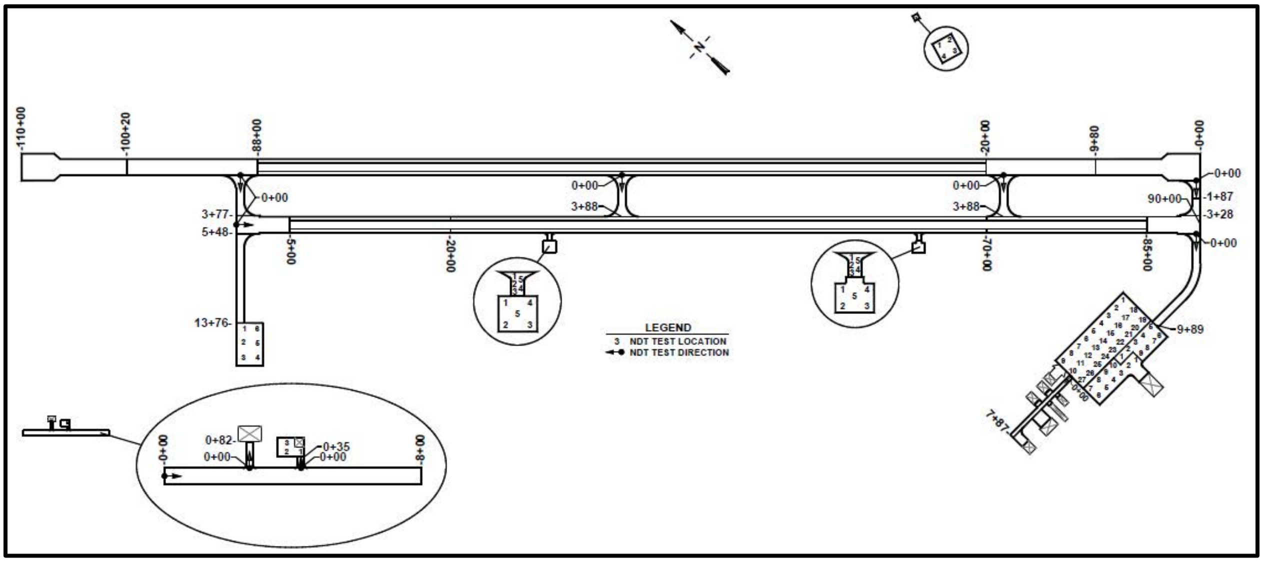
10-5.3 Falling/Heavy Weight Deflectometer (FWD/HWD) Data.

As described in paragraph 3-4.1, FWD is the generic term for the device, with the HWD capable of applying a heavier load than other FWDs, but the terms are used synonymously. FWD data is reported using one or more report types, including maps, charts, and tables.

10-5.3.1 FWD Data Maps.

FWD data maps report the test locations. They can vary from a map that shows the general location of tests to one based on the GPS coordinates of each test location. The latter are typically included at a larger scale. Figure 10-16 shows a map of the general location and direction of testing. Both the general map and the more detailed GPS-based map show distance measurements on long, linear structures such as a runway. The distance measurement can be used to identify the test location or, more typically, the test is just given a number. The term station is used for either the test number or the test location.

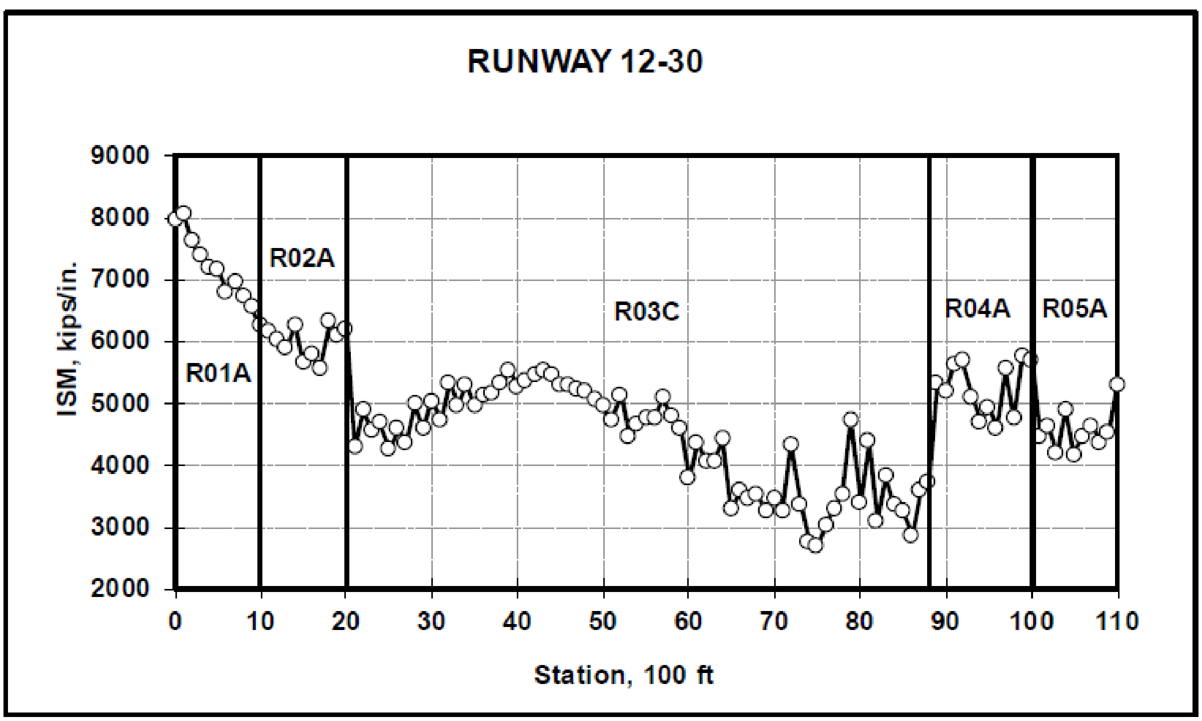
Figure 10-16 FWD Test Location Map



10-5.3.2 FWD Data Charts.

FWD data charts typically display the impulse stiffness modulus (ISM) as described in paragraph 5-3.5.1. These ISMs provide a quantitative stiffness comparison between test stations and between pavement sections. The ISM values are plotted on the Y axis for each station (test point) in the section. These data are used to visually determine if a change in strength exists and define where sections change when the FWD file has basin data from multiple sections, as shown in Figure 10-17.

Figure 10-17 ISM Plot



10-5.3.3 FWD Data Tables.

When included in a report, FWD data are typically limited to the representative basin that is used for analysis for each section (see paragraph 5-3.8) rather than reporting all basin data. The representative basin data is presented in a table that includes the section identification, the ISM, and load, as well as the deflection data (in mils) for each FWD sensor. Figure 10-18 shows a typical representative basin table.

Figure 10-18 Representative Basin Table

Section	ISM, kips/in.	Load, lb	Deflection, mils						
			D1	D2	D3	D4	D5	D6	D7
Runway 12-30									
R01A	7,182	49,985	6.96	6.41	5.85	5.42	5.00	4.52	4.03
R02A	6,075	50,303	8.28	7.95	7.38	6.93	6.38	5.70	5.15
R03C	4,411	50,062	11.35	10.74	9.78	8.82	7.83	6.68	5.62
R04A	5,323	50,040	9.40	8.88	8.16	7.71	6.93	6.05	5.30
R05A	4,602	49,930	10.85	10.26	9.48	8.73	7.84	6.96	5.94

10-5.4 Ground Penetrating Radar (GPR).

As described in paragraph 3-4.2, GPR is used to determine pavement and soil layer thicknesses and determine the presence of voids. When used to determine thickness, the average thickness values for a section are populated in the physical property data table. When used to identify the location of anomalies such as voids, images from the GPR application may be included in the report.

10-6 PHYSICAL PROPERTY DATA (PPD).

PPD is the term used to describe the pavement layer structure. When included in a report, these data are presented in tabular format. At a minimum, this table will include the section ID as well as the thickness, description, and strength index or property for each layer. Flexural strength is reported for any PCC layer. The description can range from a general layer description (e.g., drainage layer or stabilized base) to a USCS when soil laboratory testing was performed. The table may include the backcalculated modulus value as shown in Figure 10-19 or a strength index like CBR or k for soil layers as shown in Figure 10-20. When testing includes coring and DCP tests, it is typical to report the CBR and k values. Reporting modulus values is typically done when only HWD data is collected although there may be instances when a PPD table may include both, e.g., some sections had coring, DCP, and HWD data collected because they were new or when the impulse stiffness modulus was below 400, making an airfield pavement analysis (APE) analysis preferable for that section.

Figure 10-19 PPD Table with Modulus

Branch	Section	Length (ft)	Width (ft)	General Condition PCI	Overlay Pavement			Pavement			Base			Subbase			Subgrade	
					Thick-ness[a] (in.)	Type	Flex. Str.[a] (psi)	Thick-ness[a] (in.)	Type	Flex. Str. (psi)	Thick-ness[a] (in.)	Material[a]	Modulus psi	Thick-ness[a] (in.)	Material[a]	Modulus (psi)	Material[a]	Modulus (psi)
TWB	T07A	500	150	Good				15.0	PCC	650	4.0 6.0	Drainage GW	225,000[c] 225,000[c]				Lean Clay (CL)	18,031
	T08A	3,000	75	Fair				5.0	AC		10.0 4.0	GW Drainage	–	6.0	Separation	–	Lean Clay (CL)	–
	T09A	5,000	75	Fair				4.0	AC		11.0 4.0	GW Drainage	–	6.0	Separation	–	Lean Clay (CL)	–

Figure 10-20 PPD Table with CBR/k

SUMMARY OF PHYSICAL PROPERTY DATA Installation Name																
SECT	IDENT	OVERLAY PAVEMENT			PAVEMENT			BASE			SUBBASE			SUBGRADE	
		THICK (in)	DESCRP	FLEX (psi)	THICK (in)	DESCRP	FLEX (psi)	THICK (in)	DESCRP	K/CBR	THICK (in)	DESCRP	K/CBR	DESCRP	K/CBR
A01B	South Arm/Disarm Pad	-	-	-	12.25	PCC	710	6.00	GP-GM$_{ss}$	400 -	5.00	SC$_{ss}$	275 -	SP-SM$_{ss}$	200 -
A02B	Apron 01	-	-	-	14.00	PCC	575	6.00	STABILZED BASE	400 -	8.00	SP-SM$_{ss}$	225 -	SM-SC$_{ss}$	125 -
A03B	Apron 01	-	-	-	12.75	PCC	650	6.00	GW-GM$_{ss}$	400 -	5.00	SP-SM$_{ss}$	325 -	SC$_{ss}$	300 -

10-7 BACKCALCULATION RESULTS.

Backcalculation results are presented in a layered elastic modulus table. This table may include either the backcalculated modulus values for each section or the modulus values used for Layered Elastic Evaluation Program (LEEP) analysis for each section, the distinction being that the latter shows values that were manually set for analysis as in the case of capping PCC modulus values or using the temp option for asphalt modulus values in analysis. At a minimum, a modulus table shows the section ID and the modulus for each layer. It may also include information on the layer type (e.g., PCC or AC), the layer thickness (including depth to bedrock), or the percent error of closure for reported backcalculated modulus values. Figure 10-21 shows a layered elastic modulus value generated by the Pavement-Transportation Computer Assisted Structural Engineering (PCASE) application.

Figure 10-21 Layered Elastic Modulus Table

Layered Elastic Model Data Installation Name															
Section	Layer 1				Layer 2				Layer 3			Layer 4		
	Thickness (in)	Type	Modulus (psi)	Flex. Str. (psi)	Thickness (in)	Type	Modulus (psi)	Flex. Str. (psi)	Thickness (in)	Type	Modulus (psi)	Thickness (in)	Type	Modulus (psi)
A01B	10.00	PCC	3,930,965	616	-	-	-	-	-	-	-	230.00	SUBG	18,025
A02B	5.50	AC	240,208	650	6.00	BASE	52,969	-	12.00	SUBAS	31,000	216.50	SUBG	22,888
A03B	8.25	PCC	4,586,409	727	-	-	-	-	-	-	-	231.75	SUBG	27,573
A04B	5.50	AC	360,647	650	6.00	BASE	70,334	-	-	-	-	228.50	SUBG	31,907
A05B	10.00	PCC	2,679,401	427	-	-	-	-	-	-	-	230.00	SUBG	27,622
A06B	6.00	PCC	2,982,971	474	12.00	BASE	73,316	-	24.00	SUBAS	28,220	198.00	SUBG	19,936
A07B	5.50	AC	249,994	650	6.00	BASE	100,998	-	-	-	-	204.50	SUBG	22,328

10-8 ANALYSIS RESULTS.

Analysis results are typically in tables but the results from these tables may also be displayed on maps. At a minimum, analysis results tables will include the section ID, allowable passes, allowable gross load (AGL), Pavement Classification Number (PCN), and the basis of the PCN. These results are reported in one or more tables, e.g., PCNs may be reported in a separate table than allowable passes and AGLs. These tables may also include other data, such as overlay requirements, critical aircraft, Aircraft Classification Number (ACN, and the structural index (ACN/PCN ratio). The presentation of the results is largely defined by whether the analysis is done based on standard, mission, or mission/representative aircraft groups as well as whether an individual or mixed traffic analysis was performed.

10-8.1 Aircraft/Gear Type Load Table.

An analysis results table may be organized based on specified loads for specific aircraft or gear types. In this case, the report in Figure 10-22 shows the PCN and design passes (basis of the PCN) as well as the allowable passes.

Figure 10-22 Aircraft/Gear Type PCN – Allowable Pass Table

GEAR TYPE	ST			DT			STT			DTT			TRT		
AIRCRAFT	F-35C			P-8A			C-130H			KC-135			C-17A		
SECTION	PCN	DESIGN PASSES	ALLOWA BLE PASSES	PCN	DESIGN PASSES	ALLOWA BLE PASSES	PCN	DESIGN PASSES	ALLOWA BLE PASSES	PCN	DESIGN PASSES	ALLOWA BLE PASSES	PCN	DESIGN PASSES	ALLOWA BLE PASSES
APCR-A06D	35/R/C/W/T	87,393	564,964	75/R/C/W/T	289	1,033	32/R/C/W/T	298,545	237,157	52/R/C/W/T	10,866	12,360	47/R/C/W/T	2,239	789
APLA-A05D	38/R/C/W/T	87,393	1,585,438	79/R/C/W/T	289	1,545	34/R/C/W/T	298,545	404,170	54/R/C/W/T	10,866	17,982	49/R/C/W/T	2,239	1,112
APLA-A49D	24/F/B/W/T	7,406	1,202	46/F/B/W/T	331	181	29/F/B/W/T	5,872	8,458	43/F/B/W/T	725	1,013	52/F/B/W/T	216	540
APRP-A08D	9/F/A/W/T	8,543,298	4,407	31/F/A/W/T	20,041	278	17/F/A/W/T	8,928,664	24,662	27/F/A/W/T	159,846	1,554	29/F/A/W/T	18,873	709
APRP-A09D	39/R/B/W/T	80,153,228	UNLIMITED	86/R/B/W/T	20,054	1,624,848	37/R/B/W/T	> 99 M	UNLIMITED	57/R/B/W/T	2,552,572	UNLIMITED	54/R/B/W/T	1,092,516	4,685,595

10-8.2 Aircraft Group Allowable Gross Load (AGL) Table.

An aircraft group AGL table is organized by groups of aircraft with similar characteristics. AGLs are reported for specified pass levels of each group. These tables may be color-coded to indicate when the AGL is above the maximum aircraft load for the group (green), when it is between the maximum and minimum load for the group (yellow), and when it is below the minimum load for the group. The AGL table is accompanied by a separate table that defines the aircraft in each group and the pass levels. Figure 10-23 shows an AGL table from PCASE.

Figure 10-23 Aircraft Group AGL Table

PAVEMENT CAPACITY IN KIPS FOR AIRCRAFT GROUP INDEX NUMBERS																
SECTION	PCN	PASS INTENSITY LEVEL	1	2	3	4	5	6	7	8	9	10	11	12	13	14
R01A2	17/R/B/W/T	I	27	29	45	82	42	53	58	146	162	202	382	222	338	121
		II	31	34	52	91	48	59	65	164	181	224	423	248	377	142
		III	36	39	58	109	57	70	77	195	215	262	496	294	448	176
		IV	43	47	69	140	72	89	97	246	273	323	612	370	565	224
R02C1	19/F/B/W/T	I	34	36	67	100	61	77	85	181	190	301	574	261	405	183
		II	39	41	76	109	66	84	93	198	208	329	628	286	443	206
		III	42	45	84	124	75	95	105	224	234	371	709	323	500	258
		IV	48	51	94	155	94	119	132	281	294	466	889	404	626	322
R02C2	19/F/B/W/T	I	34	36	67	100	61	77	85	182	190	302	576	262	406	183
		II	39	41	77	110	66	84	93	199	208	330	630	286	444	206
		III	42	45	84	124	75	95	105	224	235	372	711	323	501	259
		IV	48	51	95	155	94	119	132	281	294	467	891	405	628	323

10-8.3 Controlling Aircraft AGL Table.

A controlling aircraft AGL table is organized by section like the other tables but defines the controlling aircraft load and passes and reports the AGL and PCN. The example in Figure 10-24 also shows overlays.

Figure 10-24 Controlling Aircraft AGL Table

Pavement Facility	Section	Test Number or Station, ft	Type Traffic Area	Subgrade Strength[a] CBR or K, % or psi/in.	Design Aircraft[b]				Allowable Gross Load, kips	PCN	Theoretical Overlay Requirements, in.		
					Aircraft	Weight, lb	Passes	ACN			AC	PCC No Bond	PCC Partial Bond
Taxiway Maintenance	T27B	0+00-5+00	B	174	C-17	585,000	9,436	54/R/C/W/T	528	48/R/C/W/T	6.1	6.5	8.6
Hanger 2,3,4 TW	T28B	5+00-6+00	B	136	CH-47	50,000	5,321	11/R/C/W/T	50	18/R/C/W/T	-	-	-
	T29B	6+00-5+00	B	116	CH-47	50,000	5,321	11/R/C/W/T	50	18/R/C/W/T	-	-	-
	T30B	5+00-5+00	B	171	CH-47	50,000	5,321	11/R/C/W/T	50	20/R/C/W/T	-	-	-
	T31B	5+00-5+00	B	300	CH-47	50,000	5,321	10/R/B/W/T	50	22/R/B/W/T	-	-	-
Assault Ramp TW	T20B	0+00-8+00	B	5	CH-47	50,000	11,495	10/F/C/W/T	50	12/F/C/W/T	-	-	-
Compass Rose Ramp	A01B	1-5	B	207	C-17	585,000	9,436	54/R/C/W/T	567	52/R/C/W/T	-	-	-
Maintenance Ramp	A02B1	1-7	B	199	C-17	585,000	9,436	54/R/C/W/T	284	22/R/C/W/T	17.8	11	12.8

10-8.4 Pavement Classification Number (PCN) Table.

As with other reports, PCN tables are organized by section and show the PCN for each respective section. These tables may also show the structural index (ACN/PCN ratio) for the controlling aircraft or may show the controlling PCN for a branch with multiple sections. Figure 10-25 shows an example of a basic PCN table from PCASE.

Figure 10-25 PCN Table

PAVEMENT CLASSIFICATION NUMBER Normal Period							
SECTION	PCN	SECTION	PCN	SECTION	PCN	SECTION	PCN
A01B	21/R/C/W/T	A08B	2/R/C/W/T	H08A	3/R/C/W/T	R05A	116/F/A/W/T
A02B	16/F/A/W/T	A09C	29/R/C/W/T	H09A	4/R/D/W/T	R06A	135/F/A/W/T
A03B	19/R/B/W/T	A10B	12/R/B/W/T	H11A	18/R/C/W/T	T09A	15/F/A/Y/T
A04B	32/F/A/W/T	A11B	15/R/C/W/T	R01C	201/F/A/W/T	T14A	175/F/A/Y/T
A05B	16/R/B/W/T	H02A	10/R/C/W/T	R02A	102/F/A/W/T	T15A	34/F/A/Y/T
A06B	5/R/B/W/T	H04A	11/R/C/W/T	R03A	97/F/A/W/T	T16A	2/F/A/Y/T
A07B	19/F/A/W/T	H06A	8/R/C/W/T	R04C	156/F/A/W/T	T17A	120/F/B/Y/T

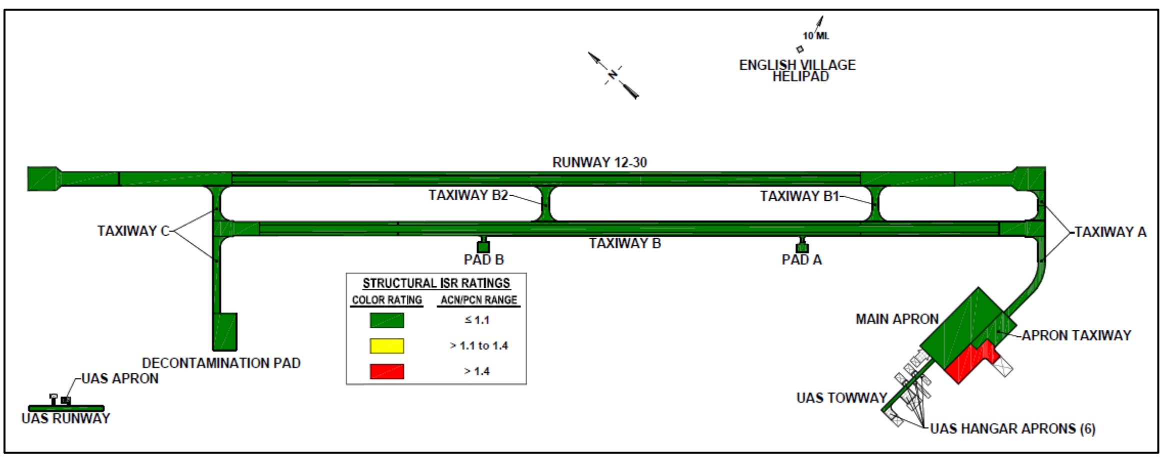
10-8.5 Structural Index (ACN/PCN) Ratio.

As described in paragraph 9-5.1, the structural index (SI) is used to define whether a pavement is structurally adequate to sustain mission traffic. As mentioned in paragraph 10-8.4, the SI can be incorporated in other tabular reports as shown in the example in Figure 10-26 in which it is included in the PCN table or it can be displayed in a map as shown in Figure 10-27. This objective is to indicate whether each pavement section is structurally capable of supporting the anticipated mission traffic for the expected life of the pavement. The concept can be extended to address the issue of service life, which is discussed in paragraph 10-8.6.

Figure 10-26 SI Example

SECTION	PRIMARY AIRCRAFT	ACN	PCN	STRUCTURAL INDEX
A01B	T-6A	3/R/B	21/R/B/W/T	0.14
A02B	T-6A	3/R/C	23/R/C/W/T	0.13
A03B	T-6A	3/R/B	31/R/B/W/T	0.10
A04B	T-6A	3/R/B	33/R/B/W/T	0.09
A05B	T-6A	3/R/B	18/R/B/W/T	0.17

Figure 10-27 Pavement Life Expectancy Based on SI



10-8.6 Pavement Life Expectancy.

The ACN/PCN ratio concept can be extended to similar Service-specific criteria as described below and shown in the color-coded example map in Figure 10-28. In this example, the ACN of the critical aircraft at various load levels (loaded, half-loaded, and unloaded aircraft) is compared to the PCN for the section. These ACN/PCN relationships correspond to the color codes shown below:

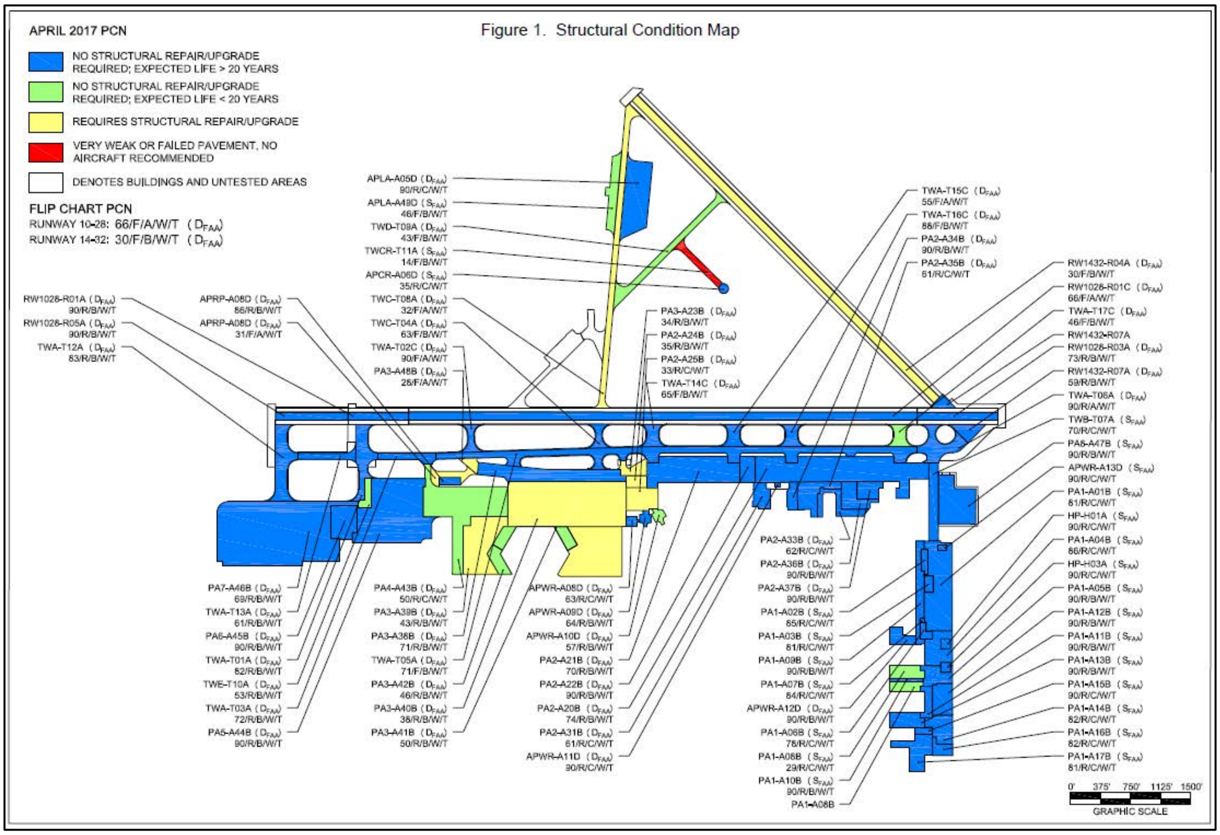
- B (BLUE): $ACN_{\text{fully loaded}} \leq PCN$
- G (GREEN): $ACN_{\text{half-loaded}} \leq PCN \leq ACN_{\text{fully loaded}}$
- Y (YELLOW): $ACN_{\text{empty}} \leq PCN \leq ACN_{\text{half-loaded}}$

- R (RED): PCN ≤ ACN_{empty}.

Figure 10-28 depicts this 4-color structural condition map in terms of life expectancy:

- B (BLUE): Expected pavement life is greater than 20 years
- G (GREEN): Expected pavement life is less than 20 years
- Y (YELLOW): Pavement in need of structural repair/upgrade
- R (RED): Very weak or failed pavement, limit or cease aircraft operations

Figure 10-28 Pavement Life Expectancy Based on Service-Specific Criteria



10-8.6.1 Life Expectancy Weight Restrictions.

The example map in Figure 10-28 also identifies weight restrictions based on the color code. The color codes below define the limitations necessary (at the original level of passes) to ensure the section will provide a service life of twenty years.

- B (BLUE): No weight restriction
- G (GREEN): Reduce departure weights by 50 percent
- Y (YELLOW): Reduce use to unloaded aircraft
- R (RED): Aircraft traffic operations suspended until pavement is repaired.

10-8.6.2 Life Expectancy Pass Level Restrictions.

The colors in the map in Figure 10-28 also imply pass level restrictions (at the original weight) necessary to ensure that the Section provides a 20-year service life. Areas with a blue color code can accommodate pass level increases up to 50 percent without significantly affecting the pavement service life.

APPENDIX A SAMPLING AND TESTING METHODS

A-1 INTRODUCTION.

The Table A-1 provides a summary of the sampling and testing procedures used in pavement evaluation and published standards for the respective tests. The remainder of this appendix provides an overview of some of the commonly used test methods and details on procedures that do not have established standards.

Table A-1 Sampling and Testing Procedures

Testing or Sampling Procedure	Publication
General Testing	
Pavement condition index (PCI) inspection	UFC 3-260-16 ASTM D5340
Falling weight deflectometer (FWD)	ASTM D4694 and D4695
Ground penetrating radar (GPR)	ASTM D6432
Pavement coring	Paragraph A-2.4
Dynamic cone penetrometer	TM 3-34.48-2
Asphalt Testing	
Sampling bituminous paving mixtures	ASTM D979
Unit weight, Marshall stability, and flow of bituminous mixtures	CRD-C 649
Density and percent voids of compacted bituminous paving mixtures	CRD-C 650
Recovery of asphalt from solution by Abson method	ASTM D1856
Extraction of bitumen from bituminous paving mixtures	ASTM D2172
Asphaltic concrete recompaction	Paragraph A-3.1
Penetration of bituminous materials	ASTM D5
Ductility of bituminous materials	ASTM D113
Softening point of asphalt and tar materials	ASTM D36
Test for bitumen	ASTM D4

Testing or Sampling Procedure	Publication
Concrete Testing	
MIRA ultrasonic tomography	ASTM C597
Flexural strength of concrete	ASTM C78 as modified in paragraph A-4.1
Compressive strength tests	ASTM C39
Splitting tensile strength tests	ASTM C496
Specific gravity of concrete	ASTM C642
Absorption by concrete	ASTM C642
Voids in concrete	ASTM C642
Soil Testing	
In-place density, sand cone method	ASTM D1556
In-place (field) CBR	CRD-C 654
Laboratory CBR relations of soils	CRD-C 654
Moisture-density relations of soils	CRD-C 653
Sieve analysis	ASTM C136
Particle size analysis	ASTM D6913
Specific gravity of soils	ASTM D854
Specific gravity and absorption of coarse aggregate	ASTM C127
Specific gravity and absorption of fine aggregate	ASTM C128
Moisture content of soil or aggregate (total sample)	ASTM D2216
In-place density, drive cylinder method	ASTM D2937
Liquid limit, plastic limit, and plasticity of soils	ASTM D4318
Soils sampling	ASTM D1586M
Plate-bearing tests	CRD-C 655
Classification tests	ASTM D2487

Testing or Sampling Procedure	Publication
Sampling and preparing test specimens	ASTM C42
Flexural strength of soil-cement	ASTM D1635
Deep, quasi-static, cone, and friction-cone penetration tests of soils	ASTM D3441

Note: ASTM is the designation of standards and test methods issued by the American Society for Testing and Materials.

A-2 GENERAL PAVEMENT EVALUATION TESTING.

A-2.1 Pavement Condition Index (PCI) Inspection.

UFC 3-260-16 implements the PCI inspection procedures in ASTM D5340 for DoD. Additional details are found in the PAVER User manual and Distress Identification Manuals posted on the Tri-Service Pavement-Transportation site, https://transportation.erdc.dren.mil/paver/Manuals.htm

A-2.2 Falling Weight Deflectometer (FWD).

Chapter 3 provides DoD-specific procedures on use of the FWD. This guidance supplements that found in the Dynatest user manual, ASTM D4694, and ASTM D4695.

A-2.3 Ground Penetrating Radar (GPR).

Chapter 3 provides a general description on DoD GPR use. Appendix B addresses GPR use for void detection. This guidance supplements the manufacturer's user manual and ASTM D6432.

A-2.4 Pavement Coring and Drilling.

Chapter 3 provides general DoD guidance on the number and locations for taking pavement core samples.

A-2.5 Dynamic Cone Penetrometer (DCP).

Chapter 3 provides a general overview of the types of DCP devices used by DoD as well as guidance on the number and locations for drilling pavement to perform DCP testing.

The DCP (or automated DCP) consists of a rod that is driven into the soil using a 17.6-pound hammer dropped from a constant height of 22.6 inches (574 millimeters). The manual system is portable and has options that automate data collection so testing is performed by a single operator. DCPs are designed to penetrate to a depth of 36 to 48 inches (900 to 1,220 millimeters), which is typically sufficient to test weak areas for voids.

A-2.6 Standard Penetration Test.

The standard penetration test (SPT) is also called the split-spoon test because of the split-barrel used for soil sampling. The test (ASTM D1586) provides a representative soil sample and a measure of the soil resistance to penetration by driving a split-barrel sampler using a 140-pound mass from a 30-inch height. The number of blows is recorded for each 6-inch increment of penetration and is assumed to be representative of the soil strength. Typically, the DCP has been easier to conduct than the SPT.

A-3 ASPHALT TESTING.

A-3.1 Recompaction of Asphaltic Concrete.

Samples of existing pavements may be recompacted in the laboratory for comparison with the in-place conditions. Pavement samples should be approximately 10-inch (254-millimeter) maximum dimension so the various layers or course can be identified. If the pavement consists of more than one course, the courses should be separated and treated individually. The courses may be separated by heating the pieces of pavement and driving a hot knife between the layers or by other similar methods. After a course has been separated, break it into small pieces and heat it to a temperature of 240 °F to 260 °F (115 °C to 127 °C) as rapidly as possible in an oven or on a hotplate, with constant stirring to ensure uniform heating. Thoroughly mix the material during heating and compact the hot mixture in accordance with the standard Marshall method procedures. Compact samples with 50 or 75 blows on each side of the specimen for comparison with criteria for tire pressures of 100 psi and 200 psi (0.7 MPa and 1.4 MPa), respectively. Compact six to eight specimens with each effort and test in accordance with standard procedures for the Marshall method. Note that reheating produces a hardening of the asphalt cement. This hardening causes somewhat higher stability values but has little effect on the other test values when analyzing the test data.

A-3.2 All-Bituminous Concrete and Flexible Overlays.

Use the same procedures described in paragraph A-3.1 when testing all-bituminous concrete base-course material and flexible overlays except when the all-bituminous concrete or flexible overlay exists between two thicknesses of rigid pavement (composite pavement). In this case, the only test necessary on the bituminous concrete portion of the overlay is an extraction test to determine the gradation of the aggregate and the bitumen content, so only one or two samples of the bituminous concrete are needed from each test pit. Take a large enough sample of the base course portion of the flexible overlay for a gradation test.

A-3.3 AC Layer Separation by Construction.

Split the cores at the interface of each AC layer (or lift) when a flexible pavement consists of more than one AC layer so that each layer can be tested separately. Test each layer for Marshall stability, flow, percentage of asphalt by weight, penetration of bitumen, aggregate type, shape and gradation, specific gravity of bitumen and aggregate, and density (CRD-C 649). Evaluate each course of the cores for percentage of asphalt by weight, aggregate gradation, and specific gravity according to ASTM D2172, ASTM D2726, and ASTM D5444 when the pavement was designed according to Superpave criteria. Compute the voids in the total mix and the percentage of voids filled with asphalt from the test results (CRD-C 650, ASTM D2041 and ASTM D2726).

A-3.4 AC Core Extraction Analysis.

Determine aggregate gradation, specific gravity of bitumen and aggregate, and penetration, ductility, and softening point of the bitumen from a portion of the samples. Other samples are recompacted as described in paragraph A-3.1 to determine Marshall stability, flow, density, and their voids relations. The stability of the cores cut from the pavement will often be lower than the recompacted sample. A part of this difference is due to differences in density since the field cores seldom have density as high as the laboratory-compacted samples. A major part of this variation in stability is due to differences in the structure of the field and laboratory samples and also the fact that the asphalt hardens some during reheating. Since the stability value is not the sole criterion for evaluating the mix, the lack of correlation between the stability of the field and laboratory samples is not particularly significant.

A-3.5 Resistance to Fuel Spillage.

There are currently no standard tests to determine resistance to spillage. However, spilling a small amount of jet fuel on one of the samples from each test pit to see if the fuel penetrates the samples quickly or if it “puddles” on the surface gives an indication of resistance to fuel spillage.

A-3.6 AC Separation Tests between PCC Layers.

The gradation and bitumen content of the bituminous concrete and the gradation of the base-course material, if any, are the only tests required when the non-rigid overlay is between two thicknesses of rigid pavement.

A-4 CONCRETE TESTING.

Retain all concrete cores collected and all test specimens cut from test pits for laboratory tests to determine the flexural strength. Visually examine concrete samples to determine the type of aggregate and estimate the maximum size of aggregate. Determine flexural strength from cores by conducting tensile splitting tests on 6-inch (152-millimeter) -diameter cores. Ensure the test specimens from pits are three times as long and three times as wide as the pavement thickness except when cutting 6- by 6-

inch (152- by 152-millimeter) beams from the top and bottom of the specimens for three-point load beam tests.

A-4.1 Flexural Strength Test.

Determine the flexural strength of rigid pavement using the third-point loading procedure set forth in ASTM C78, with the following modifications.

A-4.1.1 Test Specimens.

The test specimens should have a square section with the width and thickness equal to the pavement thickness for pavement thicknesses less than or equal to 12 inches (305 millimeters). For pavement greater than 12 inches (305 millimeters), either cut a square section with width and thickness equal to the pavement thickness or cut 6- by 6-inch (152- by 152-millimeter) beams from the top and bottom of the slab then average test to obtain a strength representative of the full section. When cutting 6- by 6-inch (152- by 152-millimeter) beams from the top and bottom of the slab, ensure the length of the specimen is three times the thickness of the specimen plus approximately 6 inches (152 millimeters).

A-4.1.2 Procedure.

Place the specimen in the third point loading apparatus and test it in the as-cast position. That is, apply the load at the third points on the surface of the beam that represents the pavement surface. Locate the load reaction on the bottom of the beam, which represents the bottom of the pavement.

A-4.2 Splitting Tensile Strength Tests.

The splitting tensile test can be conducted in the laboratory or in the field in accordance with ASTM C496 standard practices and uses the correlation in Equation A-3 to measure concrete flexural strength. Portable field splitting tensile test equipment is a modified version of the laboratory test equipment shown in Figure A-1.

Figure A-1 Portable Split Tensile Tester

The test involves laying a concrete core with its longitudinal axis horizontal and then applying a vertical compressive load at a constant rate along the longitudinal until the core fails in tension across the diameter from stresses induced by the compression load. Figure A-1 shows a failed specimen following a splitting tensile test. Record the diameter and the length of the core and maximum load at failure. Use Equation A-3 to calculate the tensile splitting strength and use the empirically developed relationship (WES, 1974) in Equation A-1 to compute flexural strength (Equation A-2 is a variation of Equation A-1).

Equation A-1 Flexural Strength

$$f = \left[\frac{2p}{\pi \cdot ld} \right] 1.02 + 210$$

Where:

f = *flexural strength (pounds per square inch)*

p = *applied load (pound-force)*

l = *length of the sample (inches)*

d = *diameter of the sample (inches)*

Equation A-2 Flexural Strength

$$F = 1.02T + 210$$

Where:

F = flexural strength in psi

T = tensile splitting strength in psi

The splitting tensile strength T is then computed from the equation:

Equation A-3 Tensile Splitting Strength

$$T = \frac{2P}{\pi l d}$$

Where:

P = maximum load at rupture, pounds-force (Newtons)

l = length of core, inches (millimeters)

d = diameter of core, inches (millimeters)

A-5 SOIL TESTING.

Conduct laboratory testing on samples of the base course, subbase course, and subgrade materials to classify them using the USCS in accordance with ASTM D2487. The size of the samples depends on the type of sampling and laboratory tests performed.

A-5.1 Disturbed Sampling.

Auger borings and bag samples are the two types of disturbed sampling used for airfield pavement evaluation.

A-5.1.1 Auger Borings.

The most suitable method of obtaining samples of the foundation materials for developing soil profiles is by auger borings. These borings are taken in test pits or through small 4- or 6-inch (102-millimeter or 152-millimeter) -diameter holes cored through the pavement. Take samples of the foundation materials at each 6-inch (152-millimeter) vertical increment to a depth of 2 feet (610 millimeter) and for each 12-inch (305-millimeter) increment thereafter to the desired depth. Take additional samples whenever there is a change in materials or moisture conditions. Seal the samples in clearly marked jars before transporting to the laboratory for moisture content testing and soil classification.

A-5.1.2 Bag Samples.

Bag samples of the foundation materials from test pits are used for compaction tests. Take samples of each type of material encountered. The size of the bag samples required depends on the type of material and the type of test to be performed. Collect a 100-pound (45 kilogram) sample of fine-grained soil for determining moisture-density. Collect a 450-pound (204-kilogram) sample of fine-grained soil when developing the moisture-density-CBR relationship. Increase the sample size to 200 pounds (90 kilograms) for the moisture-density tests and 600 pounds (272 kilograms) for moisture-density-CBR tests of granular soils.

A-5.2 Undisturbed Sampling.

Undisturbed samples may be required for laboratory CBR tests if the subgrade is composed of a fine-grained cohesive material. There is no prescribed method for obtaining undisturbed samples of subgrade material. Any method that provides enough material and maintains it in its existing condition is satisfactory. The method most widely used for undisturbed sampling is to trim a sample by hand to fit into a split cylinder of galvanized metal approximately 8 inches (203 millimeters) in diameter and at least 12 inches (305 millimeters) high. Seal the sample at the sides and ends with paraffin to prevent moisture loss.

A-5.3 Soil Testing for Rigid Pavements.

Collect bag samples of base and subbase courses underlying rigid pavements for classification and compaction tests. In general, a 200-pound (91 kilograms) sample is sufficient. However, when laboratory CBR tests are necessary, which may be the case when evaluating a non-rigid overlay on rigid pavements, a minimum 600-pound (272 kilogram) base-course sample is required. Determine gradation, Atterberg limits, specific gravity, and moisture-density relations. The moisture-density and CBR values may be required when evaluating a non-rigid overlay on rigid pavements. Perform an adaptation of the consolidation test on undisturbed samples of the subgrade to determine the correction for saturation of the plate-bearing test results. The undisturbed samples may also be used for density determinations. Soaked laboratory CBR tests on undisturbed subgrade material may be required when evaluating a non-rigid overlay on rigid pavement.

A-5.4 Soil Testing for Flexible Pavement.

Conduct tests on samples of base course, subbase, and subgrade materials, including Atterberg limits, gradation, dry soil color, and specific gravity, to classify the soil. Table A-2 summarizes testing requirements for project design that UFC 3-260-02 describes in more detail. Determine moisture-density and CBR relations from available data or from samples of base course, subbase, and subgrade materials remolded at three compaction efforts as described in CRD-C 653 and CRD-C 654. Take the base and subgrade samples in a manner that assures representative materials.

Table A-2 Flexible Pavement Sampling Requirements

Material	Samples Per Pit	Remarks
Pavement	8 cores, 200 pounds (91 kilograms) per sample	Samples should be 8 to 10 inches (203 to 254 millimeters) in minimum dimension to permit separation of courses
Base and subbase courses	600 pounds (272 kilograms)	Disturbed sample
	3 samples	Undisturbed cylinders to be taken of material with plastic fines where applicable
Subgrade	450 pounds (204 kilograms)	Disturbed sample; increase to 600 pounds (272 kilograms) if much coarse material is present
	3 samples	Undisturbed cylinders

A-5.5 Subgrade Soil Testing.

Collect a 100-pound (45-kilogram) bag sample of fine-grained material when samples of the subgrade are required. Obtain a 200-pound (91-kilogram) bag sample when the subgrade is composed of a granular material. If laboratory CBR tests are required, which may be the case in the evaluation of a non-rigid overlay on rigid pavements, increase the bag samples of subgrade material to 450 pounds (204 kilograms) and 600 pounds (272 kilograms) for fine-grained and granular materials, respectively.

A-5.6 Field Density Tests.

A-5.6.1 Field Density Frequency.

When taking samples of 0.5 cubic foot (0.014 cubic meter) volume or less, make three density determinations at each elevation tested. When taking larger samples, decrease the number of density determinations to two. When there is not a reasonable agreement between the tests results, perform two additional tests. A reasonable agreement is a tolerance of 5 pounds per cubic foot (80 kilograms per cubic meter) wet density. For example, test results of 108, 111, and 113 pounds per cubic foot (1,730, 1,778, and 1,810 kilograms per cubic meter) wet density are in reasonable agreement, and their average is 111 pounds per cubic foot (1,778 kilograms per cubic meter).

A-5.6.2 Field Density Test Procedure.

Field density tests are performed on the base course and subgrade materials. The most satisfactory methods of obtaining the density are by the sand-displacement or balloon methods when the base course or subgrade is composed of granular materials. These tests are described in ASTM D1556 and ASTM D2167, respectively. If the subgrade is composed of a fine-grained cohesive material, the density is best obtained either by drive-sampling (ASTM D2937) or balloon methods (ASTM D2167) or by the undisturbed sampling that may be required in connection with the plate-bearing test. Conduct all field density tests adjacent to the area that was loaded during the plate-bearing test. When the overlay portion of a non-rigid overlay on rigid pavement is composed of a bituminous concrete and base course, conduct density tests on the base-course portion of the overlay.

A-5.7 Moisture Content Tests.

The strength of base courses composed of substantial portions of fine materials is governed by the moisture content of the fine fraction. Therefore, moisture-content determinations are made on the fine-grained portion of the soil. The fine fraction is that portion passing any of several sieve sizes ranging from No. 200 to No. 4. For the purposes of this UFC, material passing the No. 40 sieve is the critical sieve size. This is the same sieve used for separations for liquid and plastic limit determinations. Determine the moisture content of both the material passing the No. 40 sieve and the total sample and recorded in the test data tables. If it is impractical to separate the material at the No. 40 sieve without affecting the moisture present, perform an absorption test following ASTM C127. The percentage of absorption thus determined is considered the moisture content of the coarse fraction. It is used to determine the moisture content of the remainder (assuming all other moisture to be in this finer fraction) mathematically. Comparing the moisture content of the material passing the No. 40 sieve with the liquid limit of the material is an indication of the stability of the base-course material. If the moisture content is near the liquid limit, the material is considered unstable. When the moisture content exceeds the liquid limit, the base material becomes more unstable as the percentage of fines increase.

A-5.8 California Bearing Ratio (CBR) Test.

A-5.8.1 CBR Test Locations within Test Pit.

When selecting CBR test locations in the test pit, place the CBR piston at a location that represents an average condition of the surface being tested, ensuring it is not set on unusually large pieces of aggregate or other unusual materials. The general practice is to space the CBR tests in the pit where the areas covered by the surcharge weights of the individual tests do not overlap. Perform these tests on the surface and at each full 6-inch (152-millimeter) depth (especially if a strength problem is suspected) in the base and subbase courses, on the surface of the subgrade, and on underlying layers in the subgrade as needed. Make density and moisture-content determinations in the subgrade at 1-foot (0.3 meter) intervals to a total depth of 4 feet (1 meter) below the surface of the subgrade. Use the results of the density and moisture tests at these depths to ascertain whether there is a need for additional CBR tests. Make density determinations between adjacent CBR tests. Perform three in-place CBR tests in test pits at each elevation tested. However, if the results of these three tests do not show reasonable agreement, make three additional tests. Reasonable agreement means a tolerance of 3 between three tests when the CBR is less than 10; a tolerance of 5 when the CBR is from 10 to 30; and a tolerance of 10 when the CBR is from 30 to 60. Variations in the individual readings are not as important for CBR values greater than 60. For example, actual test results of 6, 8, and 9 are reasonable and their average is 8; results of 23, 18, and 20 are reasonable and their average is 20. If the first three tests do not fall within this tolerance, then perform three additional tests at the same location and use the numerical average of the six tests as the CBR for that location. Round off CBR values below 20 to the nearest point. For example, round off 18.7 to 19. Round off to the nearest five points for CBR values above 20. For example, round off 23.4 to 25. Obtain a moisture content at the point of each penetration.

A-5.8.2 Using CBR Tests for Rigid Pavements.

In-place CBR tests may be required on the subgrade materials in addition to plate-bearing tests to evaluate a non-rigid overlay on rigid pavement. When the k value of the subgrade material is greater than 200 pci (5,536 g/cm3) or the concrete flexural strength is less than 400 psi (2.8 MPa), the load-carrying capability for the non-rigid overlay or rigid pavement should be evaluated using both rigid and flexible pavement evaluation procedures. In the latter case, assume the rigid pavement is a high-quality base course material and conduct in-place CBR tests on the base and subgrade materials in addition to the plate-bearing tests. Conduct the in-place CBR tests the same as if it was for a flexible pavement evaluation.

A-5.8.3 Moisture-Density-CBR Relations.

Develop the moisture-density-CBR relationships of the foundation materials as outlined in UFC 3-260-02 when required to evaluate a non-rigid overlay on rigid pavement.

A-5.9 Plate-Bearing Tests.

A-5.9.1 Estimating the Subgrade k Value.

Determine the modulus of subgrade reaction of the subgrade or base course using the plate-bearing test for rigid pavements as discussed in CRD-C 655. Conduct the plate-bearing test on the surface of the unbound material immediately beneath the pavement, that is, on the granular base course or on the subgrade when there is no base course. When the plate-bearing test cannot be conducted, determine an approximate k value by determining CBR values of each layer in the pavement structure using the DCP and use the procedure outlined in paragraph 7-3.4 to determine the effective k. When the pavement structure includes a high-quality stabilized base course as defined in UFC 3-260-02, conduct the plate-bearing test on the layer beneath the stabilized layer and test the stabilized layer to determine its modulus.

A-5.9.2 Plate-Bearing Tests on Rigid Overlays of Flexible Pavement.

When evaluating a rigid overlay of a flexible pavement, conduct the test in a pit with the concrete overlay removed. When the temperature of the existing asphalt pavement surface is above 75 °F (24 °C), remove the asphalt concrete pavement and run the plate bearing test on the base, then use the effective k procedure in paragraph 7-3.4 to determine the effective k at the top of the asphalt and use that value for the analysis. When the temperature of the existing asphalt pavement surface is below 75 °F (24 °C), run the tests on the asphalt concrete pavement and use that value for the analysis. Place load reaction far enough away from the plates so the stresses created by the load reaction will not influence the results of the plate-bearing tests. In general, place the load reactions on slabs adjacent to the slab being tested and not less than 12.5 feet (3.8 meters) from the bearing plate.

A-5.9.3 Plate Bearing Tests on Composite Pavements.

A composite pavement is composed of rigid overlay over a rigid base pavement with 4 inches (102 millimeters) or more of flexible or all-bituminous overlay. If the flexible overlay is less than 4 inches (102 millimeters), evaluate the rigid overlay using the unbonded overlay equation. When evaluating a composite pavement, perform the plate-bearing test on the surface of the granular base course beneath the rigid pavement layer or on the subgrade when there is no base course. Place load reaction far enough away from the plates so the stresses created by the load reaction will not influence the results of the plate-bearing tests. In general, place the load reactions on slabs adjacent to the slab being tested and not less than 12.5 feet (3.8 meters) from the bearing plate.

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APPENDIX B VOID DETECTION UNDER AIRFIELD PAVEMENTS

B-1 GENERAL.

This appendix outlines a reliable, cost-effective method to detect subsurface voids under airfield pavements to minimize the risk of premature airfield pavement failure. The Services determine whether to perform airfield void detection surveys as part of regularly scheduled evaluation or as required based on the airfield location and history of issues with voids. The term void encompasses actual voids, voids filled with water, or pockets of very loose subgrade with low bearing capacity.

B-2 BACKGROUND.

Past aircraft accidents and airfield pavement failures due to subsurface voids increase the risk of future accidents and threats to life safety, especially given aging DoD facilities and scarce M&R resources. A pavement failure under the front gear of a trainer aircraft at NAS Pensacola in 1999 prompted a review of available pavement evaluation technology and procedures to detect subsurface weakness. The resulting approach outlined below uses a combination of visual, nondestructive, and destructive testing and targets pavements above drainpipe crossings, but the same method is applied for any airfield pavement where there is the potential for a void.

B-3 VOID DETECTION.

B-3.1 Visual Inspection.

Perform visual inspection of the airfield pavements with sufficient frequency to locate potential problem areas and satisfy the airfield manager of their operational safety. Base testing frequency on local physical conditions and operational tempo. Monitor pavements for conditions that may affect aircraft movement, with a focus on depressions and cracking that are indicative of subsurface deterioration. Depressions are evident in flexible pavements after a rainfall or by the concentric marks left by the evaporated water. Concrete slabs cracked into two or more pieces or slabs that exhibit faulting at joints may indicate underlying voids or loss of support. Carefully inspect areas above drainpipe crossings since most problems appear above or near drainage structures. Inspect unpaved areas adjacent to the pavement above drainage structures. Problems observed in these areas are early warning signs of problems in nearby paved areas. Depressed pavement or shattered slabs surrounding drainage structures (catch basins) indicate infiltration of soil materials into the structure or pipe. Use UFC 3-260-16 (ASTM D5340 and ASTM D6433) for visual inspections.

B-3.2 Heavy-Weight Deflectometer (HWD) Testing.

After performing a visual inspection, evaluate areas of concern using an HWD. Test all drainage structure crossings and any other areas that have visual indications of voids or loss of subgrade support.

B-3.2.1 Data Collection.

- The following outlines the data collection procedure for drainage structures under asphalt pavements. The procedure for concrete pavements is the same, with adjustments for performing HWD tests at the center of each slab.
  - o Identify the location of each pipe and mark it on the pavement.
  - o Test at 10-foot (3-meter) intervals, offset 10 feet (3 meters) to the left of the drainage structure. This is “Line A” for reporting purposes.
  - o Test at 10-foot (3-meter) intervals above the drainage structure in the same direction as Line A. This is “Line B” for reporting purposes.
  - o Test at 10-foot (3-meter) intervals, offset 10 feet (3 meters) to the right of the drainage structure in the same direction as Line A. This is “Line C” for reporting purposes.
- This procedure typically produces three sets of readings at 10-foot (3-meter) intervals along the drainage structure except for the case where the pipe falls just in between two rows of concrete slabs, then only two sets of readings are needed. The procedure uses 10-foot (3-meter) intervals based on the assumption the HWD cannot “sense” loss of pavement support beyond a 5-foot (1.5-meter) radius.
- A single drop at each location is typically sufficient to compare successive drops at adjacent locations. Configure the HWD with seven geophones numbered D1 though D7, where D1 is the deflection under the load point and D2 through D7 are typically at 12 inches (305 millimeters) (15 inches [381 millimeters] for some configurations), 24, 36, 48, 60, and 72 inches (381, 610, 914, 1219, 1524, and 1829 millimeters) from D1, respectively. This results in seven deflection measurements at each test location.
- Use the deflection data to determine the impulse stiffness modulus (ISM), which is a measure of the relative pavement strength at each test location. Calculate ISM1 by dividing the load by the deflection at D1. Determine ISM2 through ISM7 using the same procedure: ISM(X) = load/deflection at D(X).
- D1 primarily indicates the state of the pavement itself, whereas D7 primarily indicates the state of the subgrade. Therefore, using D1 alone is not sufficient to successfully detect voids under the pavement.

B-3.2.2 Data Analysis.

Analyze data during data acquisition and mark weak areas immediately for penetrometer testing. Plot ISM1 through ISM7 results for each test along the drainage structure. Normalize the data by dividing each plot by the highest value in the plot to determine relative effects of pavement weaknesses on each sensor. Once the ISM plots are completed, use the following rules to determine potentially weak areas.

- An absolute ISM1 value below about 300 kips/inch is of concern for asphalt pavements.
- An absolute ISM1 value below 1000 kips/inch is of concern for concrete pavements.
- A relative ISM decay indicates an unexpected weakness.
    - A relative weakness in ISM1 indicates it is shallow.
    - A relative weakness in ISM7 indicates it is deep (3 to 20 feet [1 to 6 meters]).
    - A relative weakness in both ISM1 and ISM7 indicates a general lack of support.

B-3.2.3 Load-Carrying Capacity.

Use the HWD data to determine the effect of any subgrade weakness (or void) on the load-carrying capacity of the pavement using the layered elastic evaluation procedure in paragraph 5-3.

B-3.2.4 Frequency.

When an airfield has a history of problem with voids, perform void detection procedures at all drainage structures as outlined in paragraphs B-3.1 and B-3.2, in conjunction with regularly scheduled structural evaluations.

B-3.2.5 Large Area Testing.

When large areas may be subject to voids, such as where karst formations are prevalent, adjust the procedure on asphalt pavement by testing at 10- to 20-foot (3- to 6-meter) intervals along a linear structure (e.g., a runway) at 10-foot (3 meters) offsets on both sides of the centerline. Perform testing at each slab center (e.g., 15-foot (4.6 meters) spacing for Navy airfields) on PCC pavements. Test composite pavements as asphalt pavements when overlaid joints are not visible. Perform testing with the concrete procedure when the overlaid concrete joints are visible. Test outer portions of the linear structures with GPR if deemed necessary. GPR testing is faster but less reliable. Perform HWD testing on any anomalies found with GPR.

B-3.3 Penetrometer Testing.

Test weak areas revealed by the HWD (or the GPR and the HWD) with DCP or SPT as outlined in Chapter 3 and Appendix A to determine the depth of the weakness and identify the type of repair needed. Ensure there are no buried utilities present prior to testing.

Use PCASE or a spreadsheet to plot CBR or k (modulus of subgrade reaction) versus depth. A low CBR value (less than 3) or a low k (less than 75) indicates a weak layer or an actual void. When coring concrete pavement, the core may drop, indicating a void between the concrete pavement and the underlying base. When drilling the pavement, this separation is more difficult to observe, so a bore scope may be used to assess the existing void.

B-3.4 Capture Drainage Structure Video.

When testing and/or visible failure is evident near or around drainage structures, capture video of the interior of these drainage structures to help pinpoint the location of potential problem areas and define the need for M&R. Give special attention to assessing pipe joints because accumulations of fines near joints or other penetrations are a good indicator of a loss of subgrade material and concurrent subgrade strength loss.

B-3.5 Alternative Nondestructive Testing (NDT).

As described in paragraph 3-4.2, GPR is an alternate nondestructive void detection technique. Acoustic reflection sounding is another technique. Based on testing, neither is as effective for detecting voids in all circumstances as the procedures outlined in paragraph B-3.2. However, they can provide useful complementary information.

B-3.5.1 Ground Penetrating Radar (GPR).

GPR provides a cost-effective and nondestructive means of examining subsurface conditions. On the airfield, GPR can be used to detect utilities, pavement reinforcement, and anomalies in base and subgrade material, such as voids. There are distinct advantages and disadvantages to using GPR in lieu of the HWD. GPR techniques will never provide an estimate of the pavement strength. However, GPR methodologies are very fast and accurate if used in areas suitable for GPR technology. It is essential to make sure GPR is suitable for the site. The United States Department of Agriculture’s Natural Resources Conservation Service Ground-Penetrating Radar Soil Suitability Maps are an essential resource in early planning to determine if GPR is the correct approach to take in a pavement void detection analysis. The GPR works by sending a tiny pulse of energy into a material and recording the strength and the time required for the return of any reflected signal. A series of pulses make up what is called a scan. Reflections are produced whenever the energy pulse enters a material with different electrical conduction properties or dielectric permittivity. The strength, or amplitude, of the reflection is determined by the contrast in dielectric constants and conductivities of the two materials. The GPR displays the changes in dielectric constant on the screen, indicating changes in material type. The display allows interpretation of data in the field. Subsurface features can be identified with the GPR by how fast the energy can travel though the material type. Air has a dielectric constant of 1 and energy travels very quickly through materials with a dielectric constant of 1. Water has a dielectric constant of 81 and energy travels slowly through water. Metal has a dialectic constant of infinity and acts as a reflector. The dielectric constant of subsurface soils typically ranges from

4 to 32, depending on the soil type and saturation. With the knowledge of pavement, base, and material types, unanticipated anomalies and changes in scan response can be identified as weak base or subgrade or air- and water-filled voids.

The following procedures are used for effective void detection using GPR.

- The GPR will first be calibrated to accurately measure stations along the storm drainage lines. This is done at each pavement type to account for the roughness in the pavement surface.
- At each differing pavement and geological condition, the dielectric constant of the cross-section of pavement, base, and subgrade must be determined for accurate depth calculations and appropriate contrast while performing the scan onsite. This can be done by either identifying the soil type or ground truthing to known underground structure depths. The dielectric constants and the GPR data are recorded at each run.
- Once the storm drainage structures have been identified and the approximate location of the storm drainage line to be tested is known, the GPR unit will make several perpendicular scans to determine the exact location of the storm pipe. The pipe will then be marked on the pavement surface for future data collection. Sometimes, as with concrete or PVC pipes, it is difficult to locate the pipe due to the dielectric constant being similar to the in situ soil. In these instances, the field team uses maps and locations of drainage structures to determine the most likely place for the pipe to be located and the tests are run along those alignment locations.
- Once the location of the pipe is properly identified, collection of data is taken parallel to the storm pipe approximately 12 inches (305 millimeters) left and right of the pipe edge. Another pass is made directly over the pipe. Data is collected in the same direction each time so the stations of each run are comparable.
- Based on the observed pavement conditions and the observations made with the GPR scans, suspicious void locations may be marked on the pavement for further testing to verify the presence of a void or soft subgrade.
- The identified areas could be voids or could be utilities. Before proceeding with soil penetration techniques, it is best to locate the utilities and ensure the suspect areas are not utilities. If the suspect areas are not utilities, then they can be investigated using one of the soil penetration techniques such as the DCP.

B-3.5.2 Acoustic Reflection Sounding

Acoustic reflection sounding (ASTM D4580, *Standard Practice for Measuring Delaminations in Concrete Bridge Decks by Sounding*) has been used to detect concrete bridge deck delamination. In some instances, a person walking alongside the HWD can hear a difference in the sound of the pavement when it is spanning a shallow void, especially with thin concrete pavements. This provides another tool in detecting potential voids just under the slab. Once coring or drilling is complete, a borescope is useful to assess the existence of voids.

B-4 VOID REPAIR AND PREVENTION.

- Prior to proceeding with repair, determine if an actual void (or very loose area) is present or if a deep layer of weak material is responsible for the readings, using FWD/HWD testing.
- Void repair methods include pressure grouting, polymer injection, and removal and replacement. If an actual void is present, lightweight polymer or grout injection is generally preferred to removal and replacement because of the minimal impact on aircraft operations.
    - Pressure grouting and polymer injection may successfully fill a void (or compact a locally loose area) but may only have very limited success for a deep layer of weak material.
    - When a void or weak layer is deep, injection may simply create polymer (or grout) lenses (i.e., thin layers) that will lift the pavement but not provide additional support.
    - When pavement surface integrity is sound and load-carrying capacity is adequate, pressure grouting or polymer injection can be used to lift pavement and re-establish ride quality.
    - Once set, grout provides a stiff material typically usable for any type of subgrade and can also be used to fill gaps just under the slab.
    - If no void is present and a weak subgrade is undermining the load carrying capacity, remove and replace the weak layer. If the weak layer is under the water table, removal and replacement can become very difficult.
- Lightweight polymer injection has some advantages over grout injection.
    - Polymer injection adds less weight when dealing with soft subgrades and large voids.
    - A properly mixed polymer typically reaches most of its strength in a few minutes.
    - Quick-setting polymer can seal large cracks in drainpipes or fill deep sinkholes, while grout could flow down the sinkhole and proceed into the pipes.
- If polymer injection is used, the modulus of elasticity of the polymer needs to exceed the stiffness of the layer where it is injected; therefore, it should typically only be injected into the subgrade. Even then, tests on some limited data indicate that this requires a minimum density of:

  - o 6 pcf (96 kg/m^3) for subgrades with elastic modulus of 6,000 psi (41 MPa)
  - o 10 pcf (160 kg/m^3) for subgrades with elastic modulus of 15,000 psi (103 MPa)
  - o 15 pcf (240 kg/m^3) for subgrades with elastic modulus of 25,000 psi (172 MPa)

- If lightweight polymer or grout injection is not available, then use pavement and base removal and replacement down to the prescribed depth. When pipe deterioration is extensive, consider internal pipe repair, jacketing, or pipe replacement.

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APPENDIX C AIRCRAFT GEAR CONFIGURATION NOMENCLATURE

C-1 PURPOSE.

This appendix outlines the standard convention for naming and characterizing aircraft landing gear configurations. It is primarily intended for fixed-wing aircraft but is applicable to any aircraft using wheels for landing. This appendix is used in conjunction with FAA Order 5300.7, *Standard Naming Convention for Aircraft Landing Gear Configurations*.

C-2 BACKGROUND.

Landing gear configuration and aircraft gross weight are an integral part of airfield pavement design and evaluating pavement strength. Historically, most aircraft used relatively simple gear geometries such as a single wheel per strut or two wheels side by side on a landing strut. As aircraft became larger and heavier, they required additional wheels in groups or placed side-by-side and in tandem configurations to prevent excessively high individual wheel loads that impart high stresses on the pavement structure.

C-2.1 Typical Gear Configurations.

Originally, most civilian and military aircraft used three basic gear configurations: the “single wheel” (one wheel per strut), the “dual wheel” (two wheels side by side on a strut), and the “dual tandem” (two wheels side by side followed by two additional side-by-side wheels). As aircraft gross weight increased, manufacturers added additional landing struts to the aircraft. For example, Boeing used four landing struts with dual tandem configurations on the B-747 to reduce its impact on airfield pavement.

C-2.2 Complex Gear Configurations.

Other aircraft used gear configurations with multiple wheels in arrangements that could not be described by the three simple gear configurations. There was no coordinated effort between the FAA and the Services to provide a uniform naming convention resulting in naming systems that were not easily cross-referenced.

C-3 DEFINITIONS.

C-3.1 Main Gear.

“Main gear” means the primary landing gear that is symmetrical on either side of an aircraft. When multiple landing gears are present and are not in line with each other, the outermost gear pair is considered the main gear. Multiples of the main gear exist when a gear is in line with other gears along the longitudinal axis of the aircraft.

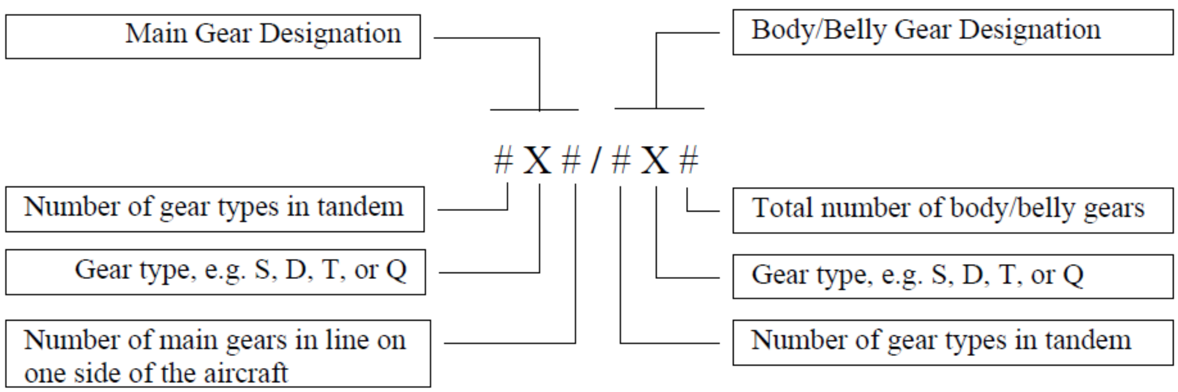
C-3.2 Body/Belly Gear.

"Body/belly gear" refers to an additional landing gear or gears in the center portion of the aircraft between the main gears. Body/belly gears may be different than the main gear and may be asymmetric.

C-4 INTENDED USE.

DoD is adopting the naming convention used by the FAA, as shown in Figure C-1.

Figure C-1 Aircraft Gear Naming Convention



C-5 AIRCRAFT GEAR GEOMETRY NAMING CONVENTION.

C-5.1 Basic Name for Aircraft Gear Geometry.

As shown in Figure C-1, abbreviated aircraft gear designations may include up to three variables. The two primary variables are the main gear configuration and the body/belly gear configuration if body/belly gears are present. An optional tire pressure code can also be used.

C-5.2 Basic Gear Type.

Gear type for an individual landing strut is determined by the number of wheels across a given axle (or axle line) and whether wheels are repeated in tandem. There are instances when multiple struts are in close proximity and are best treated as a single gear, e.g., the Antonov AN-124 (see Figure C-14). If body/belly gears are not present, the second portion of the name is omitted. For aircraft with multiple gears, such as the B-747 and the A380, the outer gear pair is treated as the main gear.

C-5.3 Basic Gear Codes.

The naming convention in Figure C-1 uses the gear designation codes in Table C-1.

Table C-1 Gear Designations

S	Single
D	Dual
T	Triple
Q	Quadruple

C-5.4 Use of Historical Tandem Designation.

Note that while the verbal description continues to use the term “tandem” to describe tandem gear configurations, the tandem designation “T” no longer appears in the gear name. “T” now indicates triple wheels.

C-5.5 Main Gear Portion of Gear Designation.

As shown in Figure C-1, the first portion of the aircraft gear name is the main gear designation that may consist of up to three characters. The first character indicates the number of tandem sets or wheels in tandem and the second character indicates the gear code (S, D, T, or Q). If a tandem configuration is not present, the leading value of “1” is omitted. Typical names are S = single, 2D = two dual wheels in tandem, 3D = three dual gears in tandem, 5D = five dual wheels in tandem, and 2T = two triple wheels in tandem.

The main gear designation indicates the number of gears on one side of the aircraft but assumes the gear is present on both sides (symmetrical) of the aircraft. The third character of the gear designation is a numeric value that indicates multiples of gears. An aircraft with one gear on each side of the aircraft has a value of 1 but, for simplicity, it is omitted from the main gear designation. Aircraft with more than one main gear on each side of the aircraft and where the gears are in line will use a value indicating the number of gears in line. For example, as shown in Figure C-20, the Ilyushin IL-76 has two gears containing quadruple wheels on each side of the aircraft and has the designation Q2.

C-5.6 Body/Belly Gear Portion of Gear Designation.

The second portion of the aircraft gear name is used when body/belly gears are present. If body/belly gears are present, the main gear designation is followed by a forward slash (/), then the body/belly gear designation. For example, the B-747 aircraft has two dual wheels in tandem main gear and two dual wheels in tandem body/belly gears. The full gear designation for this aircraft is 2D/2D2. The body/belly gear designation is similar to the main gear designation except that the trailing numeric value denotes the total number of body/belly gears present, e.g., 2D1 = one dual tandem body/belly gear; 2D2 = two dual tandem body/belly gears. Because body/belly gear arrangement may not be symmetrical, the gear code must identify the total number of gears present; a value of 1 is not omitted if only one gear exists.

C-5.7 Extension of Naming Convention.

Future aircraft might require additional body/belly gears that are nonsymmetrical and/or non-uniform. In these instances, the body/belly gear designation will contain a hyphen to indicate the non-uniform gear geometry. For demonstration purposes, consider adding one dual wheel body/belly gear to the existing 2D/2D2 gear configuration. The resulting gear name would be 2D/2D2-D.

C-5.8 Unique Gear Configurations.

The Lockheed C-5 Galaxy has a unique gear type and is difficult to name using this method. This aircraft will continue to be referred to directly as the C5. Gear configurations such as those on the Boeing C-17, Antonov AN-124, and Ilyushin IL-76 might also cause some confusion. In these cases, it is important to observe the number of landing struts and the proximity of the struts. In the case of the AN-124, it is more advantageous to address the multiple landing struts as one gear, i.e., 5D or five duals in tandem, rather than use D5 or dual wheel gears with five sets per side of the aircraft. Due to wheel proximity, the C-17 gear is more appropriately called a 2T as it appears to have triple wheels in tandem. In contrast, the IL-76 has considerable spacing between the struts and has a Q2 designation.

C-5.9 Gear Geometry Naming Convention Examples.

Table C-1 and paragraphs C-5.3 to C-5.8 provide examples of generic gear types in individual and multiple tandem configurations. Figures C-2 through C-20 provide examples of known gear configurations.

C-5.10 Tire Pressure Information.

The gear naming convention includes a third variable to report tire pressure using ICAO codes. While tire pressure effects on airfield pavements are secondary to aircraft load and wheel spacing, they can have a significant impact on the ability of the pavement to accommodate a specific aircraft.

C-5.10.1 ICAO codes associated with the ACN and the PCN system categorize aircraft tire pressures into four groups for reporting purposes. Table C-2 lists tire pressure codes by category.

Table C-2 Standard Tire Pressure Categories

Category	Range		Code Designation
	psi	MPa	
Unlimited	No limit	No limit	W
High	182–254	1.26–1.75	X
Medium	74–181	0.51–1.25	Y
Low	0–73	0.0–0.5	Z

C-5.10.2 Include the ICAO tire pressure in parentheses after the standard gear name. Table C-3 shows sample gear names with and without the additional tire pressure code.

Table C-3 Sample Gear Names with and without Tire Pressure Codes

Gear Name without Tire Pressure	Gear Name with Tire Pressure
S	S(W)
2S	2S(X)
2D/2D1	2D/2D1(Z)
Q2	Q2(Y)
2D/3D2	2D/3D2(Z)

C-5.11 Historical Naming Convention Comparison.

Table C-4 provides a comparison of the naming convention outlined in this UFC and past FAA, Air Force, and Navy methods. Note that while the old Air Force methodology addresses nose gear configuration, the new method does not due to the minimal impact of the nose gear on the pavement load.

Table C-4 Naming Convention with Historical FAA, U.S. Air Force, and U.S. Navy Nomenclatures

		Historic FAA Designations					U.S. Air Force Designations				U.S. Navy Designations			
Proposed Nomenclature	Reference Figure	FAA Name	Main Gear	Belly Gear	# Belly Gear	Total # Wheels, Excluding Nose	Air Force Designation	Air Force Types	Air Force Name	Nose Gear	Navy Name	Navy Designation	DOD Flight Information	Typical Aircraft
S	3	Single Wheel	SW			2	S	A	Single, Tricycle	Single Wheel	Single Tricycle	ST	S	F-14, F-15
S	4	Single Wheel	SW			2	S	B	Single, Tricycle	Dual wheel				
D	5	Dual wheel	DW			4	T	C	Twin, Tricycle	Single Wheel				Beech 1900
D	6	Dual wheel	DW			4	T	D	Twin, Tricycle	Dual wheel	Dual Tricycle	DT	T	B-737, P3 (C-9)
2S	7	Single Tandem				4	S-TA	E	Single, Tandem Tricycle	Dual wheel	Single Tandem Tricycle	STT	ST	C-130
2T	8					12	TR-TA	L	Twin-Tandem, Tricycle	Dual wheel	Triple Tandem	TRT	TRT	C-17
2D	9	Dual Tandem	DT			8	T-TA	F	Twin-Tandem, Tricycle	Dual wheel	Dual Tandem Tricycle	DTT	TT	B-757, KC-135, C 141
2D/D1	10	Dual tandem	DT	DW	1	10	T-TA	H	Twin-Tandem, Tricycle	Dual wheel	Single Belly Twin Tandem	SBTT	SBTT	L1011, DC-10
2D/2D1	11	Dual Tandem	DT	DT	1	12				Dual wheel				A340-600
2D/2D2	12	Double Dual Tandem	DT	DT	2	16	T-TA	J	Twin-Tandem, Tricycle	Dual wheel	Double Dual Tandem	DDT	DDT	B-747, (E-4)
3D	13	Triple dual Tandem	TDT			12				Dual wheel				B-777
5D	14					20				4 across				An-124
7D	15					28				4 across				An-225
2D/3D2	16		DT	TDT	2	20				Dual wheel				A380
C5	17					24	T-D-TA	K	Twin-Delta-Tandem, Tricycle	4 across	Twin Delta Tandem	TDT	TDT	C-5
D2	18					8	T-T	G	Twin-Twin, Bicycle	No Nose Gear - single outrigger	Twin Twin Tricycle	TT	TT	B-52
Q	19					8								HS-121 Trident
Q2	20					16								IL-76

Figure C-2 Generic Gear Configurations (Increase Numeric Value for Additional Tandem Axles)

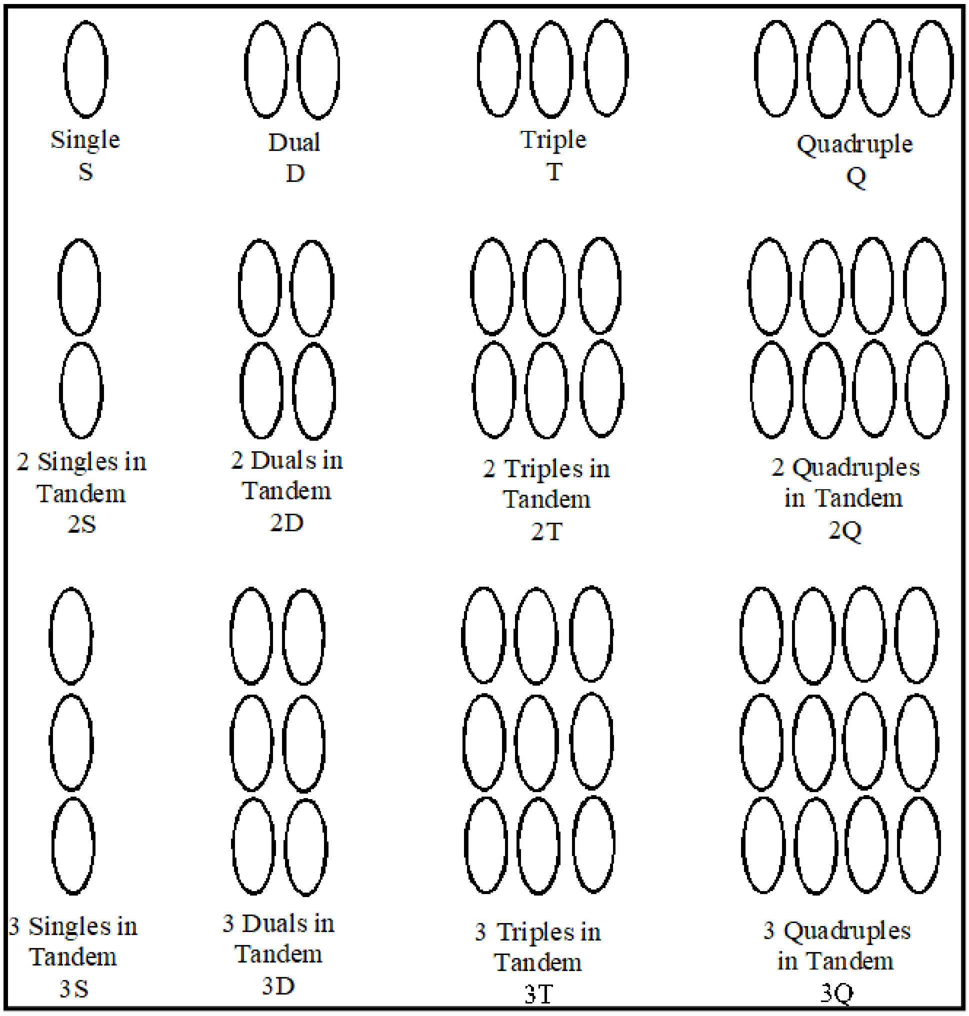


Figure C-3 S - Single Wheel Main Gear with Single Wheel Nose Gear

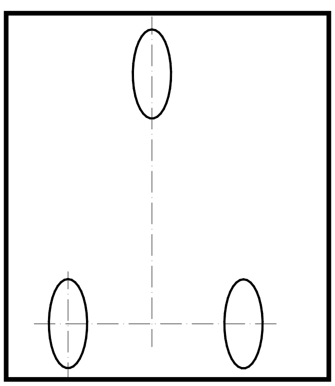


Figure C-4 S - Single Wheel Main Gear with Dual Wheel Nose Gear

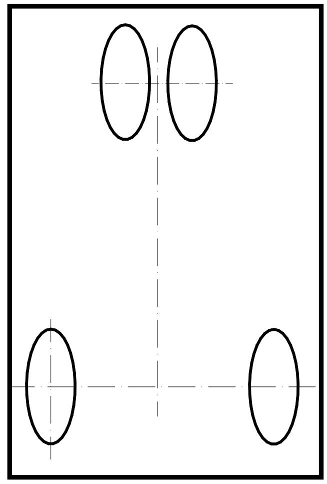


Figure C-5 D - Dual Wheel Main Gear with Single Wheel Nose Gear

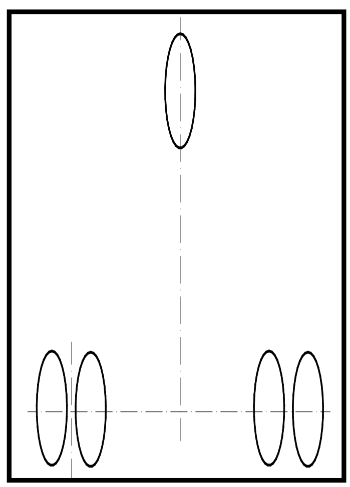


Figure C-6 D - Dual Wheel Main Gear with Dual Wheel Nose Gear

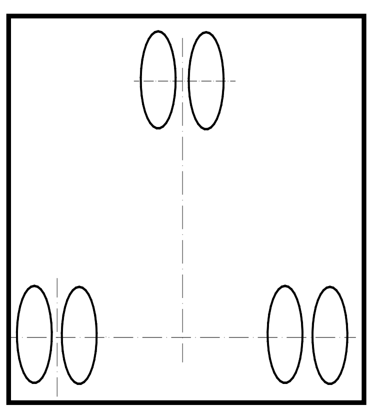


Figure C-7 2S - Two Single Wheels in Tandem Main Gear with Dual Wheel Nose Gear, Lockheed C-130

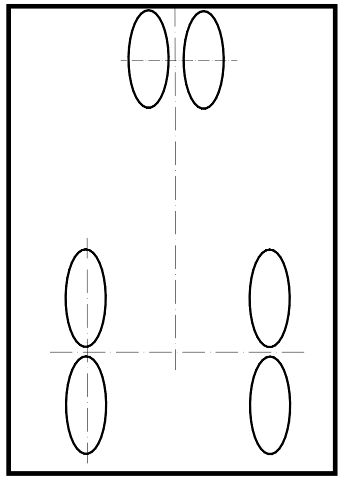


Figure C-8 2T - Two Triple wheels in Tandem Main Gear with Dual Wheel Nose Gear, Boeing C-17

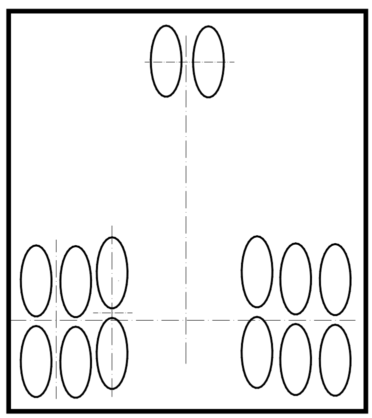


Figure C-9 2D - Two Dual Wheels in Tandem Main Gear with Dual Wheel Nose Gear

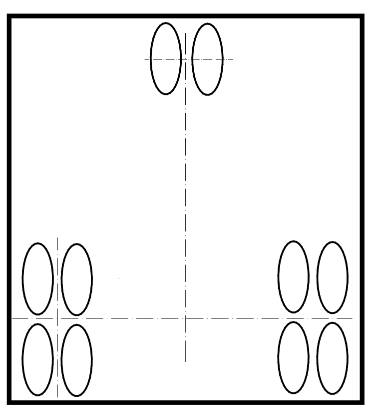


Figure C-10 2D/D1 - Two Dual Wheels in Tandem Main Gear/Dual Wheel Body Gear with Dual Wheel Nose Gear, McDonnell Douglas DC-10, Lockheed L-1011

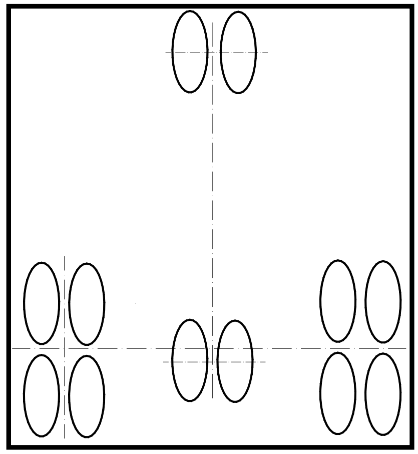


Figure C-11 2D/2D1 Two Dual Wheels in Tandem Main Gear/Two Dual Wheels in Tandem Body Gear with Dual Wheel Nose Gear, Airbus A340-600

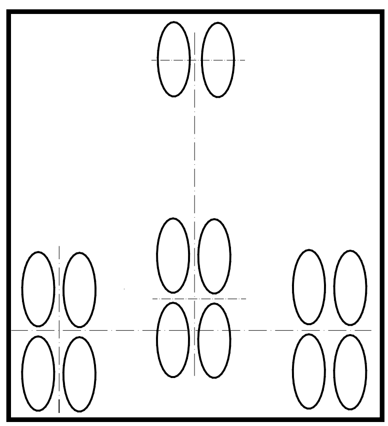


Figure C-12 2D/2D2 - Two Dual Wheels in Tandem Main Gear/Two Dual Wheels in Tandem Body Gear with Dual Wheel Nose Gear, Boeing B-747

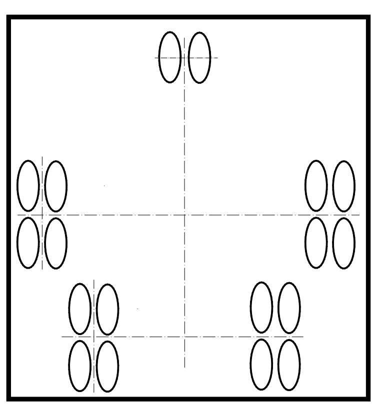


Figure C-13 3D - Three Dual Wheels in Tandem Main Gear with Dual Wheel Nose Gear, Boeing B-777

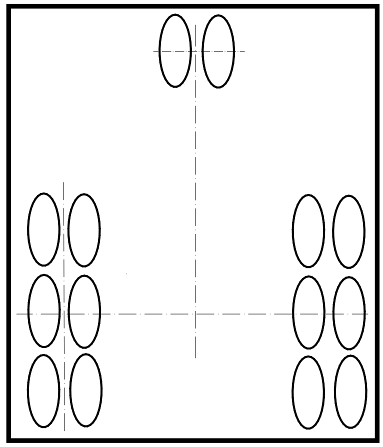


Figure C-14 5D - Five Dual Wheels in Tandem Main Gear with Quadruple Wheel Nose Gear, Antonov AN-124

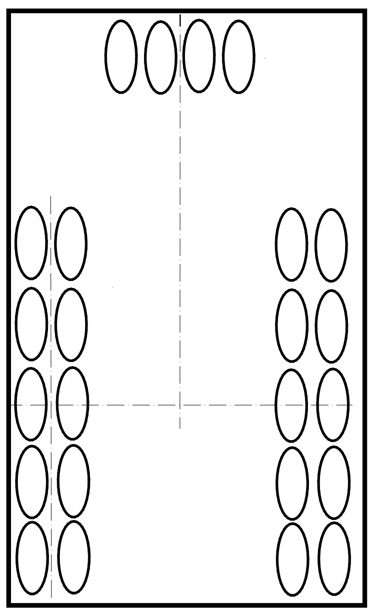


Figure C-15 7D - Seven Dual Wheels in Tandem Main Gear with Quadruple Nose Gear, AN-225

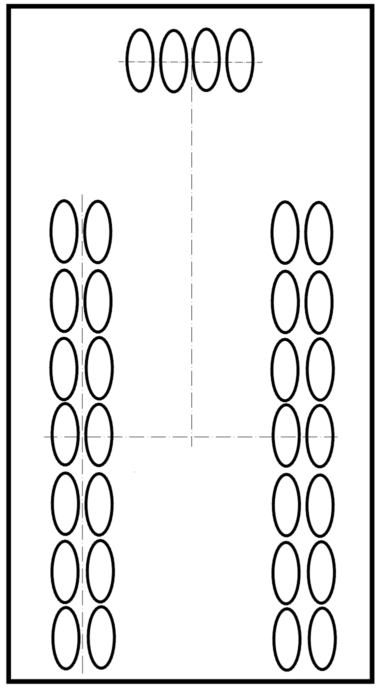


Figure C-16 2D/3D2 - Two Dual Wheels in Tandem Main Gear/Three Dual Wheels in Tandem Body Gear with Dual Wheel Nose Gear, Airbus A380

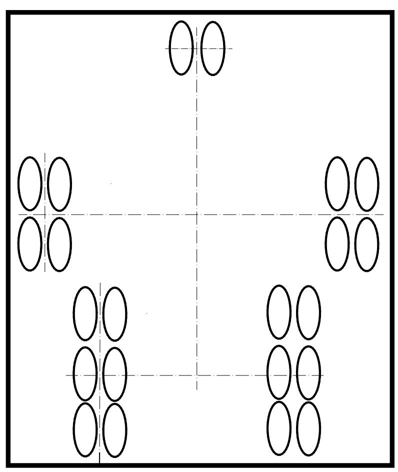


Figure C-17 C5 - Complex Gear Comprised of Dual Wheel and Quadruple Wheel Combination with Quadruple Wheel Nose Gear, Lockheed C5 Galaxy

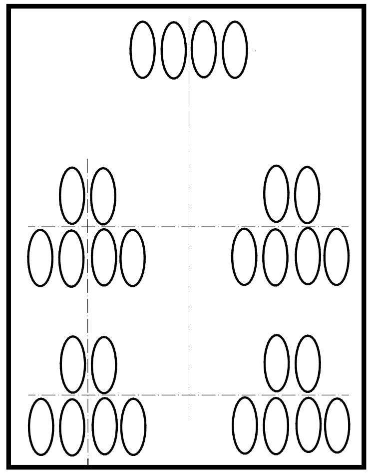


Figure C-18 D2 - Dual Wheel Gear Two Struts per Side Main Gear with No Separate Nose Gear (note that single wheel outriggers are ignored), Boeing B-52 Bomber

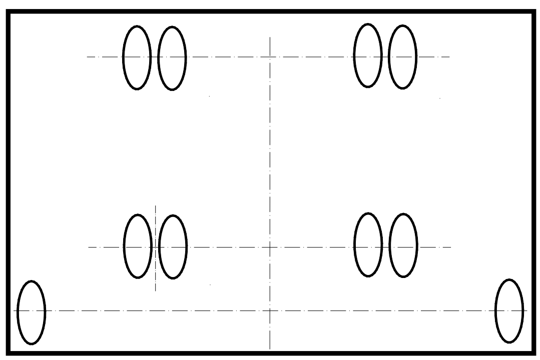


Figure C-19 Q - Quadruple Wheel Main Gear with Dual Wheel Nose Gear, Hawker Siddeley HS-121 Trident

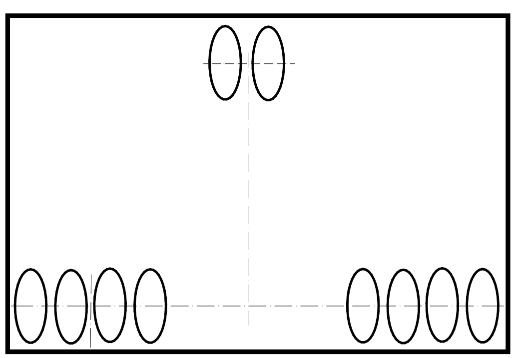
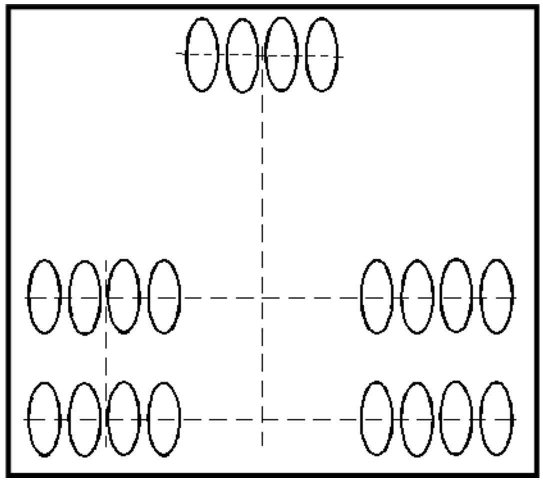


Figure C-20 Q2 - Quadruple Wheels Two Struts per Side with Quadruple Nose Gear, Ilyushin IL-76



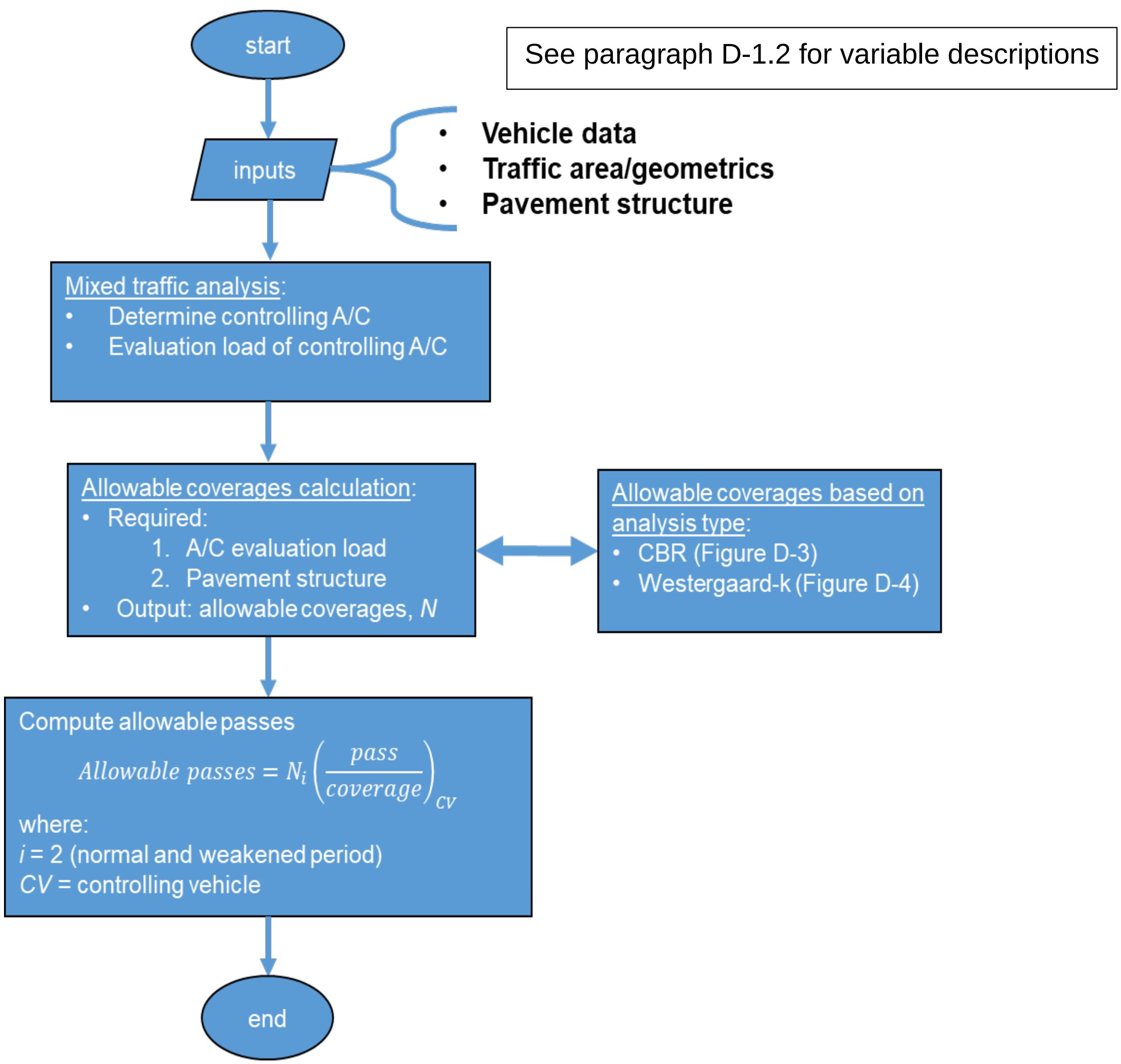
APPENDIX D STRUCTURAL ANALYSIS PROCESS

D-1 CBR-K PAVEMENT ANALYSIS PROCESS FLOW.

D-1.1 Overall CBR-k Analysis Process Flow.

The general process flows for each of the analysis models, Alpha-Beta Hybrid (CBR), and Westergaard (k) are the same. The objective of the first process flow shown in Figure D-1 is to determine the allowable passes. The second, shown in Figure D-2, is to determine the allowable load. Each of these process flows call the CBR procedure for flexible pavement analysis in Figure D-3 and the Westergaard procedure for rigid pavement analysis shown in Figure D-4.

Figure D-1 CBR-k Procedure for Allowable Passes Computation



D-1.2 Analysis Variables for Figure D-1.

- A/C = aircraft
- AGL = allowable gross load of controlling aircraft
- AGL_{trial} = the trial AGL assumed by PCASE during a given iteration
- CBR = California Bearing Ratio (evaluation methodology for flexible pavements)
- CDF = cumulative damage factor, a ratio of applied coverages to allowable coverages of the controlling aircraft
- CV = controlling vehicle (aircraft) determined from mixed traffic analysis
- k = Modulus of subgrade reaction (evaluation methodology for rigid pavements)
- N = Allowable coverages of controlling aircraft at trial AGL
- n = applied coverages of controlling aircraft based on equivalent evaluation passes
- N_i = the number of allowable coverages determined for the controlling aircraft, where the subscript i = 2 for a normal period and a weakened (typically due to thawing) period
- pass/coverage = the ratio of passes to coverage for the controlling aircraft for a specified traffic area

Figure D-2 CBR-k Procedure for Allowable Gross Load Computation

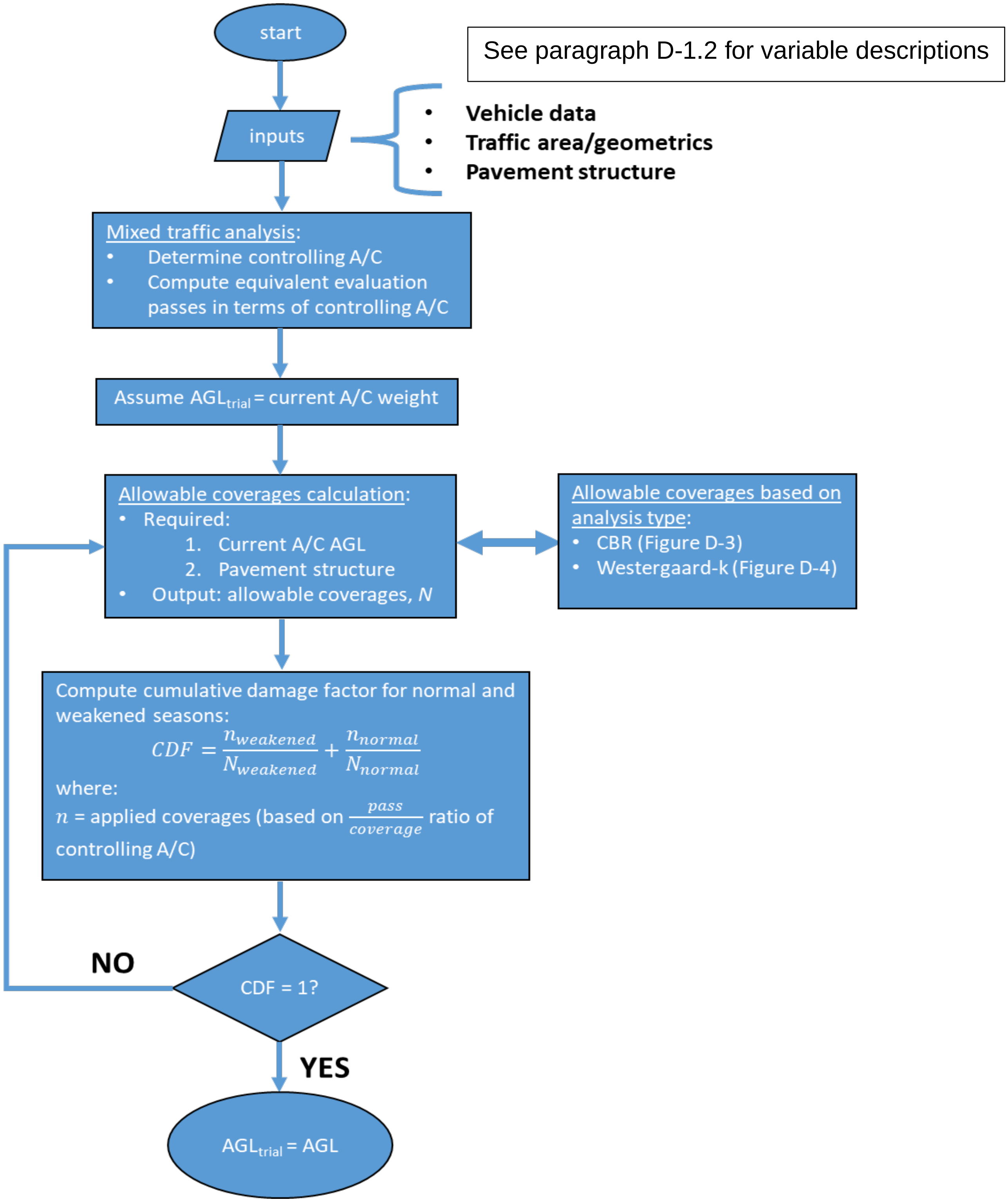
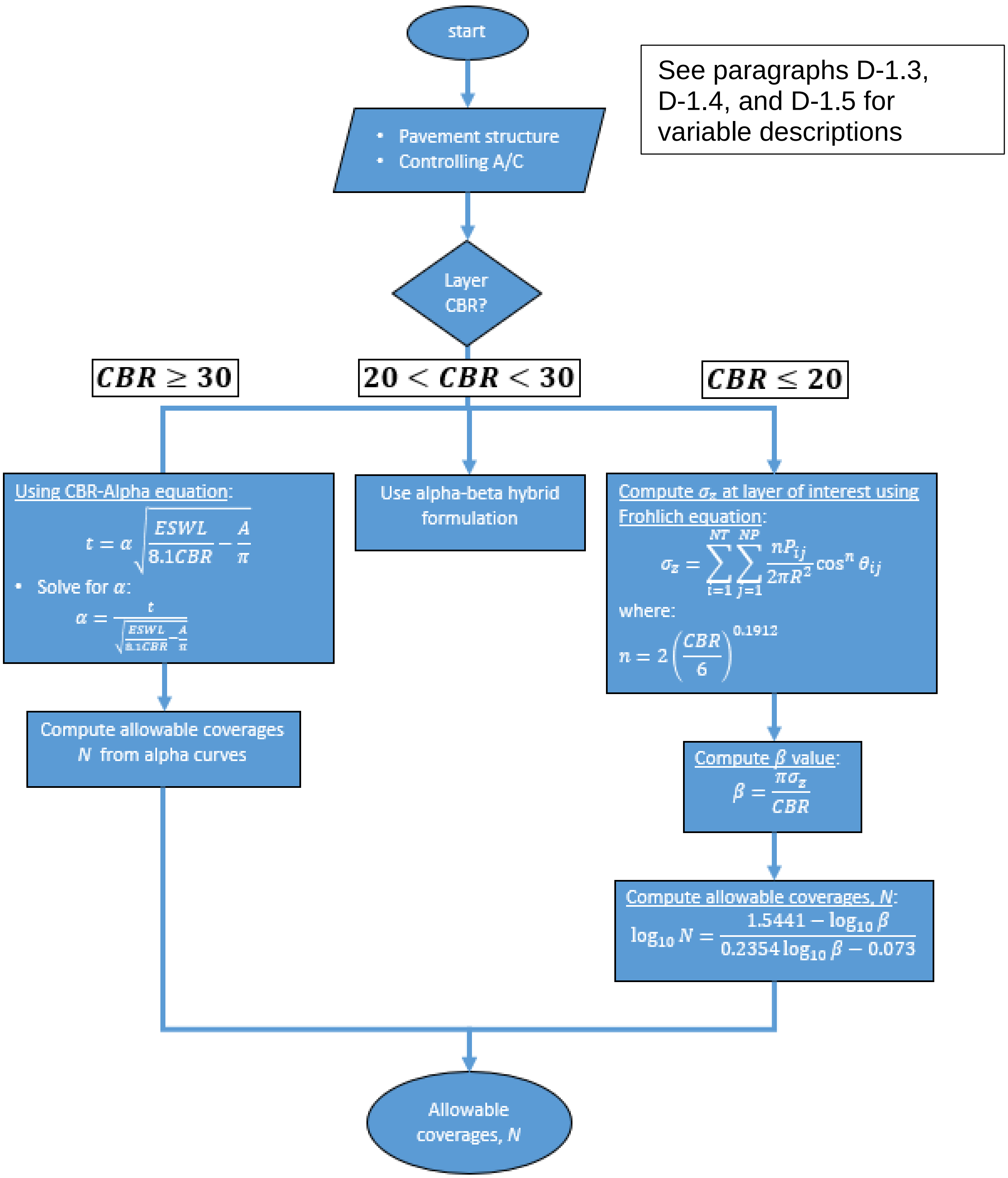


Figure D-3 CBR Procedure for Allowable Coverage Computation



D-1.3 CBR-Alpha Equation Variables in Figure D-3.

- t = total thickness of pavement structure above layer of interest
- α = thickness reduction factor, from alpha curves (function of number of tires in controlling vehicle)
- ESWL = equivalent single wheel load of controlling vehicle
- CBR = California Bearing Ratio of layer of interest
- A = contact area of controlling vehicle

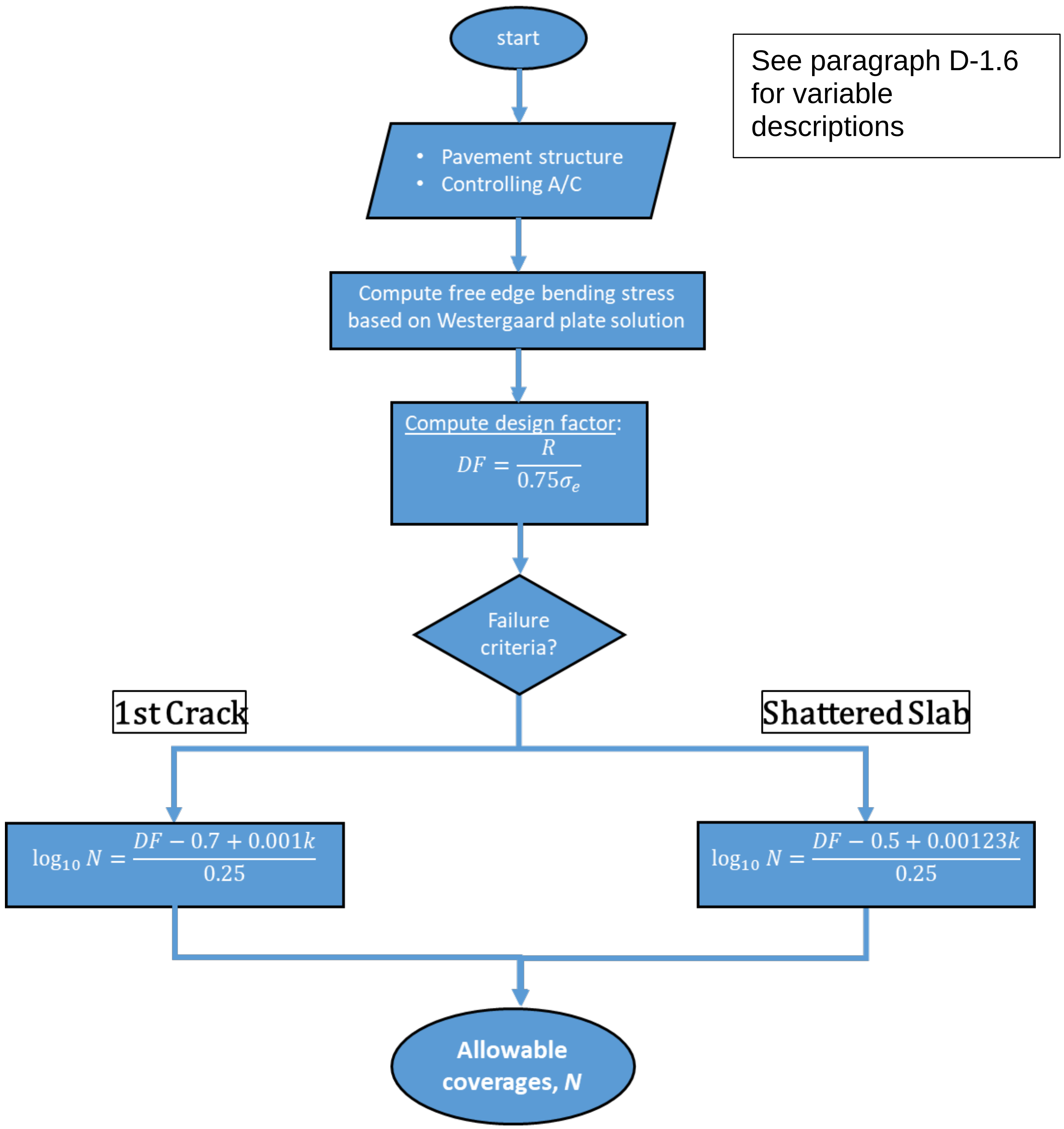
D-1.4 CBR-Beta Frohlich Equation Variables in Figure D-3.

- σ_z = vertical stress computed at the top of the layer of interest
- NT = number of tires in the controlling vehicle main landing gear
- NP = as the Frohlich equation is a *point load solution* (as opposed to a uniform pressure over a circular area solution), the inner summation is conducted over a given number of point loads NT used to estimate the tire inflation pressure in the shape of an elliptical contact area
- i,j subscripts = “i” is the current tire number in the outer summation and “j” is the current point load number in the inner summation
- n = Frohlich stress concentration factor, an empirical value which modifies the vertical stress distribution with depth
- P_{ij} = j^{th} point load in the i^{th} main landing gear tire of the controlling vehicle
- θ_{ij} = horizontal angle between the (x,y) coordinate of point load P_{ij} and the (x,y) coordinate of the calculation point at the top of the layer of interest
- R_{ij} = straight line distance from the z coordinate of the surface point load P_{ij} and the z coordinate of the calculation point at the top of the layer of interest
- β = Beta parameter, a function of the computed Frohlich σ_z and layer CBR, used to compute the allowable coverages of the controlling vehicle

D-1.5 Alpha-Beta Hybrid Formulation.

To compute the allowable gross load for a given flexible pavement structure with CBR > 20 and < 30, the Alpha-Beta Hybrid formulation must be used. This requires the CBR-Beta procedure to be used to compute the AGL at CBR = 20 and the CBR-Alpha procedure to compute the AGLs at CBR = 25 and CBR = 30 to establish a bilinear approximation of the nonlinear relationship between the two formulations. Interpolation is then used to compute the AGL at a specified CBR. This is only an interim solution to address the problems that arise when evaluating contingency structures with thin asphalt layers and marginal base materials.

Figure D-4 Westergaard-k Procedure for Allowable Coverage Computation



D-1.6 Variables for Figure D-4.

- σ_e = “free edge bending stress” = the maximum tensile stress at the bottom edge of the slab due to loading on the slab’s free edge (i.e., no joint) computed from Westergaard plate solution
- *DF* = design factor, a function of concrete flexural strength and the free edge stress reduced by 25 percent considering joint load transfer, used to compute the allowable coverages of the controlling vehicle
- *R* = concrete flexural strength
- *k* = modulus of subgrade reaction used to characterize entire supporting structure beneath slab

Figure D-5 Layered Elastic Procedure for Allowable Passes Computation

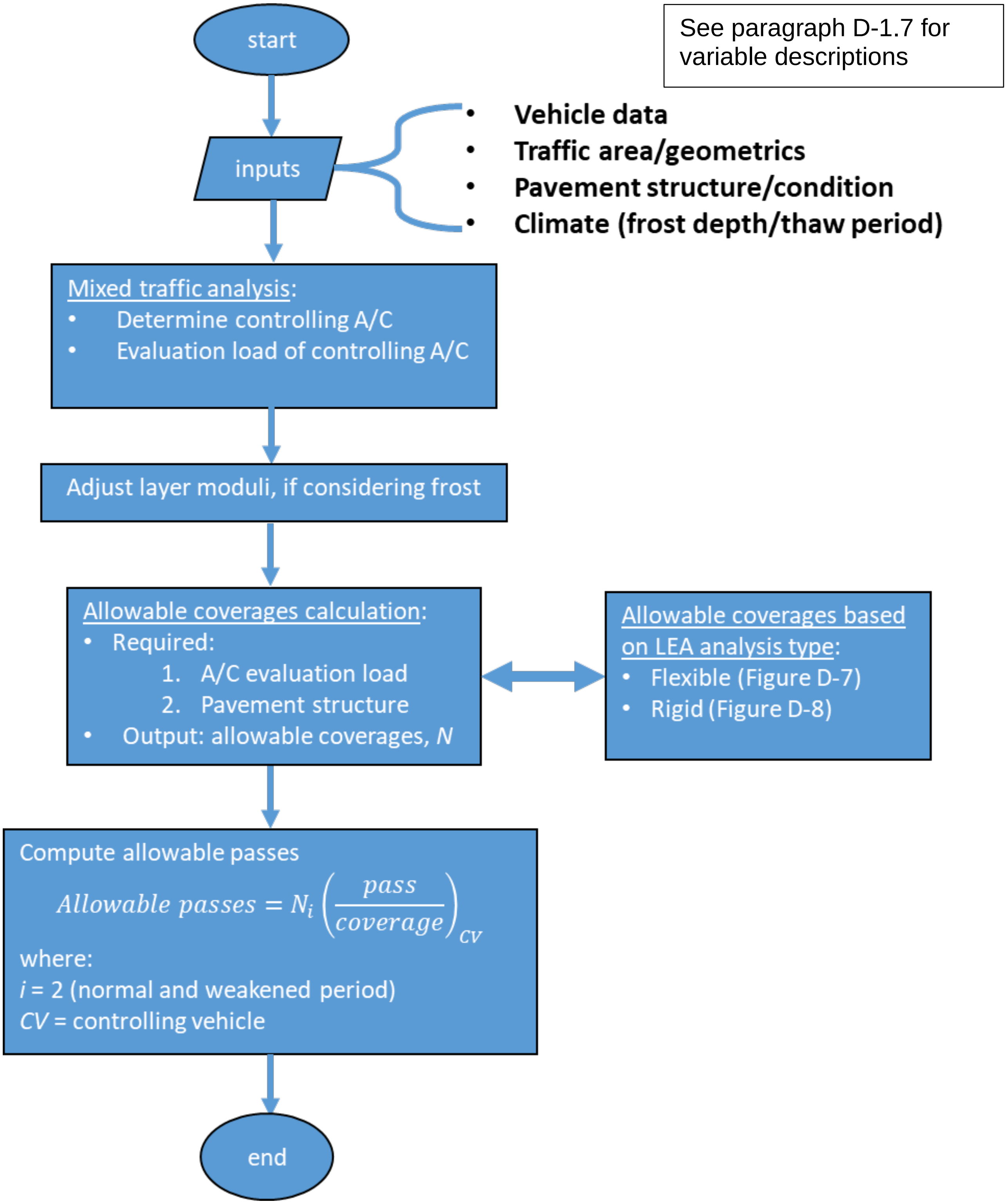
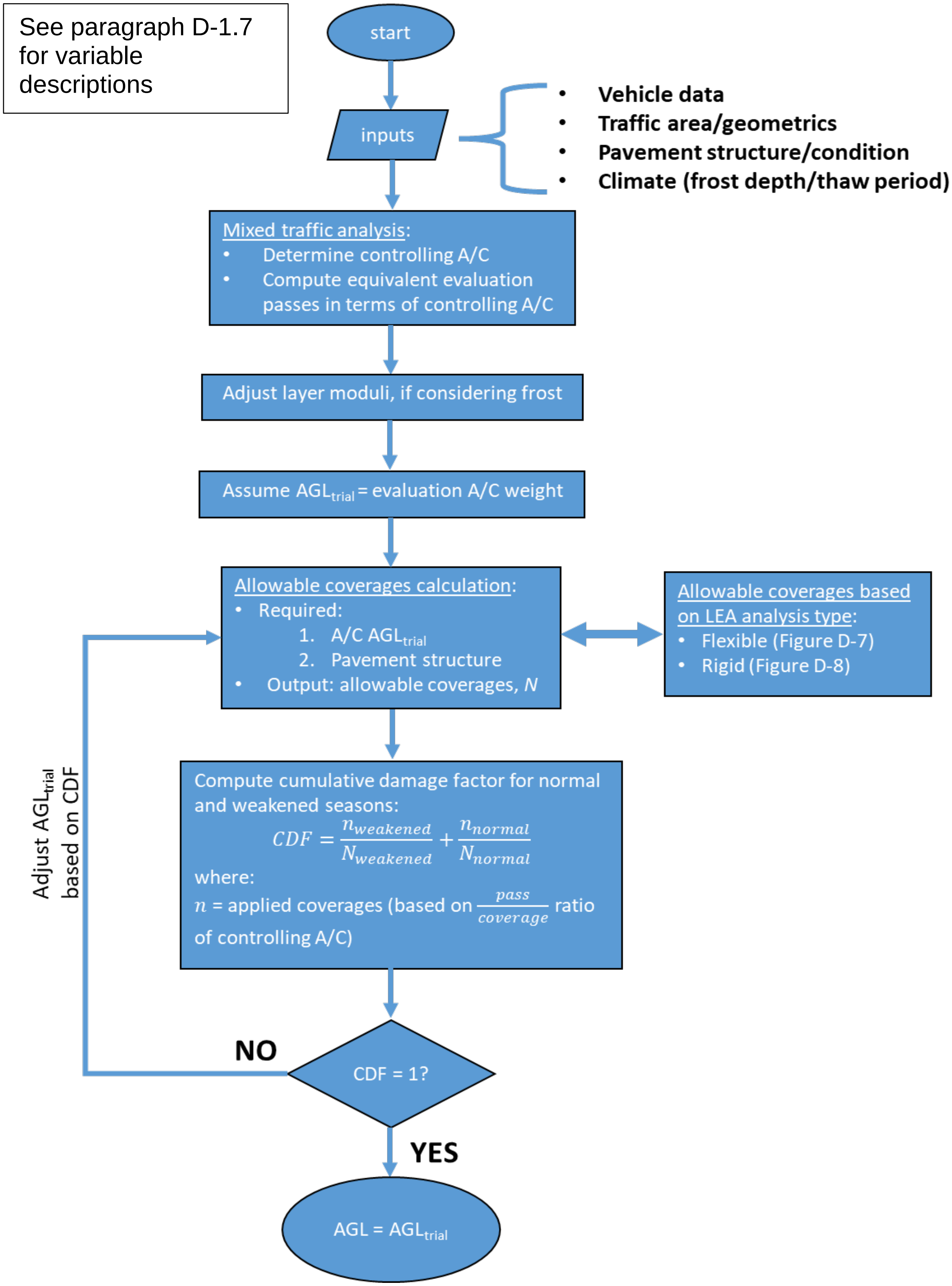


Figure D-6 Layered Elastic Procedure for Allowable Gross Load Computation

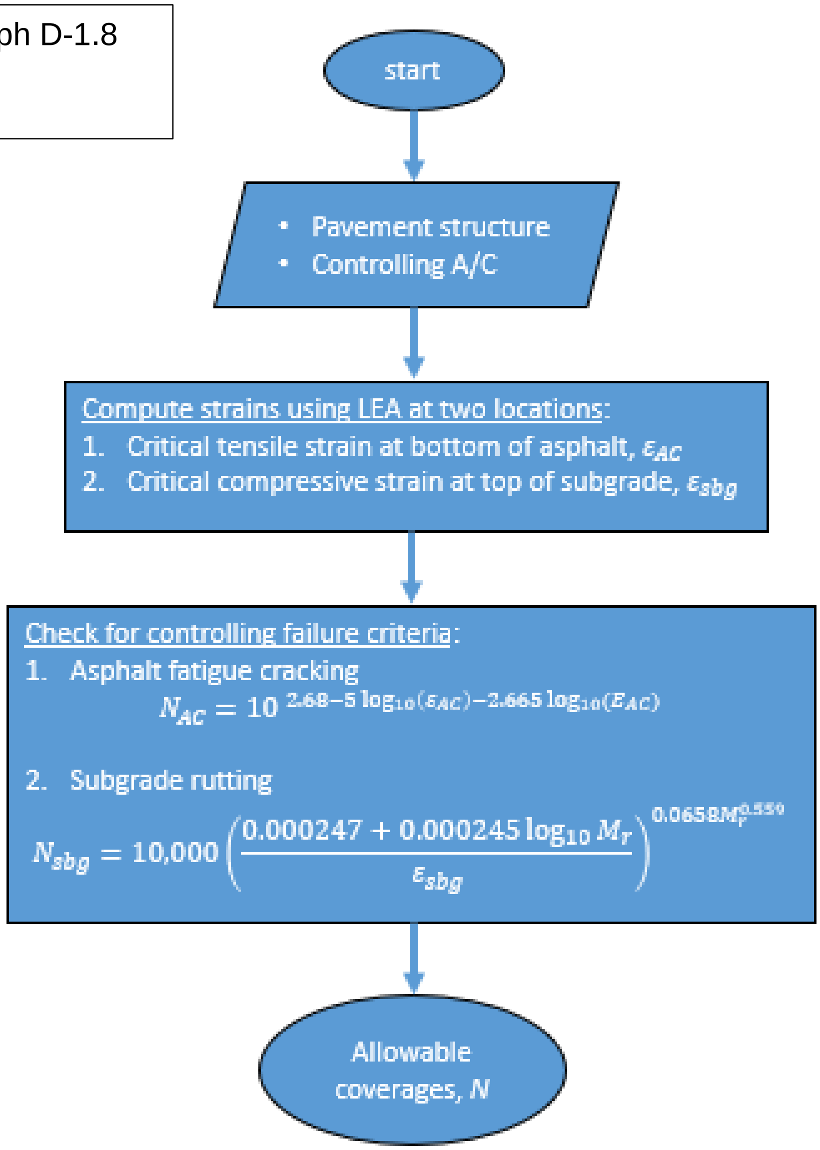


D-1.7 Variables for Figures D-5 and D-6.

- n_{thaw} = the number of applied coverages during the thaw period
- n_{normal} = the number of applied coverages during the normal period
- N_{thaw} = computed allowable coverages from performance model during thaw period
- N_{normal} = computed allowable coverages from performance model during normal period

Figure D-7 Layered Elastic Analysis Flexible Pavement Allowable Coverage Computation

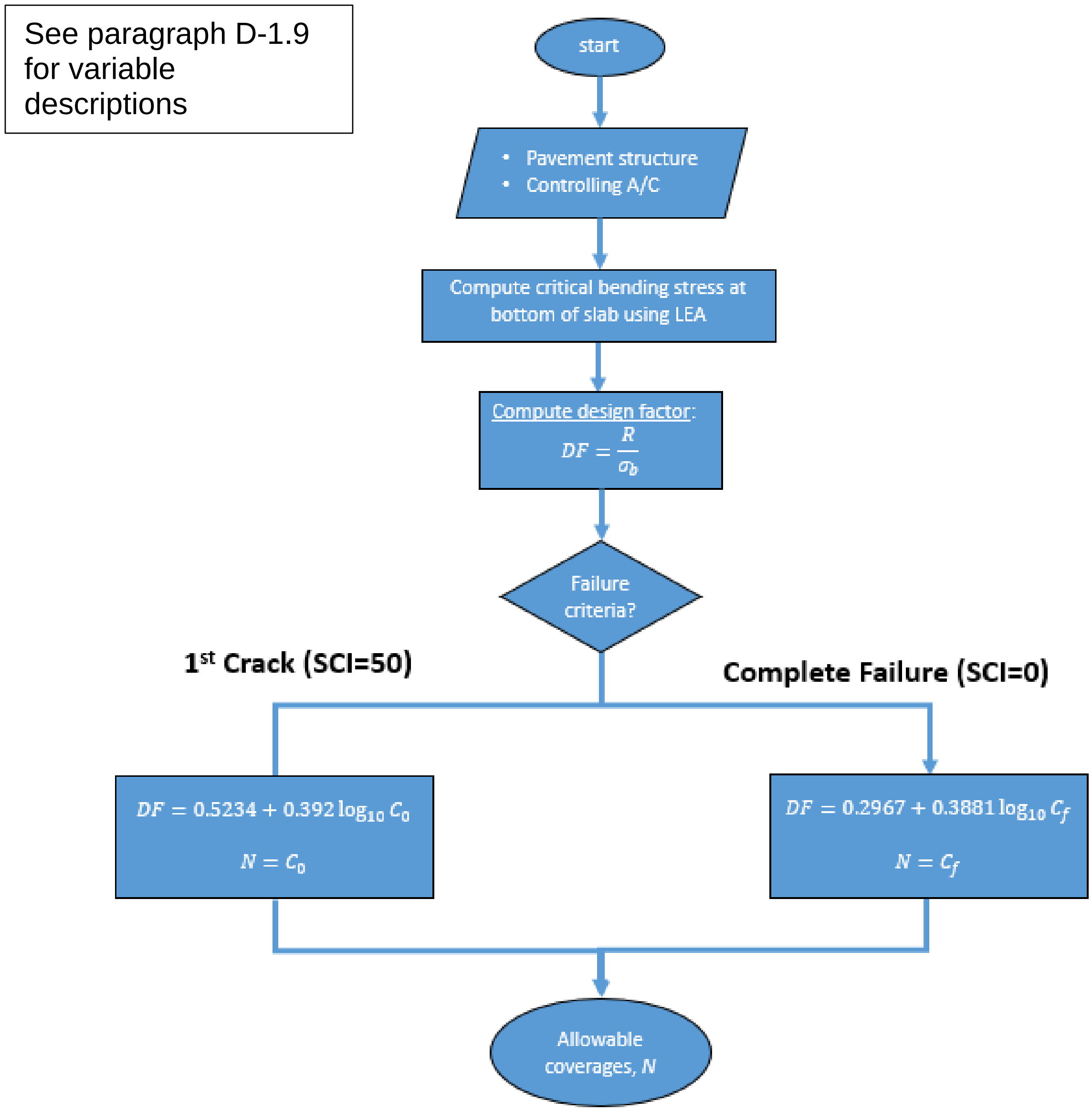
See paragraph D-1.8 for variable descriptions



D-1.8 Variables for Figure D-7.

- ε_{AC} = tensile strain at the bottom of the asphalt layer (in/in)
- ε_{sbg} = compressive strain at the top of the subgrade layer (in/in)
- N_{AC} = computed allowable coverages using asphalt fatigue cracking performance model
- N_{sbg} = computed allowable coverages using subgrade rutting performance model
- E_{AC} = asphalt layer Young's modulus of elasticity (psi)
- Mr = subgrade layer resilient modulus (psi)

Figure D-8 Layered Elastic Analysis Rigid Procedure for Allowable Coverage Computation



D-1.9 Variable for Figure D-8.

- σ_b = interior bending stress in slab
- SCI = structural condition index
- C_0 = computed allowable coverages before first crack failure criteria (SCI = 50)
- C_f = computed allowable coverages before complete failure criteria (SCI = 0)

APPENDIX E PCASE PAVEMENT EVALUATION APPLICATION

E-1 BACKGROUND.

The Services use the Pavements-Transportation Computer Assisted Structural Engineering (PCASE) application to design and evaluate airfield and road and parking pavements. The program is managed Jointly by the US Army Corps of Engineers Transportation Systems Center (TSC) and Engineer Research and Development Center (ERDC) Geotechnical and Structures Lab, with support from a Tri-Service governance working group. TSC and ERDC continuously update, expand, and improve the application and provide technical assistance, consulting services, and training. PCASE training is highly encouraged to ensure the latest criteria and technology is used to design and evaluate pavements. TSC contact information is below:

U.S. Army Corps of Engineers
Transportation Systems Center
1616 Capitol Ave.
Omaha, NE 68102-4901
Telephone: 402-995-2399

E-2 USING PCASE.

Details on PCASE installation and use for design and evaluation are available in the *PCASE User Manual.* The guide and latest version of the application are available at:

https://transportation.erdc.dren.mil/pcase/

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APPENDIX F GLOSSARY

F-1 ACRONYMS.

A/C	Aircraft
AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt Concrete
ACN	Aircraft Classification Number
ADCP	Automated Dynamic Cone Penetrometer
AFI	Air Freezing Index
AGL	Allowable Gross Load
APE	Airfield Pavement Evaluation
ASTM	American Society for Testing and Materials
BIA	Bilateral Infrastructure Agreement
CBR	California Bearing Ratio
CDD	Cumulative Degree Days
CDF	Cumulative Damage Factor
CP	Coordinating Panel
CRREL	Cold Regions Research and Engineering Laboratory
DCP	Dynamic Cone Penetrometer
DFI	Design Freezing Index
DoD	Department of Defense
DWG	Discipline Working Group
ERDC	Engineer Research and Development Center
FAIR	Frost Area Index of Reaction
FASSI	Frost Area Soil Support Indices
FDD	Freezing Degree Days

FLIP	Flight Information Pamphlet
FOD	Foreign Object Debris
FWD	Falling Weight Deflectometer
GHz	Gigahertz
GIS	Geographic Information System
GPR	Ground Penetrating Radar
GPS	Global Positioning System
Hz	Hertz
ICAO	International Civil Aviation Organization
ISM	Impulse Stiffness Modulus
LEEP	Layered Elastic Evaluation Program
LL	Liquid Limit
M&R	Maintenance and Repair
MHz	Megahertz
MPa	Megapascal
NDT	Nondestructive Testing
NFS	Nonfrost Susceptible
NGA	National Geospatial-Intelligence Agency
PCC	Portland Cement Concrete
pcf	Pound per Cubic Foot
PCI	Pavement Condition Index
pci	Pound per Cubic Inch
PCN	Pavement Classification Number
PPD	Physical Property Data
psi	Pound per Square Inch

PSPA	Portable Seismic Pavement Analyzer
RMSE	Root Mean Square Error
RSS	Reduced Subgrade Strength
SCI	Structural Condition Index
SHRP	Strategic Highway Research Program
SI	Structural Index
TM	Technical Manual
TSPWG M	Tri-Service Pavements Working Group Manual
UFC	Unified Facilities Criteria
UFGS	Unified Facilities Guide Specifications
USCS	Unified Soil Classification System

F-2 DEFINITION OF TERMS.

Average Daily Temperature: The average of the maximum and minimum temperatures for one day, or the average of several temperature readings taken at equal time intervals, generally hourly, during a day.

Combined Base Thickness: Term used in frost analysis that means the combined thickness of base, subbase, drainage layer, and separation layer.

Critical Weakening Period: Interval during the period of thaw weakening when the base, subbase, or subgrade are at their lowest strength.

Degree-Days: The Fahrenheit degree days for any given day equal the difference between the average daily air temperatures and 32 degrees F (0 degrees C). The Centigrade degree hours for any given day equal the average daily temperatures (degrees C) multiplied by 24 hours. The degree-days or degree-hours are negative when the average daily temperature is below 32 degrees F (0 degrees C) (freezing degree-days or hours) and positive when above (thawing degree-days or hours). Usually, the degree-days or hours are reported in terms of their absolute values and the distinction is made between freezing and thawing.

Design Freezing Index: The average air freezing index of the three coldest winters in the latest 30 years of record. If 30 years of record are not available, the air freezing index for the coldest winter in the latest 10-year period may be used. The design freezing index at a site need not be changed more than once in 5 years unless the more recent temperature records indicate a significant change in thickness requirements for frost protection.

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

Freezing Index: The number of degree-days between the highest and lowest points on a curve of cumulative degree-days versus time for one freezing season. It is used as a measure of the combined duration and magnitude of below-freezing temperatures occurring during any given freezing season. The index is determined from air temperatures measured approximately 4.5 feet (1 meter) above the ground and is commonly designated as the air freezing index.

Frost Action: A general term for freezing and thawing of moisture in materials and the resultant effects on these materials and on structures of which they are a part, or with which they are in contact.

Frost Area Soil Support Indices (FASSI): The weighted average of CBR values for the annual cycle. These values are used in flexible pavement evaluation for the frost-melt period, as if they are true CBR values.

Frost Area Index of Reaction (FAIR): The weighted average of k values for the annual cycle. These values are used for rigid pavement evaluation for the frost-melt period, as if they are true k values.

Frost Susceptible Soil: Soil in which significant detrimental ice segregation will occur when the requisite moisture and freezing conditions are present. These soils will lose a substantial portion of their strength upon thawing.

Frost Heave: The raising of the pavement surface due to formation of ice lenses in the underlying soil.

Frost-melting (Thaw) Periods: Intervals of the year when the ice in the base, subbase, or subgrade returns to a liquid state. A period ends when all the ice in the ground has melted or when the previously frozen material is refrozen. In general, there may be several significant frost-melting periods during the winter months prior to the spring thaw.

Mean Daily Temperature: The mean of the average daily temperatures for a given day, usually calculated over a period of several years.

Mean Freezing Index: The freezing index determined based on mean daily temperatures. The period of record over which average daily temperatures are averaged is usually a minimum of the latest 10 years, preferably 30.

Non-frost Susceptible Materials: Cohesionless materials such as crushed rock, gravel, sand, slag, and cinders that do not experience significant detrimental ice segregation under normal freezing conditions. Cemented or stabilized materials that do not experience significant detrimental ice segregation, loss of strength upon thawing, and freeze thaw degradation are also considered to be non-frost susceptible materials.

Normal Period: Interval during the year when the base, subbase, and subgrade strengths are at their normal strength.

Recovery Period: Interval from the end of the critical weakening period to the beginning of the normal period. During this time the base, subbase, and subgrade strengths are recovering to normal strength from their lowest strength.

Surface Freezing Index: The n factor * Design Freezing Index = the Surface Freezing Index.

Thaw-Weakened Periods: Intervals of the year when the base, subbase, or subgrade strength are below normal summer values. These intervals correspond to thaw periods. The period ends when either the material is refrozen or when the subgrade strength has returned to the normal summer value at the end of the spring thaw-weakening period.

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APPENDIX G REFERENCES

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CRD-C 654, *Standard Test Method for Determining the California Bearing Ratio of Soils*, https://www.wbdg.org/ffc/army-coe/standards/crd-c654

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C42, *Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete*

C78, *Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)*

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C128, *Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate*

C136, *Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates*

C496, *Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens*

C597, *Standard Test Method for Pulse Velocity Through Concrete*

C642, *Standard Test Method for Density, Absorption, and Voids in Hardened Concrete*

D4, *Standard Test Method for Bitumen Content*

D5, *Standard Test Method for Penetration of Bituminous Materials*

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UFC 3-260-04
16 May 2018

UNIFIED FACILITIES CRITERIA (UFC)

AIRFIELD AND HELIPORT MARKING

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

UNIFIED FACILITIES CRITERIA (UFC)

AIRFIELD AND HELIPORT MARKING

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER CENTER (Preparing Activity)

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

Change No.	**Date**	**Location**

This UFC supersedes Air Force ETL 04-2, *Standard Airfield Pavement Marking Schemes*, 19 July 2004; Army TM 5-823-4 C1, *Marking of Army Airfield-Heliport Operational and Maintenance Facilities*, July 1987; UFC 3-260-05A, *Marking of Army Airfield Heliport Operational and Maintenance Facilities,* 16 January 2004*;* Army Engineering and Construction Bulletin*, Marking of Army Airfields and Heliports,* 1 October 2012; and Army ETL 1110-3-512, *Army Airfield and Heliport Markings*, 30 September 2015.

FOREWORD

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

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Defense agencies should contact the preparing Service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale should be sent to the respective Service proponent office by the following electronic form: Criteria Change Request. The form is also accessible from the Internet site listed below.

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

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

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

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UNIFIED FACILITIES CRITERIA (UFC)
NEW DOCUMENT SUMMARY SHEET

Document: UFC 3-260-04, *Airfield and Heliport Marking*

Superseding: Air Force Engineering Technical Letter (ETL) 04-2, *Standard Airfield Pavement Marking Schemes*, 19 July 2004; Army TM 5-823-4 C1, *Marking of Army Airfield-Heliport Operational and Maintenance Facilities*, July 1987; UFC 3-260-05A, *Marking of Army Airfield Heliport Operational and Maintenance Facilities*, 16 January 2004; and Army Engineering and Construction Bulletin, *Marking of Army Airfields and Heliports*, 1 October 2012, and Army ETL 1110-3-512, *Army Airfield and Heliport Markings*, 30 September 2015

Description: The purpose of this document is to provide standard dimensions, colors, retro-reflectivity requirements, layout, placement, and orientation standards for marking airfield pavements. It gives the minimum level of marking necessary for paved surfaces of fixed and rotary wing runways, taxiways, helipads, and landing lanes. It also provides authority to mark hazards to air navigation as obstructions in accordance with national standards or military agreements within host countries. See TM 3-34.48-2, *Theater of Operations: Roads, Airfields, and Heliports – Airfield and Heliport Design*, Volume II, for landing zone marking requirements. This document applies to all Department of Defense (DoD) activities except those operating at airports owned and controlled by an authority other than the DoD. For airports under Federal Aviation Administration (FAA) jurisdiction, use FAA Advisory Circular (AC) 150/5340-1, *Standards for Airport Markings*. For DoD facilities overseas, if a written agreement exists between the host nation and DoD that requires application of North Atlantic Treaty Organization (NATO), International Civil Aviation Organization (ICAO), or FAA standards, those standards apply as stipulated within the agreement. For cases where a Status of Forces Agreement (SOFA) specifically requires international standards, use ICAO Annex 14, Volume I, *Aerodromes* (for fixed wing runways), or Annex 14, Volume II, *Heliports* (for rotary wing helipads and runways), as appropriate. Air Force tenant organizations on civil airports use these standards on the military portion of the airfield to the maximum extent practicable.

Reasons for Document: This document combines and consolidates standards for the Services to ensure uniformity in visual guidance aids on DoD airfields.

Impact: Impacts of implementing these updated standards have been minimized by allowing existing markings to remain pending a need to remark pavement due to age or normal wear.

Unification Issues: Naval Air Systems Command (NAVAIR) is the Office of Primary Responsibility for airfield marking on U.S. Navy facilities. The NAVAIR standard is NAVAIR 51-50AAA-2, *General Requirements for Shore Based Airfield Marking and Lighting*. Additionally, the NAVAIR publication includes airfield lighting standards which are not unified with UFC 3-535-01, *Visual Air Navigation Facilities*. The Pavements Discipline Working Group (DWG) continues to work with NAVAIR to unify airfield marking standards across DoD. Waiver processing differs among the Services due to differences in organizational structure.

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FIGURES

TABLES

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CHAPTER 1 BACKGROUND AND GENERAL INFORMATION

1-1 BACKGROUND.

These criteria are a compilation of U.S. and international standards, adopted from the International Civil Aviation Organization (ICAO) standards, North Atlantic Treaty Organization (NATO) agreements, and Federal Aviation Administration (FAA) standards, as well as individual Service- or aircraft-specific technical orders. Prior to publication of this UFC, each Service component promulgated independent airfield marking standards based upon mission needs and operational doctrine, none of which fully complied with NATO, ICAO, or FAA criteria. Because DoD Service components operate worldwide, it is desirable and necessary that visual aids be commonly recognized and universally accepted by all DoD personnel and our allies.

1-2 GENERAL INFORMATION.

Pavement markings are provided to enable and enhance safe and informed aircraft and vehicle operation on the airfield and roadways. They are required to be prominent and of uniform configuration so they are clearly understood. Do not place locally devised non-standard markings without authorization from the appropriate authority. Such markings confuse aviators and ground personnel and cause runway incursions and accidents.

1-3 PURPOSE AND SCOPE.

This UFC provides standards for marking DoD airfields and heliports. This UFC also requires use of the Federal Highway Administration's (FHWA) *Manual of Uniform Traffic Control Devices* (MUTCD) for marking roadways, vehicular traffic routes on airfields, and airfield service roads maintained and operated by the designated authority. It gives the minimum level of markings necessary for paved surfaces of fixed and rotary wing runways, taxiways, helipads, and landing lanes as well as unique apron or hard stand markings necessary for maintenance or calibration of aircraft. It refers to FAA or ICAO standards for marking the surfaces of obstructions when deemed necessary by the designated authority. For additional airfield facility types, such as the F-35 vertical landing (VL) pad, landing helicopter deck (LHD) simulated deck facilities, and other fixed-wing short takeoff and vertical landing (STOVL) facilities, see UFC 3-260-01.

1-4 APPLICABILITY.

These criteria apply to all DoD activities except those operating at airports owned and controlled by an authority other than DoD. U.S. Navy and Marine Corps pavement marking details for shore-based installations are provided in NAVAIR 51-50AAA-2, *General Requirements for Shore Based Airfield Marking and Lighting*. Download a copy at http://www.wbdg.org/ffc/dod/supplemental-technical-criteria (designated TSEWG NAVAIR 51-50111-2, *General Requirements for Shorebased Airfield Marking and Lighting*) or contact the management authority for NAVAIR 51-50-AAA-2 at: Commanding Officer Naval Air Warfare Center Aircraft Division, Lakehurst Logistics, Code 6.8.5.1, Lakehurst, NJ, 08733, phone (732) 323-5073.

Base the marking criteria used upon ownership of the facility or official agreements with the host nation or host aviation authority. For example, DoD-owned and -controlled facilities are marked in accordance with DoD criteria and municipally owned airfields and airports are marked in accordance with FAA or ICAO criteria, as applicable.

It is recommended that noncompliant markings be updated to comply with this UFC at the next painting cycle. However, existing markings are not required to be changed to comply with the updated criteria in this UFC until it is appropriate and economically feasible to remove and replace all noncompliant markings on a significant feature of the airfield. An entire runway, the taxiway system, or an individual apron are examples of significant features of an airfield for the purpose of complying with this UFC.

1-5 JOINT USE FACILITIES.

1-5.1 Within the Continental United States (CONUS).

A joint use facility is one where a written agreement between the U.S. military and a government agency authorizes use of the military runways for public transportation. For airports operated under FAA jurisdiction, use FAA AC 150/5340-1.

1-5.2 Outside the Continental United States (OCONUS).

For DoD facilities overseas, if a written agreement exists between the host nation and DoD that requires application of NATO or ICAO standards, those standards apply as stipulated within the agreement. For cases where a Status of Forces Agreement (SOFA) specifically requires international standards, use ICAO Annex 14, Volume I, *Aerodromes* (for fixed wing runways), or Annex 14, Volume II, *Heliports* (for rotary wing helipads and runways), as appropriate. DoD tenant organizations on civil airports use these standards on the military portion of the airfield to the maximum extent practicable.

1-6 GENERAL BUILDING REQUIREMENTS.

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

1-7 REFERENCES.

Appendix A contains a list of references. The publication date of the code or standard is not included in this UFC. In general, the latest available issuance of the reference is used.

1-8 SUMMARY OF BEST PRACTICES IN APPENDIX B.

1-8.1 Airfield Marking Handbook.

Appendix B-1 contains best practices for installation and maintenance of airfield and heliport markings documented by the Innovative Pavement Research Foundation (IPRF) in Project 05-1.

1-8.2 Maintenance of Marking Patterns from Previous Standards.

Appendix B-2 contains the layout and dimension details for airfield markings previously used on Air Force and Army installations prior to publication of this UFC. Details for Navy and Marine Corps pavement marking details for shore-based installations are provided in NAVAIR 51-50AAA-2. The details and reference information provided facilitates maintenance of existing markings.

1-8.3 Use of Metrics for Markings.

Appendix B-3 is a matrix of dimensional equivalencies for various line segments, markings, and distances to or from specific geographic or feature reference points identified or referenced in this UFC.

1-9 GLOSSARY.

Appendix C contains acronyms, abbreviations, and terms.

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CHAPTER 2 WAIVERS

2-1 REQUIREMENTS AND PROCEDURES.

Do not design, specify, provide, construct, or apply any airfield marking that does not comply with this UFC without first requesting and obtaining a waiver in accordance with Military Standard (MIL-STD) 3007 and agency, DoD, and Service department airfield waiver procedures. However, design markings to the extent needed to determine if a waiver is required and to prepare the waiver. Prepare and obtain separate waivers from the senior airfield authority and airfield manager if they are not included in the current agency waiver procedure. Refer to the current agency airfield markings waiver procedures in Tri-Service Pavements Working Group (TSPWG) Manual 3-260-04.18-02, *Airfield Marking Waiver Procedures*.

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CHAPTER 3 TOLERANCES, MATERIALS, APPLICATION RATES, AND COLORS

3-1 PATTERN SIZE ALLOWANCES.

3-1.1 Tolerances for New Markings and Remarking.

Apply all markings in the standard dimensions provided in the drawings. New markings are allowed to deviate a maximum of 10 percent larger than the standard dimension. The maximum deviation allowed when painting over an old marking is up to 20 percent larger than the standard dimension. Do not use less than standard dimensions.

3-1.2 Paint.

Mark flexible and rigid pavements with lead-free pavement-marking paints, available under Federal Specification TT-P-1952. Select Type I for use under normal conditions, Type II for use under adverse conditions, or Type III for increased durability. See the latest revision of Federal Specification TT-P-1952 for additional information on applications. Apply glass beads to the paint immediately after application of paint to incorporate retro-reflective properties into the markings.

3-1.2.1 Permanent Painted Markings.

Apply markings at 12 to 14 mils (0.310 to 0.360 millimeters) wet-film thickness for coverage of 121 (± 6) square feet per gallon (2.970 square meters [± 165 square millimeters] per liter). Apply beads to permanent painted markings at the rate recommended for the type beads used. (The wet film thickness of the paint is increased when the larger diameter Type IV beads are used. See paragraph 3-3.3 for details.) It is undesirable for painted markings to build up beyond a total thickness of approximately 40 mils (1.02 millimeters). This occurs after about five marking cycles unless surface abrasion (e.g., caused by snow-removal equipment) reduces this buildup. Repeated over-painting increases stresses at the initial bond with the pavement and eventually causes the marking to crack and peel.

3-1.2.2 Temporary Painted Markings.

Apply markings at 4 to 6 mils (0.100 to 0.150 millimeter) wet-film thickness in cases where new pavements need to be opened early or for temporarily displaced thresholds. Apply beads to temporary painted markings at half the normal rate; this provides markings of sufficient prominence to allow operations. Touch up the marking in case of bleeding and remark the pavement at the normal application rate after the pavement is at least 30 days old. For temporary markings, first apply a pavement-curing compound; this makes the markings easier to remove. A lime and water solution or sea-marker dyes are also used for temporary markings; however, these materials are best suited to dirt surfaces or snow-covered pavements. Temporary marking tape is also used for temporary taxi routes or for temporarily displaced threshold markings if the pre-threshold area is only planned for operation at normal taxiing speeds. High-speed operations, turning traffic, rotor-wash, or jet blast might dislodge these materials, creating a potential for foreign object damage (FOD) to jet engines. Do not use these materials on runways for this reason.

3-1.3 Alternate Marking Materials.

Thermoplastics or preformed materials such as tape are allowed for use on taxiways and aprons, but these type materials are not used on runways or helipads because of the potential FOD to aircraft if they delaminate from the pavement. Apply these materials in accordance with the manufacturer's recommendations. Pre-mix glass beads with thermoplastic materials and post-apply beads to the surface of the marking at the same application rate as noted above to provide initial retro-reflectivity. The beads are uniformly suspended throughout the material to ensure continuing retro-reflectivity as the marking wears from the effects of traffic. Add beads at a rate equivalent to that noted above for each 10 mils (0.250 millimeter) of overall application thickness.

3-1.4 Alternate Visual Aids.

When appropriate, lighted barricades, traffic cones, or portable edge markers are used instead of pavement markings during short periods of construction if addressed in the construction waiver and the construction phasing plan (see Appendix B of UFC 3-260-01). Use edge markers for daytime use or expedient airfield markings such as are used on a minimum operating strip (MOS) or a landing zone (LZ). Lighted visual aids are used for night operations or instrument flight rule (IFR) operations. Fasten or weight down all such devices to prevent them from becoming dislodged by jet blast or prop wash. Use frangible markers designed and constructed of materials that collapse if struck by an aircraft. They are colored to present a sharp contrast with the surrounding terrain.

3-1.5 Contrasting Markings to Increase Conspicuity.

If needed, use a non-reflectorized black border to outline markings on light-colored pavements (portland cement concrete [PCC] or oxidized asphaltic concrete [AC]). This makes the markings more prominent. The border is uniformly 6 inches (152 millimeters) wide (no variation in width beyond standard tolerances) and borders all edges of the marking

3-1.6 Obliteration of Extraneous Markings.

Use black paint, or a color blend of black and white to match pavement color, to temporarily hide extraneous markings rather than risk damaging the pavement during paint removal. **Note:** This method is only used temporarily because the underlying paint shows through when illuminated at night after the black paint begins to wear off the top of the previously applied glass beads. For effective guidance, remove the old paint completely by hydro-blast, grinding, or some other method, or pave over the old marking to eliminate potential confusion from obsolesced or extraneous surface markings. Take care when obliterating old markings so the resulting pattern no longer presents the appearance of a usable marking. This requires additional scarifying or overpainting for effective obfuscation of the pattern.

3-2 COLORS FOR PAVEMENT AND OBSTRUCTION MARKINGS.

3-2.1 Airfields and Roadways.

For airfield pavement applications, use the following color chip numbers from SAE-AMS-STD-595 when ordering or specifying paint. See the specific layout schemes in Chapters 5 through 8 for the specific color and retro-reflective requirements for the applicable marking.

3-2.1.1 White – 37925.

Generally, retro-reflective white is used for all runway, helipad, towway, and rotary wing runway or landing lane markings. However, there are some exceptions, such as for aircraft arresting system (AAS) warning markings, runway shoulder markings, hold short runway hold position markings, taxiway lead-in and lead-out lines, and hospital helipad markings.

3-2.1.2 Yellow – 33538.

Generally, retro-reflective yellow is used for all taxiway and apron markings, as well as displaced threshold areas used only as a taxiway and for the arrowheads and chevrons when the displacement is temporary. Exceptions: Restricted area markings and legends on some surface painted taxiway and apron signs are marked in other colors. Non-reflective yellow is used in overruns and for shoulder markings.

3-2.1.3 Red – 31136.

Red is normally used to mark restricted area boundaries and some of the legend on the restricted area signs required by AFI 31-101.

3-2.1.4 Black – 37038.

Black is used as a border to increase the conspicuity of markings on light-colored pavements. It is also mixed with white (to better match pavement surface color) and used to obliterate extraneous markings. **Note:** Covering obsolete or extraneous markings with paint is a temporary solution. The only means for permanent obliteration is to grind, scarify, burn, or hydro-blast the pavement surface or place a new surface material over the old markings.

3-2.1.5 Green – 34108.

Green is used to identify obstacle clearance boundaries at U.S. Army facilities.

3-2.2 Colors for Marking Obstructions.

For obstruction marking applications, use the following color chip numbers from SAE-AMS-STD-595 when ordering or specifying paint to mark obstructions.

- White – 17875
- Orange – 12197

3-3 RETRO-REFLECTIVE PAVEMENT MARKINGS.

3-3.1 Painted Pavement Markings.

Painted pavement markings are very difficult to see at night or during rain if they have no retro-reflective properties. Markings without beads also have a lower coefficient of friction. For these reasons, use of glass beads is encouraged for all surface painted markings. Do not place beads on black borders. Other less-expensive materials are available to improve the coefficient of friction on black painted pavement surfaces.

Note: Because thermoplastic materials are applied at a greater film thickness, these materials also have spherical beads premixed into the colored binder prior to application.

3-3.2 Post Applied Retro-Reflective Media.

Post-apply retro-reflective media (glass beads) specified under Federal Specification TT-B-1325D (or later revision) to make surface painted markings retro-reflective. Retro-reflective runway, taxiway, and apron markings are identified in the layout scheme descriptions in Chapters 5 through 8.

3-3.3 Material Selection.

Select the most appropriate material manufactured in accordance with the most current version of Federal Specification TT-B-1325D, as follows:

- Type I, Gradation A, Drop-On, Low Index of Refraction, for use on any airfield or roadway marking pattern applied with paint procured to comply with Federal Specification TT-P-1952E. Apply a minimum of 7 pounds per gallon (0.85 kilogram per liter) of paint. In accordance with the National Defense Authorization Act (NDAA) for Fiscal Year 2018, complete a life-cycle cost analysis of the beads which appropriately considers local site conditions, life-cycle cost maintenance, environmental impact, operational requirements, and the safety of flight before specifying or using beads with a refractive index of 1.6 or less, including Type I beads.
- Type II has been deleted and is no longer specified or used.
- Type III, Gradation A, Drop-On, High Index of Refraction, intended for applications where increased retro-reflectivity is needed. Apply a minimum of 10 pounds per gallon (1.2 kilograms per liter) of paint.

- Type IV Gradation A – Large coarse, direct-melt, low-index glass beads for drop-on applications are intended for highways and all airfield markings applied with paint procured to comply with Federal Specification TT-P-1952E, Type III. Apply a minimum of 8 pounds per gallon (1 kilogram per liter) of paint. A wet film paint thickness of 18 to 25 mils (0.457 to 0.635 millimeter) is specified when Type IV gradation A beads are used.
- Type IV Gradation B – Medium coarse, direct-melt, low-index glass beads for drop-on applications are intended for highways and all airfield markings applied with paint procured to comply with Federal Specification TT-P-1952E, Type III. Apply a minimum of 8 pounds per gallon (1 kilogram per liter) of paint. A wet film paint thickness of 15 to 18 mils (0.381 to 0.457 millimeter) wet film paint thickness is specified when Type IV gradation B beads are used.

3-3.4 Lifecycle Cost Analysis

In accordance with the NDAA of 2016, perform a lifecycle cost analysis at every individual location to determine what type of reflective media (glass bead) to use at the installation. This is reiterated in Unified Facilities Guide Specification (UFGS) 32 17 23. In accordance with the NDAA for fiscal year (FY) 2018, complete a lifecycle cost analysis of the beads which appropriately considers local site conditions, lifecycle cost maintenance, environmental impact, operational requirements, and the safety of flight before specifying or using beads with a refractive index of 1.6 or less, including Type I beads. TSPWG Manual 3-260-04.18-01, *Life-Cycle Cost Analysis of Retroreflective Glass Beads,* provides guidance on how to accomplish a lifecycle cost analysis (LCCA) comparing Type I to Type III retroreflective glass beads in accordance with NDAA FY 2018, Section 2872(b).

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CHAPTER 4 UNIQUE MARKING PRACTICES

4-1 PRACTICES FOR SPECIAL CIRCUMSTANCES.

Striated markings are substituted for any solid marking pattern that is 3 feet (0.9 meter) wide or wider to reduce the effects of frost heave or improve surface friction characteristics. Do not striate markings on runways intended to support operations in instrument categories II and III. Striated markings are created by painting multiple longitudinal stripes 6 inches (152 millimeters) wide with gaps from 4 to 6 inches (102 to 152 millimeters) wide.

4-2 OPEN GRADED WEARING SURFACES AND CLEANING EXISTING MARKINGS.

4-2.1 Painting Porous Pavements.

On porous friction surfaces or other open aggregate wearing surfaces, it is desirable, or in some cases necessary, to apply painted markings twice, approaching the area to be marked from opposite directions. Glass beads, necessary to add retro-reflective characteristics to the markings, are applied during each pass.

4-2.2 Cleaning Markings.

When contaminated by fuel, oil, dirt, or other impurities, clean pavement markings using high-pressure water or a combination of applying an environmentally friendly soap and sweeping with a truck- or tractor-mounted sweeper, followed by a clear-water rinse. Sweeping new markings immediately after the paint cures also improves retro-reflectivity by abrading the overspray deposited on adjacent surface-exposed beads during subsequent paint applications.

4-3 MAXIMUM PAINT THICKNESS.

Each time a surface is over-painted, the initial stress at the bond between the paint binder and the pavement increases. For this reason, remove painted markings before they build up more than about 40 mils (1 millimeter) total thickness. This occurs after about five marking cycles with Type I or Type II paints, and even more rapidly with the more heavily applied Type III (high-build) paints unless surface abrasion such as that caused by heavy accelerating, stopping, or turning traffic, or snow removal operations with plows and/or brooms, reduces the buildup by abrasion. Over-painting to excessive thickness also eventually causes the marking to prematurely crack and peel.

4-4 OBSTRUCTION MARKING.

Obstacles or obstructions defined by UFC 3-260-01, Federal Aviation Regulations (FAR) Part 77, or ICAO Annex 14, Volume I and Volume II, as applicable, are marked according to the following guidance:

- For installations in CONUS or its territories, use FAA AC 70/7460-1.

- For OCONUS installations, use the current edition of ICAO Annex 14, or the standard defined by the SOFA, Host Nation Funded Construction Agreement (HNFA), or Bilateral Infrastructure Agreement (BIA).

4-5 ROADWAY MARKING.

Markings and signs of roadways are configured in accordance with UFC 3-201-01, SDDCTEA Pamphlet 55-17, SDDCTEA Pamphlet 55-14, and the FHWA MUTCD.

CHAPTER 5 RUNWAY MARKINGS

5-1 GENERAL INFORMATION.

All markings of any color on light-colored pavement are optionally highlighted by marking a black, non-reflectorized 6-inch (152-millimeter) border (see paragraph 3-1.5).

5-2 RUNWAY MARKING SCHEMES.

5-2.1 Runway Marking Elements Based on Highest Intended Use.

There are three marking patterns for manned, fixed-wing runways; visual flight rules (VFR), non-precision instrument approach, and precision instrument approach. These are shown in Figure 5-1. Unmanned aircraft systems (UAS) are marked differently if constructed to support UAS-only operations. Determine the extent of runway markings based on the level of operations planned during day, night, and instrument meteorological conditions (IMC). Also consider available electronic navigation and visual approach lighting aids. Closed runways are marked to reflect their non-operational status. Engineers consult with the airfield managers to determine what markings are needed for each runway.

5-2.2 Additional Markings.

Installation/garrison commanders authorize additional standard markings. Non-standard markings are approved by the USAF Major Command Director of Operations (MAJCOM/A3) or U.S. Army Aeronautical Services Agency (USAASA), publicized in the DoD Flight Information Publication (FLIP). Interference with standard runway markings is not allowable. Non-standard markings are those not defined within any USAF or other DoD Service standard, Department of Transportation (FAA and FHWA), ICAO, Air Standardization Coordinating Committee (ASCC), or NATO standard appropriate for application at the given installation.

5-2.3 Unmanned Aircraft System (UAS) Runways.

For UAS-only runways, mark runway designation, centerline marking, and the letters “UAS” (without black borders), threshold bar, and runway edge stripes in retroreflective white, all centered on the runway width. These type runways are identified with the letters “UAS” on each end of the runway as shown in Figure 5-5.

5-2.3.1 Shadow (RQ-7A/B) -only runways are only marked with “UAS” without a designation number and centerline marking**.**

5-2.3.2 Global Hawk, Predator, and Reaper UAS-only runways are marked based on standard Class B airfield marking schemes and precedence (VFR, non-precision, or precision instrument; see Figure 5-1) and the standards provided herein.

5-2.4 Basic Visual Flight Rule (VFR) Runway.

For a VFR runway intended for use only during visual meteorological conditions (VMC), provide the following minimum markings (see Figures 5-1, 5-2, and 5-7):

- Centerline stripes
- Designation numbers (and letters, if appropriate)
- AAS warning markings (Runway only; do not mark these for emergency arresting systems located in overruns.)
- Runway/runway hold positions (if the runway intersects another runway and is used as a taxiway or is approved for simultaneous land and hold short operations [LAHSO] with the intersecting runway)
- Overrun chevrons
- Fixed distance (aiming point) marking (if the runway is 4,000 feet [1,200 meters] or longer and potentially used by jet aircraft)
- Add side stripes to all non-precision instrument runways and basic VFR runways where the shoulder pavement is the same as the full-strength runway pavement. On airfields where the width of the runway was reduced, creating a full-strength shoulder, the use of edge stripes is optional except that they must be used to mark the location of any non-full-strength pavement such as the shoulders of the previously wider runway.

5-2.5 Non-Precision Instrument Runways.

For an instrument, non-precision approach runway, also mark threshold bars and expand the centerline width to 3 feet (0.9 meter). See Figures 5-1 and 5-3 for examples.

Figure 5-1 Runway Marking Schemes

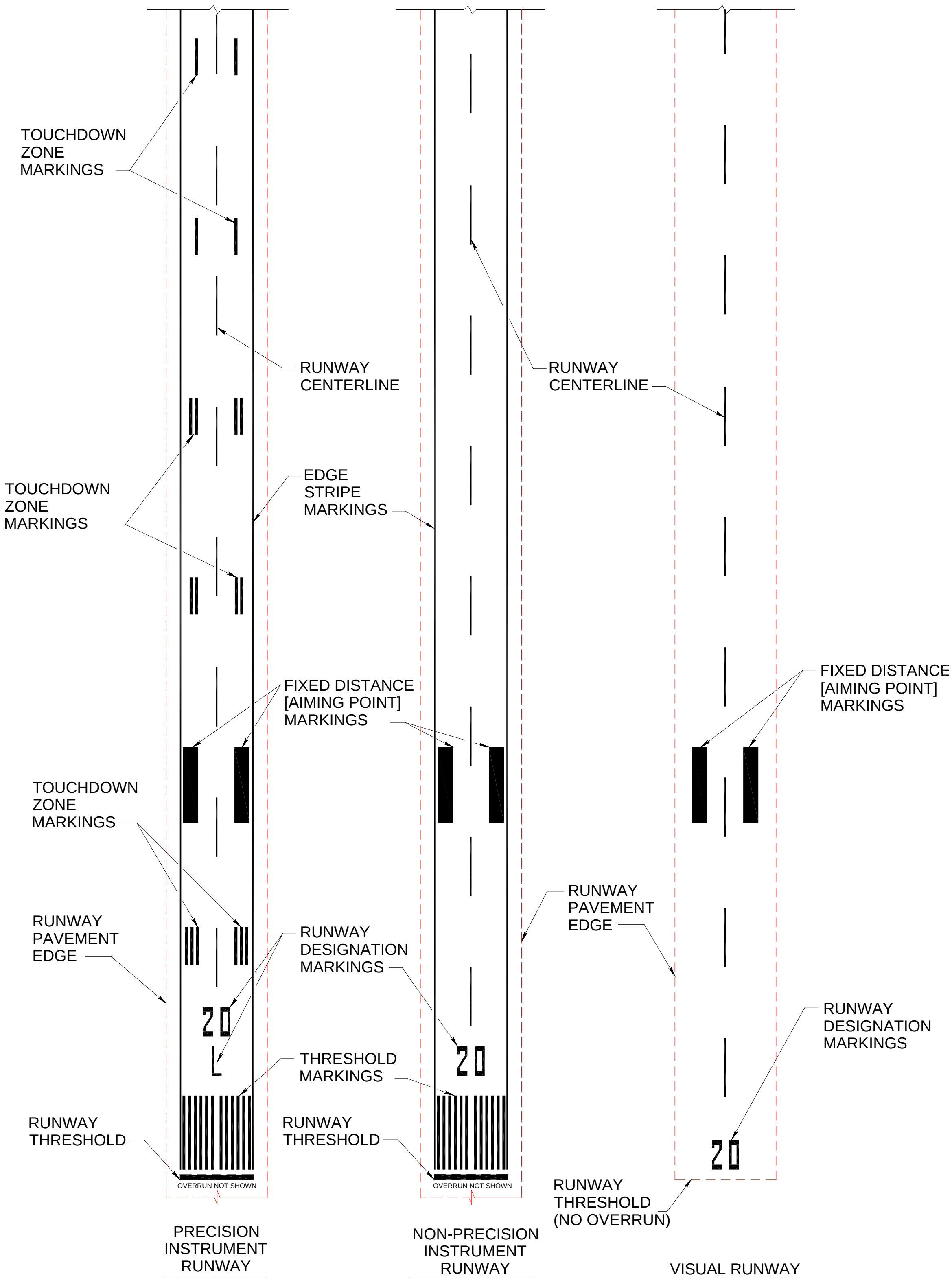


Figure 5-2. VFR Runway Markings

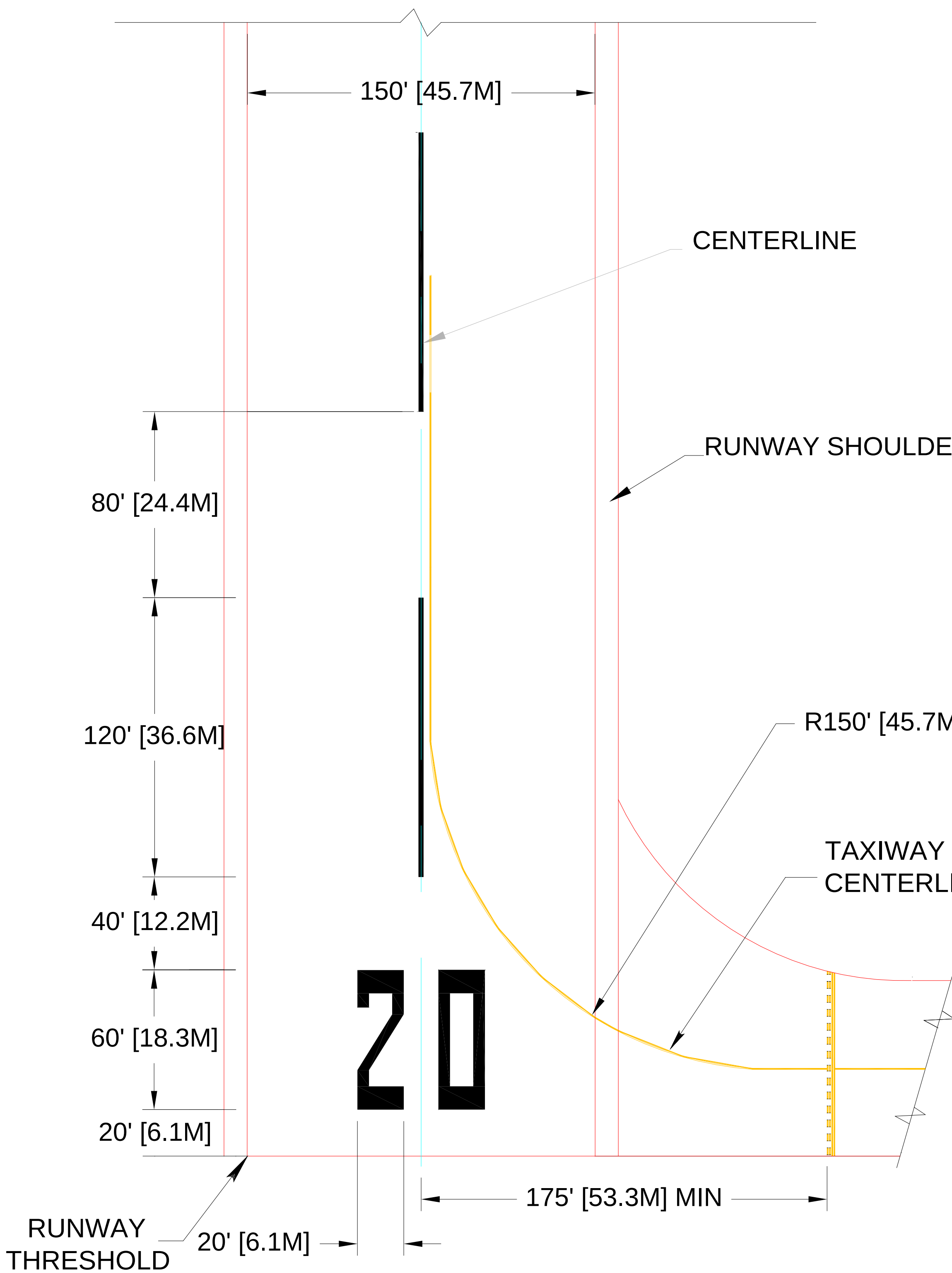
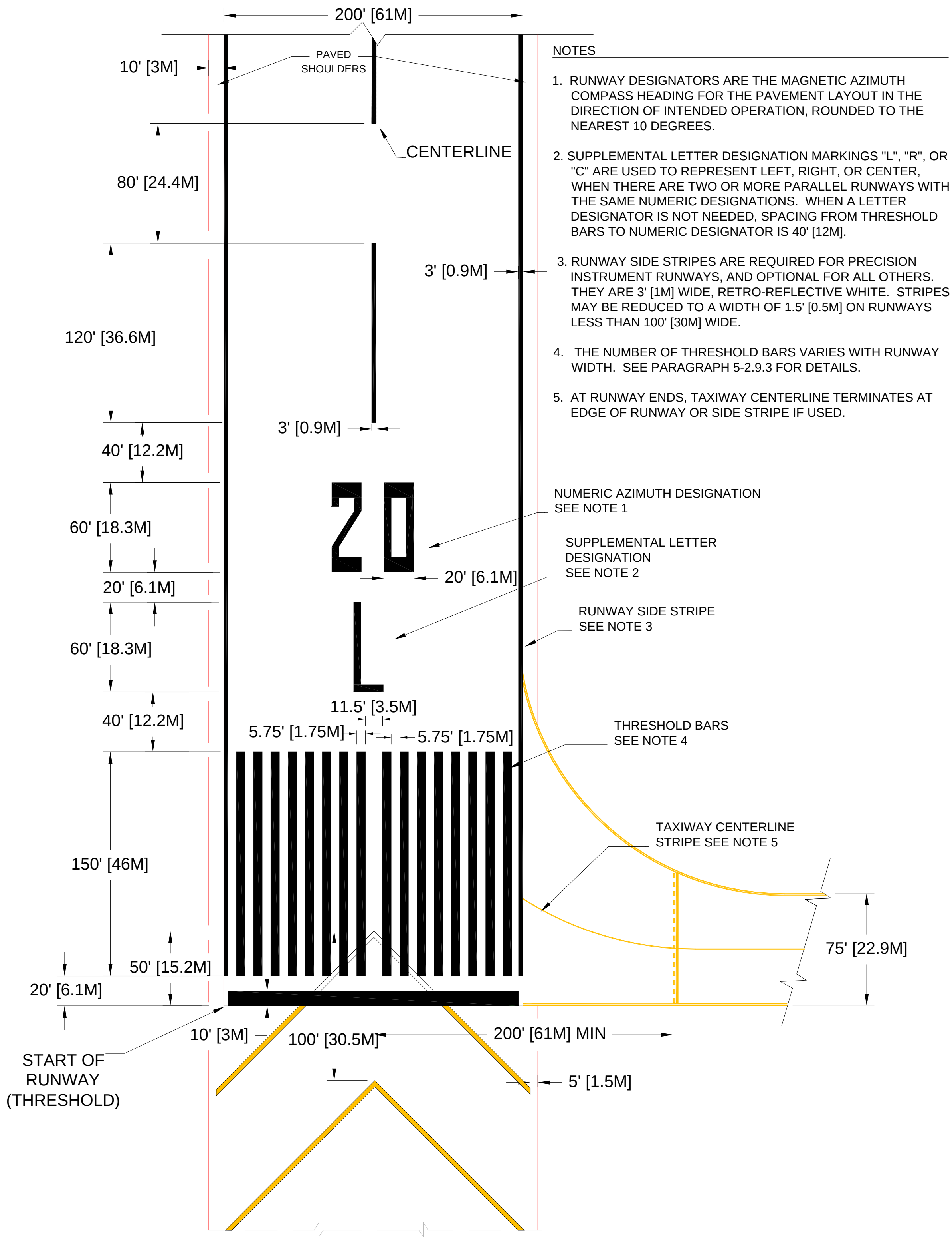


Figure 5-3. Non-Precision Instrument Runway Markings



NOTES

1. RUNWAY DESIGNATORS ARE THE MAGNETIC AZIMUTH COMPASS HEADING FOR THE PAVEMENT LAYOUT IN THE DIRECTION OF INTENDED OPERATION, ROUNDED TO THE NEAREST 10 DEGREES.
2. SUPPLEMENTAL LETTER DESIGNATION MARKINGS "L", "R", OR "C" ARE USED TO REPRESENT LEFT, RIGHT, OR CENTER, WHEN THERE ARE TWO OR MORE PARALLEL RUNWAYS WITH THE SAME NUMERIC DESIGNATIONS. WHEN A LETTER DESIGNATOR IS NOT NEEDED, SPACING FROM THRESHOLD BARS TO NUMERIC DESIGNATOR IS 40' [12M].
3. RUNWAY SIDE STRIPES ARE REQUIRED FOR PRECISION INSTRUMENT RUNWAYS, AND OPTIONAL FOR ALL OTHERS. THEY ARE 3' [1M] WIDE, RETRO-REFLECTIVE WHITE. STRIPES MAY BE REDUCED TO A WIDTH OF 1.5' [0.5M] ON RUNWAYS LESS THAN 100' [30M] WIDE.
4. THE NUMBER OF THRESHOLD BARS VARIES WITH RUNWAY WIDTH. SEE PARAGRAPH 5-2.9.3 FOR DETAILS.
5. AT RUNWAY ENDS, TAXIWAY CENTERLINE TERMINATES AT EDGE OF RUNWAY OR SIDE STRIPE IF USED.

5-2.6 Precision Instrument Runway.

For precision approach runways, in addition to the non-precision instrument approach and VFR runway marking elements, provide side stripes and touchdown zone (TDZ) markings (and instrument hold lines, if appropriate). Substitute fixed distance (aiming point) markings for the second pair of TDZ markings on each end of the runway (see Figures 5-1 and 5-4).

5-2.7 Runway Marking Precedence.

For runways that intersect or share a common end, interrupt or adjust markings on the runway with the lower priority. Give precedence in this order:

- Category III
- Category II
- Category I
- Non-precision instrument runway markings
- VFR runway markings

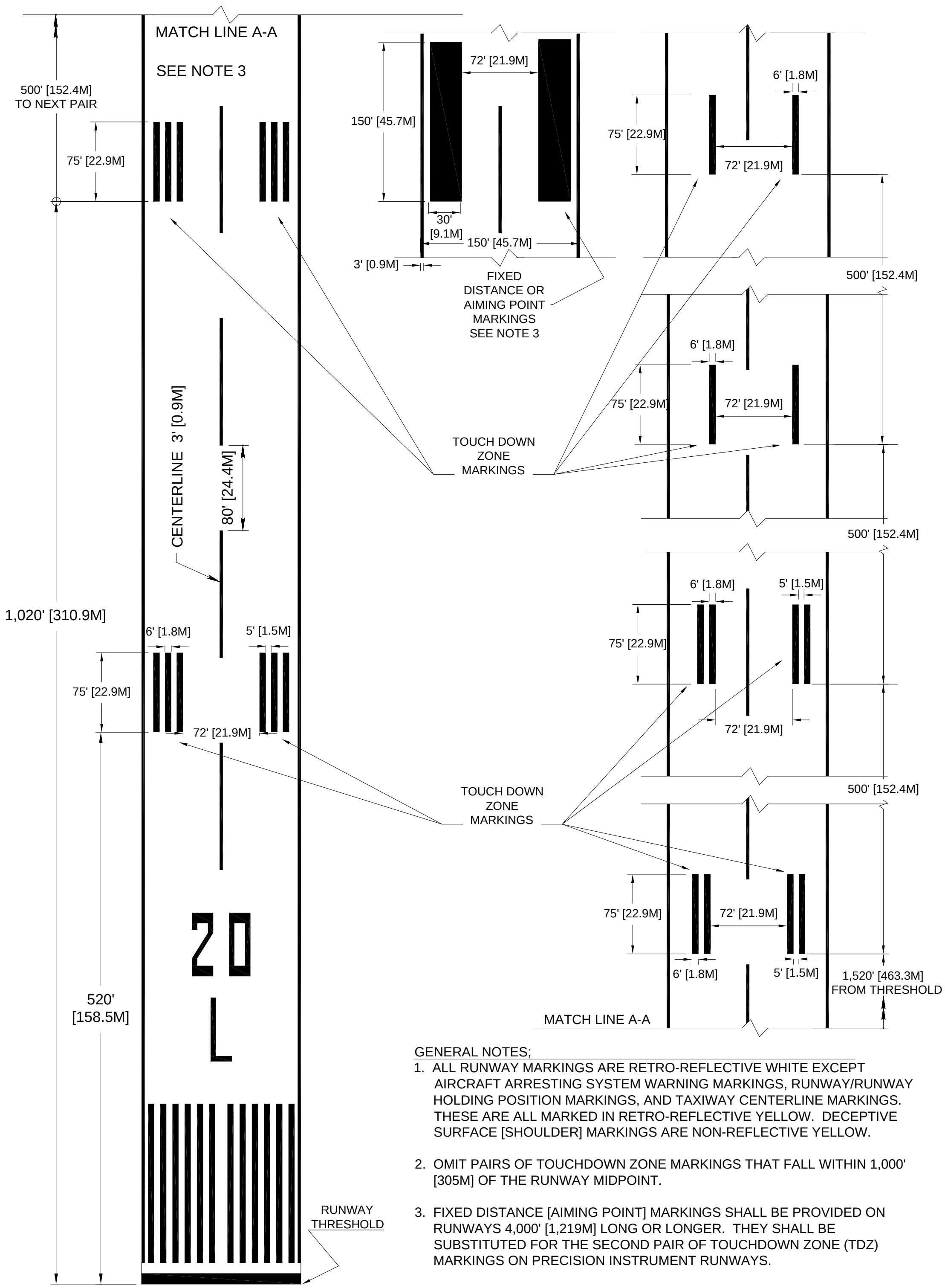
5-2.7.1 Where a need exists to mark a taxiway centerline across a runway, interrupt the marking 3 feet (0.9 meter) on either side of the runway marking.

5-2.7.2 Taxiway centerline is interrupted 5 feet (1.5 meters) either side of threshold markings or numbers.

5-2.8 Runway Centerline.

Runway centerlines are marked with a series of uniformly spaced retro-reflective white longitudinal stripes, 3 feet (0.9 meter) wide on instrument runways and at least 12 inches (305 millimeters) wide for VFR runways. Begin layout of centerline markings 40 feet (12.2 meters) from the runway designation (numeral[s]) and continue to the midpoint of the runway. Uniformly adjust the lengths of two stripes and three gaps or three stripes and two gaps (depending on which of the two falls at the center of the runway length) near the runway midpoint. See Figures 5-2 and 5-3.

Figure 5-4. Touchdown Zone and Fixed Distance (Aiming Point) Markings



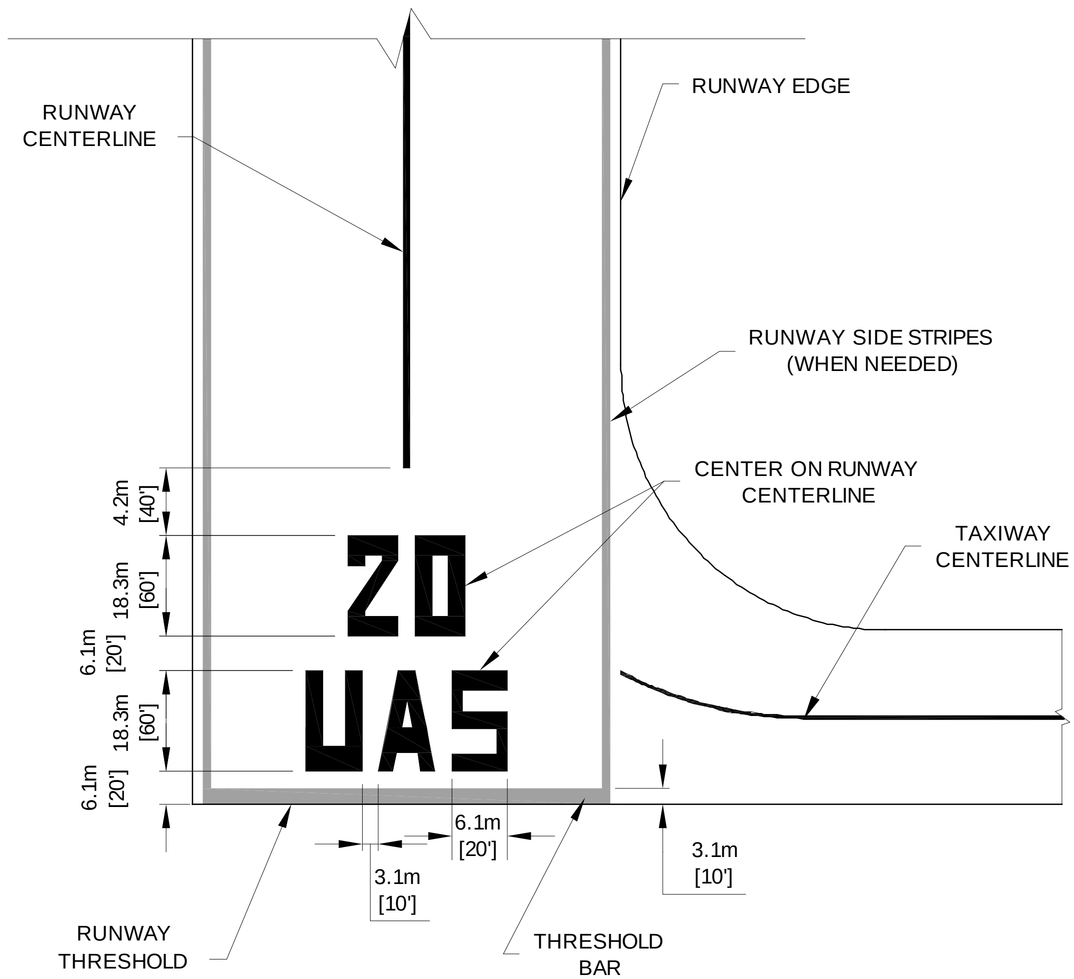
GENERAL NOTES;

1. ALL RUNWAY MARKINGS ARE RETRO-REFLECTIVE WHITE EXCEPT AIRCRAFT ARRESTING SYSTEM WARNING MARKINGS, RUNWAY/RUNWAY HOLDING POSITION MARKINGS, AND TAXIWAY CENTERLINE MARKINGS. THESE ARE ALL MARKED IN RETRO-REFLECTIVE YELLOW. DECEPTIVE SURFACE [SHOULDER] MARKINGS ARE NON-REFLECTIVE YELLOW.

2. OMIT PAIRS OF TOUCHDOWN ZONE MARKINGS THAT FALL WITHIN 1,000' [305M] OF THE RUNWAY MIDPOINT.

3. FIXED DISTANCE [AIMING POINT] MARKINGS SHALL BE PROVIDED ON RUNWAYS 4,000' [1,219M] LONG OR LONGER. THEY SHALL BE SUBSTITUTED FOR THE SECOND PAIR OF TOUCHDOWN ZONE (TDZ) MARKINGS ON PRECISION INSTRUMENT RUNWAYS.

Figure 5-5. UAS Runway Markings



NOTES:

1. SEE FIGURE 5-6 FOR DESIGNATION NUMBER AND LETTER MARKING DIMENSIONS.
2. WHEN THESE MARKINGS ARE BEING USED ON RUNWAYS FOR RQ-7A/B ONLY (50' WIDE), THEN ALL DIMENSIONS SHOWN ON THIS DETAIL SHALL BE REDUCED BY ONE HALF. RUNWAYS FOR THESE AIRCRAFT WILL NOT HAVE THE CENTERLINE OR NUMERICAL DIRECTION MARKINGS EITHER.

5-2.9 Threshold Marking.

The runway threshold is the beginning of the full-strength pavement. The 10-foot (3 meter) wide threshold bar is marked at the threshold, and the designation number(s) or longitudinal threshold bars begin 20 feet (6.1 meters) inward from the threshold.

5-2.9.1 Visual Flight Rule (VFR) Runways.

Figures 5-1 and 5-2 provide the layout details for a VFR runway. Figure 5-6 provides layout dimensions and spacing details for designators.

5-2.9.2 Instrument Runways.

Precision and non-precision instrument runway thresholds are marked with a group of retro-reflective white longitudinal stripes, and a transverse threshold bar when there is any type of pavement preceding the runway pavement. The longitudinal threshold bars are spaced symmetrically about the runway centerline on 11.5-foot (3.5-meter) centers, configured of 5.75-foot (1.75-meter) -wide stripes and gaps, except at the center of the runway, where the gap dimension is doubled to 11.5 feet (3.5 meters*).* The transverse runway threshold bar is 10 feet (3 meters) in width and extends between the runway edges (as published in the DoD FLIP or between the runway side stripes, whichever is less). Figure 5-3 provides layout details for the threshold bars and longitudinal spacing for the runway designators, and Figure 5-6 provides layout dimensions and horizontal spacing details for designators.

5-2.9.3 Variances in Longitudinal Threshold Patterns.

The number of longitudinal stripes in a threshold pattern varies for different-width runways. Threshold bar length and widths are the same in all cases. The appropriate numbers of longitudinal stripes to be used are as follows:

- Four for 60-foot (18.3-meter) -wide runways;
- Six for 75-foot (22.9-meter) -wide runways;
- Eight for 100-foot (30.5-meter) -wide runways;
- Ten for 125-foot (38.1-meter) -wide runways;
- 12 for 150-foot (45.7-meter) -wide runways, and;
- 16 for 200-foot (61-meter) -wide or wider runways

5-2.9.4 Non-standard Width Runways.

For non-standard runway widths, the same stripe-gap pattern is continued from the runway centerline until the outermost longitudinal stripe is no closer than 4 feet (1.2 meters) from the runway edge or side stripes. Do not mark more than 16 threshold bars, even for runways wider than 200 feet (61 meters).

5-2.10 Runway Designations.

Designators for runways are retro-reflective white numeric characters that indicate the magnetic azimuth of the runway centerline to the nearest 10-degree increment. The designation consists of one or two numbers, or in the case of parallel runways, the numeric designator and a retro-reflective white letter (“L” for left, “C” for center, or “R” for right) to indicate the lateral position of the runway with respect to any others with the same numeric designator on the same airfield. See Figure 5.3 for placement on the runway pavement and Figure 5-6 for letter and numeral dimensions.

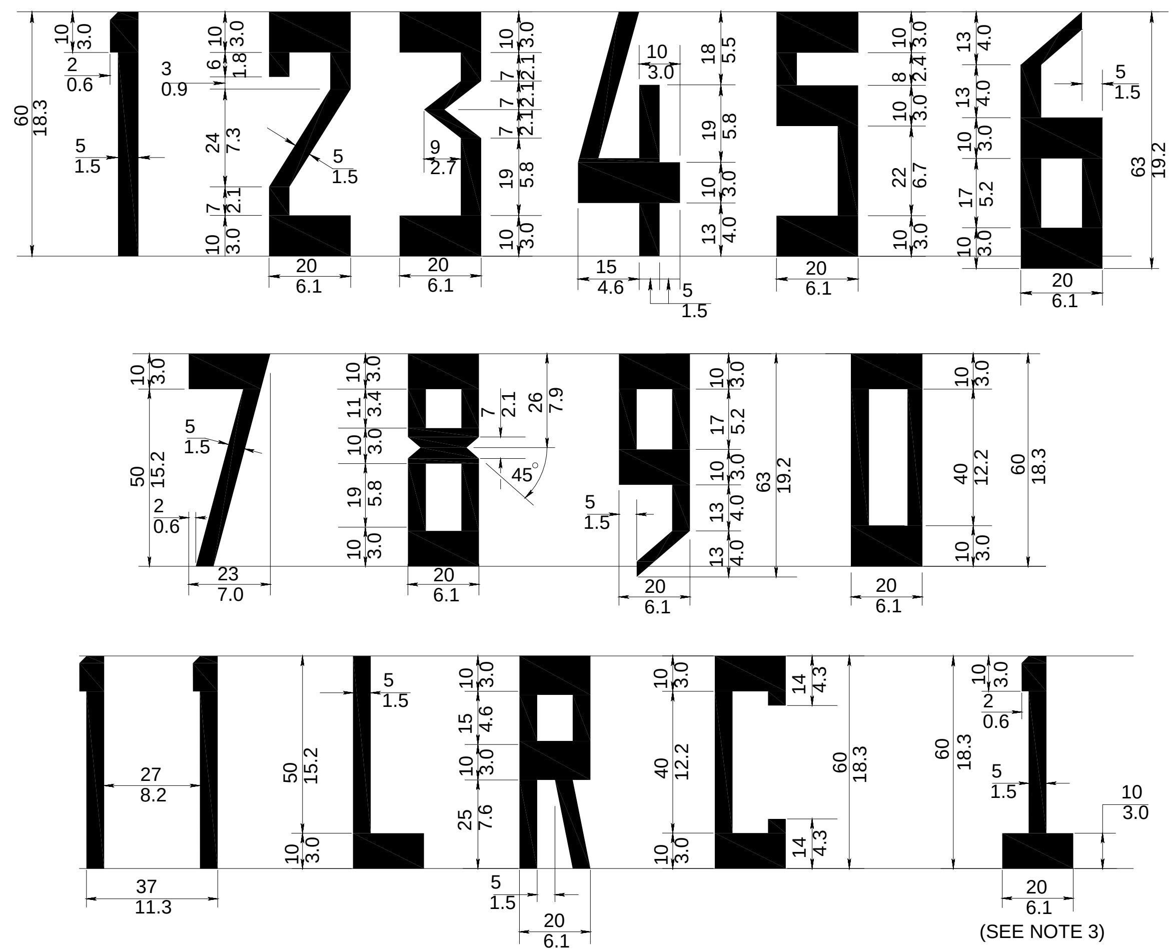
5-2.11 Dimensions for Designation Numbers and Letters.

Numbers are formed with 5-foot (1.5-meter) -wide vertical stripes and 10-foot (3-meter) -wide horizontal stripes. A zero (0) is marked to precede single-digit numbers on Class B runways except those subject to NAVAIR 51-50AAA-2. Lateral spacing between the numbers is 15 feet (4.6 meters), except for the number "11." Spacing between these numerals is 27 feet (8.2 meters). The dimensional layout is shown in Figure 5-6.

5-2.12 Runway Overruns.

Non-reflective yellow chevron markings are used on overruns to indicate the area is not a normal operational surface. For layout, the apex of the chevron is laid out (but not painted) 50 feet (15.2 meters) inward of the runway threshold. Only the portions of the chevron legs that are outward from the runway threshold are painted. Subsequent chevrons are placed at 100-foot (30.5-meter) intervals along the overrun, measured from chevron apex to chevron apex. The legs of the chevrons intersect the centerline at a 45-degree angle. The chevron legs extend laterally to within 5 feet (1.5 meters) of the paved surface edge or to align with the lateral limits of the runway shoulder markings (deceptive surface markings), if used. A typical layout plan and dimensions for these markings are shown in Figure 5-7.

Figure 5-6 Runway Designators



NOTES:

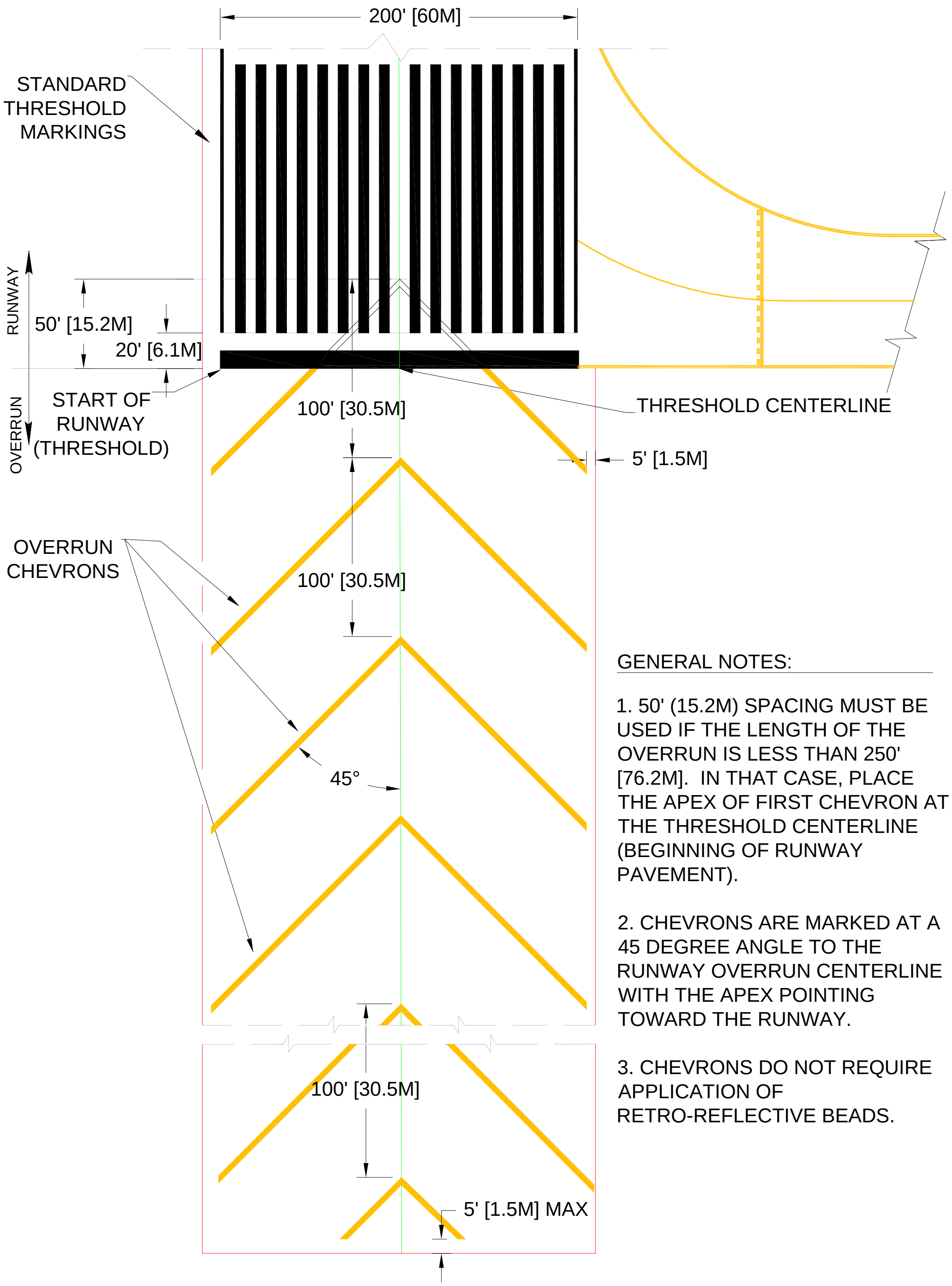
1. ALL LETTERS AND NUMERALS EXCEPT THE NUMBER ELEVEN ARE HORIZONTALLY SPACED 15' [4.6 M] BETWEEN THE NEAR EDGES. THE NUMERALS USED TO FORM "11" ARE SPACED AT 27' [8.2M] BETWEEN INNER EDGES AS SHOWN ABOVE.

2. DIMENSIONS ARE EXPRESSED AS; $\frac{\text{FEET}}{\text{METERS}}$ (E.G. $\frac{60}{18.3}$).

3. WHEN USED ALONE, THE NUMERAL 1 IS PLACED ABOVE A HORIZONTAL BAR TO DIFFERENTIATE IT FROM THE RUNWAY CENTERLINE MARKING.

4. IMPERIAL UNITS OF MEASURE ARE USED AS THE PRIMARY DIMENSIONS IN THIS FIGURE. FOR DESIGNS WHICH USE ROUNDED METRICS FOR DIMENSIONS, CARE MUST BE TAKEN TO ENSURE THE NUMBERS AND LETTERS RETAIN THE INTENDED SHAPE AND PROPORTIONS.

Figure 5-7. Overrun Markings



GENERAL NOTES:

1. 50' (15.2M) SPACING MUST BE USED IF THE LENGTH OF THE OVERRUN IS LESS THAN 250' [76.2M]. IN THAT CASE, PLACE THE APEX OF FIRST CHEVRON AT THE THRESHOLD CENTERLINE (BEGINNING OF RUNWAY PAVEMENT).

2. CHEVRONS ARE MARKED AT A 45 DEGREE ANGLE TO THE RUNWAY OVERRUN CENTERLINE WITH THE APEX POINTING TOWARD THE RUNWAY.

3. CHEVRONS DO NOT REQUIRE APPLICATION OF RETRO-REFLECTIVE BEADS.

5-2.13 Runway Side Stripes.

Retro-reflective white side stripes are marked on precision instrument runways. They are also used optionally on non-precision instrument and VFR runways. Side stripes are not intended to identify the edge of the full-strength pavement on DoD runways; they are intended to enhance the pilot's ability to recognize the runway environment at decision height on landing. If there is a lack of contrast between the full-strength runway pavement and the shoulder pavement, use non-reflective yellow shoulder markings (deceptive surface) on the shoulder pavement. See Figures 5-3 and 5-4.

Note: If there is a significant gap between the inner end of the shoulder markings (deceptive surface) and the runway side stripes (such as occurs when side stripes are spaced at 144-foot [44-meter] separation on a 300-foot [91-meter] -wide runway), also mark double 6-inch (152-millimeter) -wide retro-reflective yellow stripes, separated by a 6-inch (152-millimeter) -wide gap, to enhance delineating the limits of the useable (or full-strength) pavement. Details for these markings are the same as for taxiway or apron edge markings. Place the outer edge of the outermost stripe to coincide with the outermost edge of the useable (or full-strength) pavement and the inner end of the deceptive surface marking. These stripes are curved to follow the outer edge of fillets and terminate at the intersecting taxiway edge or joined to taxiway edge markings, if used.

5-2.13.1 Locating and Layout of Stripes.

The runway side stripe markings consist of one continuous stripe placed on each side of the runway. The side stripes are placed symmetrically about the runway centerline as shown in Figures 5-1 and 5-3. They have a minimum width of 3 feet (0.9 meter) for runways 100 feet (30.5 meters) or more in width and are at least 1.5 feet (0.5 meter) wide for runways less than 100 feet (30.5 meters) wide. The stripes begin 20 feet (6.1 meters) inward from the runway threshold and continue to within 20 feet (6.1 meters) of the runway threshold on the opposite end of the runway. There are exceptions when the threshold is displaced. See paragraph 5-2.14 and Figures 5-4, 5-8, 5-9, and 5-10 for examples.

5-2.13.2 Stripe Separation.

If special missions indicate a need for wider separation on runways 200 or 300 feet (61 meters or 91.4 meters) wide, the side stripes are placed as stated above, except the separation between the inner edges of the stripes is 194 feet (59.1 meters). Separation of side stripes greater than 194 feet (59.1 meters) is not authorized without a non-standard marking waiver.

5-2.14 Displaced Threshold Marking Schemes.

5-2.14.1 Layouts According to Intended Use of the Pavement.

There are four different schemes used to mark the pavement in the displaced area. Select a scheme from those shown in Figures 5-8 through 5-11 that indicates the appropriate and authorized use of the area. Note that for temporarily displaced thresholds, existing markings need not be obliterated. However, Notice to Airmen (NOTAM), Flight Crew Information File (FCIF) memorandum, and any other available methods are used to convey the temporary changes and potential hazards that exist during the construction or maintenance period. See UFC 3-260-01, Appendix B, Section 1, for construction waiver requirements, and Appendix B, Section 14, for a construction phasing plan and safety checklist to be used for such projects.

5-2.14.1.1 Permanently Displaced Threshold Where Displacement Area is Used for Take-Off and/or Landing Ground Roll-Out.

Relocate the longitudinal threshold bars beginning 20 feet (6.1 meters) from the new threshold and place a retro-reflective white transverse stripe to precede them, with the outboard edges on the full-strength runway pavement, or to abut the runway side stripes. Reduce the width and length of the centerline stripes in the displaced threshold area and modify them with retro-reflective white arrowheads leading to the new threshold. Mark retro-reflective white chevrons to point toward the transverse threshold bar at evenly spaced increments across the pavement. Dimensions and layout details are shown in Figure 5-8.

5-2.14.1.2 Permanently Displaced Threshold Where Displacement Area is Used as a Taxiway (Referred to as Relocated Threshold in the Airman's Information Manual [AIM]).

Relocate the longitudinal threshold bars beginning 20 feet (6.1 meters) from the new threshold and place a retro-reflective white transverse threshold bar to precede them, with the outboard edge at the beginning of the runway pavement available for landing. Mark retro-reflective yellow chevrons to point toward the transverse threshold bar at evenly spaced increments across the pavement. Dimensions and layout details are shown in Figure 5-9.

5-2.14.1.3 Permanently Displaced Threshold Where Displacement Area Used as Taxiway and Take-Off and/or Landing Ground Roll.

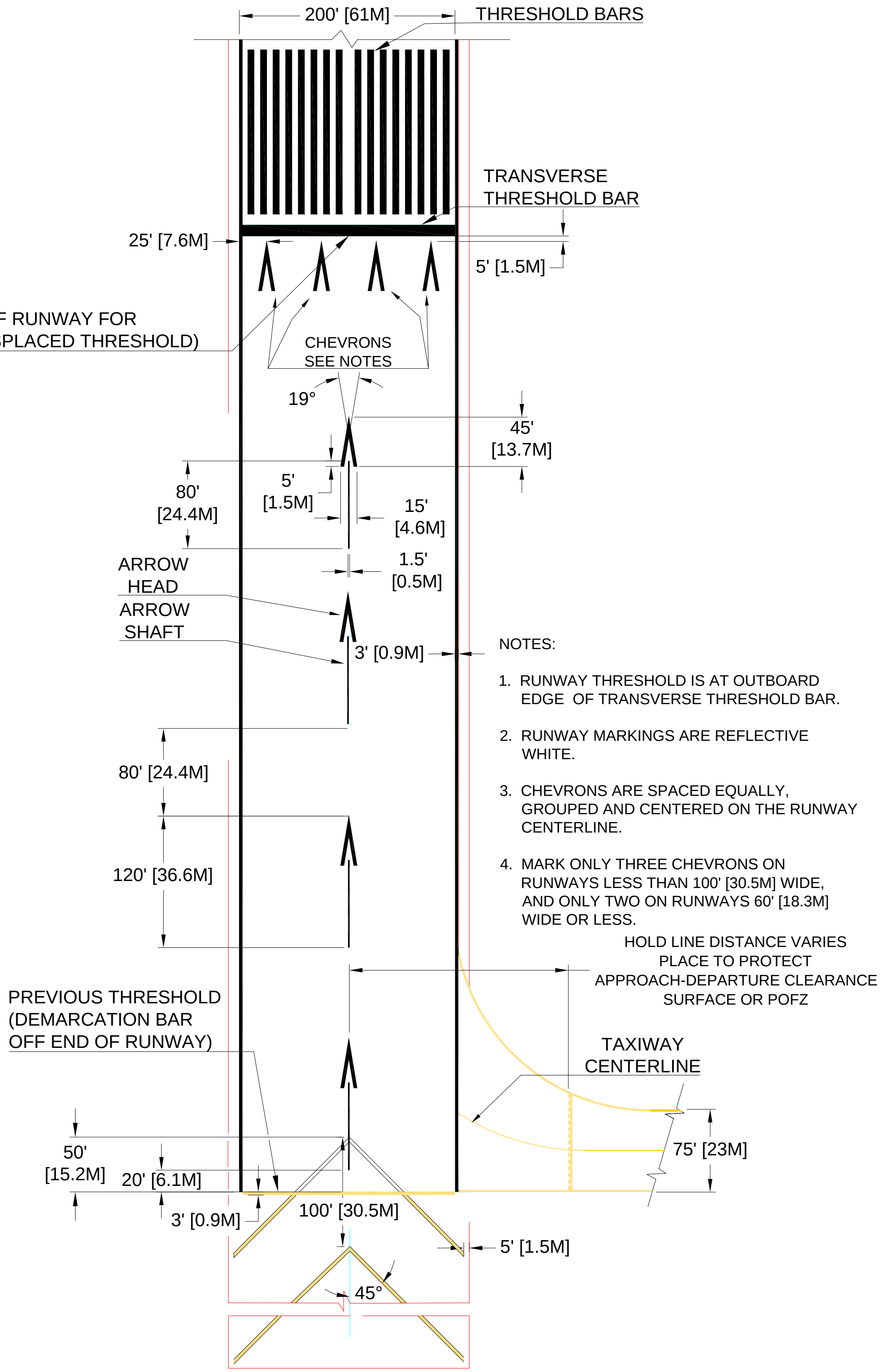
Relocate the longitudinal threshold bars beginning 20 feet (6.1 meters) from the new threshold and place a retro-reflective white transverse threshold bar to precede them, with the outboard edge at the beginning of the runway pavement. Mark retro-reflective white chevrons to point toward the transverse threshold bar at evenly spaced increments across the pavement. Modify runway centerline stripes in the displacement area used for takeoff with retro-reflective white arrowheads. Mark a retroreflective yellow demarcation bar across the full width of the pavement at the end of the aligned taxiway, delineating the point where the takeoff roll begins. Dimensions and layout details are shown in Figure 5-10.

5-2.14.1.4 Temporarily Displaced Thresholds.

For temporarily displaced thresholds, place a retroreflective white transverse stripe that extends from side stripe to side stripe (or edge to edge of pavement if side stripes are not used) at the new threshold. Modify the centerlines within the displacement with arrowheads and mark chevrons across the runway width pointing to the transverse bar.

Use retroreflective white for arrowheads and chevrons if the area is used for takeoff or roll-out, or retroreflective yellow if the area is planned only for taxiing operations. It is not necessary to reposition the standard threshold markings, modify the width and length of centerline stripes, or obliterate other existing markings within the displaced area; however, NOTAM, FCIF memorandum, and any other available methods are used to convey the temporary changes and potential hazards to pilots. Dimensions and layout details are shown in Figure 5-11.

Figure 5-8 Permanently Displaced Threshold Where Preceding Pavement is Used as Runway (Take-Off or Landing)



NOTES:

1. RUNWAY THRESHOLD IS AT OUTBOARD EDGE OF TRANSVERSE THRESHOLD BAR.
2. RUNWAY MARKINGS ARE REFLECTIVE WHITE.
3. CHEVRONS ARE SPACED EQUALLY, GROUPED AND CENTERED ON THE RUNWAY CENTERLINE.
4. MARK ONLY THREE CHEVRONS ON RUNWAYS LESS THAN 100' [30.5M] WIDE, AND ONLY TWO ON RUNWAYS 60' [18.3M] WIDE OR LESS.

Figure 5-9. Permanently Displaced Threshold Where Preceding Pavement is Used as a Taxiway

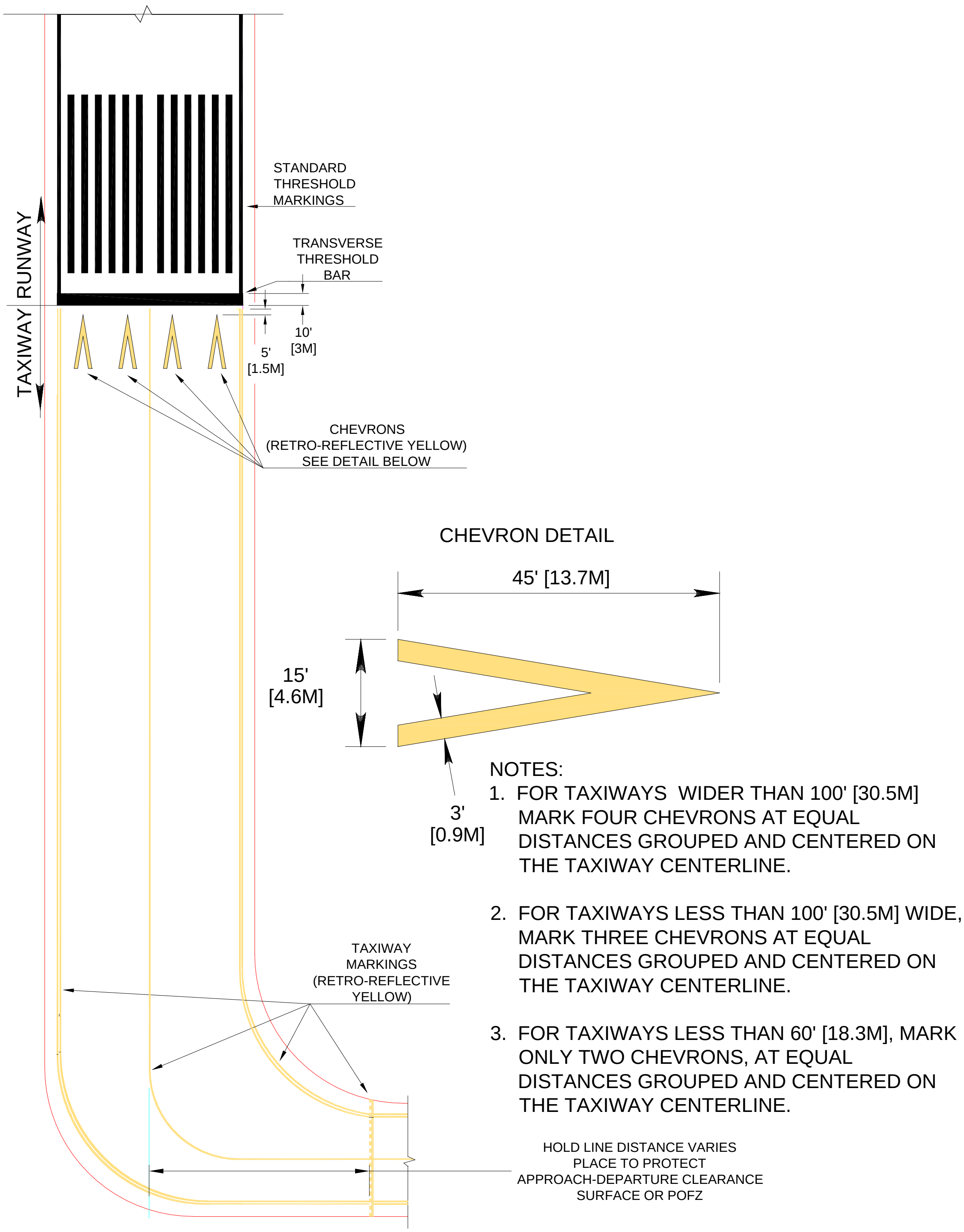


Figure 5-10. Permanently Displaced Threshold Where Displacement Area is Used as a Taxiway and for Take-Off and/or Landing Ground Roll

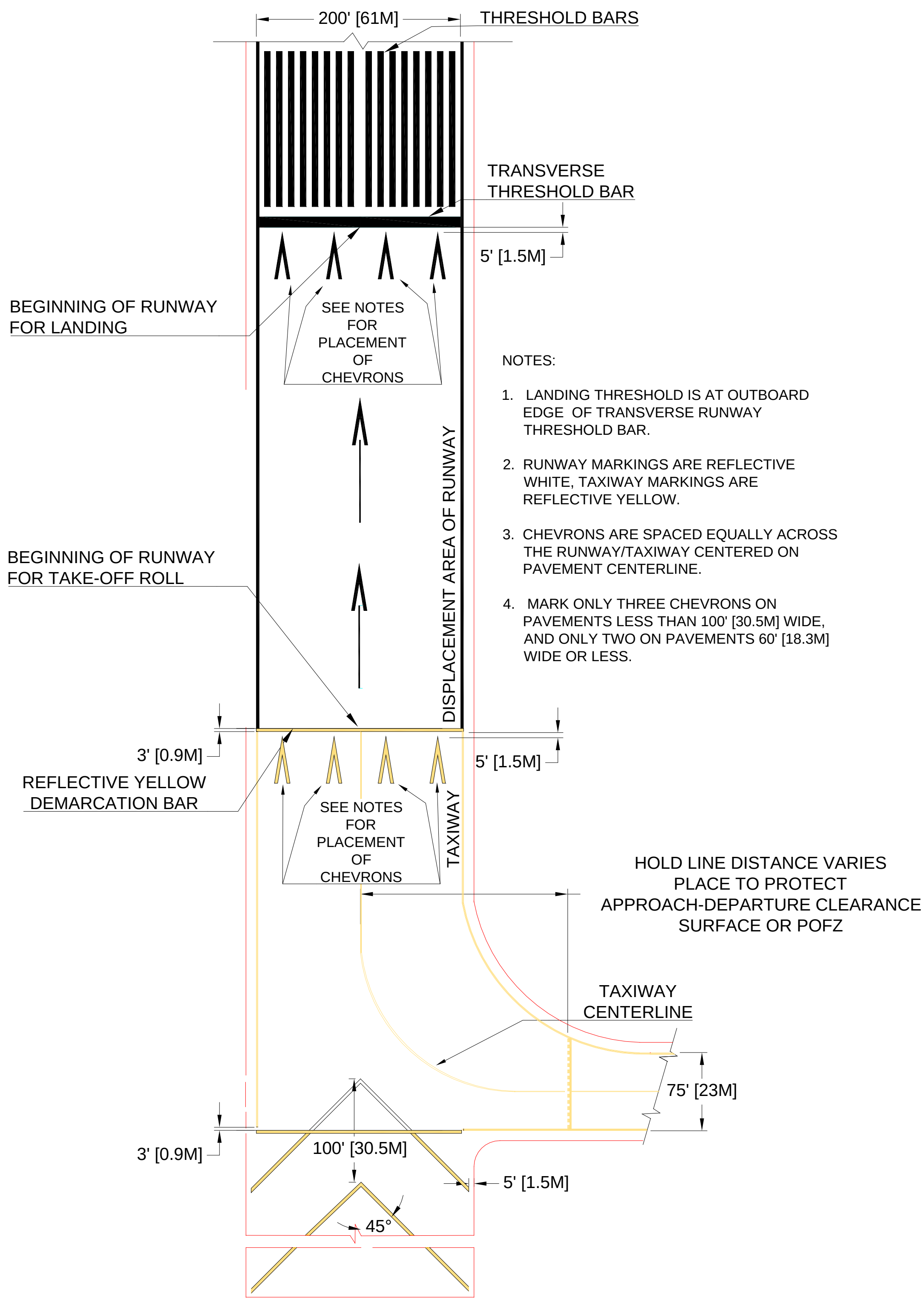
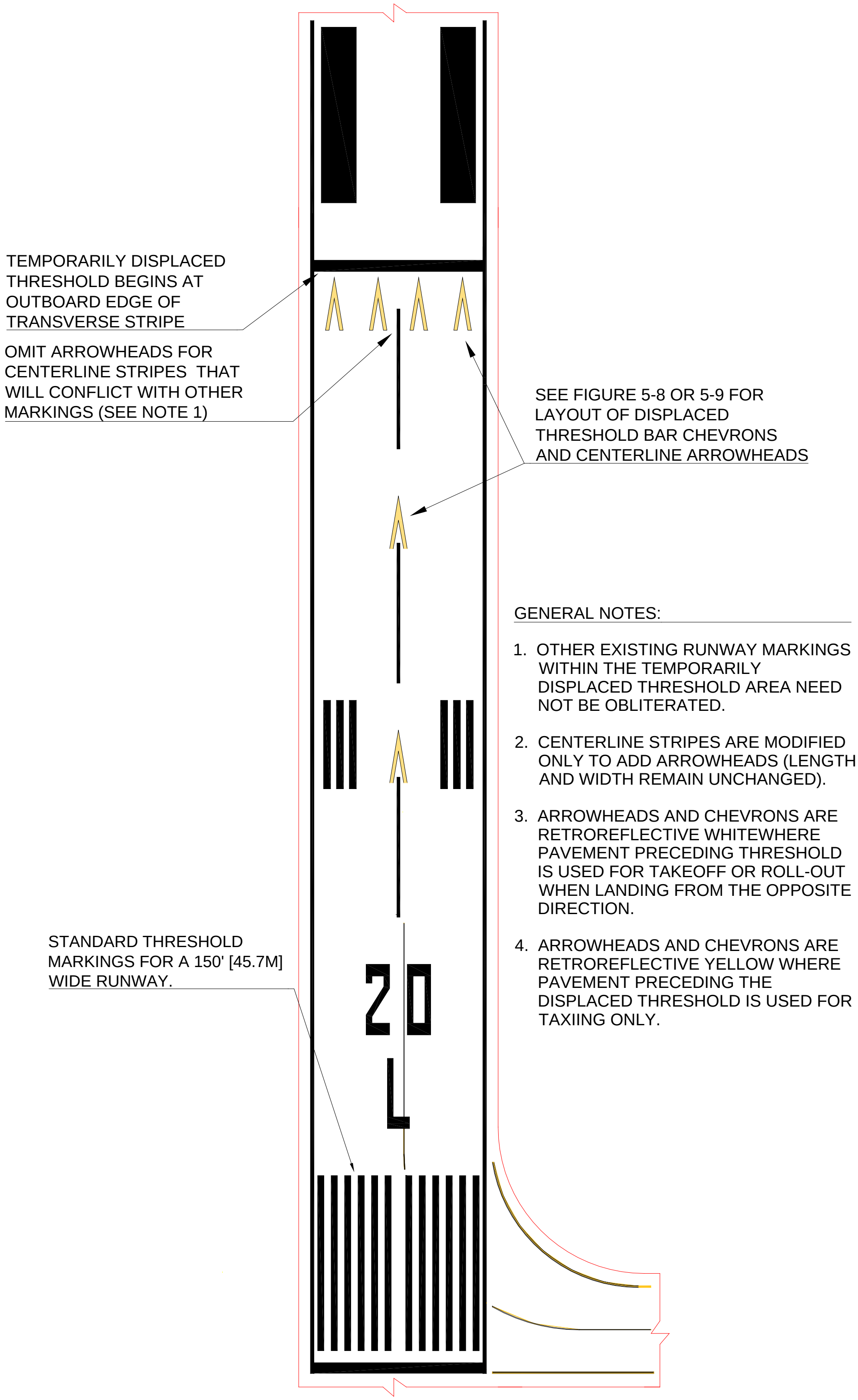


Figure 5-11. Temporarily Displaced Threshold



GENERAL NOTES:

1. OTHER EXISTING RUNWAY MARKINGS WITHIN THE TEMPORARILY DISPLACED THRESHOLD AREA NEED NOT BE OBLITERATED.
2. CENTERLINE STRIPES ARE MODIFIED ONLY TO ADD ARROWHEADS (LENGTH AND WIDTH REMAIN UNCHANGED).
3. ARROWHEADS AND CHEVRONS ARE RETROREFLECTIVE WHITEWHERE PAVEMENT PRECEDING THRESHOLD IS USED FOR TAKEOFF OR ROLL-OUT WHEN LANDING FROM THE OPPOSITE DIRECTION.
4. ARROWHEADS AND CHEVRONS ARE RETROREFLECTIVE YELLOW WHERE PAVEMENT PRECEDING THE DISPLACED THRESHOLD IS USED FOR TAXIING ONLY.

5-2.15 Touchdown Zone and Fixed Distance Markings.

5-2.15.1 Touchdown Zone (TDZ) Markings.

TDZ markings consist of pairs of longitudinal stripes placed symmetrically about the centerline. A group of three stripes are provided in the first two pairs of TDZ markings, two stripes in the next two groups of pairs, and single stripes in the last two pairs. Omit any pair of markings that fall within 1,000 feet (304.8 meters) of the runway midpoint. The lateral distance between each pair of longitudinal stripes measured at their inner edges is a constant 72 feet (21.9 meters). The layout and dimensions are shown in Figure 5-4.

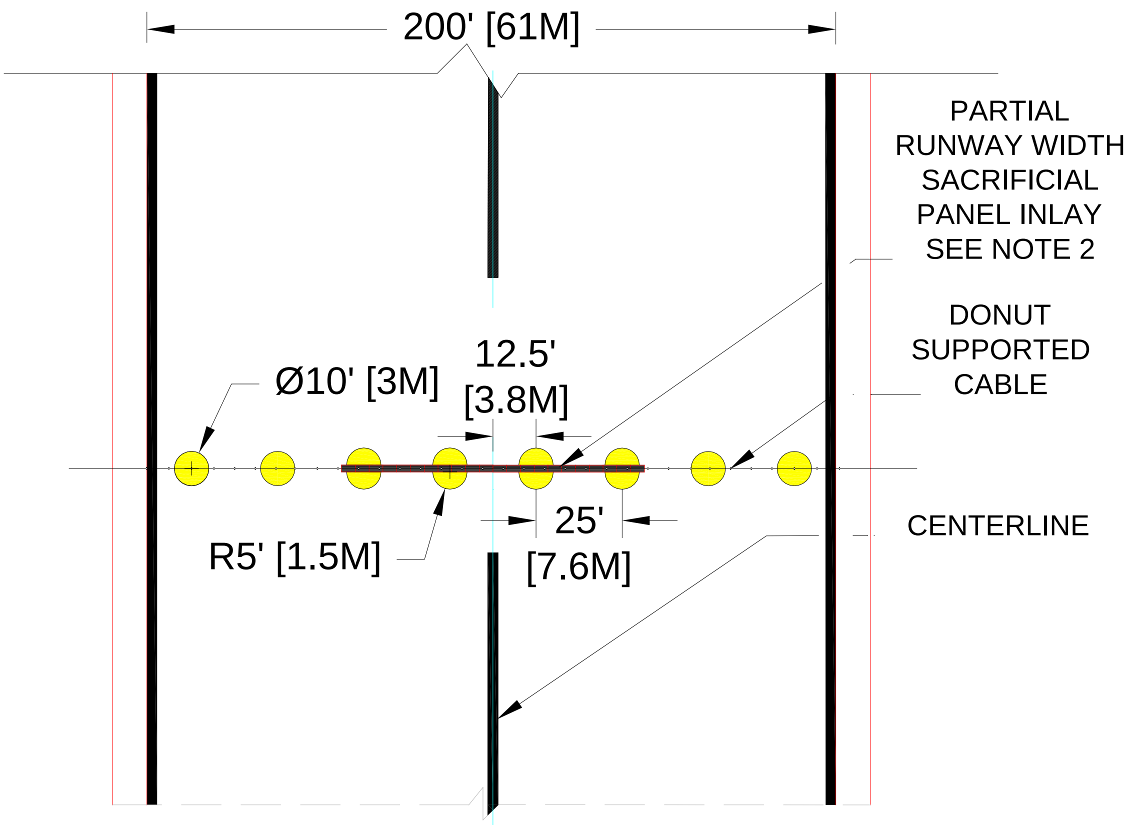
5-2.15.2 Fixed Distance (Aiming Point) Markings.

Provide aiming point markings on runways that are 150 feet (45.7 meters) or more wide and at least 4,000 feet (1,219.2 meters) long. Substitute them in place of the second pair of touchdown zone markings. The layout plan and dimensions are shown in Figure 5-4.

5-2.15.3 Aircraft Arresting System (AAS) Warning Markings.

Mark AAS locations on the runway with a series of discs placed beneath and centered on the pendant. Where TDZ and disc markings coincide, the TDZ marking is interrupted at that location for a minimum distance of 1 foot (0.3 meter) from the edge of the disc marking. If the designation and disc markings coincide, shift the designation marking longitudinally to eliminate the conflict. The layout plan and dimensions for these markings are shown in Figure 5-12. Do not use these markings in overruns.

Figure 5-12. Aircraft Arresting System (AAS) Warning Markings



NOTES

1. SIX WARNING MARKINGS ARE USED FOR 150' [46.7M] WIDE RUNWAYS, EIGHT ARE USED ON RUNWAYS 200' [61M] WIDE OR WIDER.

2. WHEN POLYETHYLENE PANELS ARE INSTALLED BENEATH PENDANTS, MARK 5' [1.5M] RADIUS SEMI-CIRCLES ON EITHER SIDE OF POLYETHYLENE PANEL INLAYS. PLACE THEM AT THE SAME SPACING ACROSS THE RUNWAY AS WHEN NO PANELS ARE USED.

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CHAPTER 6 TAXIWAY AND APRON MARKINGS

6-1 GENERAL INFORMATION.

Unless otherwise indicated, most taxiway, apron, and taxilane markings for both fixed and rotary-wing facilities are marked in retro-reflective yellow. All markings of any color on light-colored pavement are optionally highlighted by marking a black, non-reflectorized 6-inch (152-millimeter) border (see paragraph 3-1.5).

6-2 TAXIWAY AND TAXILANE CENTERLINE STRIPE.

Mark the centerline of all taxiways, guidelines on runways, and taxilanes on aprons as well as parking positions and pads, with a single continuous 6-inch (152-millimeter) -wide retro-reflective yellow stripe. The width is optionally increased to 12 inches (305 millimeters) when necessary; however, make the line width uniform (either one width or the other) wherever used over the entire airfield. Exceptions to this provision apply for parking positions and inside hangars.

6-2.1 Directional Changes.

All directional changes are accomplished with smooth, single radius curves. Position nose wheel guidelines to maintain a clearance of at least 10 feet (3 meters) between the aircraft's outermost main gear and the edge of the full-strength pavement when the cockpit is maintained over the nose wheel guideline through the turn. Also ensure adequate wingtip clearance is provided for the most demanding aircraft that uses the taxi route. On runways, the curve is tangent to a line parallel with and 3 feet (0.9 meter) from the near side of the runway centerline marking. The straight segment extends 200 feet (61 meters) beyond the point of tangency. See Figure 6-1 for these and other typical layout schemes.

6-2.2 Taxiway and Taxilane Turn Radii.

6-2.2.1 General Intersection Geometry.

On hammerheads, aprons, and pads, and at runway/taxiway and taxiway/taxiway intersections, the radius for the curves are greater than the minimum turning radius for the assigned mission aircraft and are positioned to maintain a clearance of at least 10 feet (3 meters) between the outermost main gear of a C-5 and the edge of the full-strength pavement. See USACE Transportation Systems Center Report 13-2 for aircraft turning diagrams. The recommended radius for 90-degree runway/taxiway intersections is 150 feet (45.7 meters). The recommended radius for 90-degree taxiway/taxiway intersections is 125 feet (38.1 meters). Other radii are allowed, depending on local requirements. In all cases, ensure these radii accommodate the necessary wingtip clearance distance as well as the pavement structure (clearance between outer main gear and edge of pavement) for the most demanding aircraft that uses the intersection before marking nose wheel guidelines.

6-2.2.2 Aprons for Cargo Aircraft.

Typical taxilane turning radii for cargo aircraft aprons are provided in Table 6.1 and Figure 6-2. Use these to determine the appropriate turning radii for cargo aircraft. For aircraft not shown in Table 6.1, compute the wing tip clearance and main gear distance from the appropriate aircraft characteristics found in the Facility Requirements Document (FRD) for the Mission Design Series (MDS) aircraft, or the aircraft turning diagrams found in USACE Transportation Systems Center Report 13-2. Use UFC 3-260-01, Table 6.1, “Cargo Aircraft Apron Layout Dimensions,” or Table 6.2, “Rotary Wing Aprons,” for minimum wingtip clearances. When marking an apron for a specific aircraft with features less stringent than for a C-5 or 747-8, coordinate with the airfield management and flight safety functions to ensure procedures are published to require aircraft wing-walkers be used for any aircraft that requires greater distances than those provided for safe clearance to obstacles. Publish this information in the Airfield Operating Instruction (AOI) at locations that require, have, or utilize an AOI.

6-3 TAXIWAY, APRON, AND TAXILANE EDGE STRIPES.

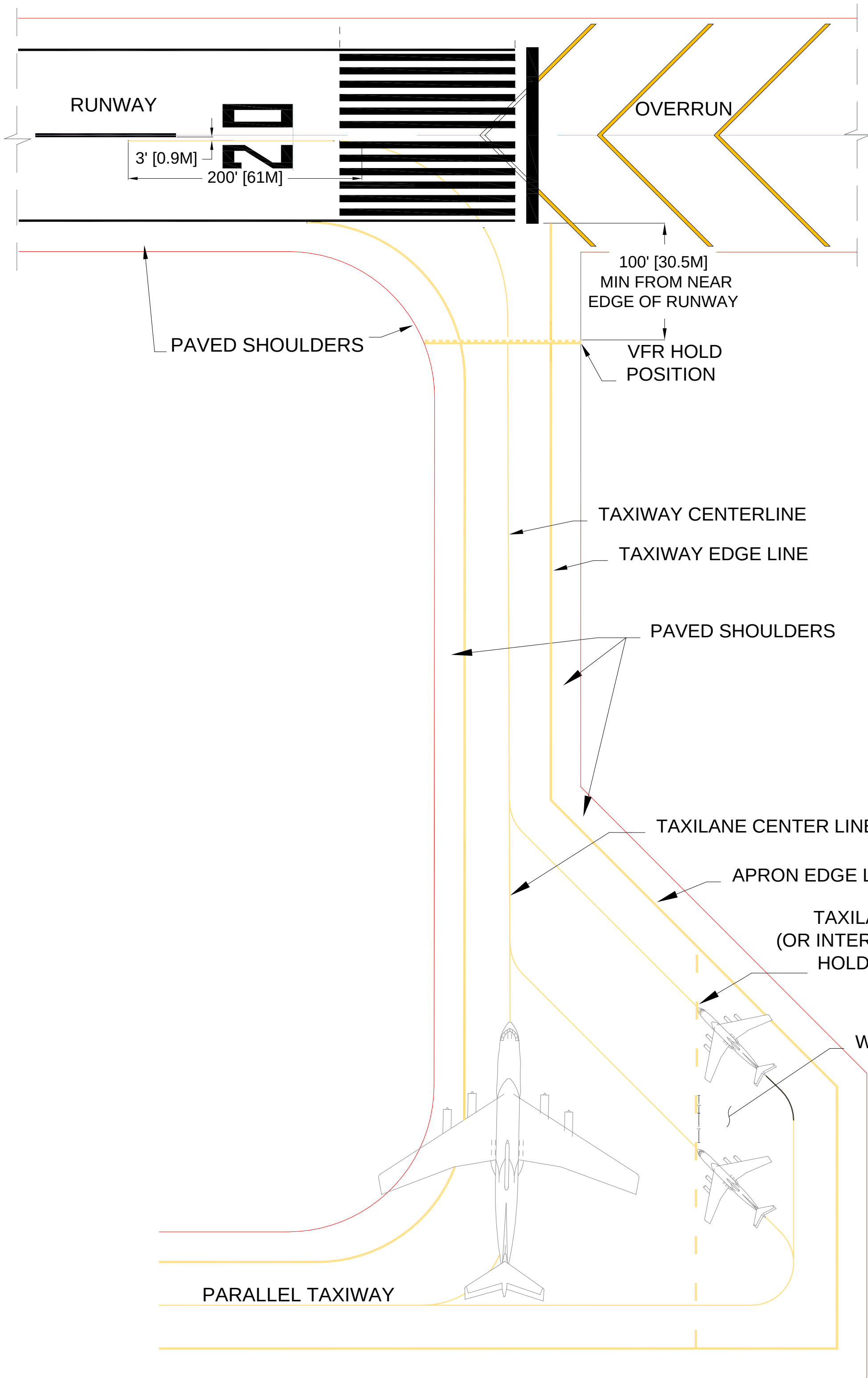
6-3.1 Taxiway and Apron Edge Stripes.

When there is little contrast between the full-strength taxiway or apron boundary and the adjacent paved shoulder or other paved area, mark the edge of the usable pavement with two continuous 6-inch (152-millimeter) -wide retro-reflective yellow stripes separated by a 6-inch (152-millimeter) -wide gap. This marking is used to delineate the usable limits of the taxiway or apron from other pavements or surfaces not intended for routine use by aircraft. It is never used in areas where aircraft are required to cross the designated boundary when operated by a pilot or qualified maintainer (towing aircraft across these markings is accepted if the adjacent area is designated and/or marked as a towway). No portion of the marking is placed on non-load-bearing pavements. Use the tangents for the taxiway centerline stripe on curves; in areas where this is not practical, form a uniform arc to establish the usable area on the full-strength pavement. Figure 6-1 shows typical taxiway/apron edge lines; Figure 6-3 provides the width of the stripes and the space between them. Edge stripes are optionally highlighted with black borders on light-colored pavement (see paragraph 3-1.5).

6-3.2 Taxilane Edge Stripes.

This marking is used to define the limits of a designated taxi route where the surrounding pavement is intended for use by aircraft. Aircraft movement across the designated boundary is permitted either by direction of air traffic control (ATC), a marshaller, or at the pilot's discretion. This marking consists of two 6-inch (152-millimeter) -wide broken stripes separated by a 6-inch (152-millimeter) -wide gap. The stripes are 15 feet (4.6 meters) long with gaps of 25 feet (7.6 meters). The detail and a typical layout are shown in Figures 6-1 and 6-9. Place the innermost edge of each stripe a distance from the centerline equal to half the wingspan of the most demanding aircraft that uses the taxilane, plus the appropriate wingtip clearance required by UFC 3-260-01, Table 6.1, items 5 or 6.

Figure 6-1. Typical Taxiway and Taxilane Markings



6-4 PARKING STOP BARS.

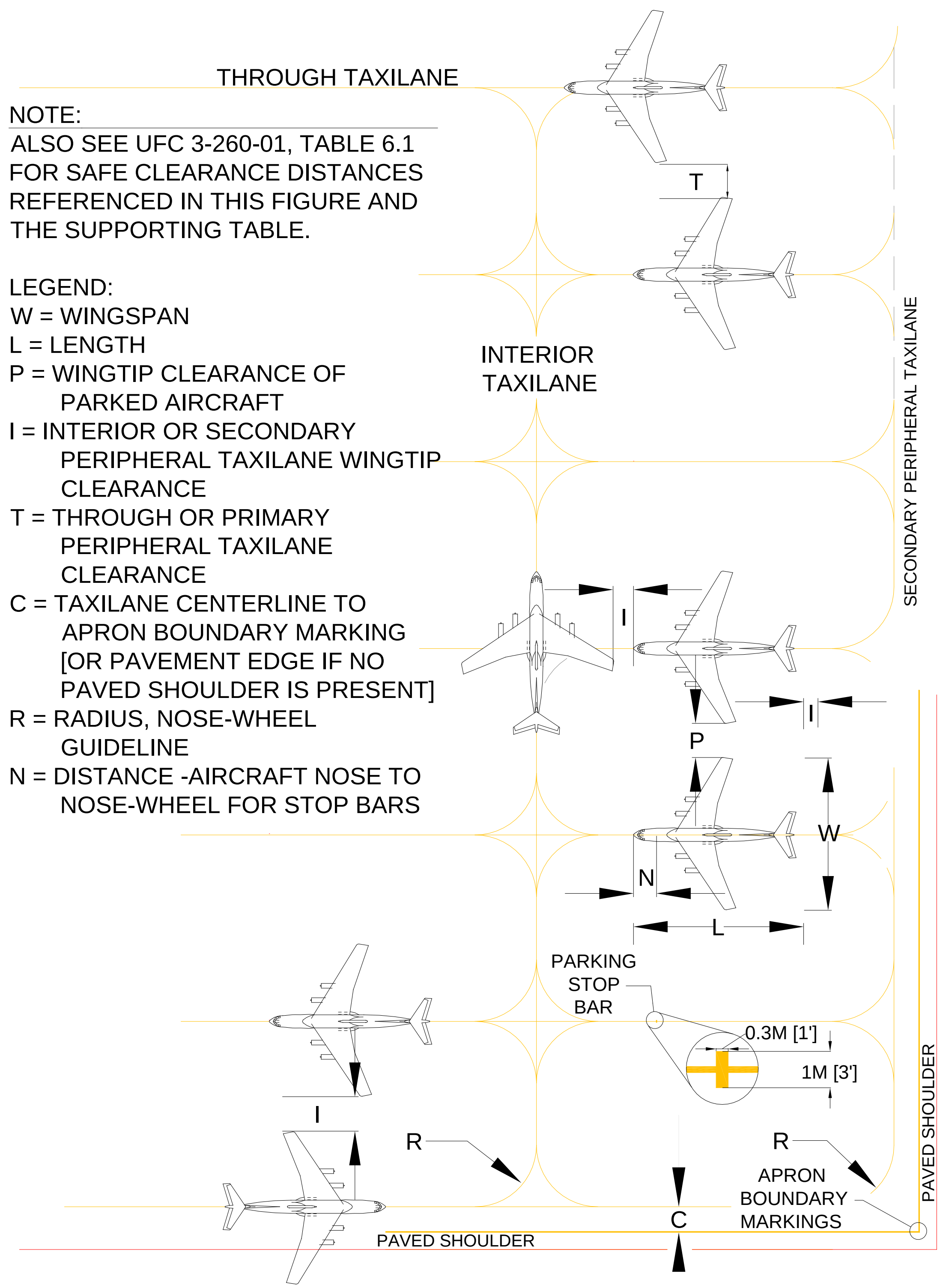
Parking stop bars are optionally painted at aircraft parking positions to indicate the intended location for the aircraft nose wheel when parked. Stop blocks are painted reflective yellow and are 3 feet (0.9 meter) long and 1 foot (0.3 meter) wide, centered on and oriented perpendicular to the nose wheel guideline. See Table 6-1 and Figure 6-2 for an example for locating these visual aids.

Table 6-1. Cargo Aircraft Apron Layout Dimensions

Aircraft	W	L*	P	I	T	C	R	N
C-5A	222.7' (67.9m)	247.8' (75.5m)	25' (7.6m)	30' (9.1m)	50' (15.2m)	37.5' (11.4m)	90' (27.4m)	34.7' (10.6m)
C-9A	93.4' (28.5m)	119.3' (36.4m)	20' (6.1m)	20' (6.1m)	30' (9.1m)	25' (7.6m)	90' (27.4m)	7.6' (2.3m)
C-17	170' (51.8m)	173.3' (52.8m)	25' (7.6m)	30' (9.1m)	50' (15.2m)	37.5' (11.4m)	90' (27.4m)	11' (3.4m)
C-130E/H/J	132.6' (40.4m)	99.5' (30.3m)	20' (6.1m)	30' (9.1m)	50' (15.2m)	37.5' (11.4m)	60' (18.3m)	11.8' (3.6m)
C-130J-30	132.6' (40.4m)	112.8' (34.4m)	20' (6.1m)	30' (9.1m)	50' (15.2m)	37.5' (11.4m)	60' (18.3m)	11.8' (3.6m)
C-141B	160' (48.8m)	168.3' (51.3m)	20' (6.1m)	30' (9.1m)	50' (15.2m)	37.5' (11.4m)	90' (27.4m)	10.3' (3.1m)
KC-135R	130.8' (39.9m)	136.2' (41.5m)	50' (15.2m)	30' (9.1m)	50' (15.2m)	37.5' (11.4m)	90' (27.4m)	17.4' (5.3m)
KC-10A	165.3' (50.4m)	182.1' (55.5m)	50' (15.2m)	30' (9.1m)	50' (15.2m)	37.5' (11.4m)	100' (30.5m)	28' (8.5m)
B767-200ER	156.1' (47.6m)	159.2' (48.5m)	50' (15.2m)	30' (9.1m)	50' (15.2m)	37.5' (11.4m)	90' (27.4m)	14.9' (4.5m)
B747-400	211' (64.3m)	231.8' (70.6m)	20' (6.1m)	30' (9.1m)	50' (15.2m)	37.5' (11.4m)	100' (30.5m)	25.4' (7.7m)
B777-300	200' (61m)	242.3' (73.9m)	20' (6.1m)	30' (9.1m)	50' (15.2m)	37.5' (11.4m)	110' (33.5m)	19.3' (5.9m)

***** Aircraft dimensions provided above do not include appurtenances such as antennas and do not include all model variations due to aircraft modifications.

Figure 6-2. Typical Mass Apron Layout for Cargo Aircraft



6-5 HOLDING POSITIONS.

Holding positions are necessary on all pavements that lead to an active fixed-wing or rotary-wing runway or helipad, and at critical taxiway or taxilane intersections. They designate a boundary intended to protect the runway, helipad, or primary taxiroute from incursions or prevent interference with signals transmitted by electronic navigational aids.

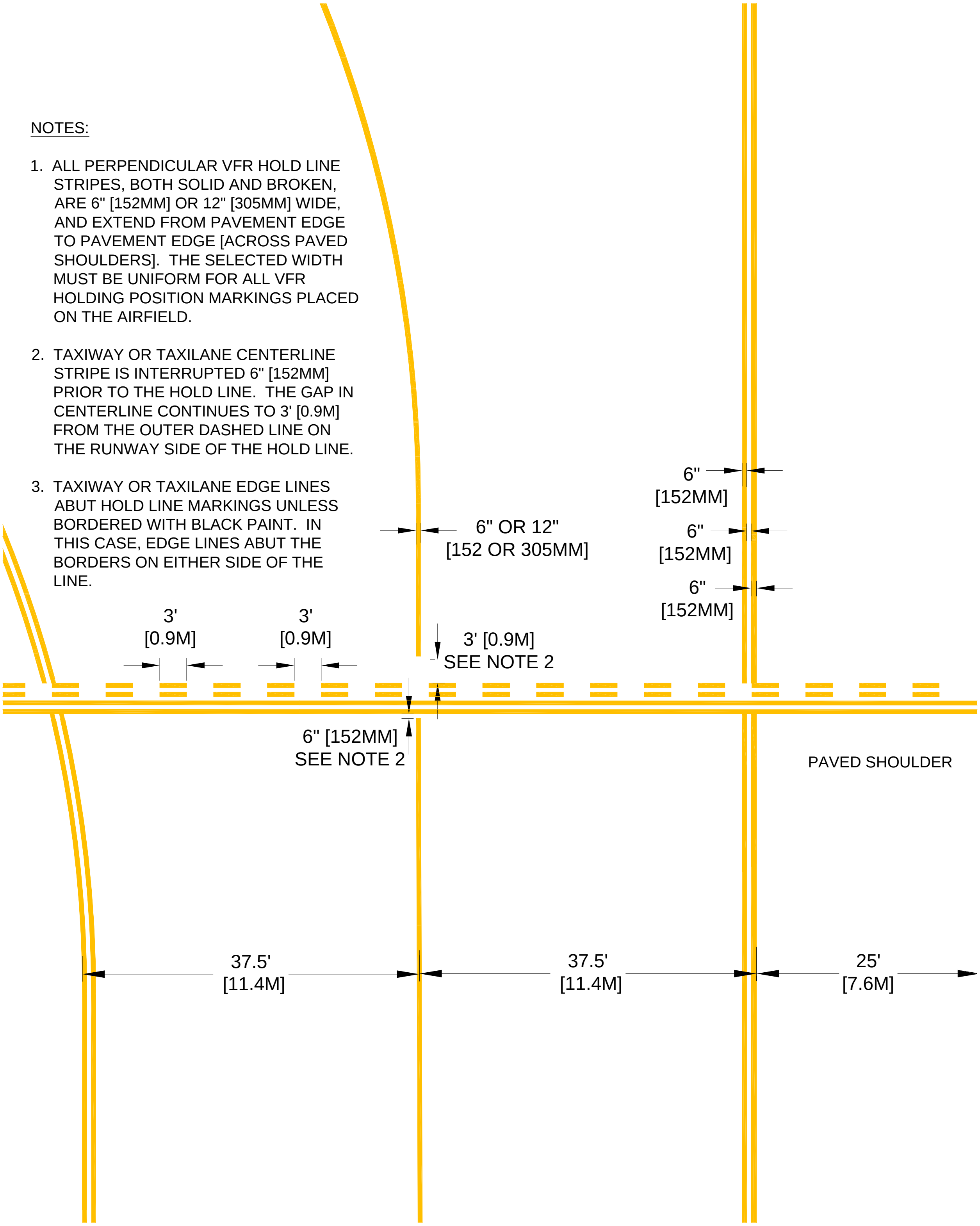
6-5.1 Runway Hold Positions.

There are two patterns for marking runway hold positions: one is used to mark holding positions used for VFR conditions and the other is used to mark holding positions for IFR conditions. Both types are marked in retro-reflective yellow paint and are optionally enhanced with black borders on light-colored pavement. Runways served by precision instrument navigation aids might require an instrument holding position be marked in addition to the VFR holding position. Where practicable, collocate these markings and mark only the VFR holding position. If required, locate the instrument holding position further from the active runway to prevent taxiing or holding aircraft from interfering with signals transmitted to inbound aircraft during IMC and to prevent aircraft and vehicles from violating the precision obstacle free zone (POFZ). This marking is also used to identify the boundary of a microwave landing system (MLS) critical area and to identify the holding position for Category (CAT) II or CAT III operations.

6-5.1.1 VFR Runway Holding Position.

In all cases, a VFR holding position is marked. This holding position is located 100 feet (30.5 meters) to 250 feet (76.2 meters) from the near edge of the runway. The minimum setback from the runway edge is 100 feet (30.5 meters). This distance is measured perpendicular to the long axis of the runway. Measure distances from the runway centerline (divide the published runway width shown in the DoD FLIP by 2 and add the required holding position distance). VFR holding positions are marked from edge to edge of the pavement surface, including paved shoulders. Interrupt taxiway edge lines at the outer edge of the holding position marking, or its black border, if provided. No gap at the edge line interruption is required. Figure 6-3 shows layout and typical positioning for a VFR hold line. Where practicable, setback distances for the VFR runway holding position are increased for instrument runways and where the wingspan of the controlling aircraft is greater than 79 feet (24.1 meters). Suggested setback distances from the runway edge are 175 feet (53.3 meters) for controlling aircraft with wingspans from 79 feet (24.1 meters) up to 171 feet (52.1 meters); and 205 feet (62.5 meters) for controlling aircraft with wingspans greater than 171 feet (52.1 meters). Increase these distances by 1 foot (0.3 meter) for each 100 feet (30.5 meters) of airfield elevation above mean sea level (MSL). Holding positions are placed perpendicular to the runway centerline on taxiways that enter at an angle to the runway; however, do not mark them to allow any portion of the holding aircraft to encroach beyond the minimum established distance.

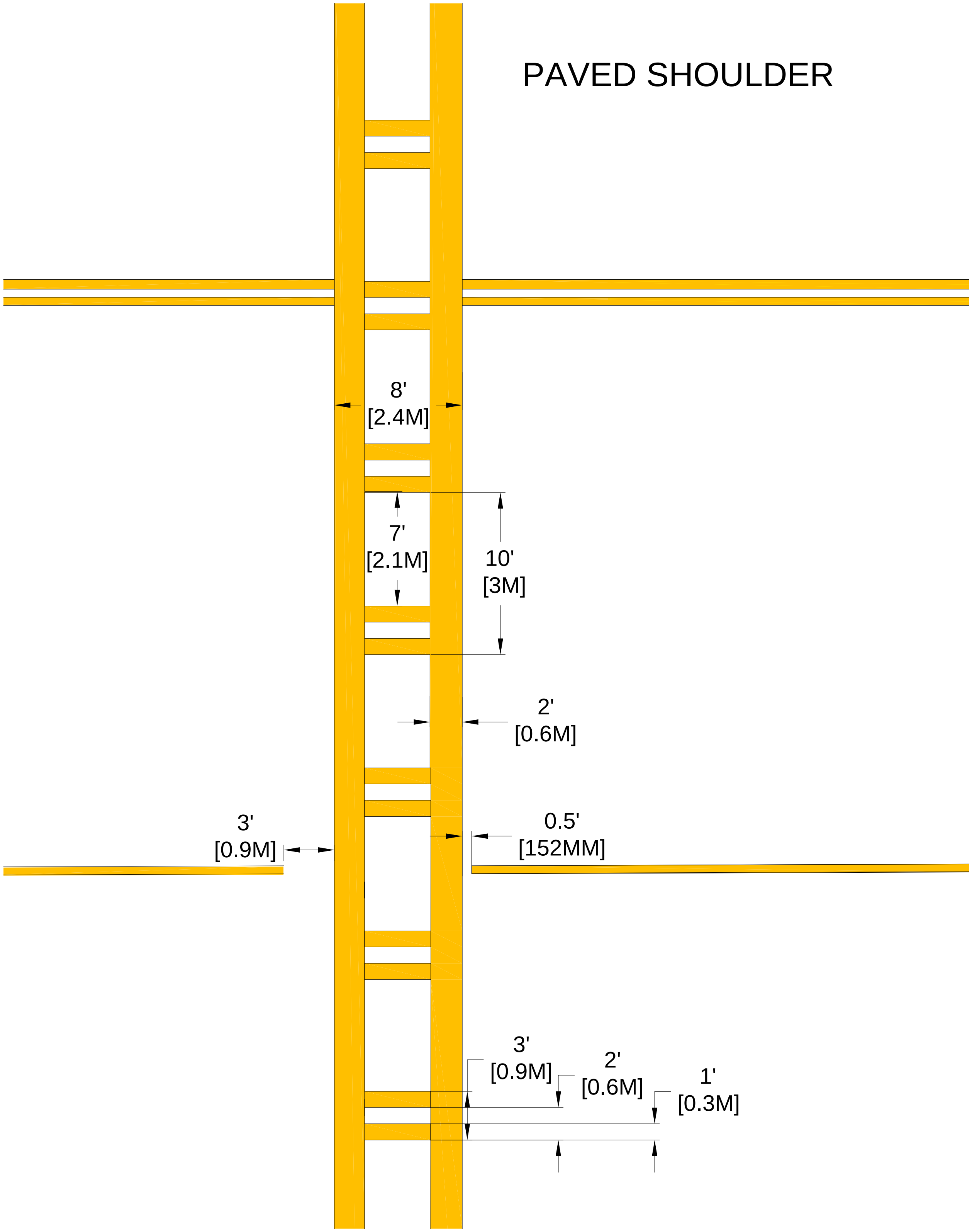
Figure 6-3. VFR Hold Position Markings



6-5.1.2 Instrument Meteorological Conditions (IMC) Holding Position.

The IMC hold position is configured differently from a VFR hold. Locations for the instrument hold line vary, depending on the type and capability of the landing aid. An IMC holding position is only marked when located at a different point along the taxiway (or on a cross-wind runway used for taxi operations or LAHSO). When needed, they are located to prevent interference with electronic navigational aids (NAVAIDs) and provide additional safety during periods of reduced visibility. If an instrument hold line is needed and the taxiway where it needs to be marked also penetrates the POFZ, only one holding position marking is installed to delineate the applicable critical area and the POFZ. The holding position marking is located at the more conservative boundary of the two areas (generally the farthest from the runway). In this instance, the instrument and POFZ holding position markings are not replaced with a VFR runway holding position marking. The airfield manager works with the instrument procedures specialist to designate the applicable critical area and POFZ boundaries, and, as appropriate, determine the holding position location. Figure 6-4 shows the layout for an instrument hold line. Figures 6-5 and 6-6 depict typical positioning for these hold lines. The markings are typically installed perpendicular to the taxiway centerline but might be canted from the perpendicular in unique situations. All holding positions are marked from edge to edge of the pavement surface, including paved shoulders. Interrupt taxiway edge lines at the outermost edges of the holding position marking, or the black borders, if provided. Interrupt centerlines 6 inches (152 millimeters) before the side of the marking where aircraft are to hold and provide a 3-foot (1-meter) gap on the runway side of the marking. No gap at the interruption of edge lines is required. The gap distances cited for the centerline include the black borders, when provided.

Figure 6-4. ILS Hold Position Details



6-5.1.3 Locating IMC Hold Position Markings.

If the height above touchdown (HAT) is 200 feet (61 meters) or greater (ask the airfield manager), mark the instrument holding position at the edge of the glide slope critical area as shown in Figure 6-5. If the HAT is less than 200 feet (61 meters), mark the holding position at the edge of the TDZ critical area or the glide slope critical area, whichever results in a distance farther from the edge of the runway. The glide slope critical area and TDZ critical areas are shown in Figures 6-5 and 6-6. The instrument hold line is placed at least 500 feet (152.4 meters) from the runway centerline when TDZ critical area criteria apply.

Figure 6-5. Locating Instrument Hold Position to Protect Glideslope Critical Area

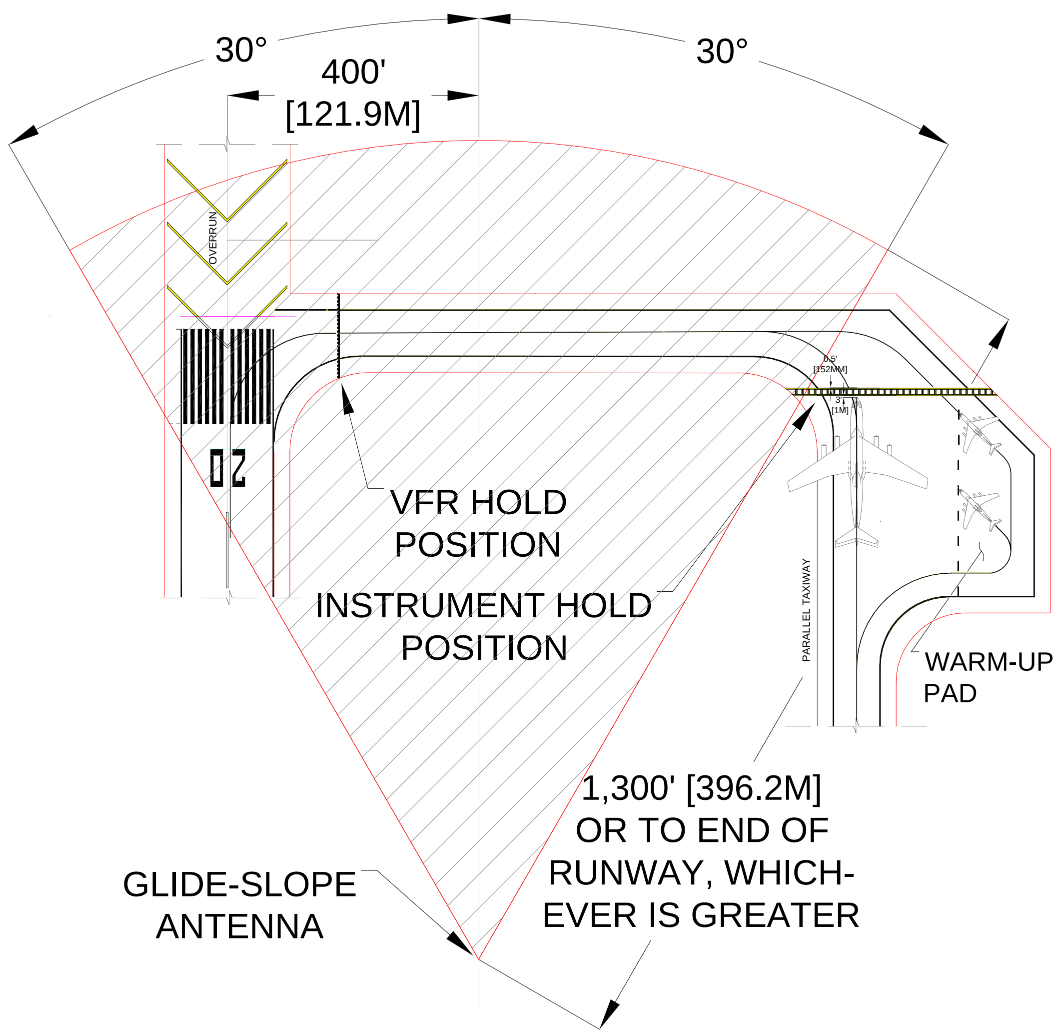
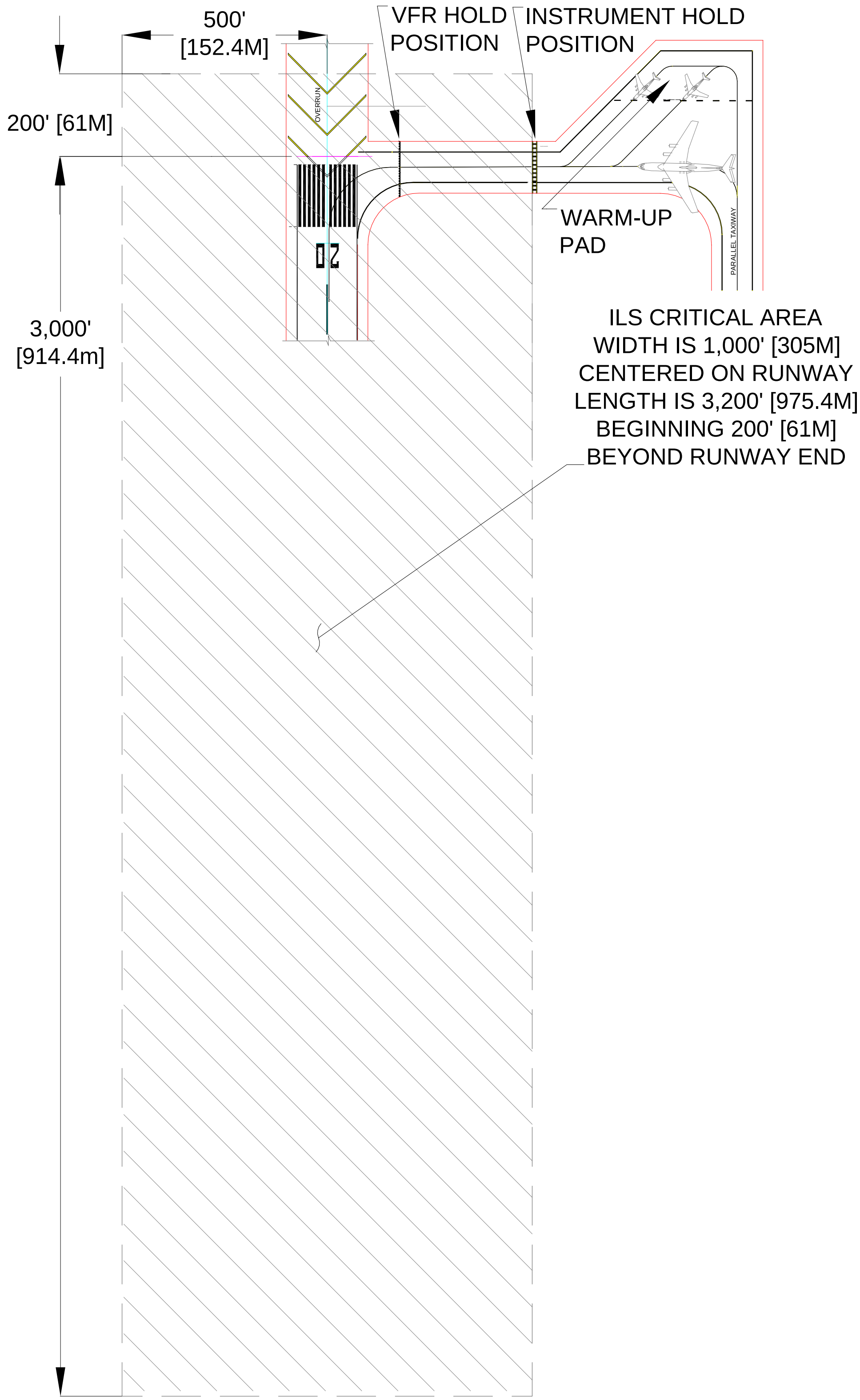


Figure 6-6. Locating Instrument Hold Positions to Protect Touchdown Zone Critical Area



6-5.2 Runway/Runway Holding Position Marking Layout and Placement.

LAHSO for runway/runway intersections require a letter of agreement between the airfield operations authority and the air traffic control tower (ATCT) authority. When a holding position is necessary for such operations, it is marked in one of the patterns described above; however, its location is not less than 280 feet (85.3 meters) from the adjacent runway centerline. This distance is increased by 1 foot (0.3 meter) for each 100 feet (30.5 meters) of airfield elevation above MSL. Such hold lines are located further away to avoid interference with intersecting taxiway clearances and interrupts all other runway markings other than a designation marking. The runway holding position marking extends across the full width of the runway but not onto the runway shoulders or onto any intersecting taxiway fillet.

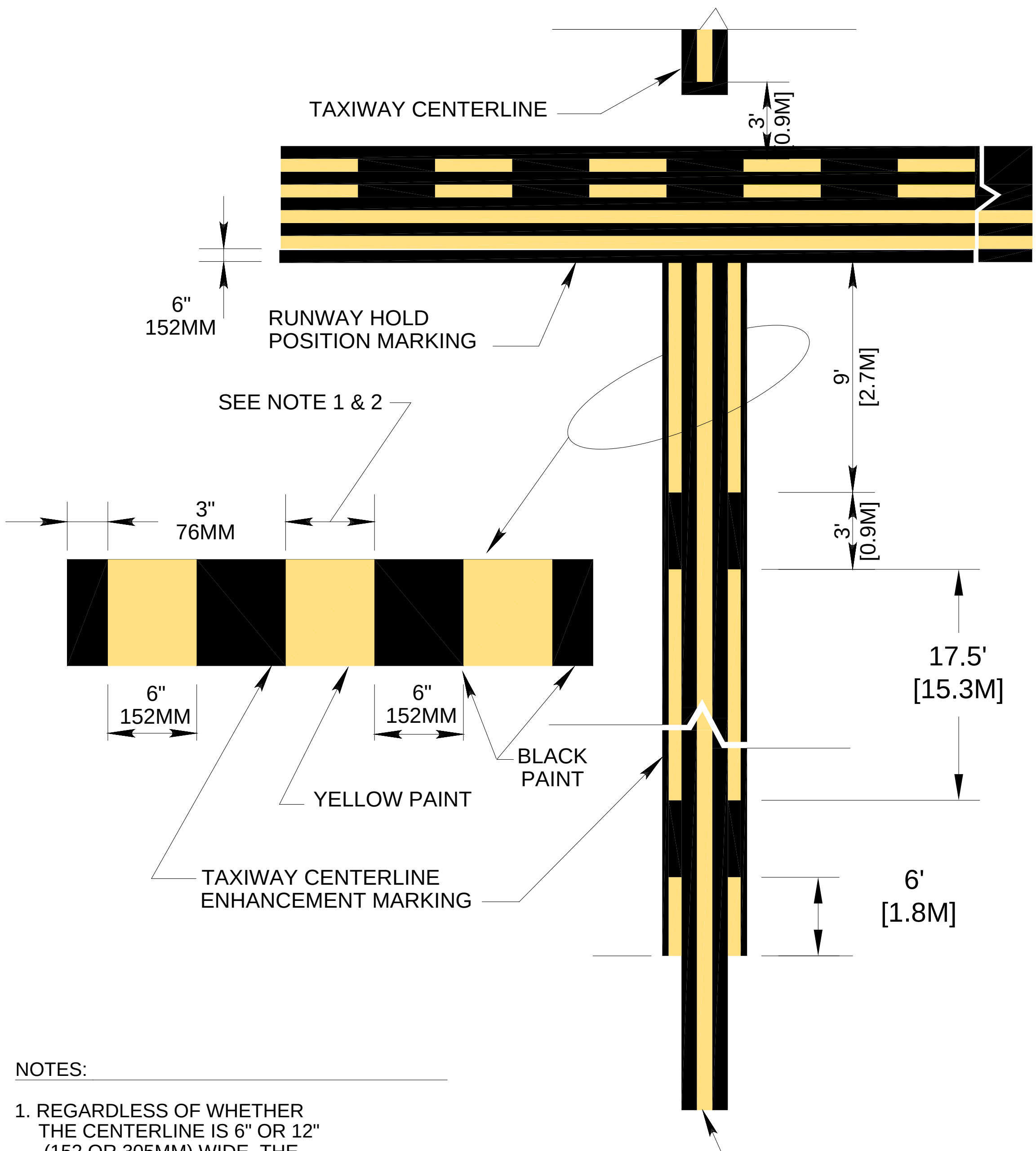
6-5.3 Enhanced Hold Position Marking.

Enhanced markings are intended to be a visual precursor to an approaching runway holding position. These markings are intended to prevent runway incursion and are optionally marked at any runway intersection for any DoD installation but are required at Part 139 (14 CFR Part 139) airports. See Figure 6-7 for details. For additional guidance on marking pavements at civil-owned facilities, see FAA AC 150/5340-1.

6-5.4 Intermediate Hold Position Markings.

Intermediate holding position markings identify the location for aircraft to hold short of an intersecting taxiway, or taxilane on an apron. These permissible markings are placed only where there is an operational need for aircraft to hold short of another taxiway or taxilane intersection. Intermediate holding position markings are retro-reflective yellow and are placed at a distance from the intersecting taxiway or taxilane to provide one-half the wingspan of the most demanding aircraft that uses the taxi path, plus the appropriate wingtip clearance as shown in Table 6-1 of UFC 3-260-01. When placing these markings to protect a taxiway, use the greater wingtip clearance as shown for a through taxilane. The intermediate hold position marking is a 6-inch (152-millimeter) or 12-inch (305-millimeter) -wide dashed line, where the dashes are 3 feet (0.9 meter) long and the gaps are 3 feet (0.9 meter) long; see Figure 6-8 for layout details. Interrupt taxiway or taxilane centerlines and edge lines 6 inches (152 millimeters) before and after the hold position line. Center a dash on the taxipath centerline. If the hold line crosses more than one centerline, center a dash on the path of highest use.

Figure 6-7. Enhanced Hold Position Markings



NOTES:

1. REGARDLESS OF WHETHER THE CENTERLINE IS 6" OR 12" (152 OR 305MM) WIDE, THE DASHED LINES PROVIDED BY THE ENHANCEMENTS WILL ALWAYS BE 6" (152MM)

2. IF TAXIWAY CENTERLINE LIGHTS ARE PRESENT, SHIFT THE TAXIWAY CENTERLINE EITHER RIGHT OR LEFT TO ENSURE THE ENHANCEMENT MARKINGS DO NOT COVER THE LIGHTS.

Figure 6-8. Intermediate Holding Position Marking

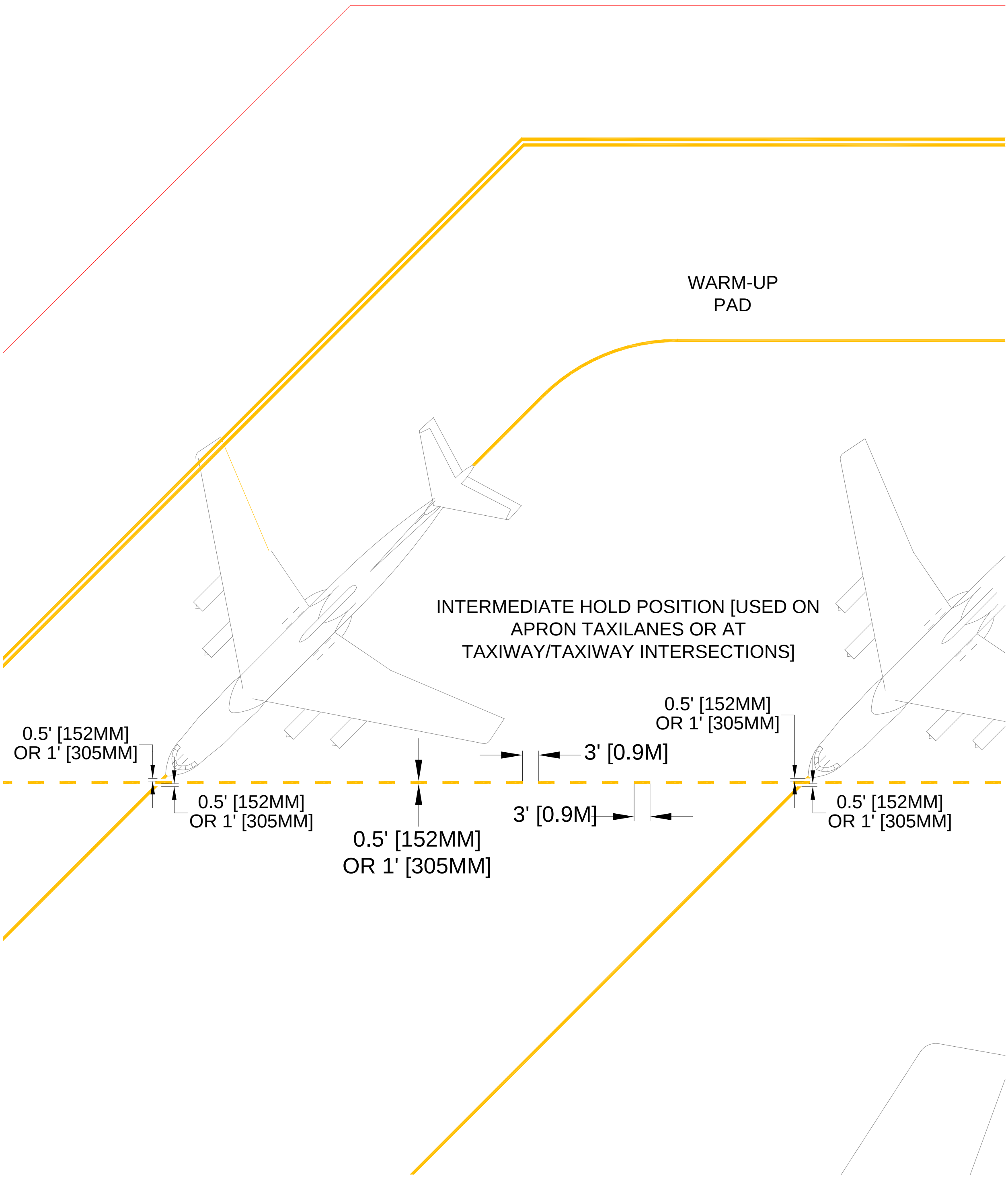
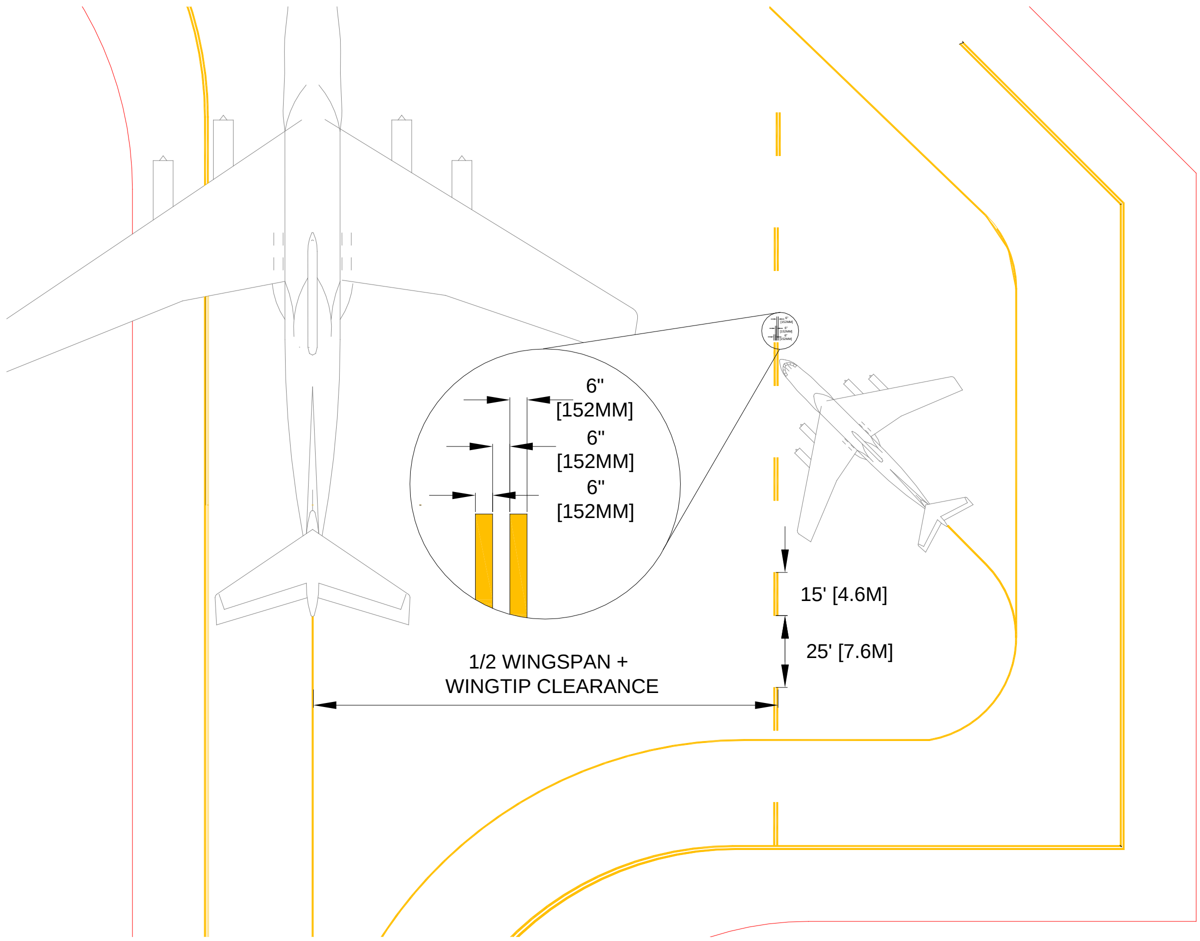


Figure 6-9. Taxilane Edge Stripes



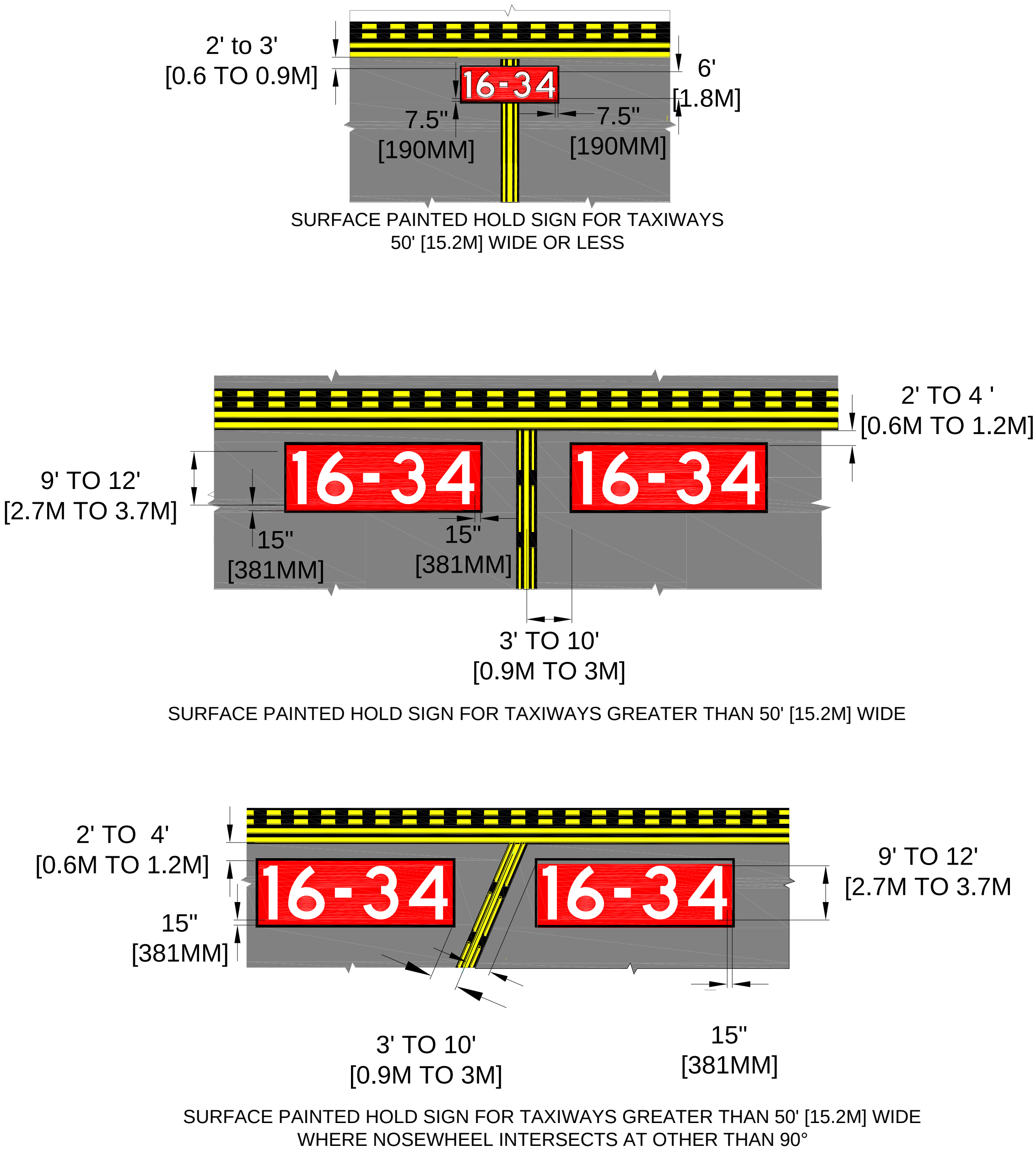
6-5.5 Surface Painted Signs.

Taxiway signs are described in UFC 3-535-01. Where it is desirable to furnish additional guidance at intersections or along taxiways or taxilanes, additional information is provided on the pavement surface. The most common surface-painted sign types are location, direction, and runway hold position signs. Under special circumstances, geographic position marking (GPM) signs are required. GPM signs are used repeatedly along a designated taxi route to serve as indicators of specific locations to allow pilots to confirm their position on the airfield during periods of low visibility. Low-visibility operations are defined as taxiing operations prior to takeoff or after landing that occur when the runway visual range (RVR) is below 1,200 feet (365.8 meters). See FAA AC 120-57 and both UFC 3-535-01 and FAA AC 150/5340-18 for sign requirements. See FAA AC 150/5340-1 for placement, layout, colors, and dimensions. Figures 6-10 through 6-12 show examples of typical runway hold position, location, and direction surface painted signs. The letters and numbers are formed according to the patterns shown in Figures 6-13 through 6-15.

6-5.6 Surface Painted Holding Position Signs.

The surface painted holding position sign provides supplemental visual cues that alert pilots and vehicle drivers of an upcoming holding position location and the associated runway designator(s) as a method to minimize the potential for a runway incursion, and, for certain airport geometries, wrong runway takeoffs. Several configurations of this surface painted sign are allowed to provide maximum flexibility. See Figure 6-10 for three possible layout scenarios. Inscriptions have a height of 12 feet (3.7 meters) where practicable; however, the height is reduced to a minimum height of 9 feet (2.7 meters) when necessary to appropriately fit the marking. Examples of these situations include taxiways with widths narrower than the applicable standard or taxiways that need to display multiple runway designations with directional arrows. In all cases, inscriptions follow inscription criteria shown in Figures 6-13 through 6-15. All other taxiway entrances to the same runway not needing the reduction are to maintain the 12-foot (3.7-meter) height dimension.

Figure 6-10. Surface Painted Runway Hold Position Signs



6-5.7 Surface Painted Taxiway Location Signs.

The surface painted taxiway location sign identifies the taxiway upon which the aircraft is located and is optional when required signage is not available. When necessary, this marking is also used to supplement other signs located along the taxiway system, or where operational experience has indicated that its presence assists flight crews in better ground navigation. These type signs are normally located on the right side of the taxiway centerline in the direction of travel. The edge (excluding the border) of the surface painted taxiway location sign is placed 3 feet (0.9 meter) from the outer edge of the taxiway centerline stripe. When adequate pavement width exists, a surface painted taxiway location sign might be located on the left side of the taxiway centerline if it is co-located with a surface painted holding position sign. In this case, the two surface painted signs mimic the mandatory holding position signs, and the surface painted taxiway location sign is placed to the left of the surface painted holding position sign to be readable in the direction of taxiing toward the runway. The inscription is 12 feet (3.7 meters) in height; however, the height is reduced if necessary to a minimum height of 9 feet (2.7 meters). See Figure 6-11 for an example and detail dimensions. The inscriptions conform in appearance and proportion with the letters, numbers, and symbols in Figures 6-13 through 6-15.

6-5.8 Surface Painted Taxiway Direction Signs.

The surface painted taxiway direction sign is always combined with an arrow to provide directional guidance at an intersection when it is not possible to provide an illuminated taxiway direction sign in accordance with UFC 3-535-01. An exception is where operational experience indicates the addition of a surface painted sign at a troublesome taxiway intersection assists aircrews.

6-5.8.1 The inner edge of surface painted taxiway direction signs (excluding the border, if used) is placed 3 feet (0.9 meter) from the near edge of the taxiway or taxilane nose wheel guideline and is placed on the same side of the nose wheel guideline as the direction the aircraft turns. For example, signs indicating left turns are located on the left side of the line and signs indicating right turns are located on the right side of the line**.**

6-5.8.2 The surface painted taxiway direction sign is not painted on runways, including runways sometimes used as a taxiway, between the runway VFR holding position marking and the runway, nor with surface painted hold position signs**.**

6-5.8.3 For crossing taxiways, a surface painted taxiway direction sign, combined with arrows, indicates the intersecting taxiway designation at the near intersection. In such cases, a single surface painted sign is located on the left side of the taxiway centerline to accommodate the possible directions of travel**.**

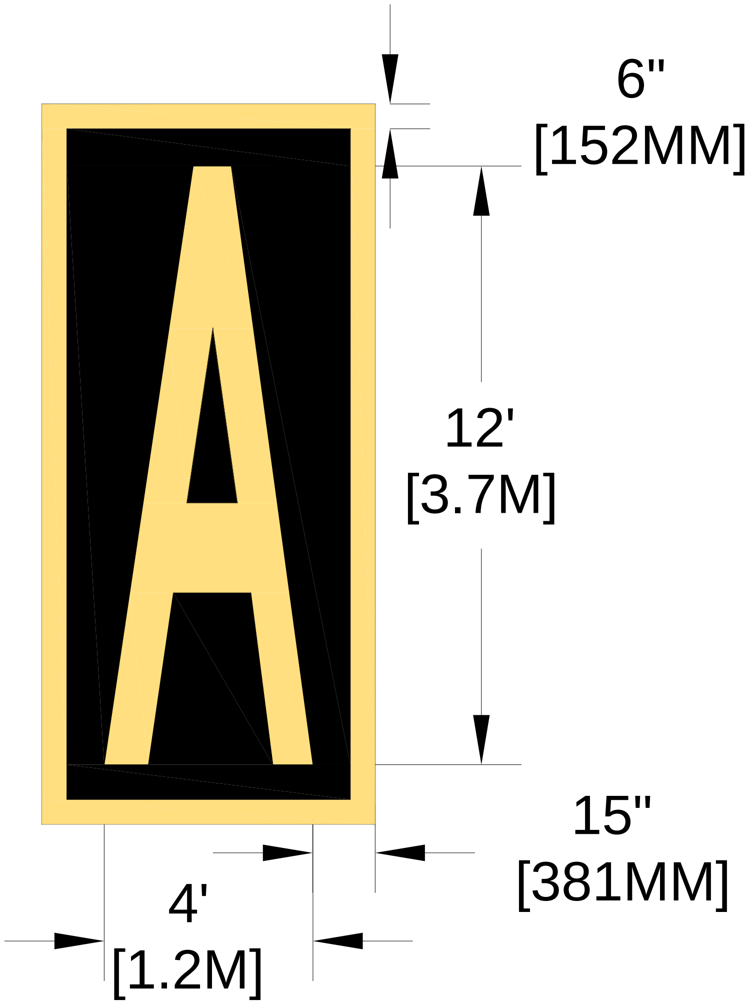
6-5.8.4 Locate these surface painted direction signs a longitudinal distance from crossing taxi routes at the appropriate aircraft wingtip clearance distance for the most demanding aircraft that uses the intersecting taxi route (taxiway or taxilane). These clearances are provided in UFC 3-260-01, Table 6-1, for fixed wing aircraft, and Table 6-2 for rotary wing aircraft**.**

6-5.8.5 The surface painted taxiway direction sign has a retro-reflective yellow background with a black inscription that includes one or more arrows. See paragraph 3-1.5 for recommended techniques to enhance this marking on light-colored pavements**.**

6-5.8.6 The black inscription is 12 feet (3.7 meters) in height; however, the height is reduced if necessary to a minimum height of 9 feet (2.7 meters). The black inscription is accompanied by an arrow oriented to show the general direction and angle of the turn. The inscriptions and arrows conform in appearance and proportion with the letters, numbers, and symbols in Figures 6-13 through 6-15.

6-5.8.7 The yellow background is rectangular and extends a minimum of 15 inches (381 millimeters) horizontally and vertically beyond the extremities of the black inscription, including the arrow head. A 6-inch (152-millimeter) -wide vertical black stripe separates any two black inscriptions when more than one is included on the same side of the nose wheel guideline**.**

Figure 6-11. Surface Painted Taxiway Location Sign

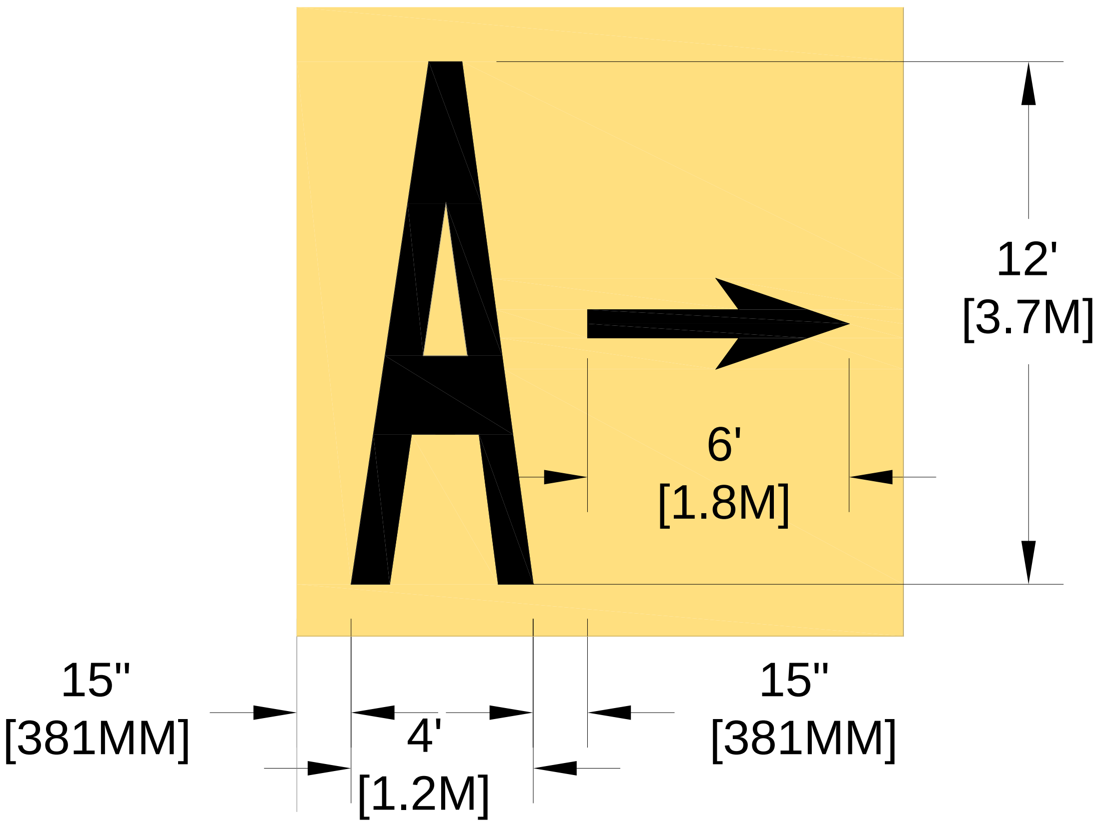


NOTES:

1. CHARACTER HEIGHT, WIDTH, AND LENGTH MAY BE REDUCED PROPORTIONATELY BY A FACTOR OF 0.75 (12' [3.7M] HEIGHT MAY BE REDUCED TO 9' [2.7M] HEIGHT IF STROKE AND CHARACTER WIDTH ARE ALSO REDUCED PROPORTIONATELY).

2. LOCATION SIGNS ARE NOT USED BETWEEN THE VFR HOLD POSITION AND THE RUNWAY, OR ON RUNWAYS USED AS TAXIWAYS.

Figure 6-12. Surface Painted Taxiway Direction Sign

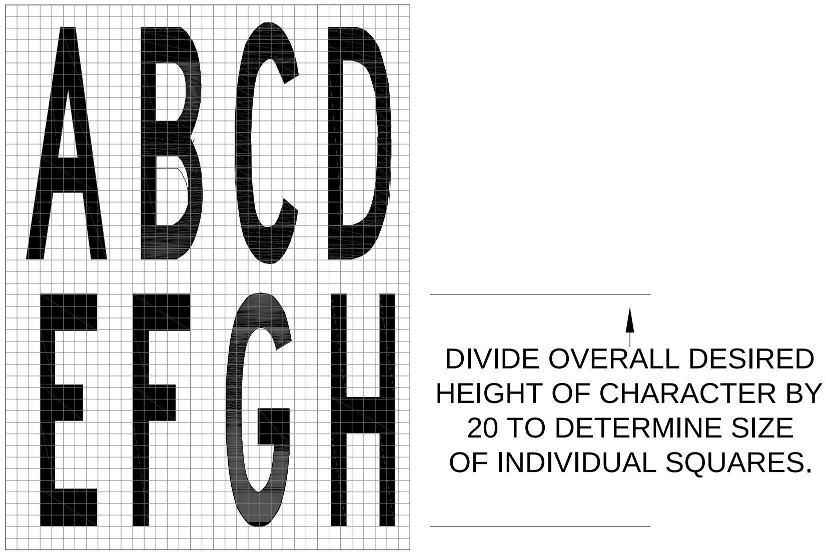


NOTES:

1. CHARACTER AND ARROW HEIGHT, WIDTH, AND LENGTH MAY BE REDUCED PROPORTIONATELY BY A FACTOR OF 0.75 (12' [3.7M] HEIGHT MAY BE REDUCED TO 9' [2.7M] HEIGHT IF STROKE AND CHARACTER WIDTH ARE ALSO REDUCED PROPORTIONATELY).

2. LOCATION SIGNS ARE NOT USED BETWEEN THE VFR HOLD POSITION AND THE RUNWAY, ON RUNWAYS USED AS TAXIWAYS, NOR ARE THEY COLLOCATED WITH SURFACE PAINTED HOLD POSITION SIGNS.

Figure 6-13. Surface Painted Sign Inscription Layout, A through P



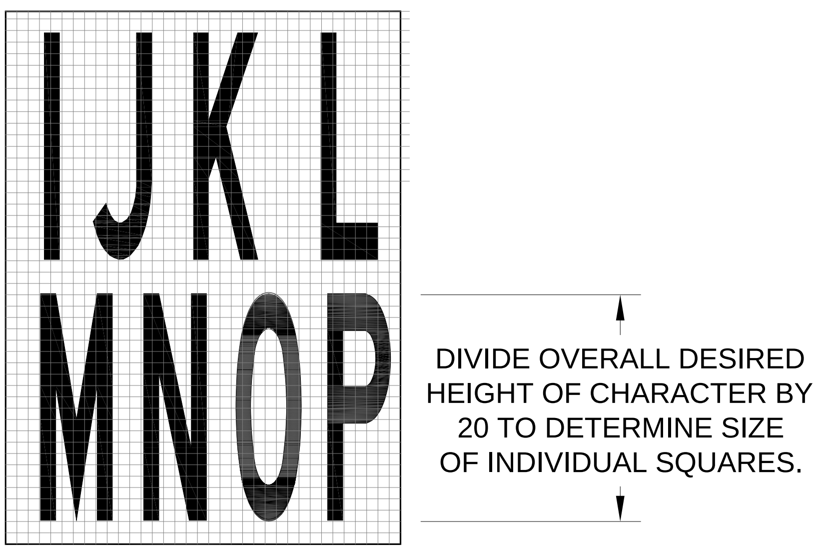
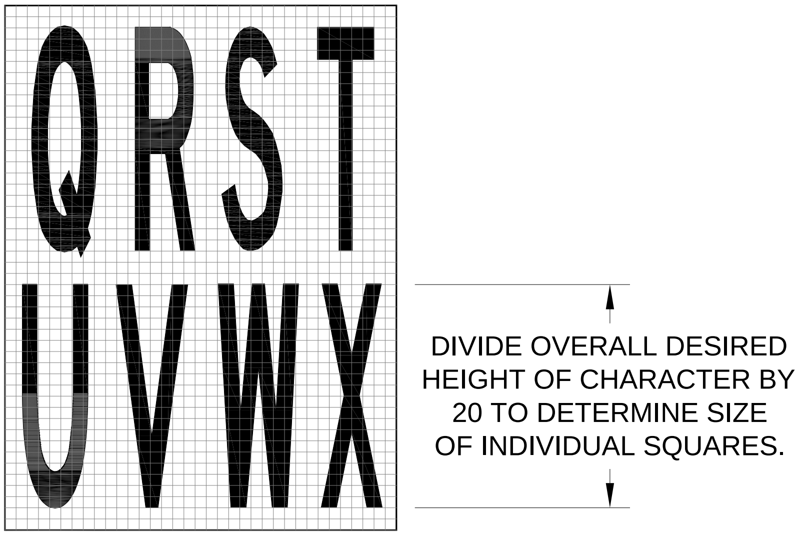


Figure 6-14. Surface Painted Sign Inscription Layout, Q through 6



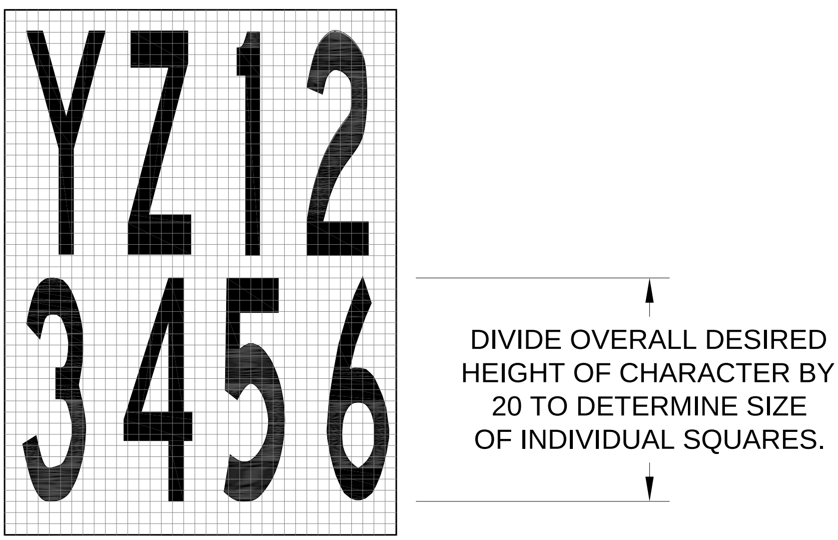
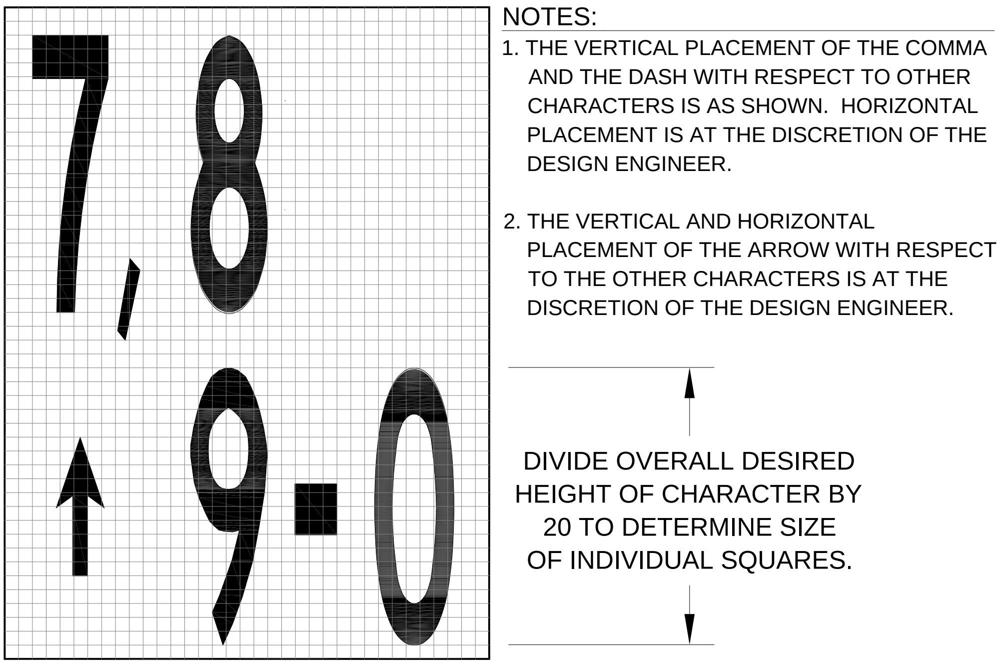


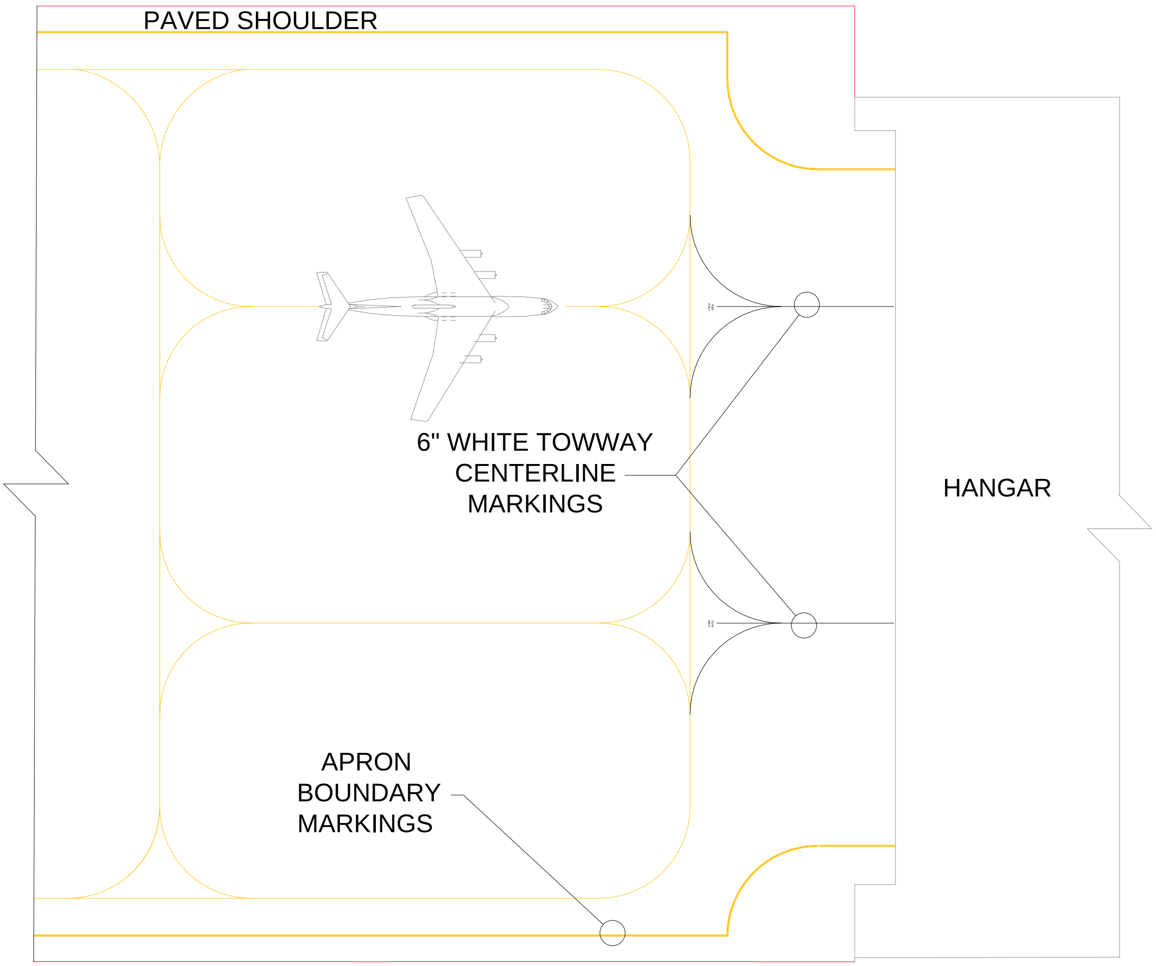
Figure 6-15. Surface Painted Sign Inscription Layout, 7 through 0 and Directional Arrow



6-5.9 Towway Markings.

For taxilanes where aircraft are to be towed, provide a single, solid, continuous 6-inch (152-millimeter) -wide white painted stripe. A significant gap is provided between the yellow taxilane marking and the white towway lane marking to allow the taxiing pilot to see that the towway is not a continuation of the taxilane. See Figure 6-16.

Figure 6-16 Towway Centerline Marking



NOTES:

1. TOWWAY CENTERLINES ARE 6" [152MM] WIDE WHITE LINES LAID OUT TO MAINTAIN MINIMUM CLEARANCES GIVEN WITHIN CHAPTER 5 OF UFC 3-260-01, *AIRFIELD AND HELIPORT PLANNING AND DESIGN*. USE OF RETROREFLECTIVE BEADS IS ALLOWED WHEN THESE MARKINGS MUST BE USED AT NIGHT.

2. TOWWAY CENTERLINES SHOULD NOT BE MARKED WITHIN THE AIRCRAFT OPERATING AREA OF THE APRON WHERE EXISTING TAXILANE CENTERLINES MAY BE USED FOR TOWING GUIDANCE. IF NECESSARY TO MARK THESE GUIDELINES WITHIN THE APRON BOUNDARIES, MARK THE BEGINNING OF EACH TOWWAY CENTERLINE "TOWWAY OR TOW ONLY" IN MIN 24" [610MM] HIGH LETTERS.

6-5.10 Restricted Area and Restricted Area Entry Control Points (ECP).

USAF AFI 31-101 and U.S. Army Regulation (AR) 190-16 prescribe signage, security force equipment, and security procedures for the protection of aircraft and the areas surrounding them. Borders and signage are necessary to identify these controlled and restricted areas. In cases where it is not practicable to establish a raised physical barrier, it is sometimes permissible to delineate such borders with a retro-reflective red, 6-inch (152-millimeter) -wide painted line surrounding the area, supplemented with ECP markings and warning signs at specific intervals. Spacing between boundary signs is usually 100 feet (30.5 meters); however, there are exceptions for areas with irregular terrain features and for abrupt changes in direction of the boundary, where the maximum distance is reduced. See UFC 3-120-01 for details necessary to mark retro-reflective signs on the pavement. See Figure 6-17 for an example of an ECP and Figure 6-18 for an example of a restricted area warning sign but refer to the specific Service component's security directives for the markings and sign legends required in each situation.

Figure 6-17. Restricted Area Entry Control Points (ECP)

NOTES:

1. ENTRY CONTROL POINT MARKINGS ARE 6" [152MM] WIDE BY 3' [0.9M) LONG RETROREFLECTIVE WHITE BARS SEPARATED BY 6" [152MM] GAPS.

2. THE RESTRICTED AREA BOUNDARY IS A 6" [152MM] WIDE RED BORDER AROUND THE RESTRICTED AREA. SEE AFMAN 31-101, *INTEGRATED DEFENSE.*

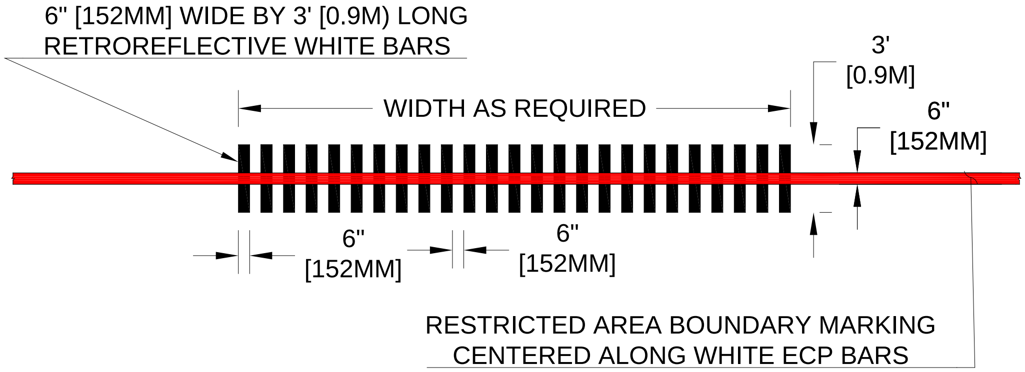


Figure 6-18. Typical Restricted Area Boundary Warning Sign

CHAPTER 7 MARKING PAVEMENTS FOR ROTARY WING OPERATIONS

7-1 GENERAL.

Marking rotary wing facilities conforms to the requirements as set forth below and govern the initial marking and re-marking of serviceable runways, taxiways, landing pads, and other areas designated for rotary wing operations.

7-2 MARKING WITH PAINT OR THERMOPLASTICS.

Do not use thermoplastics to mark rotary-wing helipads, runways, landing lanes, or taxiways due to potential for FOD.

7-3 COLORS AND REFLECTIVITY OF MARKINGS.

Rotary-wing runways, hoverpoints, and pads are marked with retro-reflective white except as noted below. Rotary-wing taxiways, taxi-lane and aprons are marked with retro-reflective yellow except as noted below. Hospital helipads incorporate red in the designator and borders. Rotary-wing shoulders (deceptive surfaces) and overruns are marked in non-reflective yellow durable marking materials except where noted otherwise. For Class A airfields and heliports that are not used strictly for missile security or survival school and are not trafficked by jet aircraft on a daily basis, identification markers, landing pads, and hoverpoints are marked using non-reflective white marking materials. In addition, taxiways, taxilanes, and apron markings on these Class A airfields and heliports are marked using non-reflective yellow durable marking materials except where otherwise noted.

7-4 PAVEMENT CURING TIME AND APPLICATION RATES.

Durable marking materials are applied only after the pavements have been allowed to cure thoroughly. New pavement surfaces are allowed to cure for a minimum of 30 days before application of marking materials. Take care to ensure the pavement surface is dry and clean prior to application of markings. See Chapter 3 for material application rates.

7-4.1 Rigid Pavements.

When painted markings are to be applied to rigid pavements cured with a membrane-type curing compound, the surface to be painted is thoroughly cleaned and the curing compound removed by sandblasting or high-pressure water blasting. Do not allow excessive blasting of the concrete surface when using high water pressure methods. Employ removal methods sufficient only to remove curing compound, old paint, or laitance, and not expose the coarse aggregate in the concrete.

7-4.2 Flexible pavements.

Flexible pavements are allowed to cure as long as practicable before marking to prevent undue softening of the bitumen by the paint or primers, as well as to limit bleeding. The maximum drying-time requirements of the paint specifications are strictly enforced.

7-5 INCREASING VISIBILITY OF MARKINGS.

A hoverpoint is a surface used as a reference or control point for arriving and departing helicopters. Mark hoverpoints with a white circle 30 feet (9.1 meter) in diameter on Class A airfields or heliports except when used for missile security or survival school or on asphalt surfaces where jet aircraft operate. On Class B airfields or Class A airfield/heliports used for missile security or survival school or on asphalt surfaces where jet aircraft operate, mark hoverpoints with a 30-foot (9.1-meter) -outside diameter circle formed with a 12-inch (305-millimeter) -wide white line. When located on a taxiway, the marking is centered on the taxiway centerline. See Figure 7-4.

7-6 HELICOPTER RUNWAY AND LANDING LANE MARKINGS.

Markings on serviceable runways consist of centerline marking, runway azimuth heading numbers, and an “H” letter without a helipad border as shown in Figure 7-1. Helicopter landing lanes are also marked to delineate three equal-length segments to accommodate four equally spaced landing pads, as shown in Figure 7-7.

7-6.1 Rotary-Wing Runway Designator.

The helipad “H” letter is located centered on the runway pavement centerline, 20 feet (6.1 meters) inboard from the beginning of the rotary-wing runway surface. The rotary-wing designator “H” is approximately 30 feet (9.1 meters) in length and 20 feet (6.1 meters) in width. See Figure 7-2 for placement on the runway pavement and Figure 7-3 for dimensions.

7-6.2 Azimuth Runway Designation Marking.

Runway designation is the numeric azimuth heading of the paved strip rounded to the nearest 10-degree increment. Each runway end is designated by number and, where required, by letter to indicate left, right, or center. Numbers and letters assigned are determined from the approach direction and conform to the form and dimensions shown in Figure 7-3.

7-6.2.1 The numeral(s) are retro-reflective white characters consisting of one or two numbers. The number assigned is the whole number nearest one-tenth of the magnetic azimuth of the centerline of the runway, measured clockwise from the magnetic north. Single-digit headings are not preceded by a zero (0). Lateral spacing between the numbers is 10 feet (3 meters), except for the numbers "10" and "11." Spacing between numerals for these runway designations are 7.5 feet (2.3 meters) and 12.5 feet (3.8 meters), respectively.

7-6.2.2 In the case of parallel runways, the retro-reflective white numeric designator and a letter (“L” for left, “C” for center, or “R” for right) are marked to indicate the lateral position of the runway with respect to any others with the same numeric designator on the same airfield.

7-6.2.3 In the case where a letter designation is required, it is placed between rotary-wing designator “H” and the numeric azimuth designator, with a 20-foot (6.1-

meter) gap between each of the characters. See Figure 7-1 for placement on the runway pavement and Figure 7-3 for letter dimensions.

7-6.3 Runway Centerline Marking.

The runway centerline is marked as a solid and continuous reflective white line, 1 foot (0.3 meter) in width. The centerline stripe of each runway terminates 20 feet (6.1 meters) from the runway direction numbers as shown in Figure 7-2.

7-6.4 Runway Side Stripe (Edge) Marking.

When there is little contrast between the runway and the paved shoulder or the surrounding area, the edge of the full-strength pavement is marked with a continuous 12-inch (0.3-meter) -wide stripe. This marking is used to delineate the edge of the runway from other pavements placed to prevent FOD or erosion. Such surfaces are not intended for routine use by aircraft. See Figure 7-1 for an example.

Figure 7-1. Helicopter Runway Markings

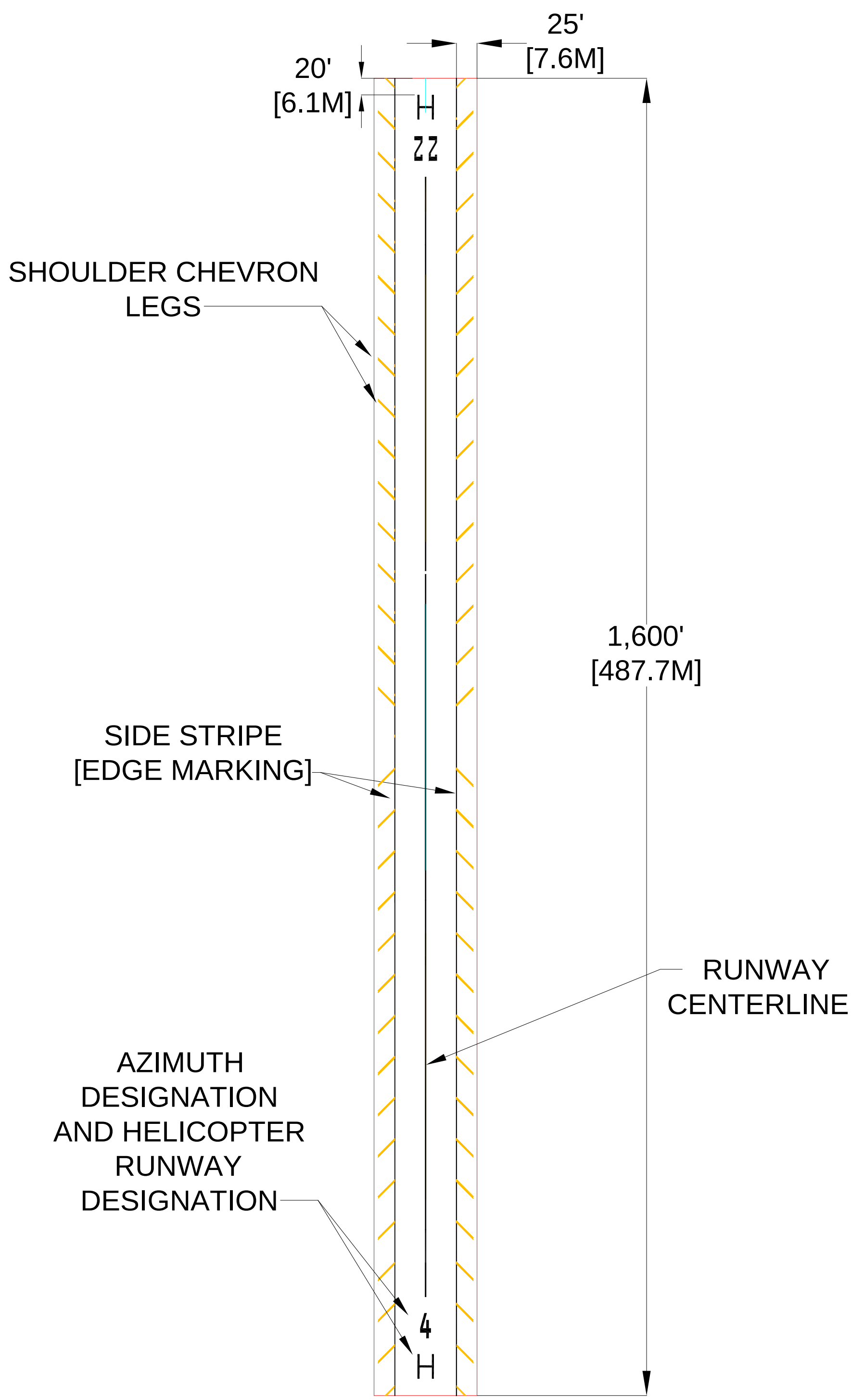


Figure 7-2. Rotary-Wing Designator and Designation Markings

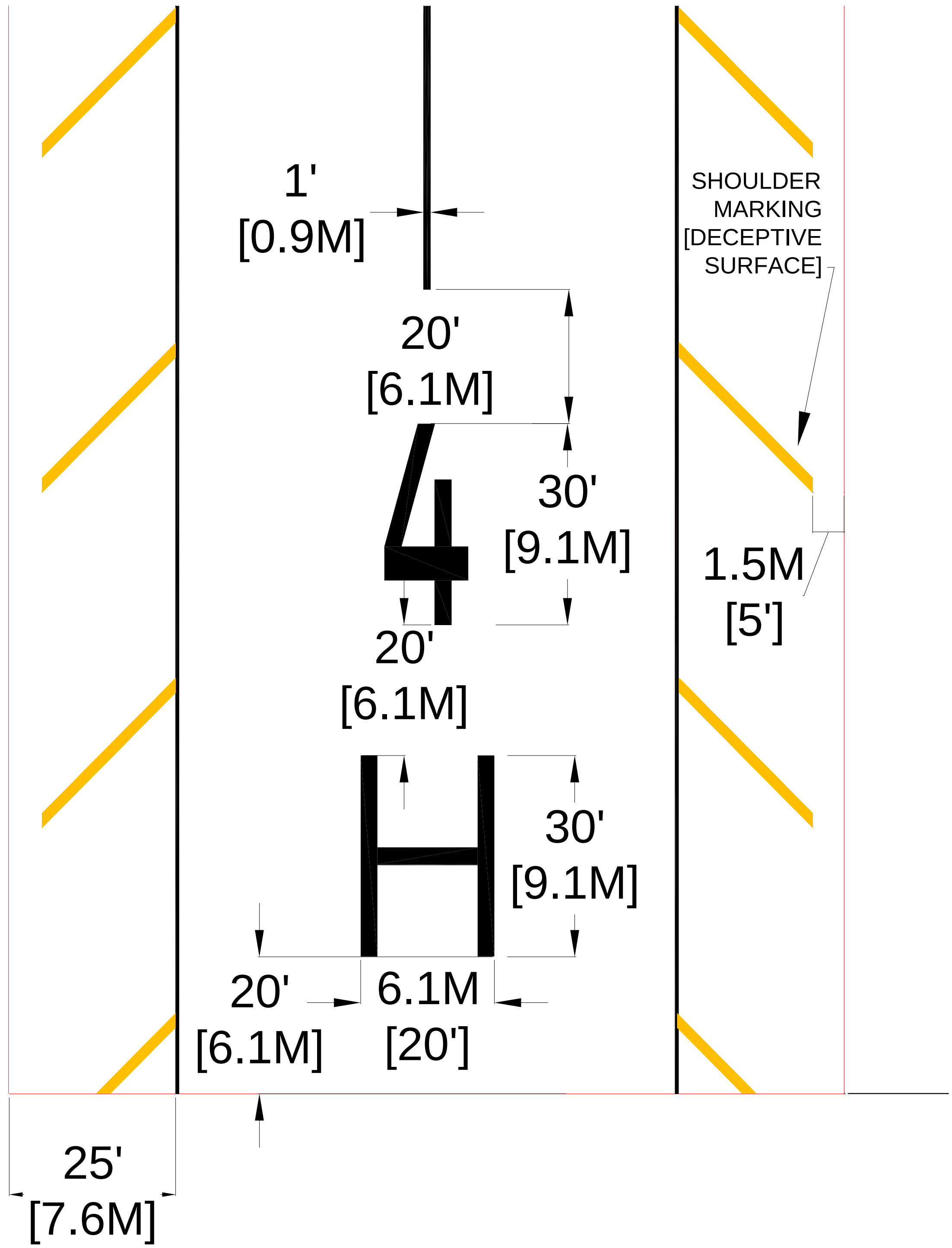
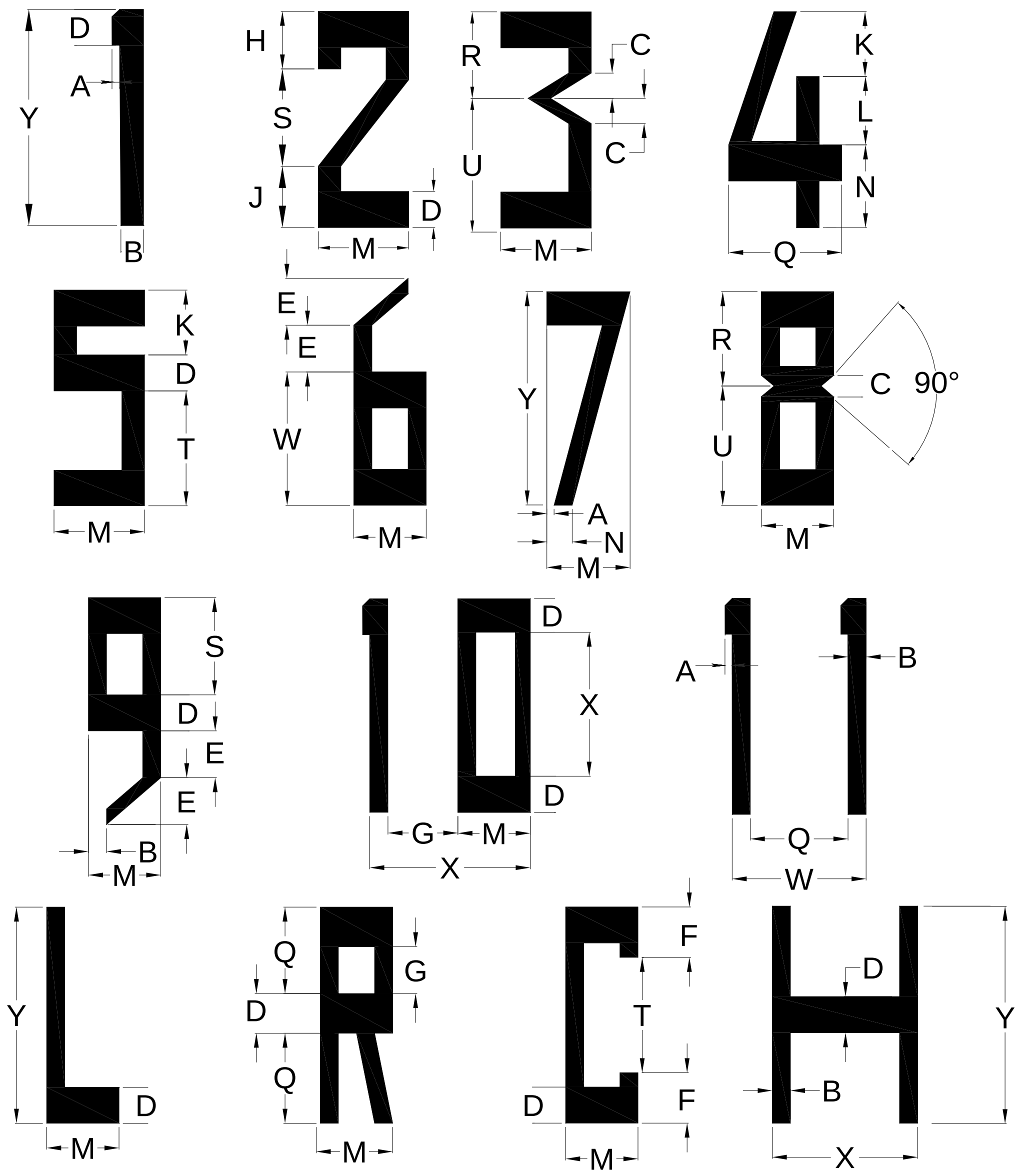


Figure 7-3. Rotary-Wing Runway Designation Numbers and Letters



DIMENSION	FEET	METERS	DIMENSION	FEET	METERS	DIMENSION	FEET	METERS
A	1	0.3	**J**	8.5	2.6	**R**	13	4.0
B	2.5	0.76	**K**	9	2.7	**S**	13.5	4.1
C	3.5	1.1	**L**	9.5	2.9	**T**	16	4.9
D	5.0	1.5	**M**	10	3.0	**U**	17	5.2
E	6.5	2.0	**N**	11.5	3.5	**V**	18	5.5
F	7.0	2.1	**O***	11	3.4	**W**	18.5	5.6
G	7.5	2.3	**P**	12	3.7	**X**	20	6.1
H	8.0	2.4	**Q**	12.5	3.8	**Y**	30	9.1

* Not used.

7-7 TAXIWAY MARKINGS.

7-7.1 Centerline Marking.

Marking on serviceable taxiways consists of a centerline stripe and a holding line configured the same as for fixed-wing runways (see Chapter 5). The centerline stripe is a solid retro-reflective yellow line 6 inches (152 millimeters) in width. Where a taxiway and a runway have a common intersection, the centerline marking of the taxiway terminates at a point in line with the inside edge of the runway as shown in Figure 7-4.

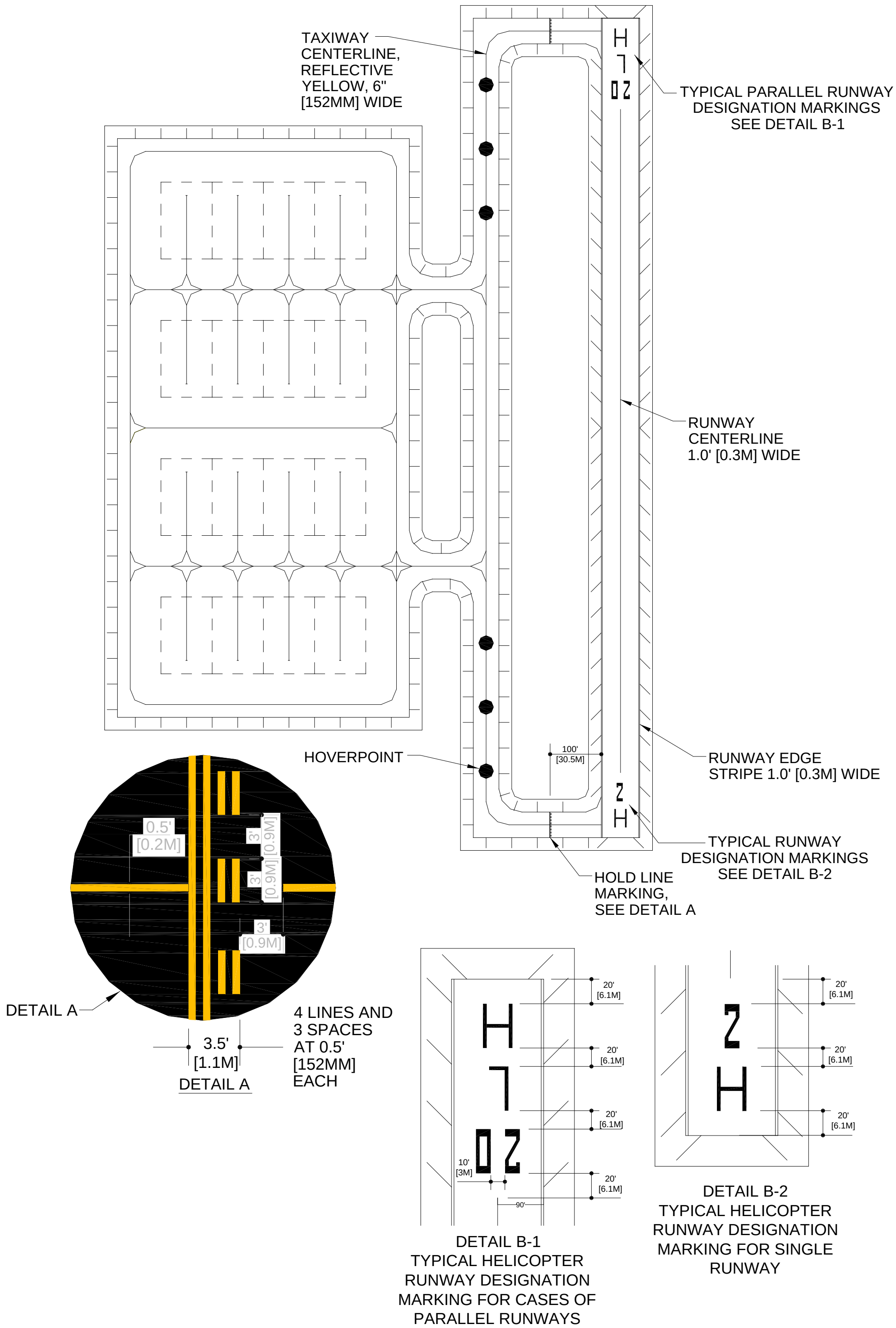
7-7.2 Hold-Line Marking.

Provide hold position markings at appropriate locations to protect against incursions. The hold-line marking for VFR conditions is shown in Detail "A" of Figure 7-4 and is located 100 feet (30.5 meters) from the near edge of the adjacent runway. Also mark an instrument hold marking for runways or helipads provided with IMC landing aids. See paragraph 6-5.1.2 to determine if an instrument hold position is needed, and, if so, where. If any taxiways enter the helipad in the normal direction of approach or departure, place a holding position marking outside the clear zone so there is no potential penetration of the approach departure clearance surface by holding aircraft. See UFC 3-260-01 for applicable dimensions and imaginary surface slopes.

7-8 HOVERPOINTS.

A hoverpoint is a surface used as a reference or control point for arriving and departing helicopters. Mark hoverpoints with a white circle 30 feet (9.1 meter) in diameter on class A airfields or heliports except when used for missile security or survival school or on asphalt surfaces where jet aircraft operate. On Class B airfields or Class A airfield/heliports used for missile security or survival school or on asphalt surfaces where jet aircraft operate, mark hoverpoints with a 30-foot (9.1-meter) -outside diameter circle formed with a 12-inch (305-millimeter) -wide white line. When located on a taxiway, the marking is centered on the taxiway centerline. See Figure 7-4.

Figure 7-4. Heliport Markings



7-9 APRON MARKINGS.

Apron taxi centerlines are a solid yellow line 6 inches (152 millimeters) in width. Rotary wing parking positions are marked with dashed white perimeter lines 6 inches (152 millimeters) in width, and centering guidelines are 6-inch [152-millimeter] -wide solid yellow as shown in Figures 7-12, 7-13, 7-14 and 7-15. Other apron markings such as apron edge markings, deceptive surface (shoulder) markings, and closed or hazardous area markings are as shown in Figure 7-11 and Chapter 8.

7-10 HELIPADS.

Mark a perimeter boundary with a capital "H" in the center to identify a pad intended for helicopter operations. Orient the “H” so it is aligned with the normal direction of approach (appears as an “H” to pilots during their approach to landing). If the facility is intended for single-direction ingress and egress, mark a bar beneath the “H” to show the intended direction of approach/departure. A bar is also placed under the “H” when it is necessary to distinguish the preferred approach direction for bi-directional helipads. The length of the bar is at least equal to the overall width of the “H” and the width equal to Dimension “C” in Figure 7-5. Provide a space between the “H” and the bar equal to half of the bar width. The perimeter boundary marking consists of a broken square marked at the corners and along the edges to delineate the limits of the safe touchdown area. The boundary is sized to accommodate the overall length of the largest helicopter using the facility. Figure 7-5 provides dimensions and layout details.

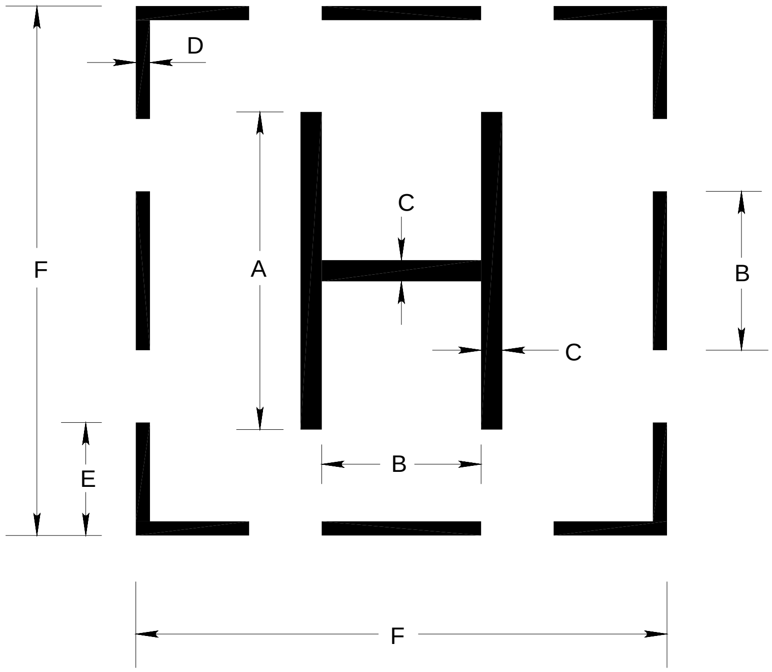
7-10.1 Hospital Helipad Markings.

Medical facility helipads are marked similarly to standard helipads, with the following exceptions: the perimeter border is formed of a solid line and bordered in red, and the letter "H" is marked in red and superimposed on a white cross. Figure 7-6 shows the dimensions and colors for this marking scheme. The cross and pad boundary markings are white and outlined with a 6-inch (152-millimeter) -wide red border to improve contrast. Pad boundary markings are either a solid or segmented line as shown in Figure 7-5.

7-10.2 Elevated Helipad Markings.

The markings are as shown in Figures 7-5 or 7-6, with two information boxes centered in the lower right-hand quadrant of the pad perimeter and oriented to be read in the preferred direction of ingress to the helipad. The boxes provide the maximum allowable helicopter weight expressed in thousands of pounds and the maximum allowable rotor diameter expressed in feet. Details for layout of the elevated helipad are shown in Figures 7-9 and 7-10.

Figure 7-5. Helipad Markings



IDENTIFIER DIMENSIONS

A : 0.6 F (maximum of 20 meters)

B : 0.5 A

HELIPAD SIZE (F)	PATTERN LINE WIDTH (C)	BORDER EDGE WIDTH (D)	CORNER EDGE LENGTH (E)
43.0 - 59 / 13.1 - 18.0	3.0 / 0.9	1.3 / 0.4	5.0 / 1.5
60.0 - 79.0 / 18.3 - 24.1	4.0 / 1.2	2.0 / 0.6	7.0 / 2.13
80.0 - 98.0 / 24.4 - 29.9	5.0 / 1.5	2.0 / 0.6	10 / 3.0
99 OR LARGER / 30.2 OR LARGER	6.5 / 2.0	2.5 / 0.8	11.5 / 3.5

NOTE:

1. DIMENSIONS IN TABLE ARE EXPRESSED AS; $\frac{\text{FEET}}{\text{METERS}}$ e.g. $\frac{3}{10}$
2. ALL COLOR IS NON-REFLECTIVE WHITE FOR U.S.ARMY FACILITIES, BUT RETRO-REFLECTIVE WHITE FOR USAF FACILITIES.

Figure 7-6. Hospital Helipad Markings

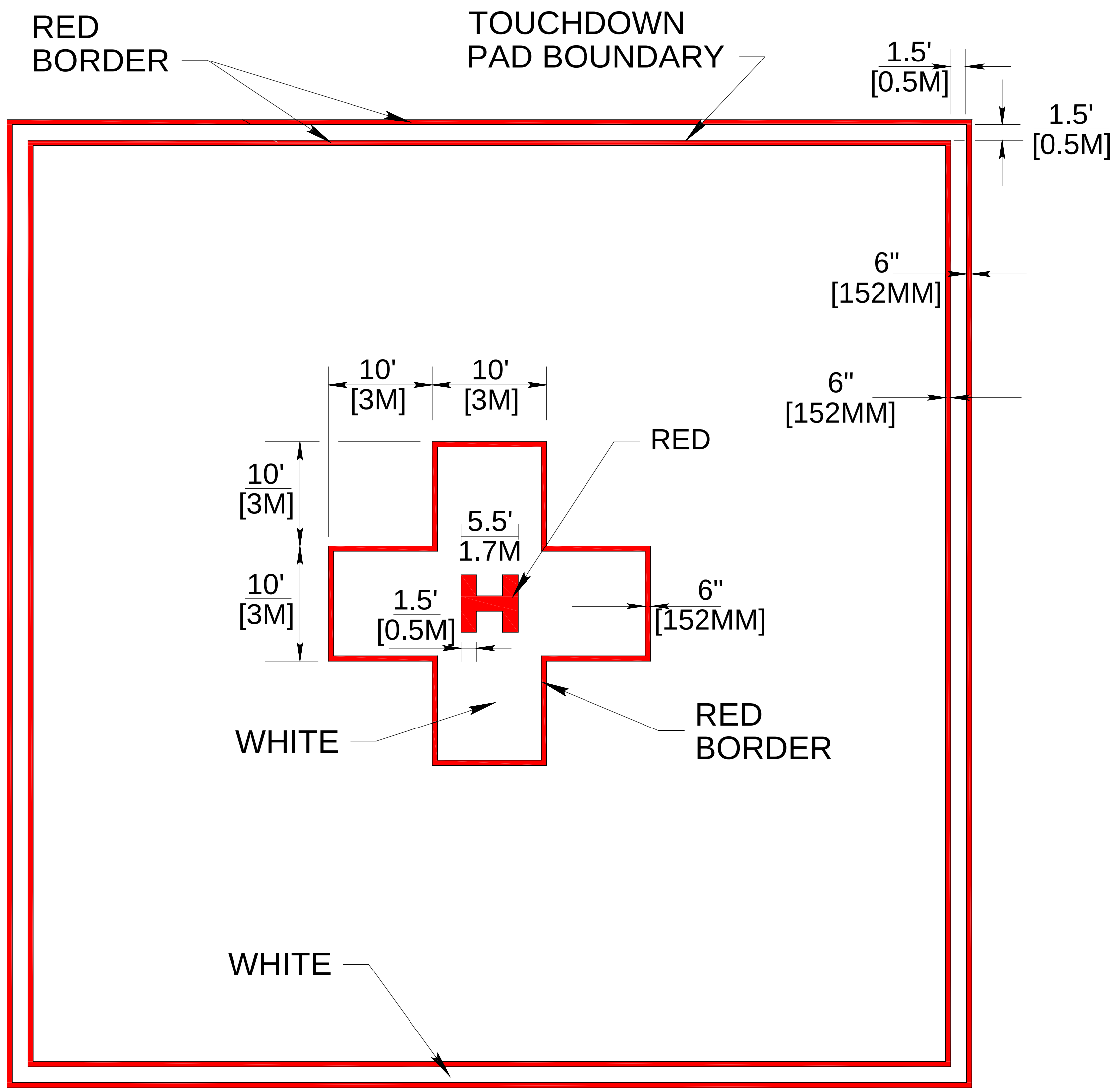


Figure 7-7. Landing Lane Layout

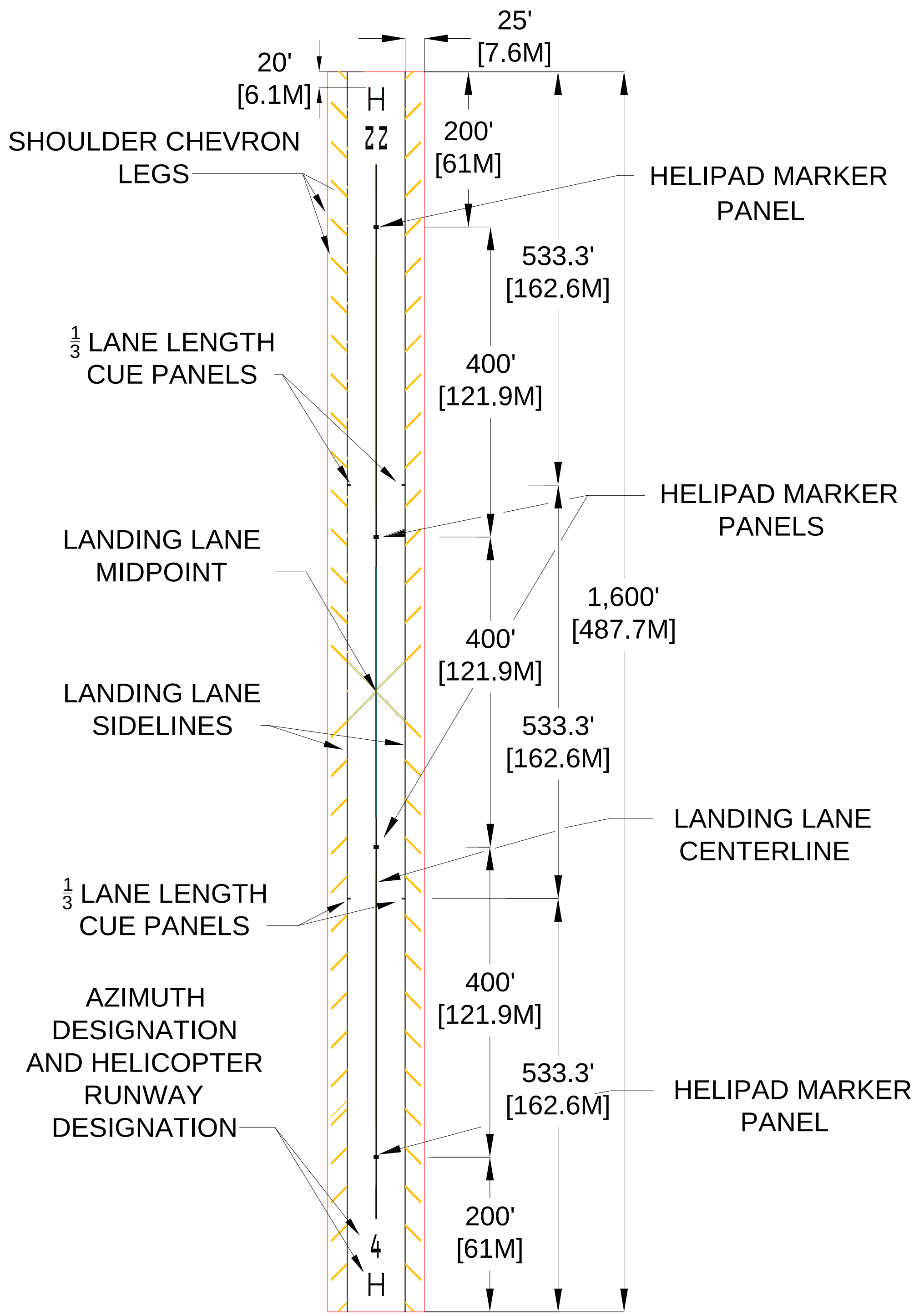


Figure 7-8. Landing Lane Helipad and 1/3rd Length Marker Panels

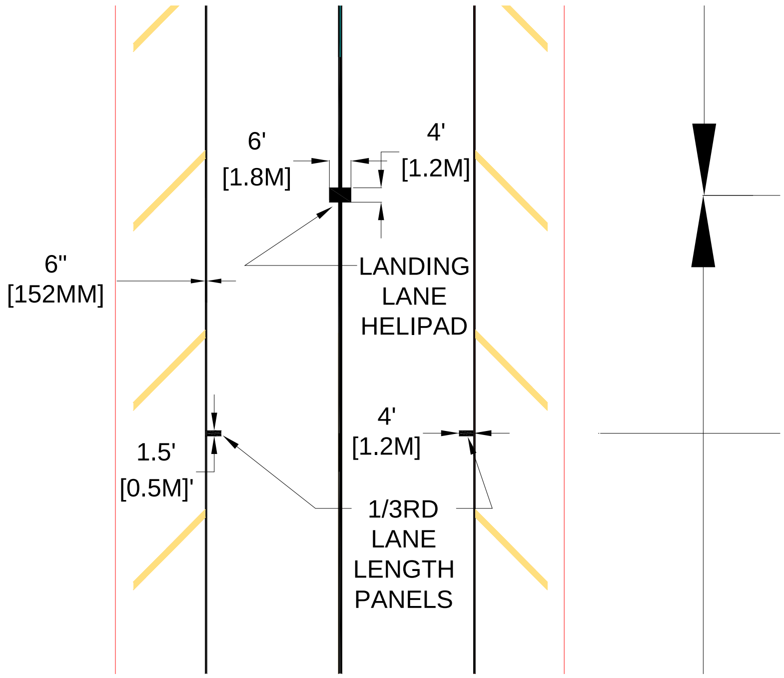


Figure 7-9. Elevated Helipad Example

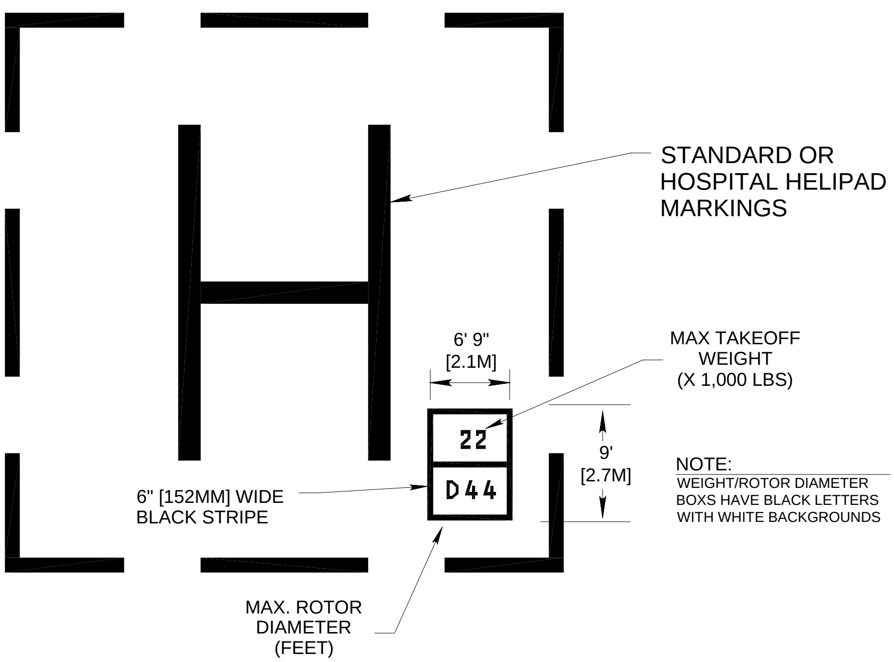
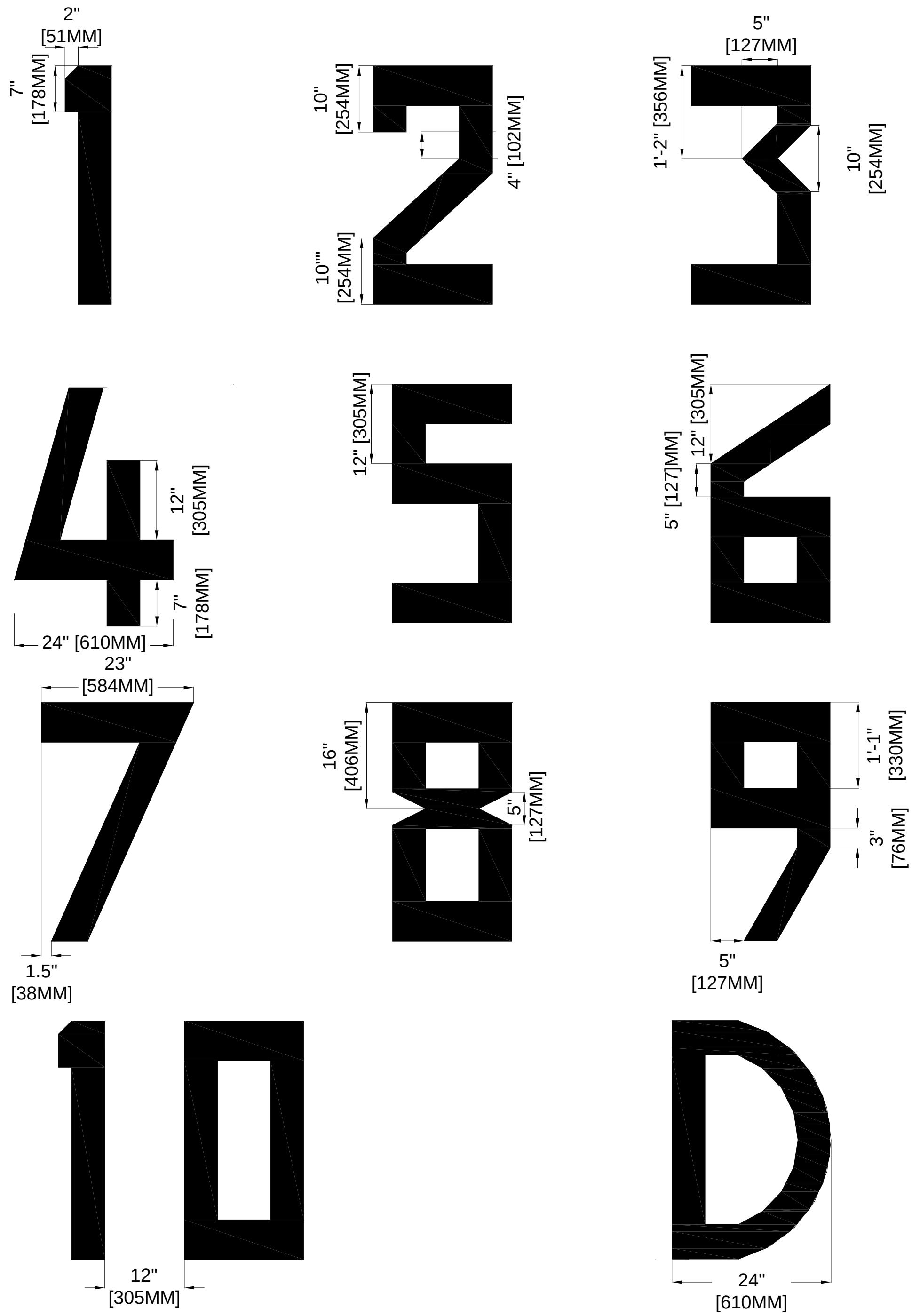


Figure 7-10. Dimensions for Supplemental Elevated Helipad Markings



ALL CHARACTERS HAVE THE FOLLOWING CHARACTERISTICS UNLESS SPECIFIED OTHERWISE:

36" [914MM] HEIGHT VERTICAL STROKE OF 5" [127MM]

18" [457MM] WIDTH HORIZONTAL STROKE OF 6" [152MM]

7-10.3 Application.

Rotary wing runway, landing lane, and helipad marking patterns, as appropriate, are used as an identification marker at all heliports, whether at ground level or elevated, and at helicopter takeoff and landing areas. All helicopter landing areas bearing the outdated day marker or nonstandard identification marking are re-marked with the proper identification marking as soon as practicable.

7-10.4 Location.

The appropriate markings are placed in the approximate center of the touchdown area of all helicopter landing pads and on the ends of all helicopter runways and landing lanes.

7-11 OVERRUNS AND SHOULDER MARKINGS.

7-11.1 General.

Overrun and shoulder areas not intended for aircraft traffic are identified with overrun chevrons and shoulder (deceptive surface) markings. These markings consist of lines 18 inches (457 millimeters) wide, marked to within 5 feet (1.5 meters) of the shoulder edge, or for a total length of 25 feet (7.6 meters), whichever is less, in accordance with the requirements below. Configurations complying with these requirements are detailed in Figure 7-11.

7-11.2 Color.

All heliport overrun and shoulder areas are marked with non-reflective yellow paint.

7-11.3 Materials.

Non-reflective paint used in marking or re-marking overrun and shoulder areas consists of any of the materials described in Chapter 3.

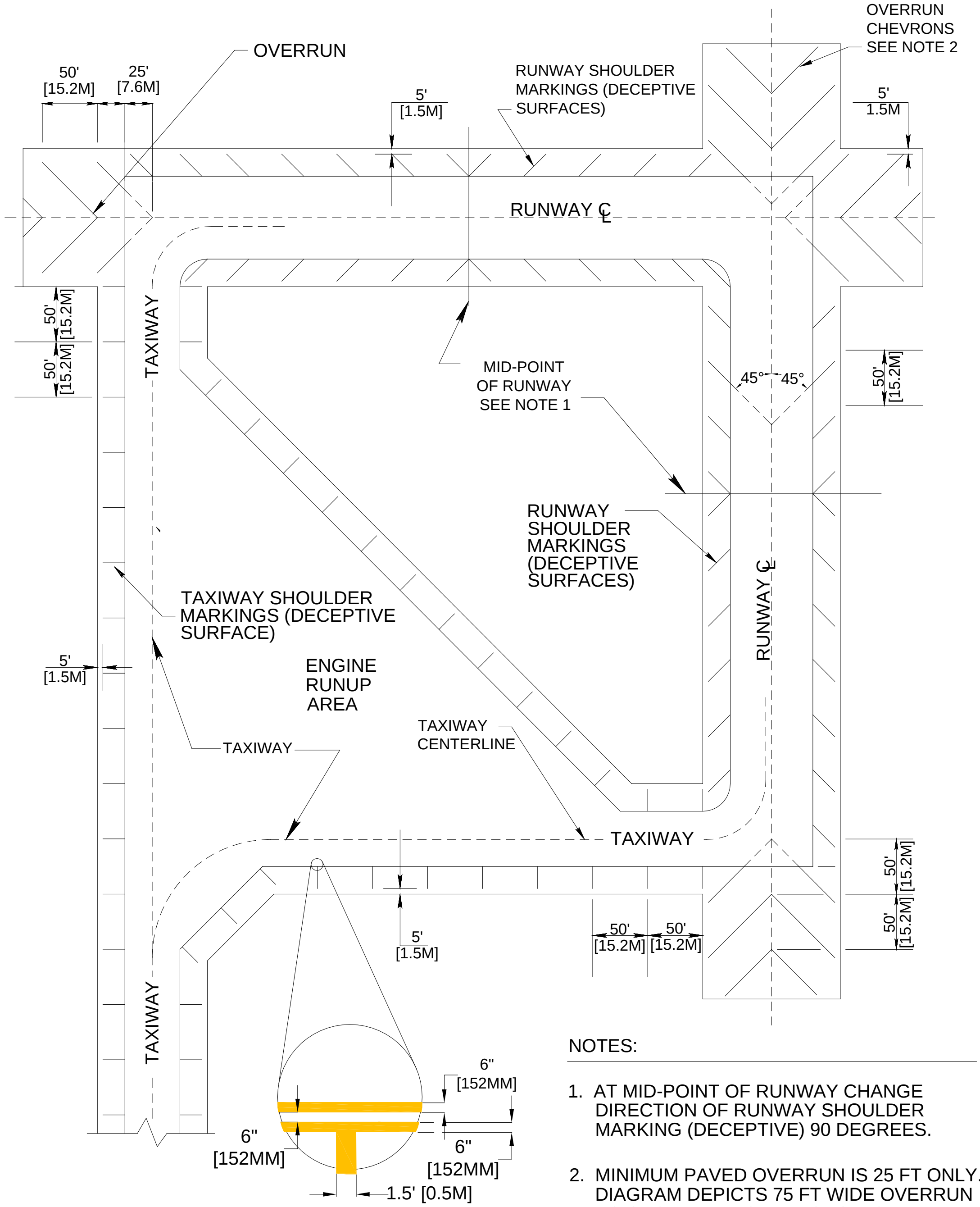
7-11.4 Overrun Areas.

Overrun areas are identified with a chevron marking layout as shown in Figure 7-11. The index point for the layout of the chevron marking is the point of intersection of the runway centerline and the runway threshold line. The apex of the first full chevron on the approach side of the threshold is placed 25 feet (7.6 meters) outward from the index point. Subsequent chevrons are placed on 50-foot (15.2-meter) centers as shown in Figure 7-11. The portion of the partial chevron that overlaps the threshold is not painted on the full-strength pavement. The apex of each chevron is on the centerline, with each leg intersecting at an angle of 45 degrees with the runway centerline, and an unmarked extension of the runway centerline. The chevrons terminate 5 feet (1.5 meters) inside the outer paved edge of the overrun.

7-11.5 Runway Shoulder Areas.

Shoulder areas are not intended for routine aircraft traffic. In cases where the surface does not provide sufficient differing contrast from the surrounding area, they are marked with shoulder (deceptive surface) markings as shown in Figure 7-11. Shoulder markings are a continuation of the chevron legs used in marking overrun areas described above. The chevrons used to form the legs are uniformly laid out from both ends of the runway as shown in Figure 7-11. Shoulder markings terminate at a length of 25 feet (7.6 meters) or at a point 5 feet (1.5 meters) inside the outer edge of the paved shoulder area.

Figure 7-11. Rotary Wing Overruns and Shoulder Markings

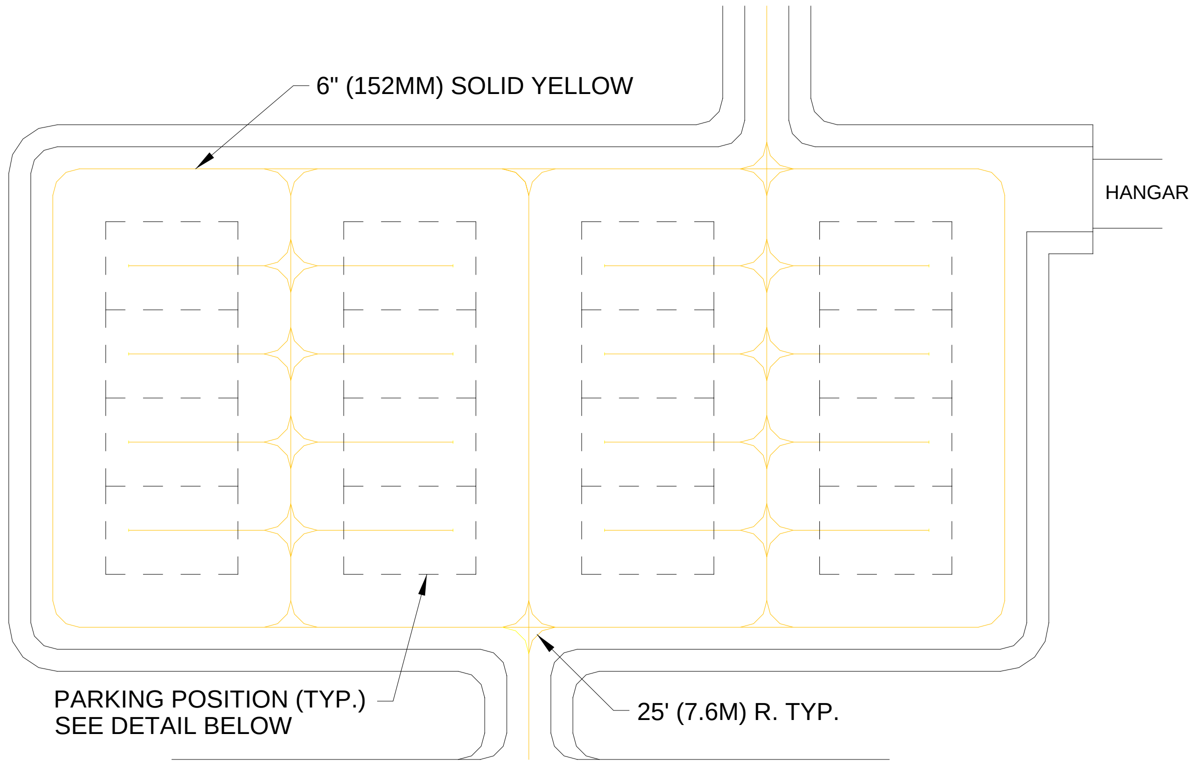


NOTES:

1. AT MID-POINT OF RUNWAY CHANGE DIRECTION OF RUNWAY SHOULDER MARKING (DECEPTIVE) 90 DEGREES.

2. MINIMUM PAVED OVERRUN IS 25 FT ONLY. DIAGRAM DEPICTS 75 FT WIDE OVERRUN TO SHOW THAT CHEVRONS WOULD BE REQUIRED AND SPACED 15.2M [50'] BETWEEN CHEVRONS FOR OVERRUNS LARGER THAN THE MINIMUM.

Figure 7-12. Type 1 Parking for CH-47



TYPE 1 PARKING FOR CH-47

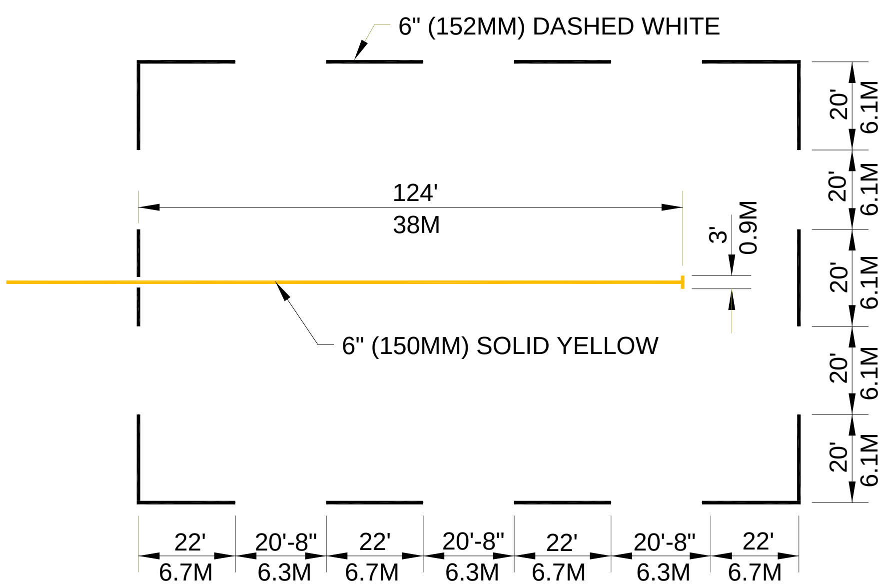
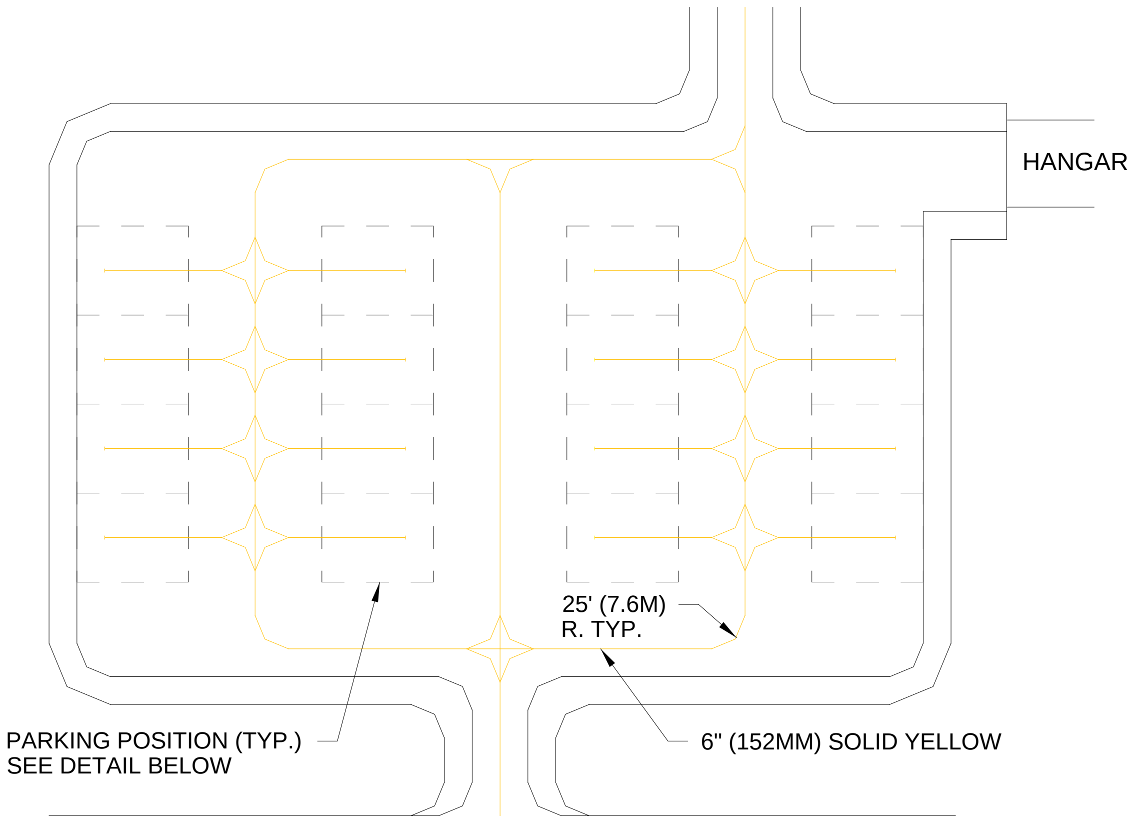
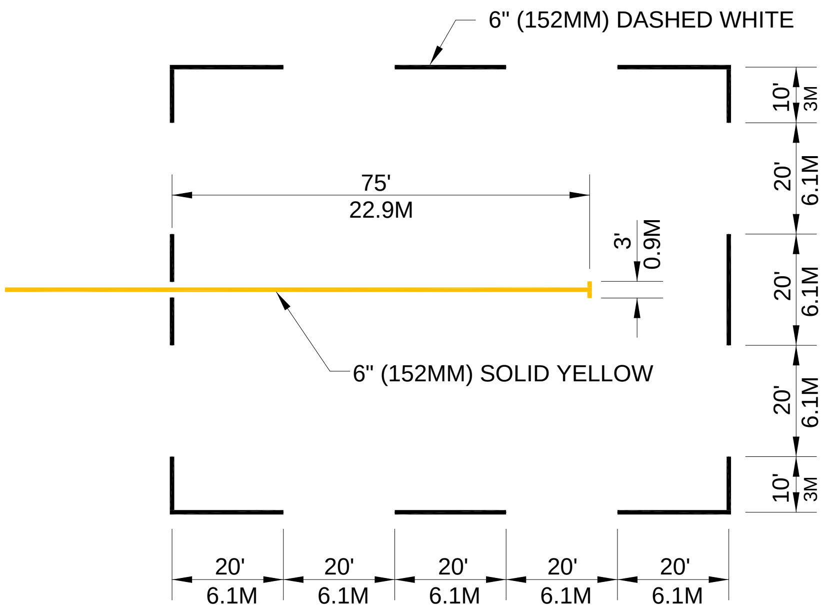


Figure 7-13. Type 1 Parking for all Rotary Wing Aircraft Except CH-47

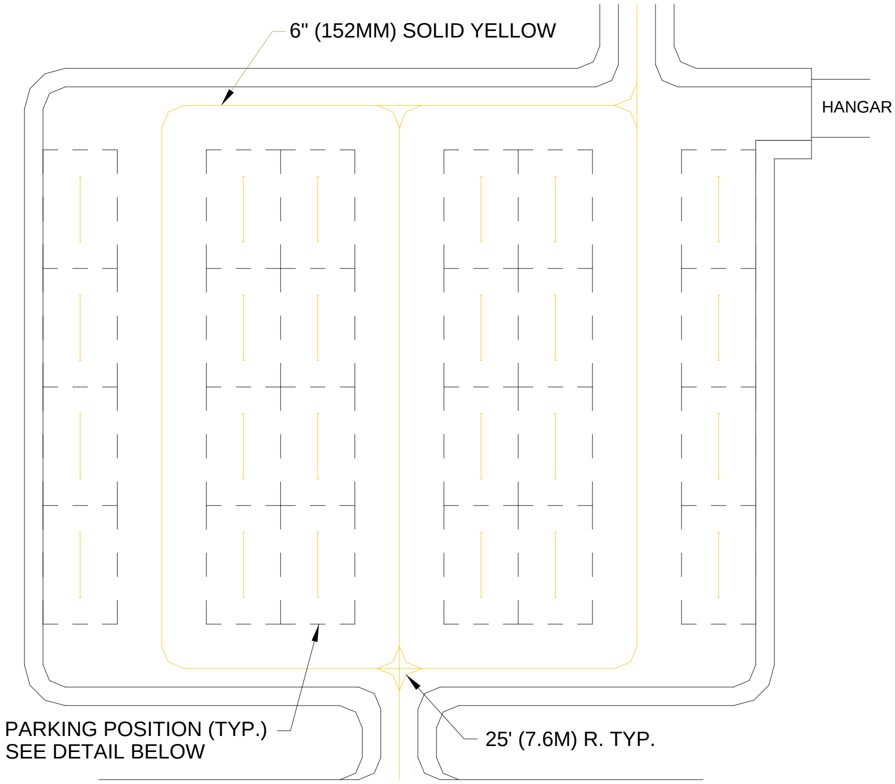


TYPE 1 PARKING FOR ALL ROTARY-WING AIRCRAFT EXCEPT CH-47

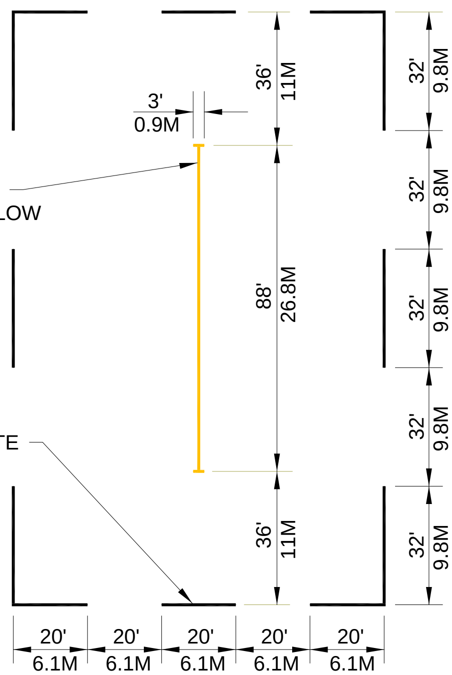


PARKING POSITION DETAIL

Figure 7-14. Type 2 Parking for Wheeled Rotary Wing Aircraft

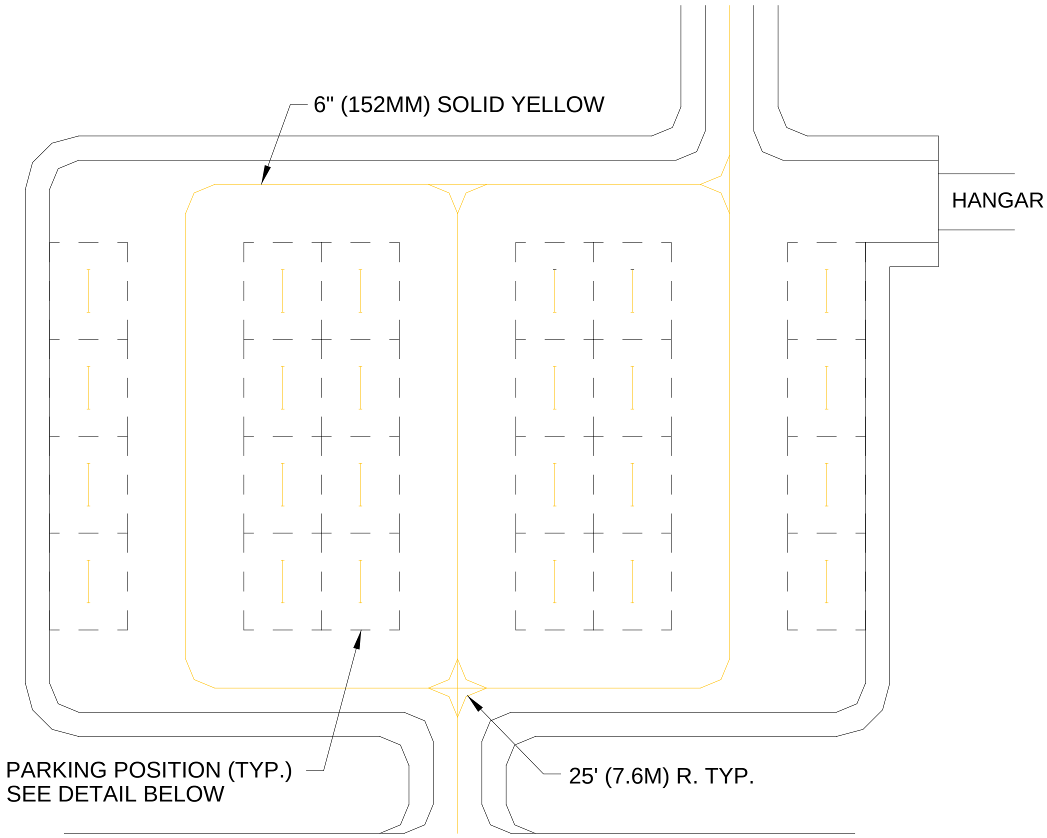


TYPE 2 PARKING FOR WHEELED ROTARY WING AIRCRAFT

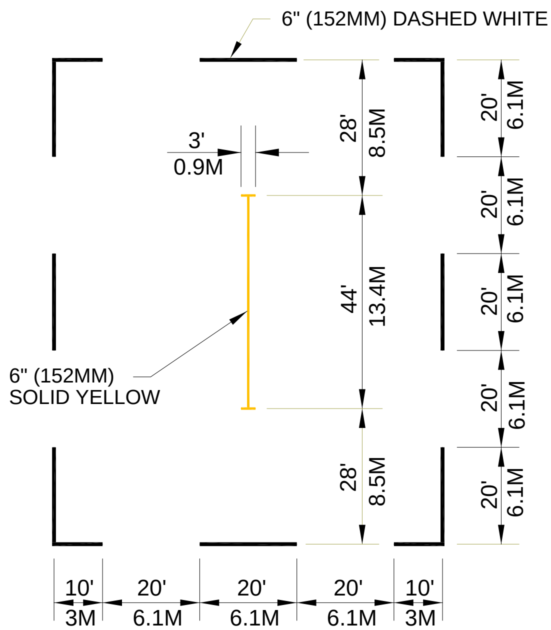


PARKING POSITION DETAIL

Figure 7-15. Type 2 Parking for Skid Rotary Wing Aircraft



TYPE 2 PARKING FOR SKID ROTARY-WING AIRCRAFT



PARKING POSITION DETAIL

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CHAPTER 8 OTHER PAVEMENT MARKINGS

8-1 CLOSED PAVEMENT MARKINGS.

All pavements that are hazardous to aircraft traffic are marked with Xs. Larger ones are used for runways. Smaller Xs, with a slightly different angle where the two legs intersect, are used for taxiways and apron areas. Additional cones, barricades, and lights are used, or sometimes substituted for the Xs, to aid in delineation of substantially hazardous areas, areas that are only hazardous during construction, or some other special project, such as an air show. Refer to Figure 8-1 and Figure 8-2 for dimensions and layout details. The following paragraphs describe the placement of these markings and alternatives for temporarily closed areas.

8-2 PERMANENTLY CLOSED RUNWAYS.

Closed runways are marked to reflect their non-operational status. Ensure markings are visible to aircrew to avoid confusion and prevent mishaps that occur from attempting operations from a pavement of unknown condition or status.

8-2.1 Runway Markings.

For permanently closed runways, obliterate the runway designation markings on both ends of the runway and mark a yellow “X” at each end of the runway and at 1,000-foot (305-meter) intervals along the length, centered on the runway centerline.

8-2.2 Intersections.

For permanently closed runways that intersect an active runway, a solid yellow “X” marking is placed on the closed runway centerline, not more than 50 feet (15.2 meters) from the center of the X to the near paved shoulder edge of the open intersecting runway. See Figure 8-2 for an example.

8-3 PERMANENTLY CLOSED TAXIWAYS OR TAXILANES.

Obliterate the centerline stripe for a minimum of 200 feet (61 meters) from the nearest edge of any serviceable pavement and mark the taxiway or taxilane with an "X" within 25 feet (7.6 meters) of every intersection with any other serviceable pavement (measured from near outer paved shoulder edge of serviceable pavement to the center of the X), and along the taxiway or taxilane centerline at evenly spaced intervals not exceeding 1,000 feet (304.8 meters). Refer to Figure 8-1 for the dimensions of the Xs and Figure 8-2 for a typical layout and placement examples. Additionally, obliterate all extraneous taxiway markings from the adjacent serviceable pavements. For example, remove or hide any line or directional information signs or other markings delineating a route from an active runway to a closed taxiway.

8-4 PERMANENTLY CLOSED APRONS.

When an apron is closed on an active airfield, taxilanes and taxiways leading to the closed area are marked as closed. If the closed apron area adjoins an active apron, supplemental markings are needed to indicate the division between the two areas. The separation is marked with two continuous apron edge stripes as described in Chapter 6 and shown in Figure 6-1. The letter "X," dimensioned as shown in Figure 8-1, is marked 3 feet (0.9 meter) inward toward the closed apron at intervals not exceeding 200 feet (61 meters) on the closed apron sides. Figure 8-3 shows the typical layout for these markings.

8-5 TEMPORARILY CLOSED AIRFIELD PAVEMENTS.

8-5.1 Temporarily Closed Runways.

Place an "X" at both ends of the runway on top of the runway designation number. For temporary purposes, the dimensions of the "X" shown in Figure 8-1 are reduced to allow use of standard 4-foot by 8-foot (1219-millimeter by 2438-millimeter) sheets of plywood. **Note:** Runways closed for periods of five days or less do not need to be marked if a NOTAM is issued to publicize the closure. When temporarily closing a runway, Fabricate the "X" from plywood, canvas, painted picket fence sections, preformed marking tape, or other materials, such as yellow snow fencing. Anchor these materials by any suitable means, such as mechanical screw or wedge-type anchors, or sandbags. Another alternative is using lighted Xs as described in FAA AC 150/5340-1 and FAA AC 150/5345-55.

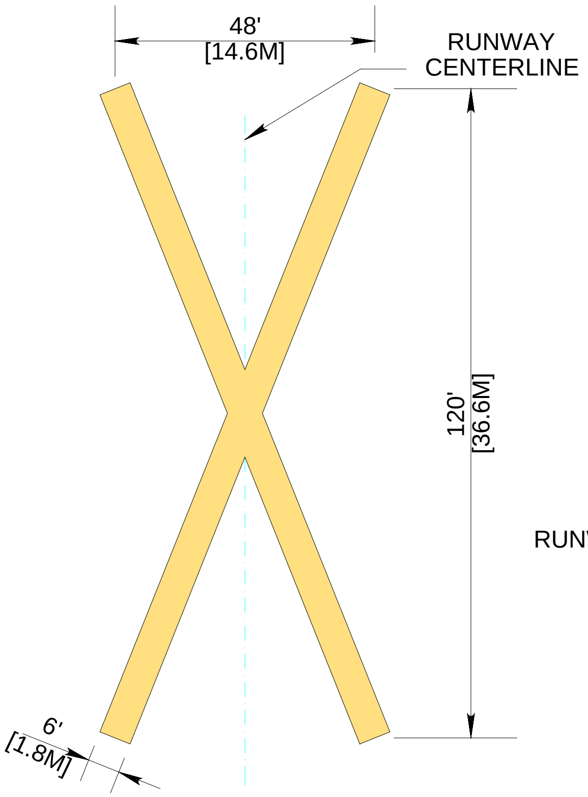
8-5.2 Temporarily Closed Taxiways or Taxilanes.

Ensure an "X" is placed at all access points to the closed pavement. In this case, it is not necessary to obliterate the existing markings. Areas used during periods of reduced visibility or darkness use lighted barricades to ensure the area is adequately marked. If lighted barricades are used to block the access point to the closed pavement, the "X" is omitted. See paragraph 8-6 and Figure 8-4. Use materials described in paragraph 8-5.1 to construct and fasten markers to the pavement.

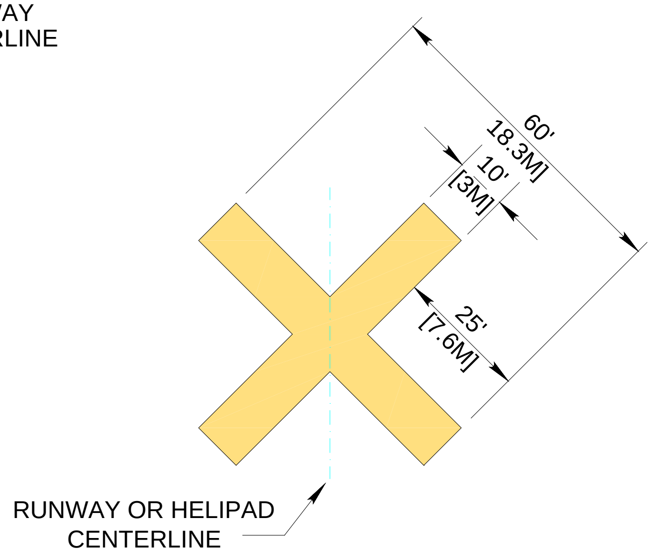
8-5.3 Temporarily Closed Aprons.

When an apron is closed on an active airfield, taxilane and taxiway centerline markings leading to the closed area are removed. However, hazardous areas on aprons caused by construction or other activities of a temporary nature are delineated using barricades or traffic cones equipped with a red light (see Figure 8-4). The lights are optionally steady burning or flashing but ensure they meet the luminance requirements of the FHWA MUTCD for safety zones. Lights are mounted on barricades and spaced at no more than 10-foot (3-meter) intervals. Lights are operated between sunset and sunrise and during periods of low visibility during operations. They are operated by photocell or manually. Solar-powered lights and light-emitting diode (LED) lights are acceptable as long as they meet the above-stated requirements.

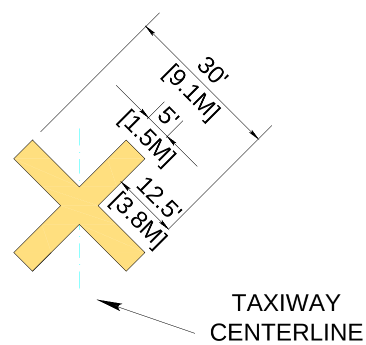
Figure 8-1. Runway, Taxiway, and Apron Area Closure Markings



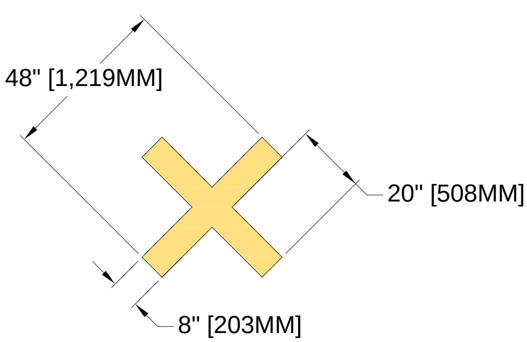
CLOSED RUNWAY
(PREFERRED)



CLOSED ROTARY OR FIXED
WING RUNWAY OR HELIPAD



CLOSED TAXIWAY

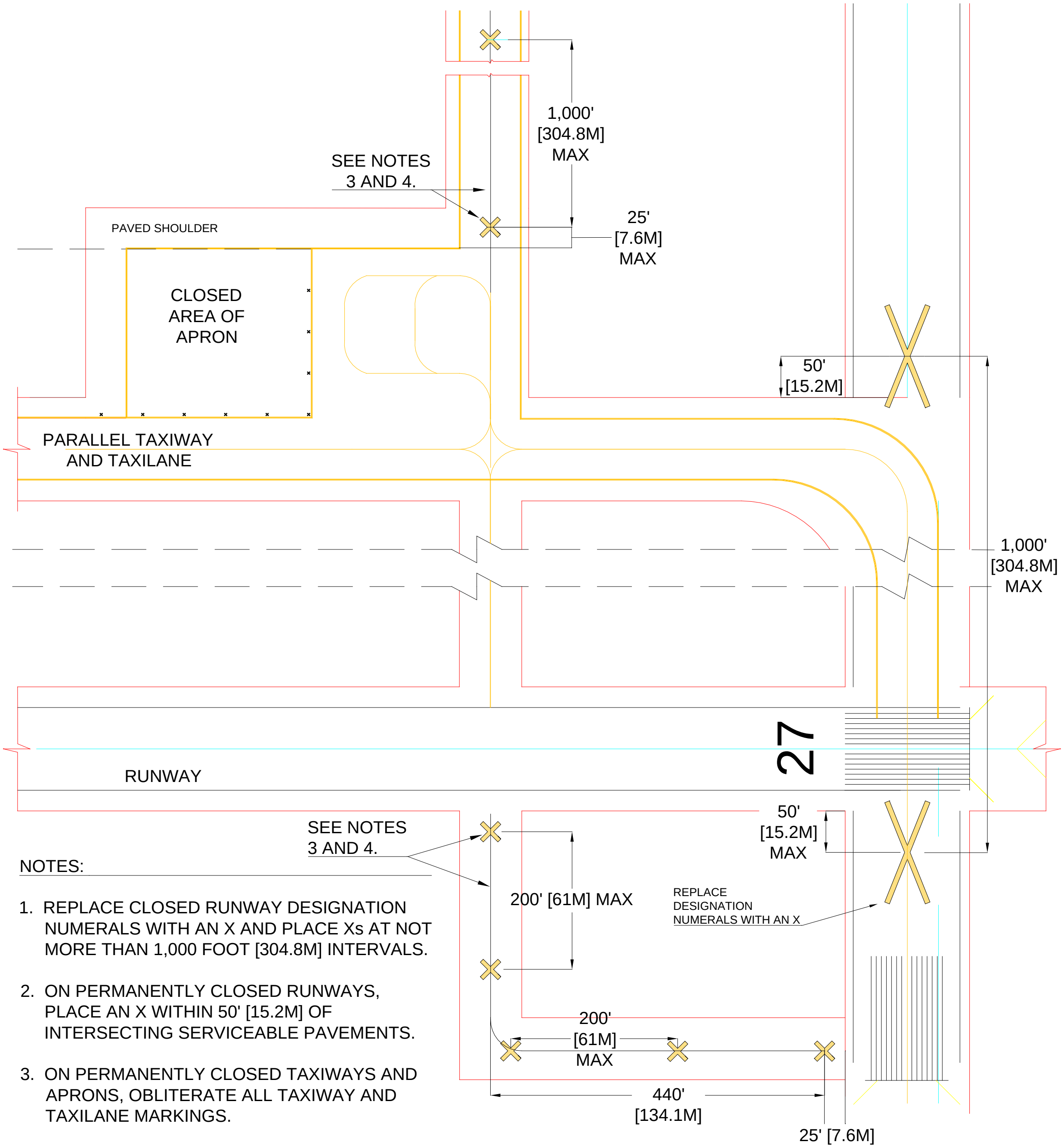


CLOSED APRON BOUNDARY X
(NOT DRAWN TO SCALE)

NOTES:

1. NON-REFLECTIVE YELLOW IS USED FOR CLOSED MARKINGS. REFLECTIVE Xs ARE RECOMMENDED WHEN USED ON AIRFIELDS WHERE OTHER AREAS ARE AVAILABLE FOR NORMAL OPERATIONS.
2. DIMENSIONS ARE SHOWN AS: $\frac{\text{FEET}}{\text{METERS}}$ E.G. $\frac{10}{3}$ EXCEPT WITHIN THE DIAGRAM FOR THE APRON BOUNDARY X.

Figure 8-2. Closed Runway, Taxiway, and Taxilane Pavement Markings



NOTES:

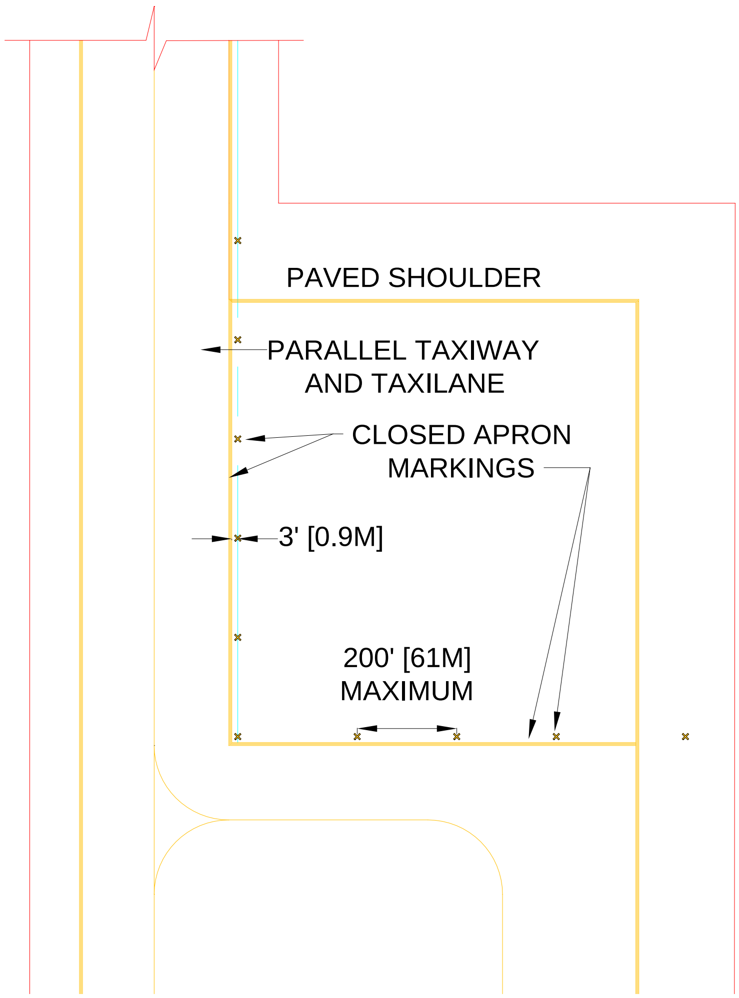
1. REPLACE CLOSED RUNWAY DESIGNATION NUMERALS WITH AN X AND PLACE Xs AT NOT MORE THAN 1,000 FOOT [304.8M] INTERVALS.

2. ON PERMANENTLY CLOSED RUNWAYS, PLACE AN X WITHIN 50' [15.2M] OF INTERSECTING SERVICEABLE PAVEMENTS.

3. ON PERMANENTLY CLOSED TAXIWAYS AND APRONS, OBLITERATE ALL TAXIWAY AND TAXILANE MARKINGS.

4. ON PERMANENTLY CLOSED TAXIWAYS AND APRONS, PLACE AN X WITHIN 25 FEET [7.6M] OF INTERSECTIONS WITH OTHER SERVICEABLE PAVEMENTS AND AT INTERVALS OF NOT MORE THAN 1,000' [304.8M].

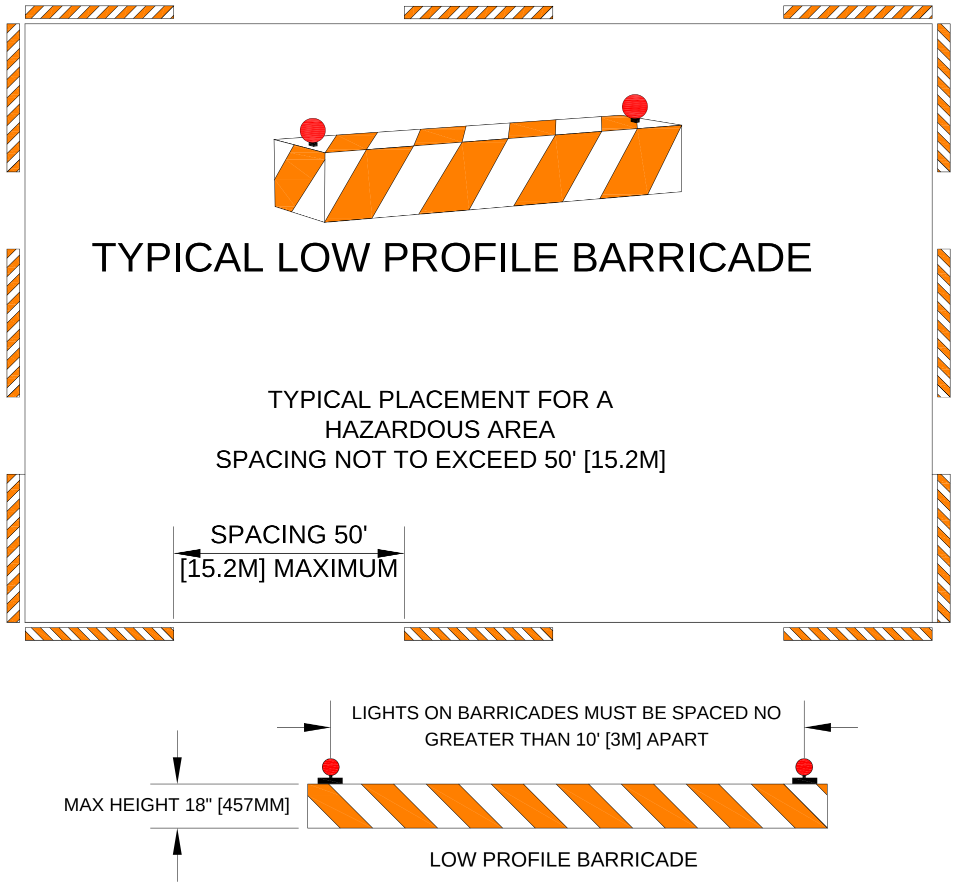
Figure 8-3. Placement of Permanently Closed Apron Pavement Markings



8-6 BARRICADES.

Where pavement markings do not provide adequate definitions of closed or hazardous areas, supplement the markings using retro-reflective orange and white barricades or traffic cones with securely fastened red lights aligned toward aircraft and vehicle ground traffic. All barricades and traffic cones are anchored or weighted to be heavy enough to remain in place during aircraft operations in near proximity. Ensure flashing lights are at least five candelas effective intensity and flash at a rate of from 55 to 160 flashes per minute. Ensure continuous burning lights have an effective intensity of 10 candelas. Low-profile barricades are the preferred method for marking construction areas. Examples are shown in Figure 8-4. Ensure lighted barricades used in close proximity to each other are all of the same type and colors. If flashing lights are used, ensure they have the same flash rates. Place barricades at maximum intervals of 50 feet (15.2 meters) and use dual barricades and lights on each corner and at the ends.

Figure 8-4. Low Profile Barricades



NOTES:

1. BARRICADES MAY NOT EXCEED 18" [457MM} IN HEIGHT(EXCLUSIVE OF SUPPLEMENTARY LIGHTS AND FLAGS) AND SHOULD BE SPACED TO PREVENT BREACH, BUT IN NO CASE GREATER THAN 50' [15.2M] APART. THEY MUST BE OF LOW MASS; EASILY COLLAPSIBLE UPON CONTACT WITH AN AIRCRAFT; AND WEIGHTED OR STURDILY ATTACHED TO THE SURFACE TO PREVENT DISPLACEMENT FROM JET BLAST OR OTHER WIND DISTURBANCE.
2. THE REQUIRED LIGHTS MUST BE RED AND MAY EITHER BE STEADY BURNING OR FLASHING. INTENSITIES AND LUMINANCE MUST BE AT LEAST FIVE CANDELAS EFFECTIVE INTENSITY AND FLASH AT A RATE OF FROM 55 TO 160 FLASHES PER MINUTE.
3. HAZARD LIGHTS MAY NOT BE SPACED GREATER THAN 10' [3M] APART.
4. LIGHTS MUST BE OPERATED BETWEEN SUNSET AND SUNRISE AND DURING PERIODS OF LOW VISIBILITY WHENEVER THE AIRPORT IS OPEN FOR OPERATIONS.
5. BARRICADES MAY BE SUPPLEMENTED WITH ALTERNATING ORANGE AND WHITE FLAGS AT LEAST 20" BY 20" (508MM BY 508MM) SQUARE.

8-7 NON-MOVEMENT AREA BOUNDARY MARKING.

Non-movement area boundary markings are used to delineate the air traffic or ground radio-controlled movement area from the non-controlled movement area. This marking is used only when there is a need specified in the AOI or the letter of agreement between the airport operator and airport traffic control tower since they are sometimes misinterpreted as a holding position marking.

8-7.1 Location.

Locate the non-movement area boundary marking on the boundary between the movement and non-movement area. To avoid confusing this marking with a VFR hold or intermediate hold position, do not place this marking to coincide with the edge of a taxiway.

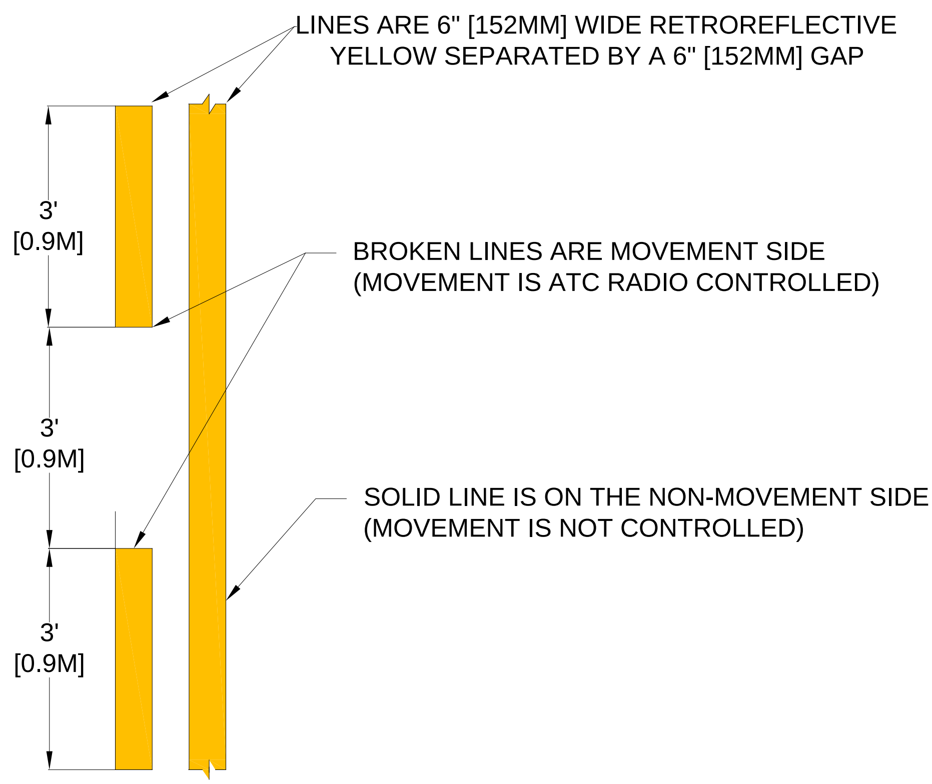
8-7.2 Layout.

The non-movement area boundary marking consists of two retro-reflective yellow lines, one solid and one dashed, as shown in Figure 8-5. The solid yellow line is located on the non-movement (or non-radio controlled) area side; the dashed yellow line is located on the movement (air traffic control/ground control-supervised and radio-controlled) area side. Each line is 6 inches (152 millimeters) in width, with a 6-inch (152-millimeter) gap between the lines. The width of the lines and spaces are optionally doubled to 12 inches (305 millimeters). The dashes are 3 feet (0.9 meter) in length with a 3-foot (0.9-meter) gap between dashes. If a taxiway centerline intersects a non-movement area boundary marking, the taxiway centerline is interrupted 6 inches (152 millimeters) from the solid line (movement area side) and 3 feet (0.9 meter) from the dashed line (non-movement area) side.

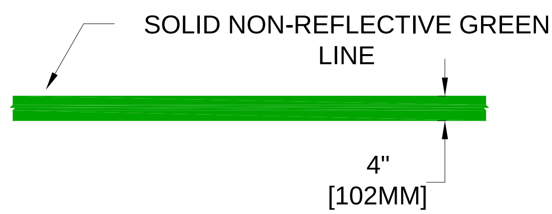
8-8 OBSTRUCTION CLEARANCE LINE.

On Class A airfields, heliports, or aprons servicing only rotary wing aircraft, and where needed, an obstruction clearance line is marked to delineate an apron lateral clearance area as defined by UFC 3-260-01. The line is placed to prevent fixed and mobile objects (e.g., maintenance vehicles, equipment, and storage bins) from being located where they encroach into the required apron lateral clearance distance. The obstruction clearance line consists of a single solid green non-reflective line 4 inches (102 millimeters) wide. The obstruction clearance line is not painted within the usable portion of the apron or on portions of the airfield traversed by aircraft under their own power such as runways, vertical landing pads, helipads, overruns, hoverpoints, taxiways, taxi-lanes, warm-up pads, arm/de-arm pads, hot cargo pads, hot refueling areas, forward arming and refueling pads, compass calibration pads, trim pads, engine run-up or engine check pads; however, it might be painted at or near hangar entrances and exits. See Figure 8-5 for obstruction clearance line details. An obstruction clearance line is not required at installations which ensure the apron lateral clear areas are accessed only by personnel trained on proper placement and movement of equipment, materials, and structures on active airfield pavements and which do not bring or leave such materials, equipment, or structures unattended or without informing the airfield managers and controllers and restricting aircraft movement in the area.

Figure 8-5. Non-Movement Area Boundary and Obstruction Clearance Line Markings



NON-MOVEMENT AREA MARKING



OBSTRUCTION CLEARANCE LINE

8-9 DECEPTIVE SURFACES (SHOULDER MARKINGS).

Shoulders and other areas of airfield pavements that are not intended for aircraft traffic but have the appearance of operational pavement are marked as deceptive surfaces. Use deceptive surface markings when the paved shoulder width exceeds the standard dimension given in UFC 3-260-01 or if experience shows there is a lack of definition between the full-strength pavement and shoulders. **Note:** If there is a significant gap between the deceptive surface markings and the runway side stripe (such as occurs when side stripes are spaced at a 144-foot [43.9-meter] separation on a 300-foot [91.4-meter] -wide runway), double 6-inch (152-millimeter) -wide yellow stripes separated by a 6-inch (152-millimeter) -wide gap are optionally added to the inner ends of the deceptive surface markings to longitudinally delineate the limit of the load-bearing pavement. Place the outer edge of the outermost stripe to coincide with the outer edge of the full-strength pavement and the inner end of the deceptive surface marking. These stripes are curved to follow the outer radius of fillets and terminated at the intersecting taxiway edge, or joined to taxiway edge markings, where used.

8-10 RUNWAY SHOULDERS.

Mark deceptive surfaces on the edges of runways with diagonal stripes as shown in Figure 8-6. The stripes are uniformly laid out from each end of the runway to the midpoint, reversing direction at the midpoint. Begin the measurement for spacing at the initial overrun chevron apex. Stripes are located so the inner edge of the marking is coincident with the edge of the full-strength pavement and the stripe extends to within 5 feet (1.5 meters) of the outer pavement edge or for a length of 25 feet (7.6 meters), whichever results in the shorter length line.

8-11 TAXIWAY AND APRON SHOULDERS.

Mark deceptive surfaces on the edges of taxiways and aprons with perpendicular stripes as shown in Figure 8-7. These markings consist of a series of 3-foot (0.9-meter) -wide stripes positioned perpendicular to the edge markings. On curves, a stripe is placed at each point of tangency and intermediate stripes are spaced uniformly up to 30 feet (9.1 meters) apart. Stripes are placed so the inner edge of the marking is coincident with the edge of the full-strength pavement.

8-12 VEHICULAR ACCESS MARKING.

Mark vehicular access routes according to the FHWA MUTCD. Additionally, ensure all vehicular access roads leading to a movement area or taxiway/taxilane are marked with a white "stop" bar. See paragraph 4.5.

8-13 INERTIAL NAVIGATION SYSTEM (INS) CHECKPOINT MARKINGS.

INS checkpoint markings are provided to allow data input or calibration of the aircraft INS. Contrasting colors are used for the border, numerals, and letters. A record of actual coordinates is normally maintained by base operations flight data, transient alert, and maintenance control. Figure 8-8 shows a typical layout scheme. Suggested locations are nose wheel parking spots on aprons and ramps; engine run-up areas adjacent to runway ends; hammerheads; or taxiway and apron holding positions. **Note:** For Air Force installations, survey support for NAVAIDs and INS checkpoints are coordinated with base and MAJCOM mapping, charting, and geodesy offices, according to AFI 14-205.

8-14 GROUND RECEIVER CHECKPOINT MARKINGS.

Identify instrument navigation checkpoint markings such as VHF omni range (VOR) and tactical air navigation (TACAN) markings as shown in Figure 8-8. Where directional alignment of the aircraft is required, paint a 6-inch (152-millimeter) -wide line through the center of the circle that extends outside the circle aligned toward the transmitter. Terminate the line with an arrowhead. Black or white paint is used to contrast this marking, as required. If the checkpoint marking conflicts with a taxiway centerline, interrupt the taxiway centerline 3 feet (0.9 meter) on either side of the checkpoint marking. A supplemental sign is required for the checkpoint marking; see UFC 3-535-01 for size, lettering, and placement. **Note:** For Air Force installations, survey support for NAVAIDs and INS points are coordinated with base and MAJCOM mapping, charting, and geodesy offices, according to AFI 14-205.

Figure 8-6. Runway Shoulder Markings (Deceptive Surfaces)

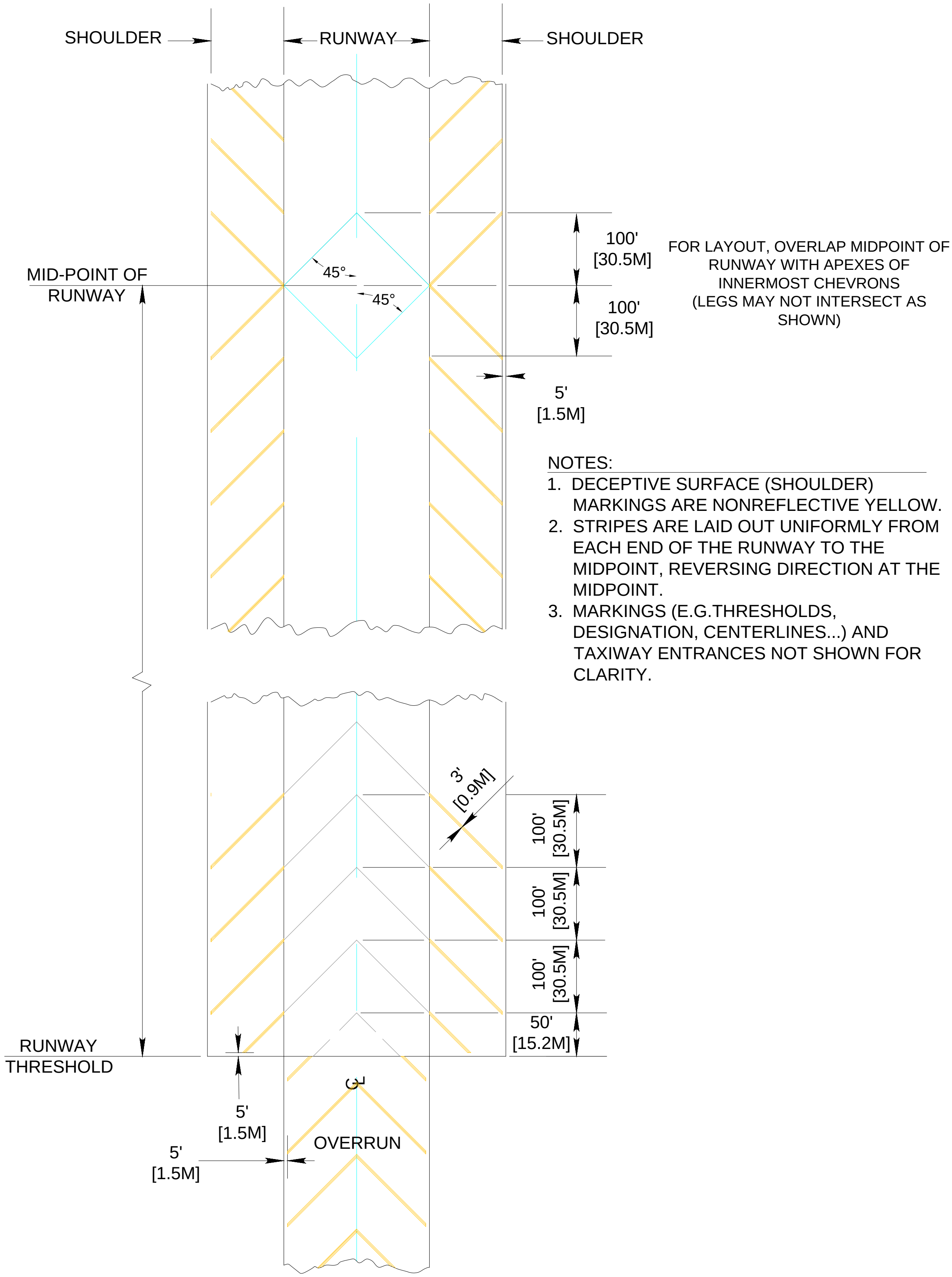


Figure 8-7. Taxiway and Apron Shoulder Markings (Deceptive Surfaces)

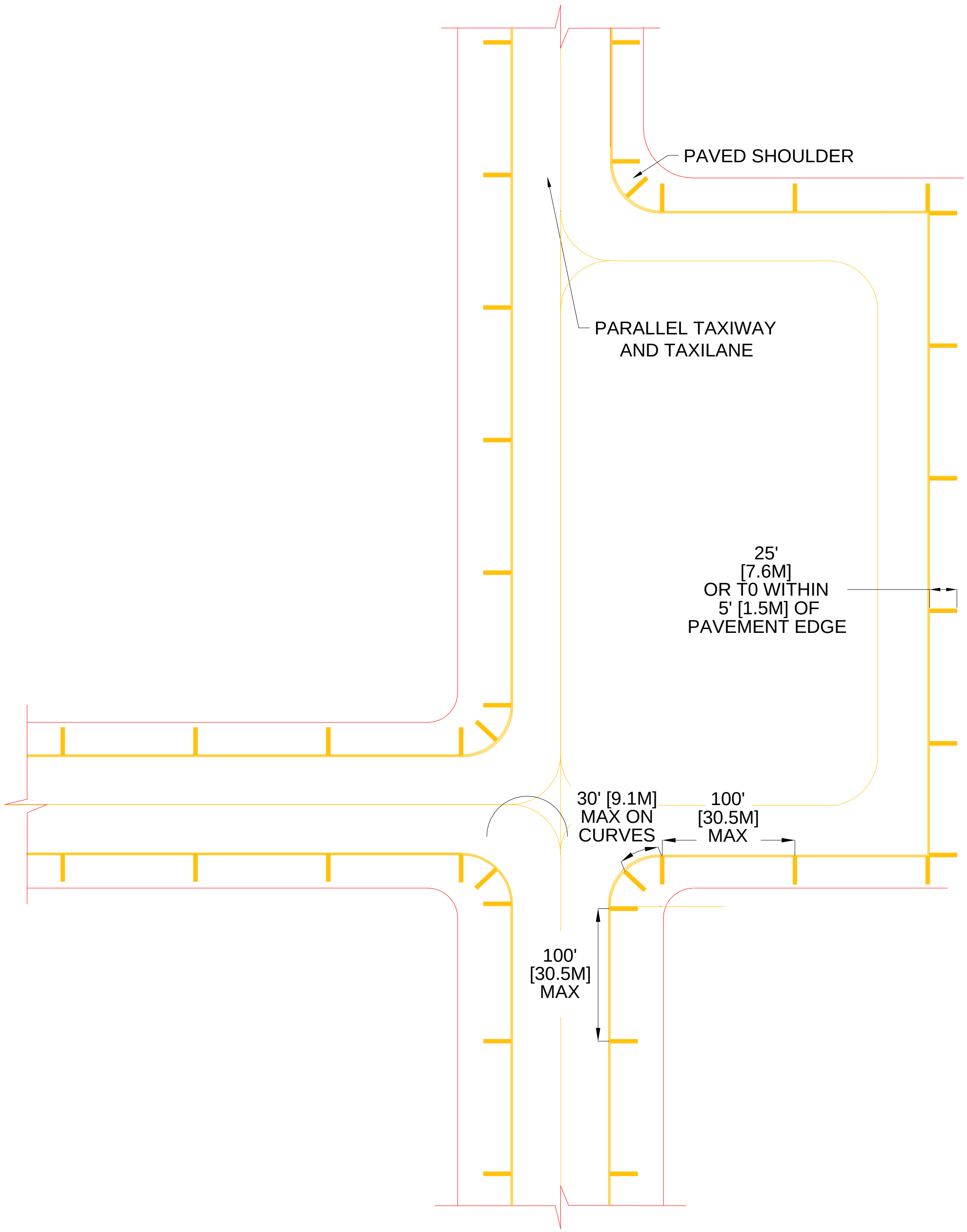
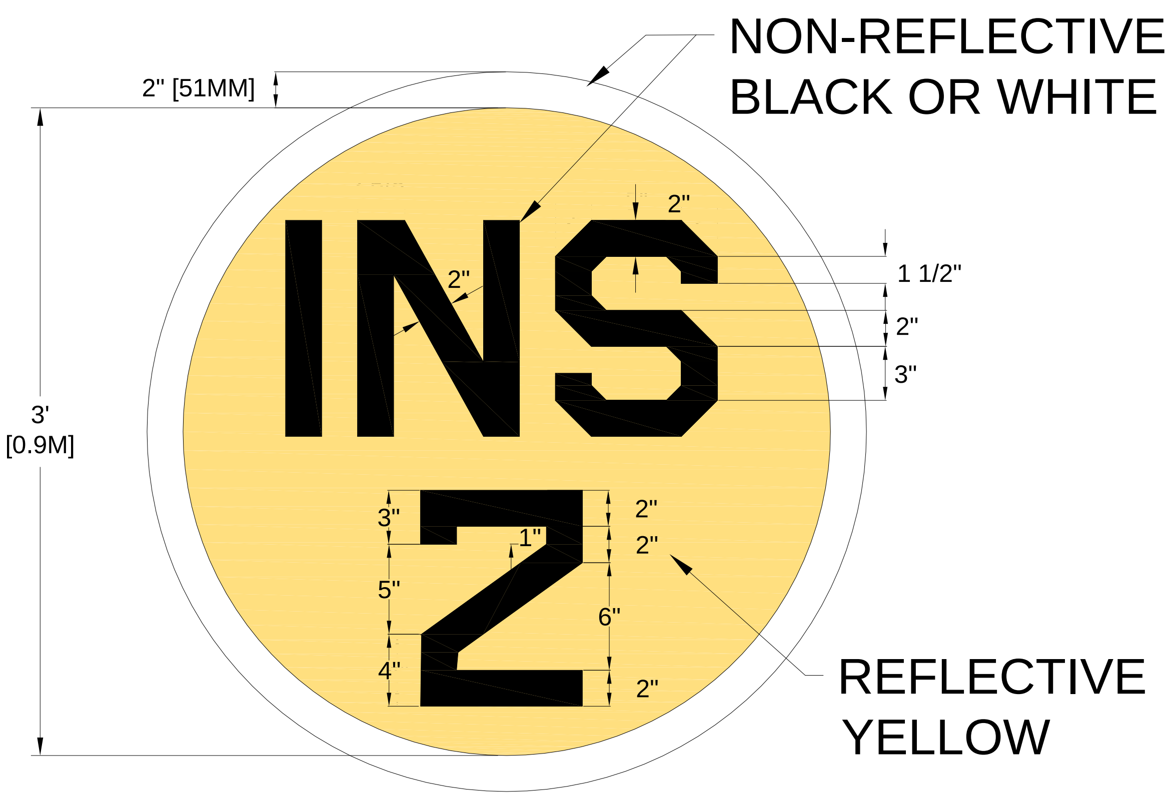
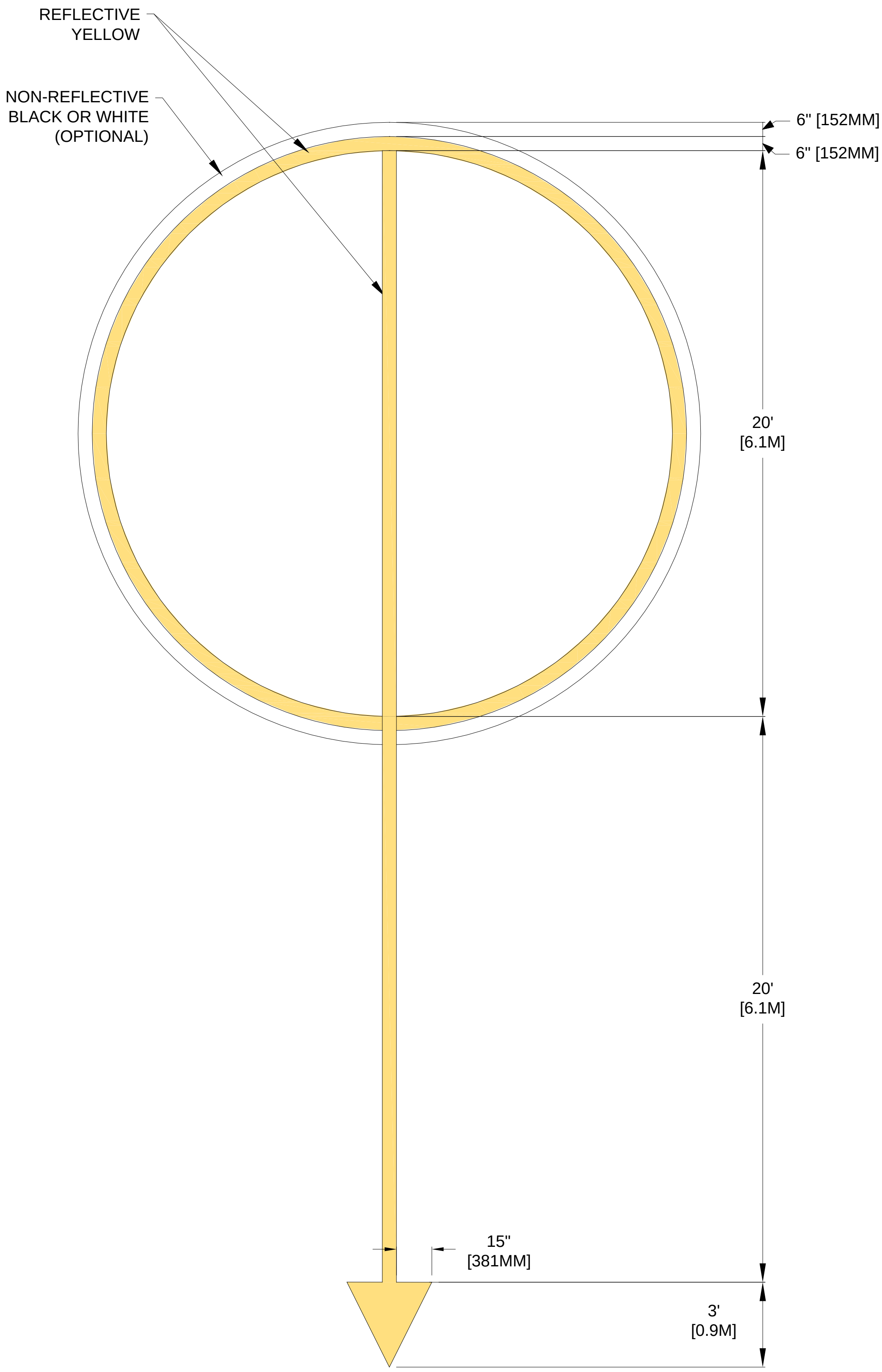


Figure 8-8. Typical Inertial Navigation System Marking



MULTIPLY BY 25.4 TO CONVERT INCHES TO MILLIMETERS

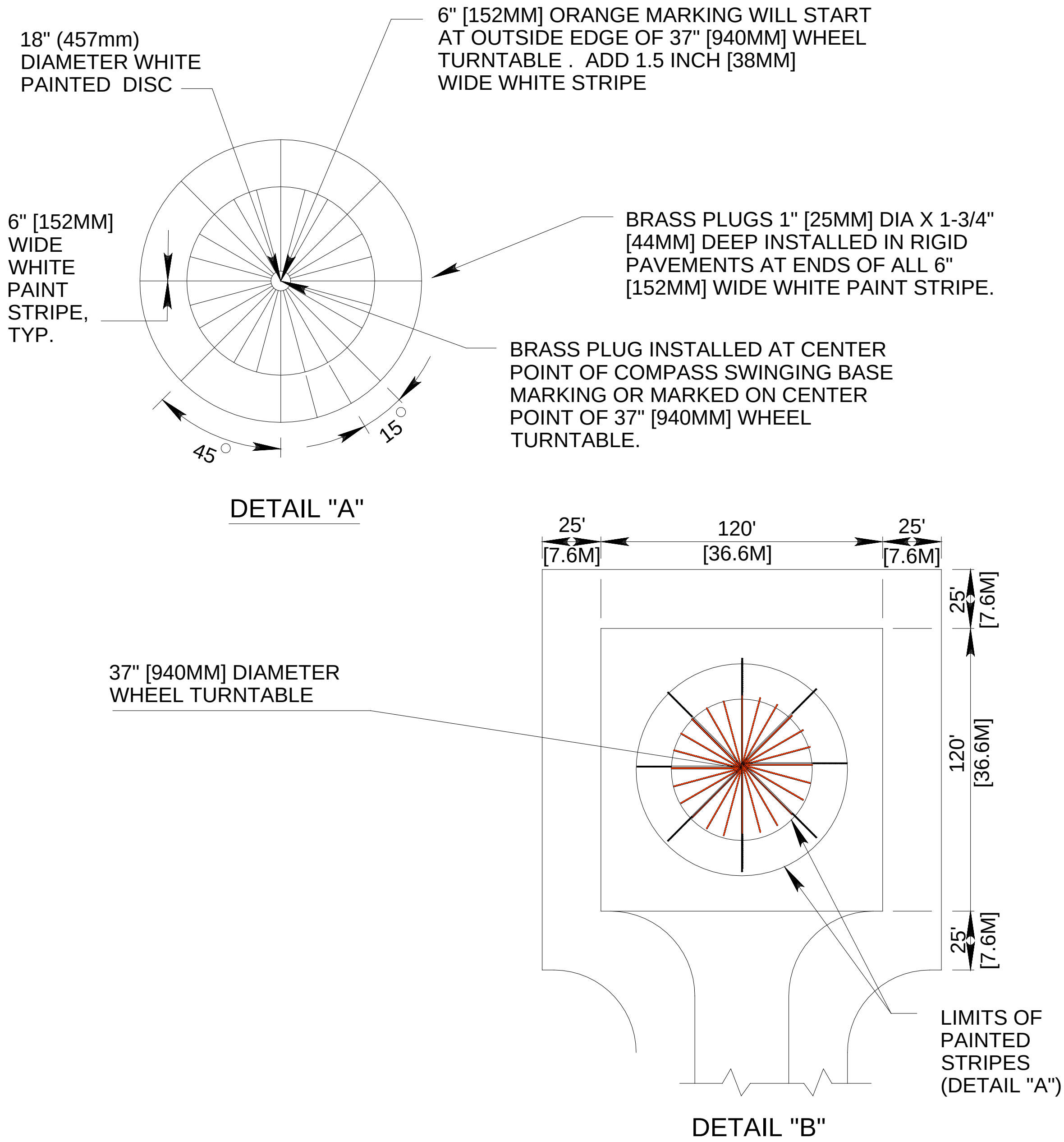
Figure 8-9. Ground Receiver Checkpoint (Directional)



8-15 COMPASS CALIBRATION PAD (CCP) MARKINGS.

Compass swinging bases are established in accordance with UFC 3-260-01, Chapter 6 and Appendix B10. Mark CCPs in accordance with the applicable aircraft maintenance Technical Order (T.O.), considering primarily the most demanding aircraft that are serviced on the apron. If aircraft are serviced which do not require a specific marking within the T.O., optionally use either the more restrictive criteria provided in UFC 3-260-01 and described below or the general guidelines for compass calibration pads in FAA AC 150/5300-13 for Class B airfields; otherwise, use the criteria described below. Swinging bases for aligning aircraft for the precise calibration of all types of air navigation equipment are marked as shown in Figures 8-10 and 8-11. The stripes are set at magnetic directions from the corresponding true compass rose control point at every 15 degrees (15°). A 6-inch (152-millimeter) -wide orange stripe is painted for each of the 24 compass rose control points. These stripes begin at the center of the pad and extend outward for a minimum length of 25 feet (7.6 meters). Border each stripe with a 1.5-inch (38-millimeter) -wide white stripe. At a distance of 27 feet (8.2 meters) from the center of the pad, identify the azimuth of each stripe as measured from magnetic north with 24-inch (610-millimeter) -high by 15-inch (381-millimeter) -wide orange block numerals (Figure 8-11). All azimuth numbers contain three numerals (e.g., 045). The stroke of each numeral is a minimum of 3.5 inches (89 millimeters) wide. Each azimuth number is painted on a solid white background formed from a rectangle 26 inches (660 millimeters) high by 51 inches (1,295 millimeters) wide.

Figure 8-10. Compass Calibration Pad Markings

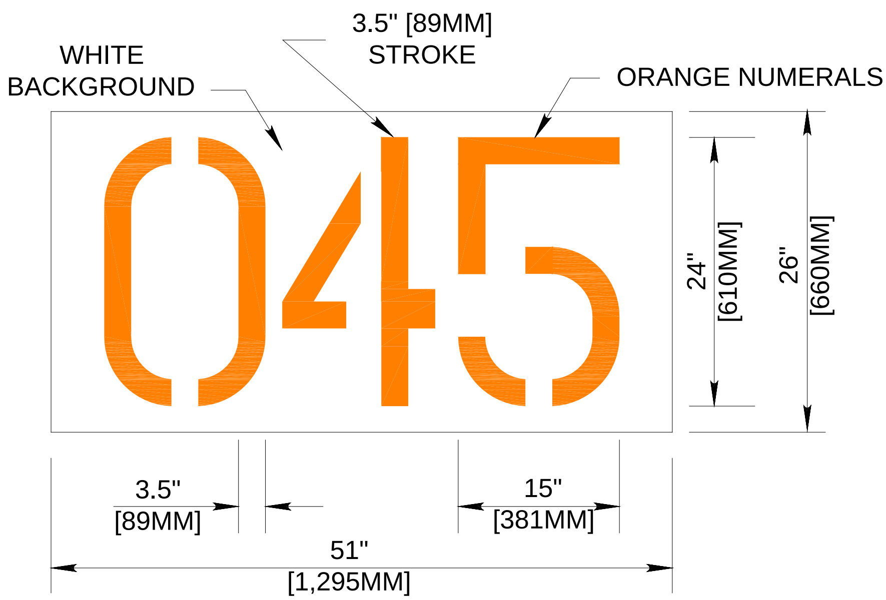


NOTES:

1. UNITS ARE EXPRESSED AS $\frac{\text{FEET}}{\text{METERS}}$ (e.g. $\frac{10}{3}$).

2. SEE UFC 3-260-01 FOR SURVEY REQUIREMENTS AND UFC 3-260-02 FOR PAVEMENT AND SUBGRADE DESIGN REQUIREMENTS.

Figure 8-11. Compass Calibration Pad Numerals



8-16 T-6 PROPELLER HAZARD PAVEMENT MARKINGS.

In an effort to reduce the hazard caused by T-6 propellers, T-6 parking positions are marked in accordance with Figure 8-12.

8-17 F-16 ENGINE INLET DANGER AREA PAVEMENT MARKINGS.

In an effort to reduce the hazard caused by F-16 engine inlet suction, F-16 parking positions are optionally marked in accordance with Figure 8-13; however, aircraft maintenance personnel determine whether the radius is established at 15 feet (4.6 meters) for idle thrust or 25 feet (7.6 meters) for mil-thrust.

8-18 HYDRANT FUEL PIT LID MARKING.

If needed to alert pilots, vehicle operators, or maintenance personnel, hydrant fuel pit covers and/or adjacent pavement is optionally marked as shown in Figure 8-14. In areas where snow is not a factor, these pits do not necessarily require markings of this type.

8-19 STATIC GROUND MARKINGS.

See UFC 3-575-01, *Lightning and Static Electricity Protection Systems,* and Army Techniques Publication (ATP) 4-43, *Petroleum Supply Operations*, for static grounding, testing, and marking requirements.

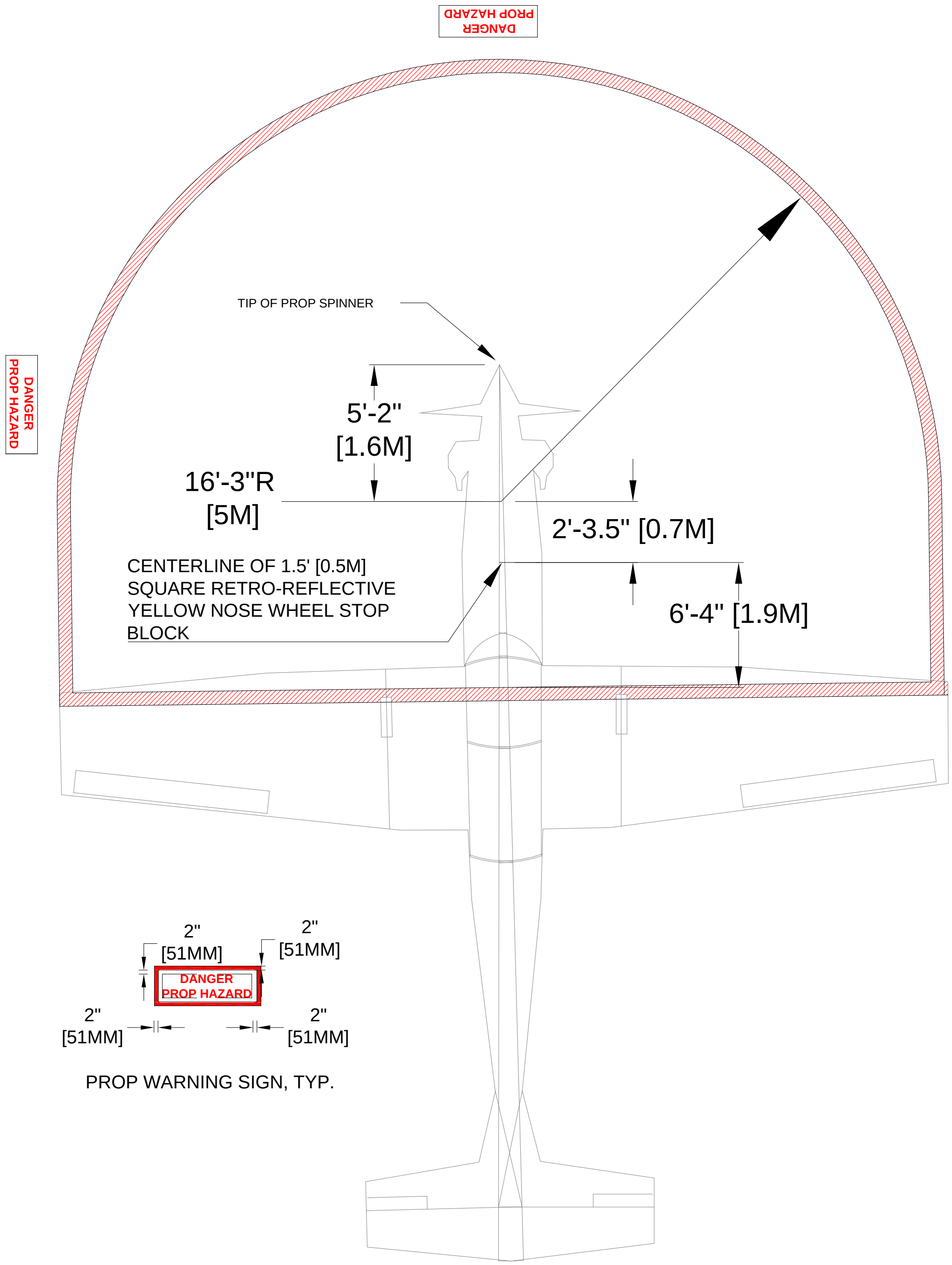
8-20 C-12 PROP HAZARD WARNING MARKING.

In an effort to reduce the hazard caused by C-12 propellers and exhaust, C-12 parking positions are marked in accordance with Figure 8-15.

8-21 EXPEDIENT AIRFIELD MARKINGS.

There are two VFR types of expedient airfields: the landing zone (LZ) (formerly called shortfields or assault landing zones) and the minimum operating strip (MOS). They are rapidly developed to support operations due to an urgent need but support different types of operations. LZs are developed to support airlift operations for C-130 and C-17 aircraft and the MOS is developed for base recovery after an attack to allow the launch and recovery of fighter aircraft. The schemes for marking an MOS are described in T.O. 35E2-6-1, *Minimum Airfield Operating Surface Marking System*. The schemes for marking an LZ are provided in TM 3-34.48-2, *Theater of Operations: Roads, Airfields, and Heliports – Airfield and Heliport Design*, Volume II.

Figure 8-12. T-6 Propeller Hazard Area Pavement Markings



NOTES:

1. WARNING SIGNS WILL BE 4" [102MM] HIGH RED LETTERS ON A WHITE BACKGROUND THAT EXTENDS AT LEAST 2' [51MM] BEYOND THE EXTREMITIES OF THE LETTERS. PLACEMENT SHALL BE AT MINIMUM, AS SHOWN ABOVE.

2. PROP WARNING ARC AND OTHER BOUNDARIES WILL BE A 6" [152MM] CONTINUOUS RED LINE WITH RETRO-REFLECTIVE BEADS EMBEDDED. AN ANTI-SKID MATERIAL SHOULD ALSO BE INCORPORATED ACCORDING TO THE MANUFACTURERS RECOMMENDATIONS.

3. PAINT AND GLASS BEADS SHALL BE IN ACCORDANCE WITH STANDARDS PROVIDED IN CHAPTER 3 OF THIS MANUAL.

Figure 8-13. F-16 Engine Inlet Danger Area Pavement Markings for Idle Thrust

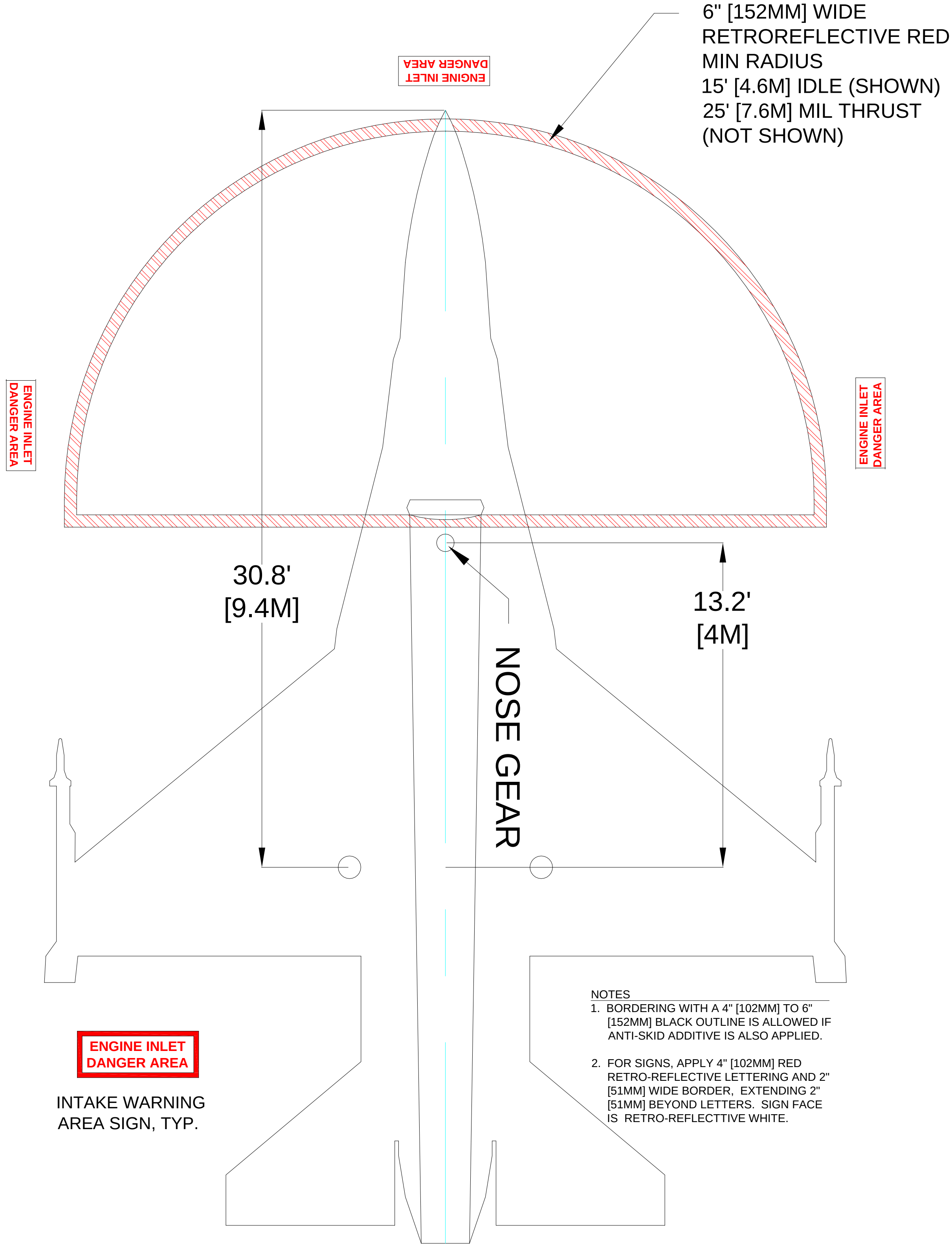


Figure 8-14. Hydrant Fuel Pit Markings

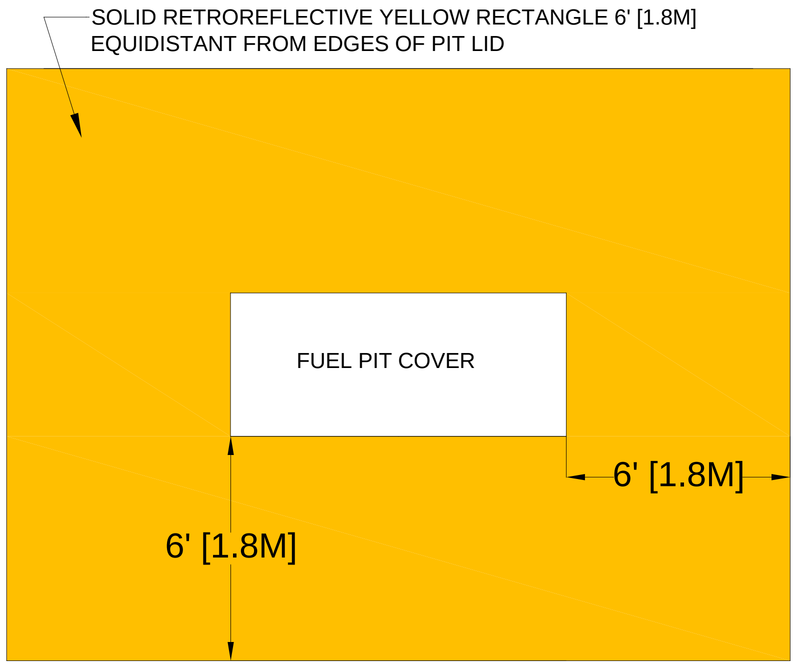
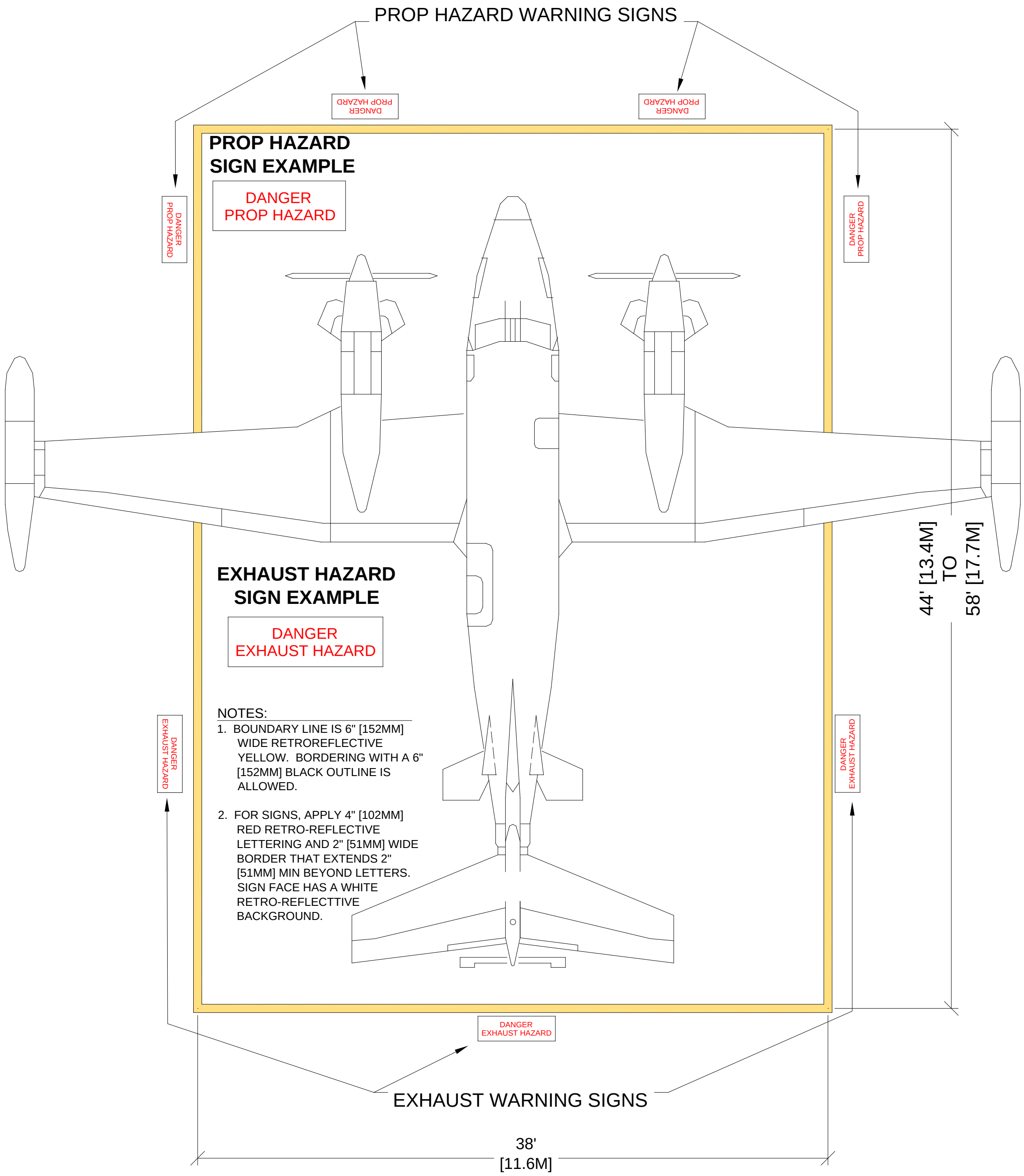


Figure 8-15. C-12 Propeller and Exhaust Hazard Area Pavement Markings



APPENDIX A REFERENCES

AIR FORCE

AFI 13-217, *Drop Zone and Landing Zone Operations*, http://www.e-publishing.af.mil/

AFI 14-205, Geospatial Information and Services (GI&S), http://www.e-publishing.af.mil/

AFI 31-101, *Integrated Defense* (FOUO)

AFI 32-1044, *Visual Air Navigation Systems*, http://www.e-publishing.af.mil/. (This AFI gives information on aircraft arresting system locations and lighted signs required for runway, taxiway, and instrument hold positions.)

T.O. 35E2-6-1, *Minimum Airfield Operating Surface Marking System*

ETL 09-6, *C-130 and C-17 Landing Zone (LZ) Dimensional, Marking, and Lighting Criteria* (FOUO), https://www.wbdg.org/ccb/browse_cat.php?c=125

ARMY

AR 190-16, *Physical Security*, https://armypubs.army.mil/Search/ePubsSearch/ePubsSearchDownloadPage.aspx?docID=0902c8518001047d

ATP 4-43, *Petroleum Supply Operations,* http://www.apd.army.mil/ProductMaps/PubForm/ATP.aspx

SDDCTEA Pamphlet 55-14, *Traffic Engineering for Better Signs and Markings*, https://www.sddc.army.mil/sites/TEA/Functions/SpecialAssistant/TrafficEngineeringBranch/Pamphlets/SDDCTEA_Pamphlet_55-14.pdf

SDDCTEA Pamphlet 55-17, *Better Military Traffic Engineering*, https://www.sddc.army.mil/sites/TEA/Functions/SpecialAssistant/TrafficEngineeringBranch/Pamphlets/SDDCTEA_Pamphlet_55-17_2011.pdf

TM 3-34.48-2, *Theater of Operations: Roads, Airfields, and Heliports – Airfield and Heliport Design*, Vol. II, https://armypubs.us.army.mil/epubs/DR_pubs/DR_a/pdf/web/tm3_34x48_2.pdf

USACE TSC 13-2, *Aircraft Characteristics for Military Aircraft*, https://transportation.erdc.dren.mil/tsmcx/criteria.aspx

NAVY

NAVAIR 51-50AAA-2, *General Requirements for Shore Based Airfield Marking and Lighting*. Download a copy at http://www.wbdg.org/ffc/dod/supplemental-technical-criteria (designated TSEWG NAVAIR 51-50111-2, *General Requirements for Shorebased Airfield Marking and Lighting*) or contact the management authority for NAVAIR 51-50-AAA-2 at: Commanding Officer Naval Air Warfare Center Aircraft Division, Lakehurst Logistics, Code 6.8.5.1, Lakehurst, NJ, 08733, phone (732) 323-5073.

JOINT PUBLICATIONS

TSPWG Manual 3-260-04.18-01, *Life-Cycle Cost Analysis of Retroreflective Glass Beads*, http://www.wbdg.org/ffc/dod/supplemental-technical-criteria/

TSPWG Manual 3-260-04.18-02, *Airfield Marking Waiver Procedures, http://www.wbdg.org/ffc/dod/supplemental-technical-criteria/*

UFC 1-200-01, *DoD Building Code (General Building Requirements)*, https://www.wbdg.org/ccb/browse_cat.php?c=4

UFC 3-120-01, *Design: Sign Standards*, https://www.wbdg.org/ccb/browse_cat.php?c=4

UFC 3-201-01, *Civil Engineering,* https://www.wbdg.org/ccb/browse_cat.php?c=4

UFC 3-260-01, *Airfield and Heliport Planning and Design*, https://www.wbdg.org/ccb/browse_cat.php?c=4

UFC 3-260-02, *Pavement Design for Airfields*, https://www.wbdg.org/ccb/browse_cat.php?c=4

UFC 3-535-01, *Visual Air Navigation Facilities*, https://www.wbdg.org/ccb/browse_cat.php?c=4

UFC 3-575-01, *Lightning and Static Electricity Protection Systems* https://www.wbdg.org/ccb/browse_cat.php?c=4

UFGS 32 17 23, *Pavement Markings*, https://www.wbdg.org/ccb/browse_cat.php?c=3

FEDERAL AVIATION ADMINISTRATION (FAA)

FAR Part 77, *Safe, Efficient Use, and Preservation of the Navigable Airspace*, http://www.ecfr.gov/cgi-bin/text-idx?SID=c957224f6e2b4fb1f2fc236f5da09558&node=pt14.2.77&rgn=div5

AC 70/7460-1, *Obstruction Marking and Lighting*, http://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentID/1028657

AC 120-57, *Surface Movement Guidance and Control System*, http://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentID/23193

AC 150/5300-13, *Airport Design*, http://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentID/1020359

AC 150/5340-1, *Standards for Airport Markings*, http://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentID/1022266

AC 150/5340-18, *Standards for Airport Sign Systems, http://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentID/321003*AC 150/5345-55, *Specification for L-893, Lighted Visual Aid to Indicate Temporary Runway Closure*, http://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentID/22296

FEDERAL HIGHWAY ADMINISTRATION (FHWA)

Manual on Uniform Traffic Control Devices (MUTCD), http://mutcd.fhwa.dot.gov/

FEDERAL SPECIFICATIONS AND STANDARDS

TT-P-1952, *Paint, Traffic and Airfield Marking, Waterborne*, http://quicksearch.dla.mil/qsDocDetails.aspx?ident_number=51859

TT-B-1325, *Beads (Glass Spheres), Retroreflective*, http://quicksearch.dla.mil/qsDocDetails.aspx?ident_number=51830

AIR STANDARDIZATION COORDINATING COMMITTEE (ASCC)

Air Standard 90/28, *Aerodrome Pavement Markings*

INNOVATIVE PAVEMENT RESEARCH FOUNDATION (IPRF)

Project 05-1, *Develop and Publish a Best Marking Practices Handbook*, http://www.iprf.org/products/main.html

INTERNATIONAL CIVIL AVIATION ORGANIZATION (ICAO)

Annex 14, Volume I, *Aerodromes*, http://www.icao.int/

Annex 14, Volume II, *Heliports*, http://www.icao.int/

NORTH ATLANTIC TREATY ORGANIZATION (NATO)

STANAG 3111, *Airfield Marking Tone-Down*

SOCIETY OF AUTOMOTIVE ENGINEERS (SAE) INTERNATIONALE

SAE-AMS-STD-595, *Colors Used in Government Procurement*, www.sae.org

APPENDIX B BEST PRACTICES

B-1 PAVEMENT MARKING.

B-1.1 DEVELOPMENT SPONSORSHIP.

The FAA funded, and the American Concrete Pavement Association (ACPA), in cooperation with the Innovative Pavement Research Foundation (IPRF), executed Project 05-1, *Develop and Publish a Best Marking Practices Handbook*. The products were delivered in September 2008 and are available for download: http://www.iprf.org/products/main.html

B-1.2 CONTENTS.

The manual is composed of the following products:

- Airfield Marking Handbook (pdf format)
- PowerPoint Presentation
- Instructional video (The instructional video requires the DivX codec, which is downloadable from the same website.)

Note: Printed copies of this report are available at no cost; however, a nominal shipping and handling fee applies.

B-1.3 EXCEPTIONS.

The practices, methods, and recommended materials provided within the report do not necessarily comply with the mandatory policies established within this UFC or individually by the Services. In cases where there are conflicts, this UFC, as well as Service, MAJCOM, and MACOM-specific policies, govern.

B-2 PREVIOUS AIRFIELD MARKING PATTERN STANDARDS.

B-2.1 PATTERN SIZES AND LAYOUTS.

Previous pavement marking standards called for smaller and differently spaced marking schemes from those standardized by the FAA or ICAO. This UFC attempts to standardize marking standards and practices across DoD in an effort to enable uniform recognition of surface painted markings and better promote aviation safety, regardless of the geographic location of the airfield.

When to Implement New Marking Patterns/Layouts.

Due to the potentially significant budgetary impact caused by arbitrary implementation of new standards, continue marking current patterns until renovation of the pavement (reconstruction or overlay) or at least 50 percent of the individual pavement feature (e.g., a runway, a taxiway system, or individual aprons and taxilanes). This allows a phased approach to replacing obsolete patterns or marking schemes.

Exceptions to Civil Standards on DoD-Owned Facilities.

Note that not all FAA-promulgated size requirements and enhancements have been made mandatory requirements in this UFC. This is because military missions, needs, and funding constraints are different from those of civil operational interests. Where FAA or ICAO standards differ from those within this UFC, these standards govern unless waivered by the appropriate authority.

B-2.2 PREVIOUS STANDARDS.

Obsolete USAF Standards.

- AFI 32-1042, *Standards for Marking Airfields*, 14 January 2015, is downloadable at https://www.my.af.mil/gcss-af/USAF/ep/contentView.do?contentType=EDITORIAL&contentId=cE3494DD0577CE8B5015790ED79F400C1&programId=t2D8EB9D6386BFB8B01394F5729351F52&channelPageId=s2D8EB9D637283B5601377B2CE4030666

- ETL 04-2, *Standard Airfield Pavement Marking Schemes*, 19 July 2004, is downloadable at https://www.my.af.mil/gcss-af/USAF/ep/contentView.do?contentType=EDITORIAL&contentId=cE3494DD0577CE8B5015790ED79F400C1&programId=t2D8EB9D6386BFB8B01394F5729351F52&channelPageId=s2D8EB9D637283B5601377B2CE4030666

Obsolete U.S. Army Standards.

- U.S. Army Technical Letter No. 1110-3-512, *Army Airfield and Heliport Markings*, is downloadable at http://www.publications.usace.army.mil/USACE-Publications/Engineer-Technical-Letters/
- UFC 3-260-05A, *Marking of Army Airfield Heliport Operational and Maintenance Facilities*, 16 January 2004, is downloadable at https://www.wbdg.org/ccb/browse_cat.php?c=4&a=1
- Engineering and Construction Bulletin 2012-28, *Marking of Army Airfields and Heliports*, is downloadable at http://www.wbdg.org/ccb/browse_cat.php?c=268&a=1

B-3 METRICATION OF DIMENSIONS.

B-3.1 METRIC VALUES TO USE.

The technologies addressed in this UFC when developed were based on the inch-pound system used in the United States. Because DoD operates in many foreign countries, and because it is beneficial and necessary to use SI units when developing and constructing projects in those theaters, rational conversions are shown here for cases where NATO or ICAO standards are not called out. In an effort to maintain compliance with both U.S. civil standards and international civil aviation standards, imperial and metric dimensions are provided where practicable within the text. The following table was developed to reduce crowding of dimensions and improve clarity and readability in some of the figures within the document. If necessary, use these values to validate the values provided in the figures.

Table B-1 Inches to Millimeters

Inch-Pound Dimension (Inches)	SI Dimension (Millimeters)
2.00 inches	51 millimeters
3.00 inches	76 millimeters
3.50 inches	89 millimeters
4.00 inches	102 millimeters
5.00 inches	127 millimeters
6.00 inches	152 millimeters
7.00 inches	178 millimeters
7.50 inches	191 millimeters
8.00 inches	203 millimeters
10.00 inches	254 millimeters
12.00 inches	305 millimeters
13.00 inches	330 millimeters
14.00 inches	356 millimeters
15.00 inches	381 millimeters
16.00 inches	406 millimeters
18.00 inches	457 millimeters
20.00 inches	508 millimeters
23.00 inches	584 millimeters
24.00 inches	610 millimeters
26.00 inches	660 millimeters
36.00 inches	914 millimeters
37.00 inches	940 millimeters
48.00 inches	1219 millimeters
51.00 inches	1,295 millimeters

Table B-2 Feet to Meters

Inch-Pound Dimension (Feet) [Nominal Tolerance Dimension]	Metric Used (rounded to nearest tenth of meter)
0.5 foot	0.2 meter
1 foot	0.3 meter
1.3 feet	0.4 meter
1.5 feet	0.5 meter
2 feet	0.6 meter
2.29 feet	0.7 meter
2.5 feet	0.8 meter
3 feet	0.9 meter
3.5 feet	1.1 meters
4 feet	1.2 meters
4.5 feet	1.4 meters
5 feet	1.5 meters
5.17 feet	1.6 meters
5.5 feet	1.7 meters
5.75 feet	1.75 meters
6 feet	1.8 meters
6.33 feet	1.9 meters
6.5 feet	1.98 meters
6.6 feet	2.0 meters
6.75 feet	2.1 meters
7 feet	2.13 meters
7.5 feet	2.3 meters
8 feet	2.4 meters
8.4 feet	2.56 meters
8.5 feet	2.6 meters
9 feet	2.7 meters
9.5 feet	2.9 meters
10 feet	3 meters
11 feet	3.4 meters
11.5 feet	3.5 meters
12 feet	3.7 meters
12.5 feet	3.8 meters
13 feet	3.96 meters
13.2 feet	4.0 meters
13.5 feet	4.1 meters
14 feet	4.3 meters
15 feet	4.6 meters

Inch-Pound Dimension (Feet) [Nominal Tolerance Dimension]	Metric Used (rounded to nearest tenth of meter)
16 feet	4.9 meters
16.25 feet	5.0 meters
17 feet	5.2 meters
17.5 feet	5.3 meters
18 feet	5.5 meters
18.5 feet	5.6 meters
19 feet	5.8 meters
20 feet	6.1 meters
20.66 feet	6.3 meters
22 feet	6.7 meters
24 feet	7.3 meters
24.5 feet	7.5 meters
25 feet	7.6 meters
26 feet	7.9 meters
27 feet	8.2 meters
28 feet	8.5 meters
30 feet	9.1 meters
30.8 feet	9.4 meters
32 feet	9.8 meters
35 feet	10.7 meters
36 feet	11.0 meters
37 feet	11.3 meters
37.5 feet	11.4 meters
40 feet	12.2 meters
43 feet	13.1 meters
44 feet	13.4 meters
45 feet	13.7 meters
48 feet	14.6 meters
50 feet	15.2 meters
59 feet	18.0 meters
60 feet	18.3 meters
63 feet	19.2 meters
72 feet	21.9 meters
75 feet	22.9 meters
79 feet	24.1 meters
80 feet	24.4 meters
88 feet	26.8 meters
98 feet	29.9 meters
99 feet	30.2 meters

Inch-Pound Dimension (Feet) [Nominal Tolerance Dimension]	Metric Used (rounded to nearest tenth of meter)
100 feet	30.5 meters
120 feet	36.6 meters
124 feet	38.0 meters
125 feet	38.1 meters
144 feet	43.9 meters
150 feet	45.7 meters
171 feet	52.1 meters
175 feet	53.3 meters
194 feet	59.1 meters
200 feet	61.0 meters
205 feet	62.5 meters
250 feet	76.2 meters
280 feet	85.3 meters
300 feet	91.4 meters
400 feet	121.9 meters
440 feet	134.1 meters
500 feet	152.4 meters
520 feet	158.5 meters
533.3 feet	162.5 meters
1000 feet	304.8 meters
1200 feet	365.8 meters
1300 feet	396.2 meters
1600 feet	487.7 meters
3000 feet	914.4 meters
3200 feet	975.4 meters
4000 feet	1,219.2 meters

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APPENDIX C GLOSSARY

C-1 ACRONYMS AND ABBREVIATIONS

AAS	Aircraft Arresting System
AC	Advisory Circular
AFI	Air Force Instruction
AFMAN	Air Force Manual
AOI	Airfield Operating Instruction
ATP	Army Techniques Publication
CCP	Compass Calibration Pad
CONUS	Continental United States
DoD	Department of Defense
ECP	Entry Control Point
ETL	Engineering Technical Letter
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FCIF	Flight Crew Information File
FHWA	Federal Highway Administration
FLIP	Flight Information Publication
FOD	Foreign Object Damage
HAT	Height Above Touchdown
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rule
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
INS	Inertial Navigation System

IPRF	Innovative Pavement Research Foundation
LAHSO	Land And Hold Short Operations
LZ	Landing Zone
m	Meter
MACOM	U.S. Army Major Command
MAJCOM	USAF Major Command
MILS	Thousandths of an Inch Film Measurement (0.000”)
MIN	Minimum
mm	Millimeters
MOS	Minimum Operating Strip
MSL	Mean Sea Level
MUTCD	Manual on Uniform Traffic Control Devices
NATO	North Atlantic Treaty Organization
NAVAID	Navigational Aid
NAVAIR	Naval Air Systems Command
NDAA	National Defense Authorization Act
NOTAM	Notice To Airmen
OCONUS	Outside Continental United States
PCC	Portland Cement Concrete
POFZ	Precision Obstacle Free Zone
SDDCTEA	Military Surface Deployment and Distribution Command Transportation Engineering Agency
SOFA	Status of Forces Agreement
STANAG	Standardization Agreement
TDZ	Touchdown Zone
TM	Technical Manual

T.O.	Technical Order
TSC	Technical Services Center
U.S.	United States
UAS	Unmanned Aircraft System
UFC	Unified Facilities Criteria
UFGS	Unified Facilities Guide Specification
USACE	U S Army Corps of Engineers
USAF	United States Air Force
VFR	Visual Flight Rules

C-2 TERMS

Precision Approach Runway Category I—A runway served by an instrument landing system (ILS), microwave landing system (MLS), or precision approach radar (PAR) and visual aids intended for operations down to 60 meters (200 feet) decision height, and down to a runway visual range (RVR) on the order of 720 meters (2,400 feet).

Precision Approach Runway Category II—A runway served by ILS or MLS and visual aids intended for operations down to 30 meters (100 feet) decision height and down to an RVR on the order of 360 meters (1,200 feet).

Precision Approach Runway Category III—A runway served by ILS or MLS (no decision height being applicable) and:

> **Category IIIa:** By visual aids intended for operations down to an RVR on the order of 210 meters (700 feet).
>
> **Category IIIb:** By visual aids intended for operations down to an RVR on the order of 45 meters (150 feet).
>
> **Category IIIc:** Intended for operations without reliance on external visual reference. (The RVR is 0).

Entry Control Point—A marked location on the periphery of a controlled and restricted area for accessing and exiting the designated area.

Index of Refraction—The ratio of the speed of radiation (as light) in one medium (as a vacuum) to that in another medium—also called *refractive index*.

Taxilane—Designated path marked through parking, maintenance, or hangar aprons, or on the perimeter of such aprons, to permit the safe ground movement of aircraft operating under their own power.

Taxitrak—A specially prepared or designated path, on an airfield other than mass parking areas, on which aircraft move under their own power to and from taxiways to dispersed platforms.

Taxiway—A specially prepared or designated path, on an airfield or heliport other than apron areas, on which aircraft move under their own power to and from landing, service, and parking areas.

Towway—Paved surface over which an aircraft is towed.

FC 3-260-06F
1 June 2015

FACILITIES CRITERIA (FC)

AIR FORCE
DESIGN, CONSTRUCTION, MAINTENANCE, AND EVALUATION OF SNOW AND ICE AIRFIELDS IN ANTARCTICA

FACILITIES CRITERIA (FC)

AIR FORCE
DESIGN, CONSTRUCTION, MAINTENANCE, AND EVALUATION OF SNOW AND ICE AIRFIELDS IN ANTARCTICA

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER CENTER (Preparing Activity)

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

Change No.	**Date**	**Location**

This FC supersedes ETL 02-16, *Design, Construction, Maintenance, and Evaluation of the Pegasus Glacial Ice Runway for Heavy Wheeled Aircraft Operations*, dated Oct 2002; and ETL 07-12, *Design, Construction, Maintenance, and Evaluation of the McMurdo Sound (Antarctica) Sea Ice Runway*, dated Sep 2007.

FOREWORD

Facilities Criteria (FC) provide functional requirements (i.e., defined by users and operational needs of a particular facility type) for specific DoD Component(s), and are intended for use with unified technical requirements published in DoD Unified Facilities Criteria (UFC). FC are applicable only to the DoD Component(s) indicated in the title, and do not represent unified DoD requirements. Differences in functional requirements between DoD Components may exist due to differences in policies and operational needs.

All construction outside of the United States is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA.) Therefore, the acquisition team must ensure compliance with the most stringent of the UFC (replace w/ FC), the SOFA, the HNFA, and the BIA, as applicable.

Because FC are coordinated with unified DoD technical requirements, they form an element of the DoD UFC system applicable to specific facility types. The UFC system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applicable to the Military Departments, Defense Agencies, and the DoD Field Activities. The UFC System also includes technical requirements and functional requirements for specific facility types, both published as UFC documents and FC documents.

FC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and the Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale should be sent to the respective service proponent office by the following electronic form: Criteria Change Request. The form is also accessible from the Internet site listed below.

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

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

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

AUTHORIZED BY:

JOE SCIABICA, SES
Director
Air Force Civil Engineer Center

FACILITIES CRITERIA (FC)
NEW SUMMARY SHEET

Document: FC 3-260-06F, *Design, Construction, Maintenance, and Evaluation of Snow and Ice Airfields in Antarctica*

Superseding:

- ETL 02-16, *Design, Construction, Maintenance, and Evaluation of the Pegasus Glacial Ice Runway for Heavy Wheeled Aircraft Operations*, and ETL 07-12, *Design, Construction, Maintenance, and Evaluation of the McMurdo Sound (Antarctica) Sea Ice Runway*

Description:

- Provides design, construction, and maintenance details, dimensional criteria, and structural evaluation criteria for compacted snow, glacial ice and ice runways used by wheeled or ski-equipped aircraft.

Reasons for Document:

- The criteria presented herein unify and standardize current airfield practices for Antarctica previously found in multiple documents. These criteria update guidance on thickness of snow topping on glacial ice runways and clarifies marking and lighting requirements.

Impact:

- Issuance of this document should not significantly impact future design costs, initial costs, energy savings, or life cycle cost as compared to current practices.

Unification Issues

- Not Applicable

TABLE OF CONTENTS

FIGURES

TABLES

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CHAPTER 1 INTRODUCTION

1-1 PURPOSE.

1-1.1 Facilities Criteria

This Facilities Criteria (FC) provides design, construction, and maintenance details, dimensional criteria, and structural evaluation criteria for compacted snow and/or ice runways used by wheeled aircraft. Three potential surface conditions are considered:

- Wheeled aircraft operations on glacial ice
- Wheeled aircraft operations on white ice (glacial ice capped with processed snow)
- Wheeled aircraft operations on sea ice

The dimensional criteria are the same for all surfaces. Although these criteria were developed from operational experience on the airfields at McMurdo Station, Antarctica, the concepts are generally applicable to any runway composed of glacial ice, white ice, or sea ice. Appendices B-12 and B-13 provide drawings of the layout of an operational glacial ice airfield which includes a skiway and sea ice airfield located on the Ross Ice Shelf and McMurdo Sound, Antarctica.

Note: The use of the name or mark of any specific manufacturer, commercial product, commodity, or service in this FC does not imply endorsement by the U.S. Air Force.

1-1.2 U.S. Antarctic Program.

The airfields in Antarctica are operated by the U.S. Antarctic Program (USAP) and primarily support Air Force aircraft. Three airfields have been used at McMurdo Station and one skiway has been maintained at the South Pole Station.

1-1.2.1 Williams Field Skiway.

Williams Field is located in an area that receives heavy annual snowfall and is built in an area with a deep snow layer overlying the Ross Ice Shelf. The Williams Field skiway is comprised of a compacted snow surface. This FC does not apply to Williams Field skiway or other skiways. See AFI 13-217 for skiway criteria.

1-1.2.2 Pegasus Glacial Ice Runway.

Starting in 1993, the Pegasus airfield supported C-130 Hercules and C-141 Starlifter aircraft from an exposed glacial ice surface. In 2002 a compacted snow surface (“white ice”) was placed over the glacial ice and C-130, C-141, and C-17 Globemaster III aircraft have since performed routine operations from this white ice surface.

1-1.2.3 Sea Ice Runway.

The sea ice runway on McMurdo Sound has previously supported C-130, C-141, C-5, and C-17 aircraft. For many years C-130 and C-17 aircraft have completed routine operations from an exposed graded sea ice surface. Since 2002, they have occasionally operated on a sea ice surface overlain by either a moderately processed thin snow cap or a thin layer of fresh, loose snow.

1-1.2.4 South Pole Skiway.

The skiway at South Pole Station is a high-altitude skiway constructed on compacted snow. It is served only by LC-130 and other ski-equipped aircraft. See AFI 13-217 for skiway criteria.

1-2 APPLICATION.

This FC applies to all Department of Defense (DOD) organizations responsible for design, construction, maintenance, and evaluation of snow and/or ice airfields.

1-2.1 McMurdo Station Operations.

1-2.1.1

It is anticipated that all of the field measurements and data collection prescribed in this FC can and will be accomplished by knowledgeable personnel within the USAP and deployed to Antarctica as part of their occupational performance. This does not preclude Air Force certification teams traveling to McMurdo Station to complete an evaluation; however, due to the logistics, coordination, cost, and uncertain nature of travel to and work in Antarctica, it is more likely that the USAP McMurdo Area airfield manager will be responsible for following all FC requirements for data collection.

1-2.1.2

Only Headquarters Air Mobility Command (HQ AMC) can determine the suitability of the airfield for operations of HQ AMC aircraft. It will be the USAP McMurdo Area airfield manager's responsibility to deliver all data and measurements, in the format prescribed in this FC, to the HQ AMC/A7OI contact (see paragraph 1-3) or designee. HQ AMC/A7OI will review the submittal and communicate its findings and decisions back to the airfield manager, who will be responsible for any remedial actions, waiver requests, and communicating the airfield status (e.g., open, closed, open with restrictions) to all impacted operational elements. When HQ AMC/A7OI determines that the airfield meets the criteria specified in this FC, HQ AMC/A3AS will be notified, and, in turn, will ensure HQ AMC/A3 provides approval for aircraft operations.

1-3 POINTS OF CONTACT.

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CHAPTER 2 CRITERIA

2-1 DIMENSIONAL CRITERIA.

Details for establishing airfields for the support of routine operations of Air Force aircraft can be found in UFC 3-260-01. Snow and ice runways in the Antarctic region are unique in a number of ways (e.g., seasonal operation only; low volume of air traffic; extremely remote location; sited on a level, “featureless” ice shelf; limited resources available for construction and maintenance). The criteria are based for the most part on Class B runway requirements; however, some terminology used in this FC differs from that used in UFC 3-260-01. Figures 2-1 and 2-2 show the typical layout, including shoulders, lateral clear area, and end clear area.

2-1.1 Runways.

Table 2-1 provides dimensional criteria for the layout and design of snow and ice runways. Minimum runway length shall be 3050 meters (10,000 feet) for fully loaded C-17 aircraft operations and 2440 meters (8000 feet) for fully-loaded C-130 aircraft unless otherwise directed by the major command (MAJCOM) Director of Operations (A3).

2-1.2 Runway Shoulders.

Shoulders are required along each outside edge of the runway. They must be prepared to the same strength as the runway surface (and be of the same surface material: glacial ice, white ice, compacted snow, or sea ice) and be free of obstacles. Shoulder geometric requirements are presented in Table 2-1. Because the shoulders are constructed to the same strength as the runway surface, C-130s and LC-130s can use the shoulders for turnarounds. However, to prevent the need for very sharp turns and potential damage to the runway surface, C-17s will not use shoulders for turns and instead turn around at widened runway ends, as shown in Figure 2-3.

2-1.3 Runway Graded Area.

A graded area is required adjacent to the runway shoulder. It is not considered a full-strength area for supporting aircraft; however, it is sloped approximately the same as the shoulder, as described in Table 2-11. Marker flags are installed within the graded area.

Table 2-1 Runway Dimensional Requirements for C-130, LC-130 and C-17 Operations

Item No.	Description	Requirement	Remarks
1	Length (minimum)	See Remarks	Minimum runway length will be determined by the MAJCOM/A3 for the most critical aircraft in support of the mission.
2	Width	46 m (150 ft)	Since snow and ice runways are devoid of traditional painted surface markings, the runway will appear to be 64 m (210 ft) wide – the distance between the inner marker flags.
3	Width of shoulders (minimum)	7.6 m (25 ft)	Remove all snow berms and snow drifts in shoulder areas. All glacial ice, white ice, compacted snow and sea ice in shoulders shall be prepared to required runway strength standards.
4	Longitudinal grade	2% maximum (up or down)	The maximum grade of any tangent, as well as the total elevation change from one threshold of the runway to the other, shall not exceed 2%.
5	Longitudinal grade change	No grade change greater than 0.5% is to occur within 300 m (1000 ft) from the runway end	Hold to minimum practicable. Grades may be both positive and negative but must not exceed the limit specified. Applies to runway and shoulders.

Item No.	Description	Requirement	Remarks
6	Rate of longitudinal grade change	Maximum 0.167% per 30.5 m (100 ft)	Grade changes will be held to a minimum and will be gradual. Application of this criterion will produce a vertical curve having a 182.9 m (600 ft) length for each percent of algebraic difference between the two grades. Minimum distance between grade changes is 61 m (200 ft). Grade changes cannot exceed 1.5% measured at 61-m (200-ft) intervals. Applies to runway and shoulders. **Note:** In addition to these grade requirements, the runway shall be checked for high-frequency, low-amplitude undulations that degrade rideability and may decrease aircraft stopping performance. Any dips, rises or “chatter” shall be noted and corrected by fine-grading and re-compacting the surface.
7	Transverse slope of runway	1.5% maximum	Transverse slopes can be flat and uniform, or crowned at the centerline. A crowned centerline is preferred. Sea ice runway is flat.
8	Transverse slope of shoulders	2% max. down 1% max. up	For a glacial ice surface, shoulders shall slope down from the runway edge. A white ice surface may slope down at 2% maximum or up at 1% maximum. Sea ice shoulders are flat.
9	Width of graded area	Minimum 12.2 m (40 ft)	The graded area is measured from the outside edge of the shoulder. Graded area will routinely have no more than 25 mm (1 in) of loose snow cover. (During clean-up following a drifting event, snow up to 300 mm [12 in] may exist immediately adjacent to runway markers while the runway proper and the shoulders are being maintained to the 25 mm (1 in) standard in order to resume critical flight operations. As soon as practicable, any drift snow in the graded area must be removed to maintain the overall runway standard.)

Item No.	Description	Requirement	Remarks
10	Transverse slope of graded area	2% maximum (up or down)	Ideally, graded area slope (up or down) will match that of runway shoulders.
11	Width of lateral clear area	79.5 m (260 ft)	The lateral clear area is measured outward from the outside edge of the graded area.
12	Transverse slope of lateral clear area	12% maximum (up)	Requirement is applied to imaginary plane extending from the outer edge of the graded area outward a distance of 79.5 m (260 ft). No object or surface feature may penetrate this imaginary plane.
13	Width of primary surface	244 m (800 ft)	Centered on the runway centerline and incorporates the runway, shoulder, graded area, and lateral clear area. No fixed or mobile objects may be located in this area unless the item is fixed by function and therefore a permissible deviation.
14	Distance between centerlines of parallel runways	305 m (1,000 ft)	Visual flight rules (VFR) without intervening parallel taxiway between the parallel runways. One of the parallel runways must be a VFR-only runway.
		633 m (2,075 ft)	VFR with intervening parallel taxiway.
		762 m (2,500 ft)	Instrument flight rules (IFR) using simultaneous operation (depart-depart) (depart-arrival).
		1311 m (4,300 ft)	IFR using simultaneous approaches.
15	Width of USAF mandatory zone of frangibility	152.5 m (500 ft)	Centered on the runway centerline. All items sited within this area must be frangible.
16	Length of USAF mandatory zone of frangibility	1829 m (6,000 ft)	Centered on the runway. All items sited within this area to the ends of the end clear zone must be frangible.

Figure 2-1 Typical Runway Layout for Bi-Directional Operations (Not to Scale)

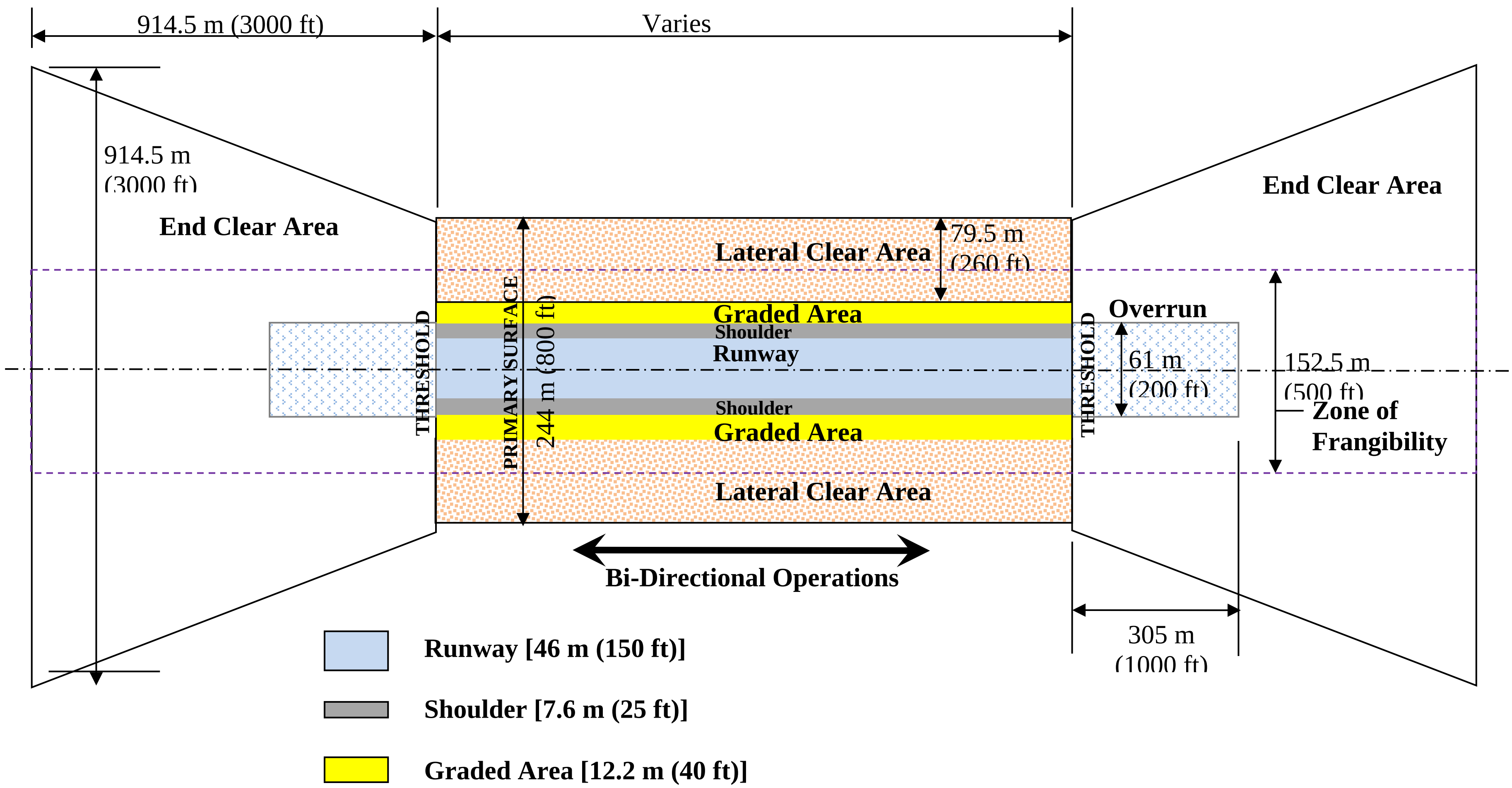
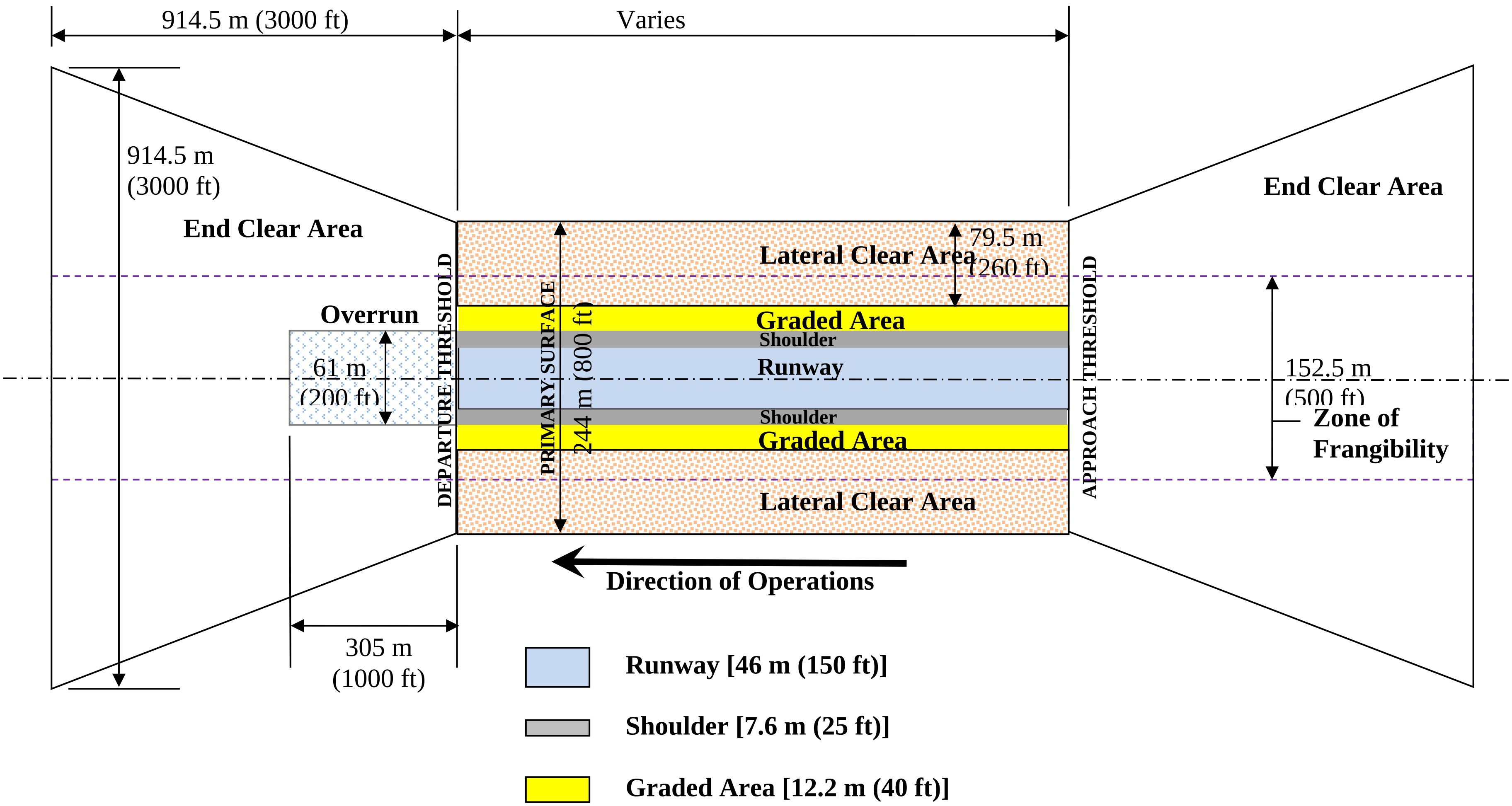


Figure 2-2 Typical Runway Layout for Uni-Directional Operations (Not to Scale)



2-1.4 Overruns.

Overrun geometric requirements are presented in Table 2-2. The overrun must be constructed to the same structural standards as the runway surface. For bi-directional operations, an overrun must be provided at both ends. For uni-directional operations, an overrun is only required at the departure end of the runway.

2-1.5 Clear Areas.

Runway end clear areas are required and their dimensions are given in Table 2-2. The layout is shown in Figures 2-3 and 2-4. Clear areas must be free of fixed or mobile objects that are not specifically identified and positioned as described in this FC.

Table 2-2 Runway Overrun and End Clear Area Requirements for C-130, LC-130, and C-17 Operations

Item No.	Description	Requirement	Remarks
1	End clear area length	914.5 m (3000 ft)	Measured along the extended runway centerline. Begins at the runway threshold.
2	End clear area width at inner edge	244 m (800 ft)	Centered about runway centerline at the threshold.
3	End clear area width at outer edge	914.5 m (3000 ft)	Centered about runway centerline at 914.5 m (3000 ft) from centerline.
4	Overrun length	305 m (1000 ft)	The runway overrun area falls within the runway end clear area. The maximum longitudinal grade (up or down) in the overrun area is 2%.
5	Overrun width	61 m (200 ft) (Runway surface + shoulders)	The overrun area will have a transverse section matching the runway (i.e., include shoulder, graded area, and lateral clear area). See Table 2-1 for transverse dimensional criteria. The longitudinal grade of the first 91.5 m (300 ft) of the overrun shall match the grade of the last 914.5 m (3000 ft) of the runway.
6	Overrun longitudinal grade	Max. 2%	Up or down.

Item No.	Description	Requirement	Remarks
7	Approach-departure clearance surface	50:1	Approach-departure clearance surface begins at the runway thresholds at the same elevation as the centerline elevation and extends away from the runway 7620 m (25,000 ft). During flight operations, no mobile or fixed object may penetrate this imaginary plane.

2-1.6 Taxiways.

Dimensional criteria for taxiways are given in Table 2-3. Taxiways (including shoulders) will have surface strength properties matching those of the runway.

Table 2-3. Taxiway Dimensional Requirements for C-130, LC-130, and C-17 Operations

Item No.	Description	Requirement	Remarks
1	Width	23 m (75 ft) minimum	Since the taxiway is devoid of traditional surface markings, it will appear to be 38.5 m (125 ft) wide (the combined width of the taxiway and the shoulders).
2	Centerline radius of turns (C-130, C-17)	30.5 m (100 ft) minimum	Curves in taxiway must be no tighter than the listed minimum turning radii, measured along the taxiway centerline. Edge of taxiway fillets at runway/ taxiway/apron turns and/or intersections must be 46 m (150 ft) minimum radii.
3	Width of shoulder	7.6 m (25 ft)	Remove all snow berms and snow drifts in shoulder areas. Glacial ice, white ice, and sea ice in shoulders will be prepared to the same strength as the taxiway.

Item No.	Description	Requirement	Remarks
4	Longitudinal grade	3% maximum	Hold to minimum practicable. Grades may be either positive or negative. Applies to taxiway and shoulders.
5	Rate of longitudinal grade change	1% maximum over 30.5 m (100 ft)	Grade changes will be held to a minimum and will be gradual. Minimum distance between grade changes is 152.5 m (500 ft). Grade changes cannot exceed 1% measured at 30.5-m (100-ft) intervals. Applies to taxiway and shoulders.
6	Transverse slope of taxiway	3% maximum	Transverse slopes can be flat, uniform, or crowned at the centerline (crowned centerline is preferred).
7	Transverse slope of shoulders	3% maximum	An exposed glacial ice surface shall slope down from the taxiway edge. A white ice surface may slope upward to a maximum extent of 1%. A sea ice surface will be flat.
8	Runway-taxiway separation	93 m (305 ft)	Measured from the runway centerline to the parallel taxiway centerline.
9	Hold position	76.5 m (250 ft)	Measured from the runway centerline.
10	Infield area		All areas located between the runway and taxiways must be cleared of obstructions not fixed by function.
11	Clearance to fixed or mobile obstacles	61 m (200 ft)	Measured from the taxiway centerline.
12	Width of lateral clear area	42 m (137.5 ft)	Lateral clear area is measured outward from the outer edge of the shoulder. No object or surface feature may penetrate this imaginary plane.

Item No.	Description	Requirement	Remarks
13	Transverse slope of lateral clear area	12% maximum (up)	Requirement is applied to imaginary plane extending from the outer edge of the shoulder outward a distance of 79.5 m (260 ft). No object or surface feature may penetrate this imaginary plane.

2-1.7 Aprons.

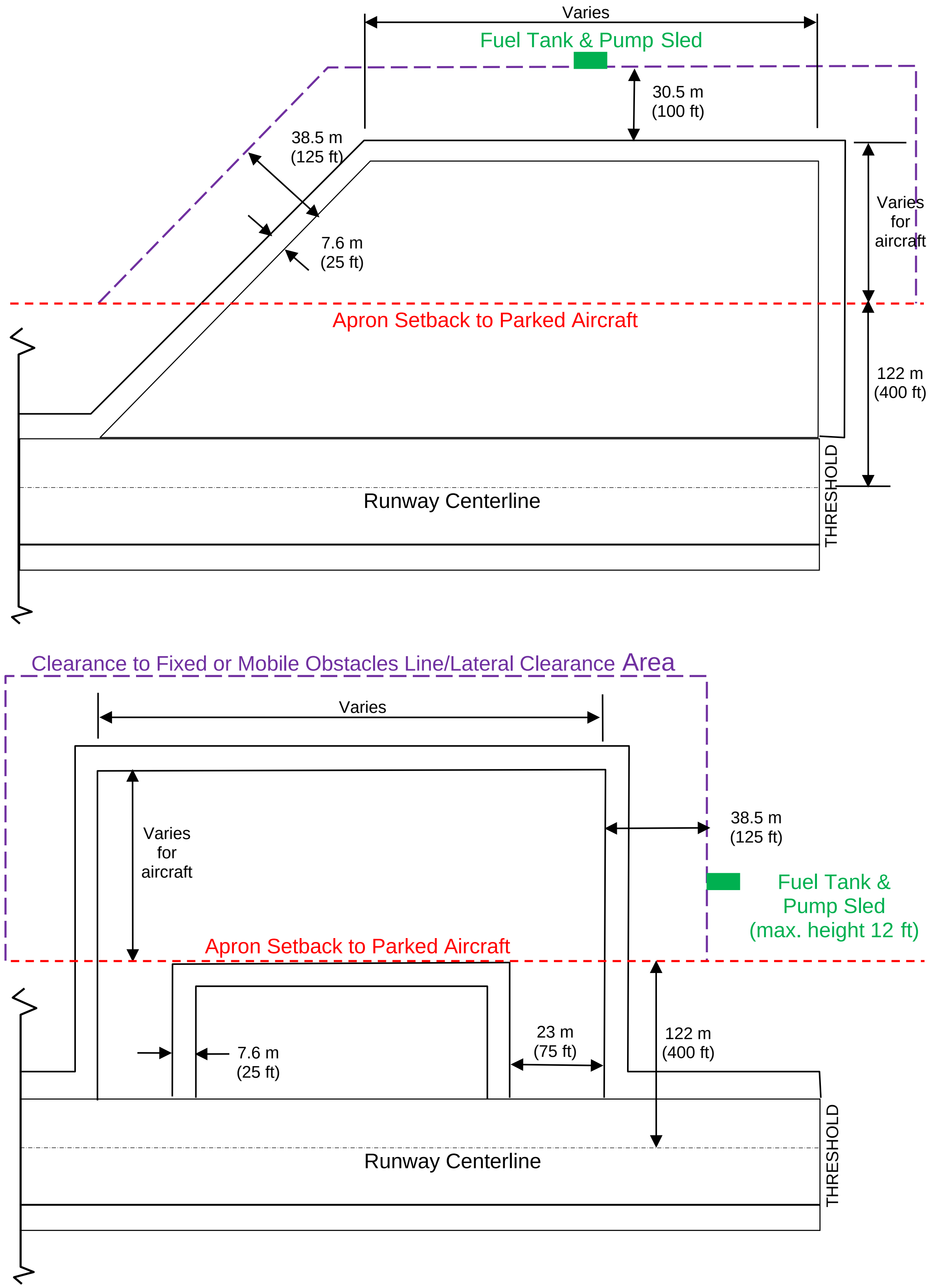
Dimensional criteria for aprons are given in Table 2-4 and plan views of suggested apron configurations are provided in Figure 2-3. Aprons will have surface strength properties matching those of the runway. An apron, parking area, or parallel taxiway is **required** if maximum on ground (MOG) will be greater than one aircraft.

Table 2-4. Apron Requirements for LC-130, C-130 and C-17 Operations

Item No.	Description	Requirement	Remarks
1	Apron size	Varies	Sized to accommodate number of aircraft on ground. Maximum visibility and minimum wingtip clearance must be maintained at all times. As a minimum, the pilot must be able to clearly see all parked aircraft when taxiing.
2	Apron grade	3% maximum	Ideally, uniform grade will exist over entire apron area.
3	Width of shoulder	7.6 m (25 ft)	Remove all snow berms and snow drifts in shoulder areas. Snow in shoulders will be prepared to the same strength as the apron.
4	Transverse slope of shoulders	3% maximum (down) 1% maximum (up)	An exposed glacial ice surface shall slope down from the apron edge. A white ice or compacted snow surface may slope upward to a maximum extent of 1%. Sea ice shoulders are flat.
5	Apron setback	122 m (400 ft)	Measured from the runway centerline to the near edge of the parking apron.

Item No.	Description	Requirement	Remarks
6	Clearance to fixed or mobile obstacles	38.5 m (125 ft)	Measured from the outer edge of the apron.
7	Width of lateral clear area	30.5 m (100 ft)	Lateral clear area is measured outward from the outer edge of the shoulder. No object or surface feature may penetrate this imaginary plane.
8	Transverse slope of lateral clear area	12% maximum (up)	Requirement is applied to imaginary plane extending from the outer edge of the shoulder outward a distance of 79.5 m (260 ft). No object or surface feature may penetrate this imaginary plane.
9	Wingtip clearance	15.2 m (50 ft)	Parked and taxiing aircraft must maintain 15.2 m (50 ft) wingtip clearance from obstructions at all times. Applies to parked aircraft as well as peripheral and internal taxilanes.
10	Centerline radius of turns	46 m (150 ft)	Lay out apron parking positions and taxi lanes to provide ample distance for aircraft to align properly in the parking position. Larger radii are needed on aprons because there are very few visual cues on the snow/ice surface for pilots to steer. In addition, sharp turns on loaded LC-130 skis are very difficult to execute.

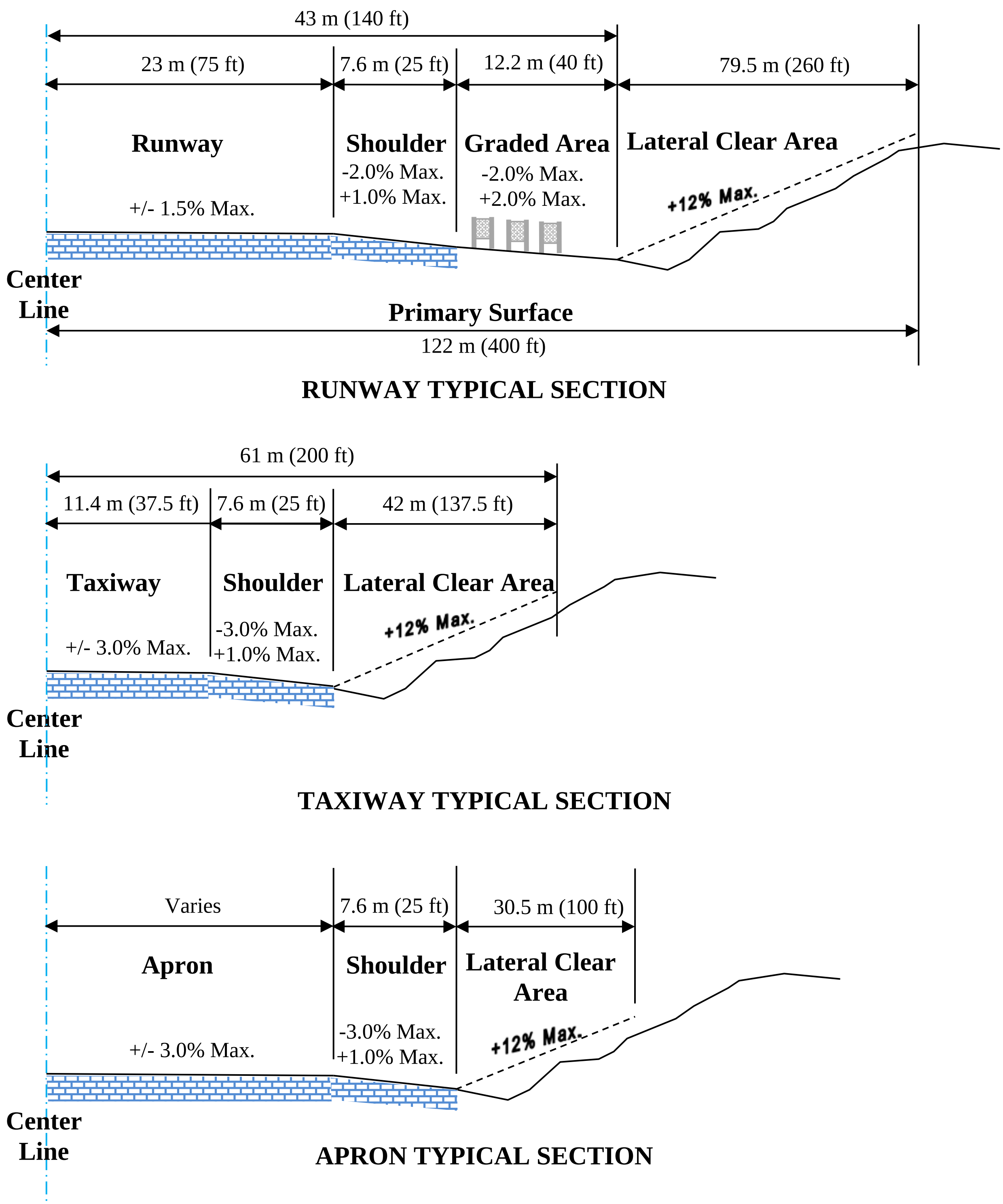
Figure 2-3 Typical Layout Arrangements for Taxiways and Aprons (Not to Scale)



2-1.8 Typical Sections.

Cross-section views of the runway, taxiway, and apron, showing the dimensions from Tables 2-1, 2-2, and 2-3, are shown in Figure 2-4.

Figure 2-4 Typical Cross-Section Dimensions for Runway, Taxiway, and Apron (Not to Scale)



2-2 SNOW/ICE SURFACE CONSTRUCTION, MAINTENANCE, AND STRUCTURAL EVALUATION CRITERIA.

2-2.1 New Runway Construction.

Construction of a new glacial ice runway is described in CRREL Monograph 98-1. For additional criteria on new construction, contact the individuals listed in paragraph 1-3.

2-2.2 Preparation for Initial Seasonal Use.

2-2.2.1 White Ice Runway Surface.

2-2.2.1.1 WinFly.

Prior to WinFly, the white ice runway surface will be graded smooth to remove drifts and snow accumulated during the austral winter. After grading and rolling, marker flags or cones will be installed as needed to support the WinFly flights.

2-2.2.1.2 Mainbody Flying.

Prior to Mainbody flying, the runway surface will be surveyed longitudinally and with transverse cross-sections to identify areas that do not meet the grading criteria stipulated in Tables 2-1 and 2-2. Bulldozers, snow blowers, and graders will be used to cut down slopes and place new snow on the runway surface where the snow cap is too thin. Some grading and dragging between roller passes may be required to make the surface smooth. After compaction is complete and strength testing has passed requirements, all marker flags will be installed per the requirements in paragraph 2-3.5.

2-2.2.2 Sea Ice Runway Surface.

Prior to initial use, clear the sea ice runway of loose snow to expose the sea ice. Check the surface for unacceptable roughness or undulations and serrate the surface with a grader blade, as needed, to smooth out the surface. In addition, fresh water may be added to the surface and allowed to freeze to fill in rough areas. Survey transverse cross-sections to verify snow moved off the runway surface does not conflict with the lateral clear area slope requirements. See the patching procedure in Appendix B-3 for additional repair criteria.

2-2.3 Maintenance During Use.

Ice irregularities, often hidden by snow cover, can do significant damage to wheels when struck at any speed. Surface preparation must include a thorough visual inspection of the landing area to look for ice irregularities and study snow depths and characteristics. Any unacceptable irregularities must be removed. Snow irregularities may be large enough to require the entire surface to be dragged or graded to fill low areas and remove high areas. All undulating surfaces must be graded to minimize the slope and prevent wheel damage.

2-2.3.1 White Ice Runway Surface.

The runway surface must be inspected following every wheeled aircraft operation. Any areas with rubber or soot deposits must be scarified and contaminated snow/ice removed to eliminate any dark material that can absorb sunlight and result in melting the surface. Between C-17 operations and after any snowfall deposits the entire surface shall be rolled with the proof load cart to keep the compacted white ice cap well compacted. When needed, thin lifts of snow may be cut from the berms on either lateral clear area and dragged onto the white ice runway surface then compacted with the proof load cart.

2-2.3.1.1

Maintaining the compacted snow surface will require periodic dragging to remove surface irregularities created by wind action (sastrugi) and to promote ice crystal deformation to harden the loose surface snow. Various types of drag devices have been successfully used. The compacted snow surface will be dragged immediately after fresh snow accumulation, windstorms, or when landings/takeoffs or cargo loading operations have disturbed the surface. Regular inspections by the airfield manager or a designated representative and pilot reports will determine if dragging or other maintenance action is required.

2-2.3.1.2

Aprons shall be groomed to harden the surface prior to supporting cargo loading operations.

2-2.3.2 Sea Ice Runway Surface.

New snow accumulation on the sea ice runway shall be either removed or compacted, depending on the depth. Thin lifts of snow can be compacted (25 millimeters [1 inch] or less compacted thickness) onto the runway surface with the proof load cart. This improves the friction and braking action on the runway.

2-2.4 Runway Strength Evaluation.

Annually, before commencing aircraft operations, the airfield surfaces will be evaluated following the structural evaluation criteria outlined in Appendices B-4 through B-11. In addition, the airfield manager is responsible for interim evaluations as conditions change and as repairs are made. All structural data and recommendations for weight-bearing capacity shall be transmitted to HQ AMC/A7OI for analysis and concurrence. See paragraph 2-6 for airfield certification procedures.

2-2.4.1 Glacial Ice Operating Surface.

The glacial ice surface must be evaluated for three failure modes: deformation, creep, and flexural. Methods for evaluating each mode are described in Appendix B-4.

2-2.4.2 White Ice Operating Surface.

The white ice surface must be evaluated for thickness and strength to avoid deformation failure. Methods for evaluating the white ice surface are described in Appendix B-5.

2-2.4.3 Sea Ice Operating Surface.

2-2.4.3.1

Sea ice is often categorized as first-year or multi-year ice. This characterization of the ice indicates much about its nature, with multi-year ice having significantly greater complexity. However, for the purposes of a sea ice runway for heavy wheeled aircraft, this FC treats both types the same, using overall ice thickness and ice temperature as governors for ice strength, which ultimately determines its ability to support a given aircraft operation.

2-2.4.3.2

The sea ice surface must be evaluated for three failure modes: deformation, flexural (landing and takeoff), and creep (parking). Methods for evaluating each mode are described in Appendix B-6.

2-2.5 Warm Weather Operations at Pegasus White Ice Runway.

Warm weather, typically occurring during the months of December and January, could restrict airlift operations on Pegasus white ice runway, requiring all aircraft to arrive and depart during restricted hours. The USAP will develop procedures for conducting airfield operations in warm weather to include monitoring, testing, and reporting requirements. The airfield manager is responsible for implementing the procedures.

2-3 AIRFIELD MARKINGS.

2-3.1 Airfield Marking Approach

Many snow/ice runways are VFR-only facilities and operated solely during daylight. However, due to their unconventional appearance (white surface, white surroundings), for compatibility with standard pilot experience, and for periods where landings are required but weather conditions are less than ideal, a minimum level of markings are required. The use of markings has evolved over the years and is expected to continue into the future. This FC does not address markings needed for night operations or skiways. See AFI 13-217 for skiway marking requirements.

2-3.2 Specific Requirements

Adopting the full extent and type of markings found at a conventional airfield is impractical for a snow/ice runway. Painted markings will degrade the snow/ice and quickly be covered by blowing snow or new snowfall. Conventional airfield directional signs will be quickly buried by snow. Sometimes other visual aids (lights) and electronic signals (navigational aid systems [NAVAIDS]) are available to assist with acquiring and lining up on the runway; therefore, a system of flags is used to indicate the limits of the runway. Required and optional markers are listed below.

Threshold markers	Required
Distance remaining and edge markers	Required
Approach line markers	Optional
Taxiway and apron flagging	Optional

2-3.3 Marking Criteria

Minimizing the number and surface area of markings is desirable for the purpose of reducing runway maintenance and increasing runway availability and longevity. Figure 2-5 shows the layout of a typical snow/ice runway, including the positions of threshold, distance remaining, and approach line markers. All markers will be made of durable, lightweight materials. Support posts must be frangible and present a tiny cross-section to the wind to minimize snow drifting, which will be accomplished by a minimum number of posts; bamboo canes are currently used with good results. The markers are ideally of a mesh material to minimize the impedance of the wind, both to limit wind loading on the support posts and, more importantly, to reduce snow drifting. Ideally, the base of a marker shall be more than 0.3 meter (1 foot) above the snow surface to avoid snow drifting. This height must be balanced against the need for adequate clearance between the base of an aircraft wing, engine, or propeller and the top of the marker. Currently, black or red fabric is used for marker flags. White numbers on the black fabric are used for distance-remaining markers. Flags without numbers are punched with up to five 50-millimeter (2-inch) -diameter holes to reduce wind resistance and bending force in the support posts. Note that all marker flags are well above the runway surface and that no surface markings are present to depict the runway centerline, shoulder edges, landing zone, or thresholds.

2-3.4 Temporary Markings

On glacial ice, white ice, and compacted snow parking aprons, temporary markings are sometimes applied to guide aircraft to parking positions. Reflective orange or red paint can be sprayed on the apron surface just prior to arrival to indicate the nose gear centerline path and stop point. When the marking is no longer needed, it shall be quickly scarified to avoid absorbing sunlight radiation that can lead to melting of the surface.

2-3.5 Marker Flags

Figure 2-6 shows details of the marker flags. Note that all markings are only present at the site during the flight periods. At all other times markers are removed from the site to discourage progressive snow accumulation.

2-3.6 Frangibility

All structures placed or constructed within the airfield environment are required to be frangible (to the maximum extent practicable). This applies for any aboveground construction within 76.5 meters (250 feet) of the runway centerline and an extension of that dimension for 914.5 meters (3000 feet) beyond the ends of the runway thresholds and within 61 meters (200 feet) of the taxiway centerline (except required NAVAIDS). Frangibility implies that an object will collapse or fall over after being struck by a moving aircraft with minimal damage to the aircraft.

2-3.7 Low Visibility Markers.

For operations during low-light or no-light periods, special high-intensity, retro-reflective and radar-detectable cones may be deployed at the locations shown in Figure 2-7. One type of suitable cone is manufactured by Reginald Bennett (RBI) International, Model Number 336.

2-3.7.1 Cone Dimensions and Characteristics.

Cones will be shaped like a square-base pyramid. Cones will be minimum 790 millimeters (31 inches) tall and 610 millimeters (24 inches) wide at the base. Cones used for marking the landing zone boxes will have red and green sides. Cones used for marking the runway edge will be silver on all sides.

2-3.7.2 Cone Layout.

Cones will be placed every 152.5 meters (500 feet) on each side of the runway next to the normal daytime flag markers (approximately 30.5 meters [100 feet] from centerline). The first 305 meters (1000 feet) of each approach end will have cones spaced 305 meters (1000 feet) apart with double cones to create a landing zone “box.” The cones shall be spaced laterally at a minimum of 1.8 meters (6 feet) apart to allow visual acquisition of two separate cones—any closer and they merge into one cone reflection. Two cones will be placed symmetrically about the centerline, spaced 1.8 meters (6 feet) apart at the departure end of the overrun.

2-3.7.3 Cone Installation.

Cones are secured to the ice runway using four lag screws, each 275 millimeters (11 inches) long and 9 millimeters (0.375 inch) in diameter, with 38-millimeter (1.5-inch) fender washers. Holes are pre-drilled in the ice, 6 millimeters (0.25 inch) in diameter and 300 millimeters (12 inches) deep.

Figure 2-5 Marker Layout for Ice Runways (Not to Scale)

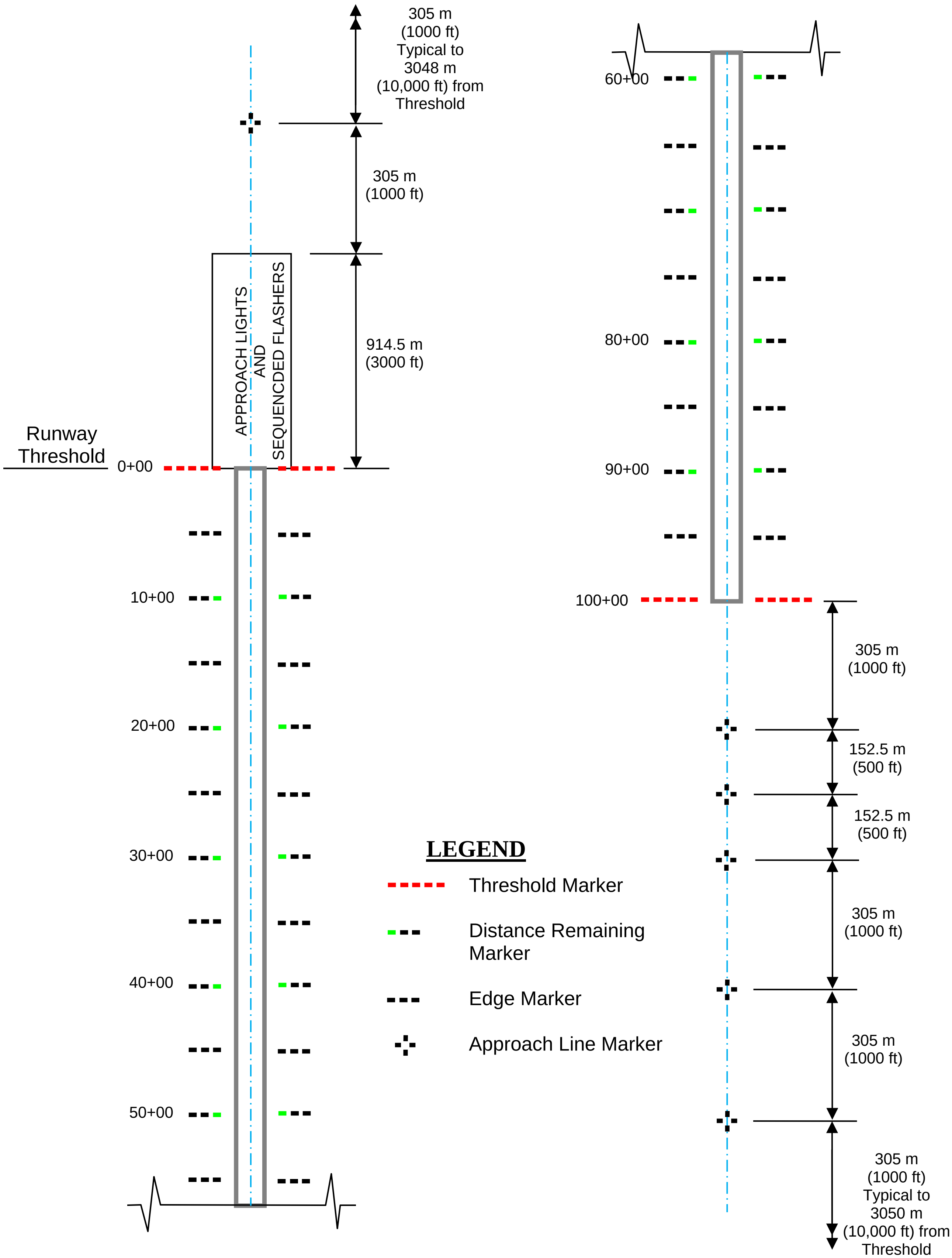
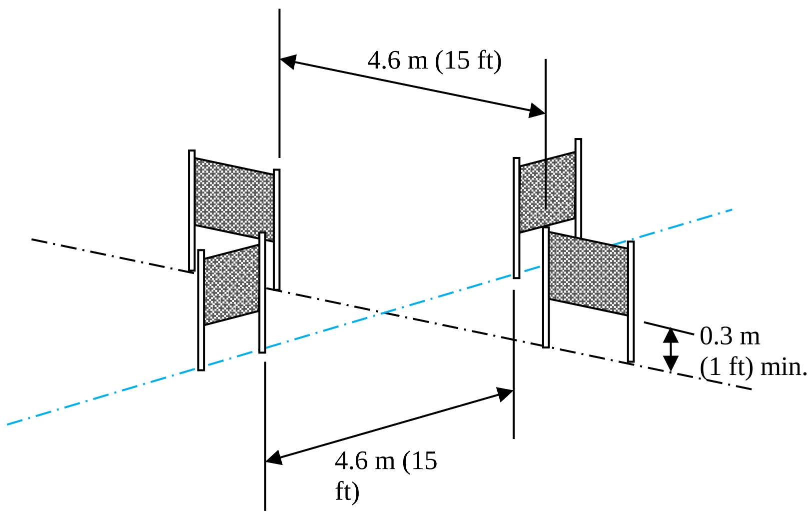
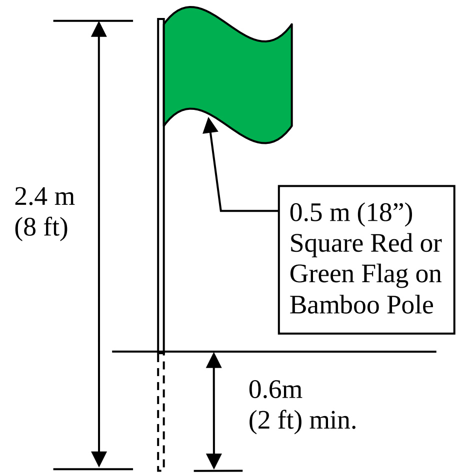


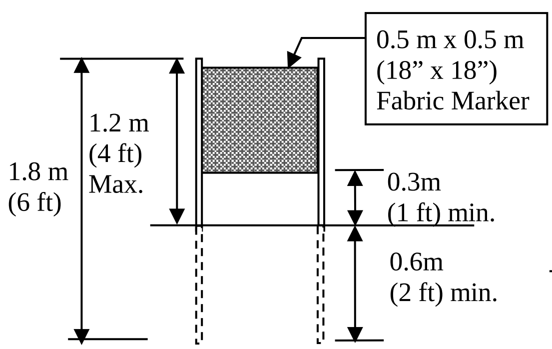
Figure 2-6 Marker Details for Snow/Ice Runways



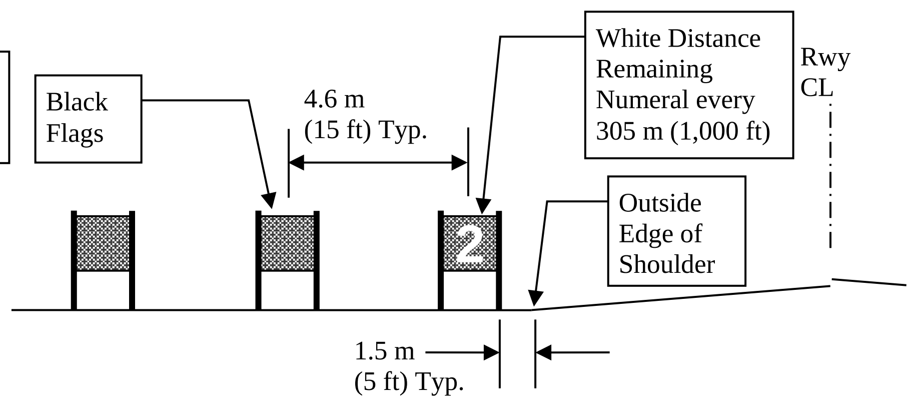
Detail 1: Four Marker Configuration for Approach Lines



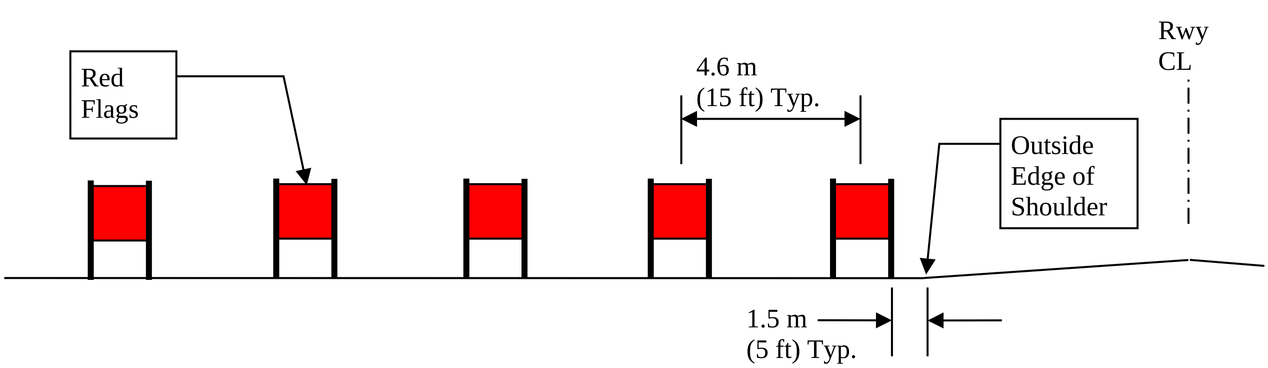
Detail 2: Taxiway and Apron Marking Flags



Detail 3: Runway Marker Flags

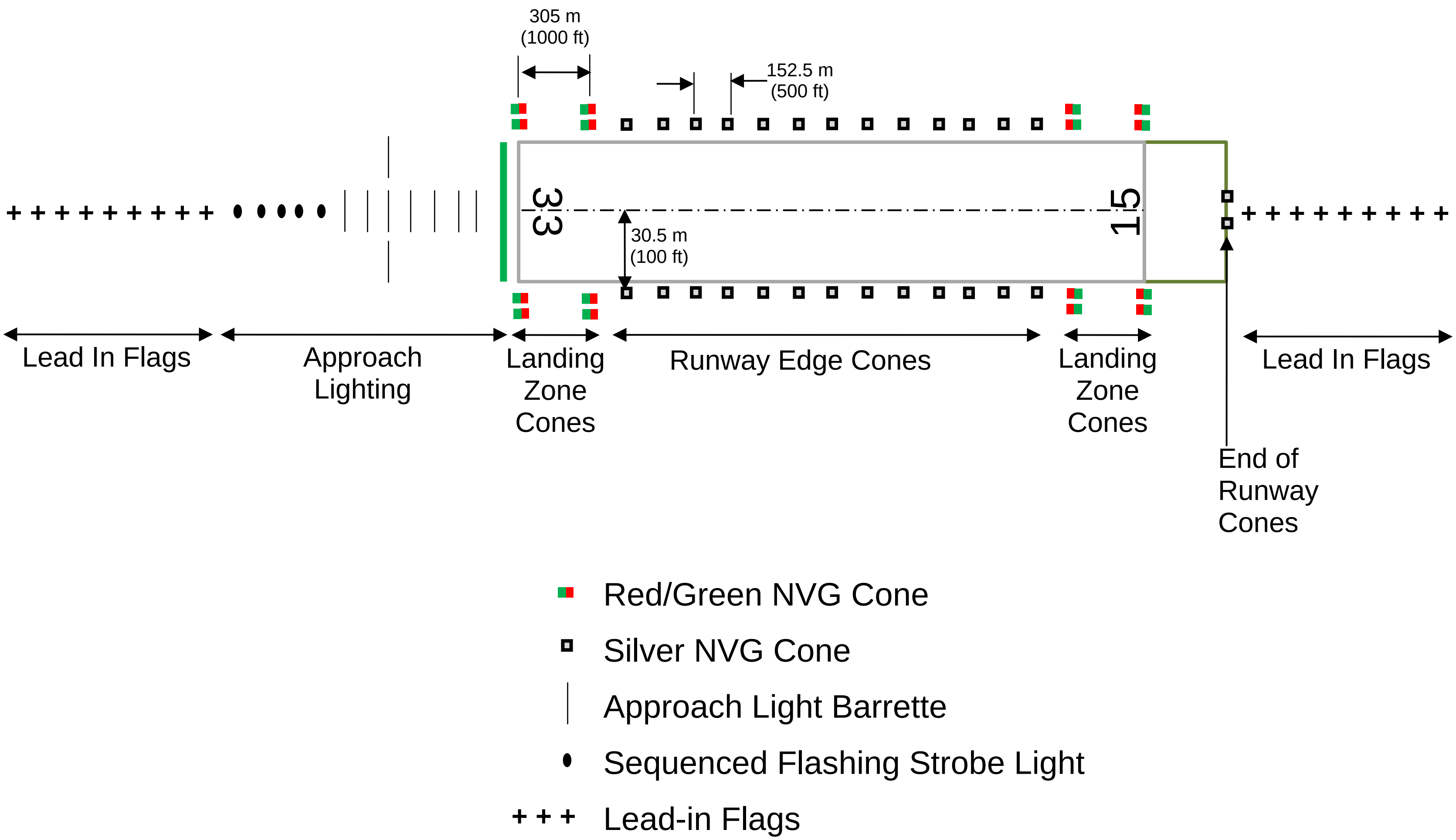


Detail 4: Runway Edge Markers



Detail 5: Runway Threshold Markers

Figure 2-7 Low Visibility Cone Layout for Ice Runway



2-4 AIRFIELD LIGHTING.

2-4.1 Lighting Approach

A limited number of lights are helpful for runway alignment acquisition, particularly during less-than-perfect weather conditions. The use of airfield lighting on snow/ice runways has evolved over the years and is expected to continue into the future.

2-4.2 Desirable Lighting Components

Adopting the full extent and type of lighting found at a conventional airport is not practical for a snow/ice runway. Runway edge lights would interfere with maintenance of the snow or ice surface and providing power with above-ground cables is not practical. Snow/ice runways can be used without airfield lights as long as the field is properly marked and the airspace is controlled. However, airfield lights are highly desirable and can significantly improve the safety of flying operations, especially at locations such as Williams Field that have nearby topographical features that require circling approaches to land. The lighting components listed below are optional but desirable and listed in the order of importance. Airfield lighting systems that are operational shall be noted in the airfield manager's certification report to HQ AMC/A3AS (see paragraph 2-6).

Threshold lights	Optional
Approach lights (modified MALSR)	Optional
Precision approach path indicators (PAPI)	Optional
Runway end identifier lights (REIL)	Optional

2-4.2.1 Threshold Lights.

Install threshold lights in a line perpendicular to the extended runway centerline prior to the threshold a distance of not more than 3 meters (10 feet). The line of lights is symmetrical about the runway centerline and extends 5 meters (15 feet) outboard of the lines of the innermost runway edge marker flags (total of 36.5 meters [120 feet] from centerline). The threshold lights consist of elevated lights with green lenses. Lights are symmetric about the runway centerline and spaced 1.5 meters ± 50 millimeters (5 feet ± 2 inches) apart (total of 48 lights). Even when threshold lights are installed, threshold marker flags must still be installed as described in paragraph 2-3.5.

2-4.2.2 Approach Lights.

Approach lights are placed in a modified SSALR (simplified short approach lighting with runway alignment indicator lights [RAILs]) configuration and consist of two different types of lights: steady burn and sequenced flashing strobes. Steady-burn elevated white lights in groups of five are placed within the 427 meters (1400 feet) prior to the approach threshold at 61 meters (200 feet) spacing. An additional two groups of five lights are placed either side of the center barrette at 305 meters (1000 feet) from the threshold. Elevated sequenced flashing strobe lights (SFL) are installed on centerline and between 488 meters (1600 feet) and 914.5 meters (3000 feet) from the approach threshold at 61 meters (200 feet) spacing. Three to eight flashing strobes can be installed, depending on equipment availability. The SFL must flash in sequence from the outer end toward the runway threshold at a steady rate between 60 and 120 times per minute. The interval between flashes of adjacent lights must nominally be 1/30 second. See UFC 3-535-01, paragraph 3.5, for specific color, intensity, and aiming criteria.

2-4.2.3 Precision Approach Path Indicators (PAPI).

The PAPI is an unattended system that provides visual glide path criteria for landing an aircraft. Sighting and configuration requirements are listed below. See UFC 3-535-01 for additional details.

2-4.2.3.1 Configuration.

The standard PAPI system consists of a light bar with four light units (FAA L-880, per FAA AC 150/5345-28G) placed on the left side of the runway in the vicinity of the touchdown point. See Figure 3-12 in UFC 3-535-01 for an illustration of the configuration.

Note: At McMurdo Station airfields, a two-bar PAPI system is commonly used. This configuration is less desirable, but acceptable, and shall be noted in the airfield suitability report (see paragraph 2-6.1).

2-4.2.3.1.1

Each light unit must be frangible mounted. It must contain two lamps minimum (three lamps preferred) and an optical system that produces a horizontally split, two-color (white over red) light beam.

2-4.2.3.1.2

Beginning at the outboard-most units, each unit in a bar is aimed into the approach at a successively higher angle above the horizontal. When on a proper approach path, the pilot sees the two inboard lights in both bars as red and the two outboard lights as white. As the approaching aircraft settles below the proper path, the pilot sees an increasing number of red lights in each outboard light bar. As the aircraft rises above the path, the pilot sees an increasing number of white lights in each inboard light bar.

2-4.2.3.1.3

The edge of the innermost unit in each bar must be no closer than 15.2 meters (50 feet) from the runway edge and the units in a bar must be 9 meters (30 feet) apart. The beam centers of all light units must be within ±0.025 meter (1 inch) of a horizontal plane. This horizontal plane must be within ±0.30 meters (1 foot) of the elevation of the runway centerline at the intercept point of the visual glide path with the runway. The units in a bar must all be within 0.025 meter (1 inch) of a line drawn perpendicular to the runway centerline. The distance from threshold to the PAPI shall be the shortest distance that will accommodate the criteria in paragraph 2-4.2.3.2.

2-4.2.3.1.4

Two-Bar PAPI System. In a two-bar system, the units are aimed such that when on a proper approach path the pilot sees the inboard light bar as red and the outboard light bar as white. As the approaching aircraft settles below the proper path, the pilot sees an increasing number of red lights in the outboard light bar. As the aircraft rises above the path, the pilot sees an increasing number of white lights in the inboard light bar.

2-4.2.3.2 Photometric Requirements.

See UFC 3-535-01, paragraph 3-7.3, for PAPI photometric criteria.

2-4.2.3.3 Siting Considerations.

Siting a PAPI must consider, as a minimum, the following: existing or planned instrument landing system (ILS) glide slope; the established glide path (aiming angle, typically 3 degrees); the threshold crossing height (TCH) for the selected aircraft height group; and the runway gradient (longitudinal slope) from the threshold to the PAPI location. See UFC 3-535-01, paragraph 3-7.4, for criteria regarding additional siting considerations.

2-4.2.4 Runway End Identifier Lights (REIL).

The REIL provides the pilot with rapid and positive identification of the runway threshold during approach for landing. The REIL assists the pilot to make landings in VFR conditions and in non-precision instrument approaches in IFR conditions.

2-4.2.4.1 Configuration/Location/Aiming.

A REIL system consists of synchronized flashing lights placed symmetrically about the runway centerline in the vicinity of the runway threshold. The optimum location is 12.2 meters (40 feet) from the runway edge and in line with the threshold lights. The lights may be located laterally up to 23 meters (75 feet) from the runway edge and longitudinally up to 12.2 meters (40 feet) downwind (away from the runway) from the threshold lights to 27.5 meters (90 feet) upwind. Adjust the location of both lights as equally as possible to maintain the symmetry of the installation. The difference in locations must not be more than 3 meters (10 feet) laterally or longitudinally. The elevation of both lights must be within 3 meters (10 feet) of the runway centerline at the threshold. See UFC 3-535-01, paragraph 3-6, for additional information.

2-4.2.4.2 Photometric Requirements.

The color and intensity requirements for sequenced flashing lights apply to REIL.

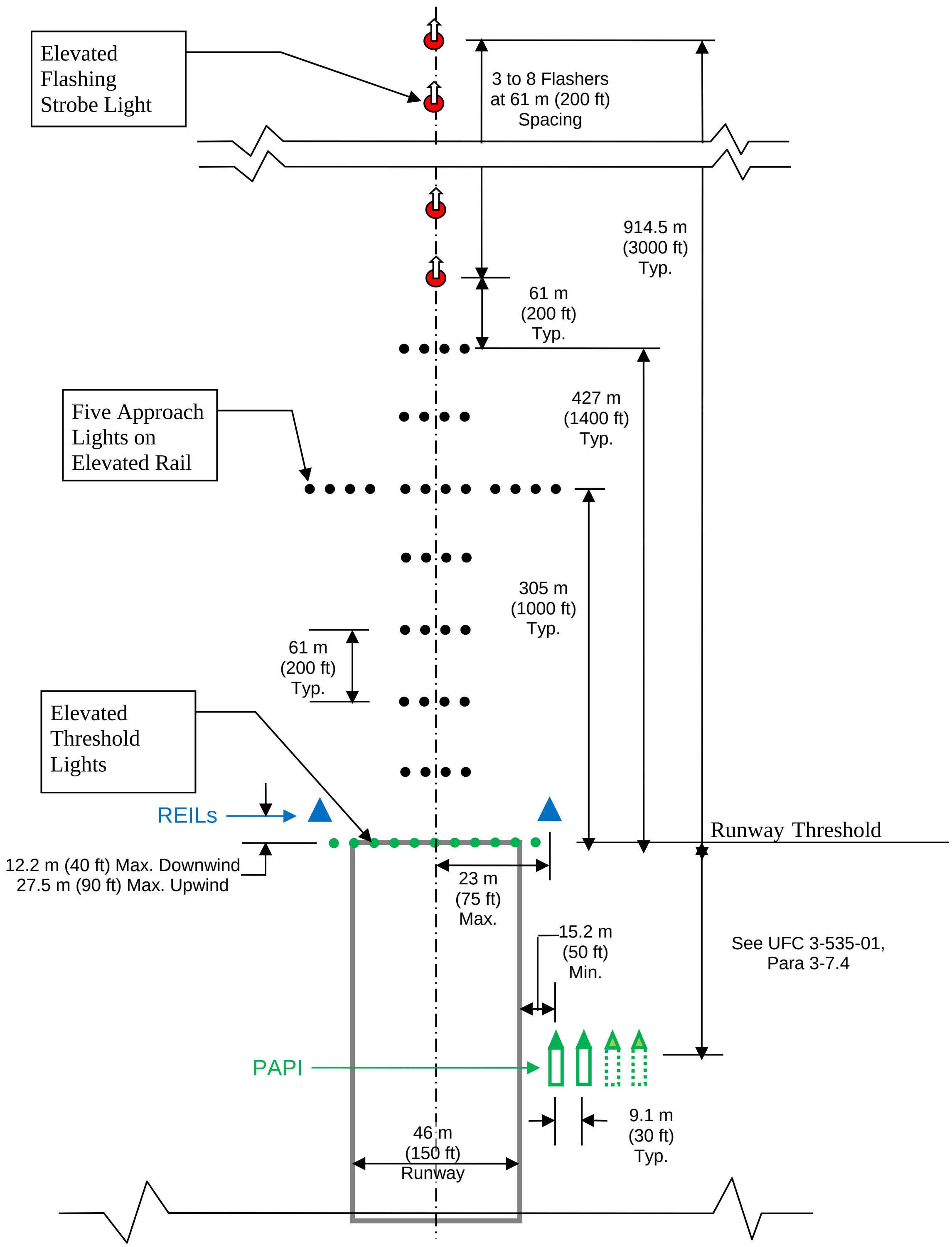
2-4.2.4.3 Power Requirements.

The system may be powered by solar cells, separately by generator, or by a power adapter unit connected to the threshold runway light circuit. There is no requirement for standby power.

2-4.3 Light Installation

Figure 2-8 shows the layout of lights on a typical snow/ice runway, including the positions of approach lights and threshold lights. Lights may be powered by solar cells or generators. All lights must be installed on frangible supports. Generators must be positioned outside the runway lateral clear area and the runway end clear area. All installations are above the surface; however, power cables may be trenched into glacial ice, white ice, and compacted snow airfields to allow the use of central and displaced power generation. **Trenches must never be cut into a sea ice airfield.**

Figure 2-8 Lighting Layout for Snow/Ice Runways



2-4.4 Lighting Details

Figures 2-9, 2-10 and 12-11 show details of the lights that may be installed on snow/ice runways. Note that lights are typically only present at the site during normal flying periods. At all other times, all equipment (except electrical cable set in trenches) is removed from the site to discourage drifting snow accumulation.

2-4.5 Taxiway and Apron Lighting

Lights are not typically installed for snow/ice airfield taxiways or aprons because operations on these features are almost exclusively during daylight. If operating during darkness, the airfield manager is responsible for using follow-me vehicles, temporary lighting, or other suitable systems to guide the aircraft.

Figure 2-9 Typical SSALR Elevated 6.1-m (20-ft) Light Barrette

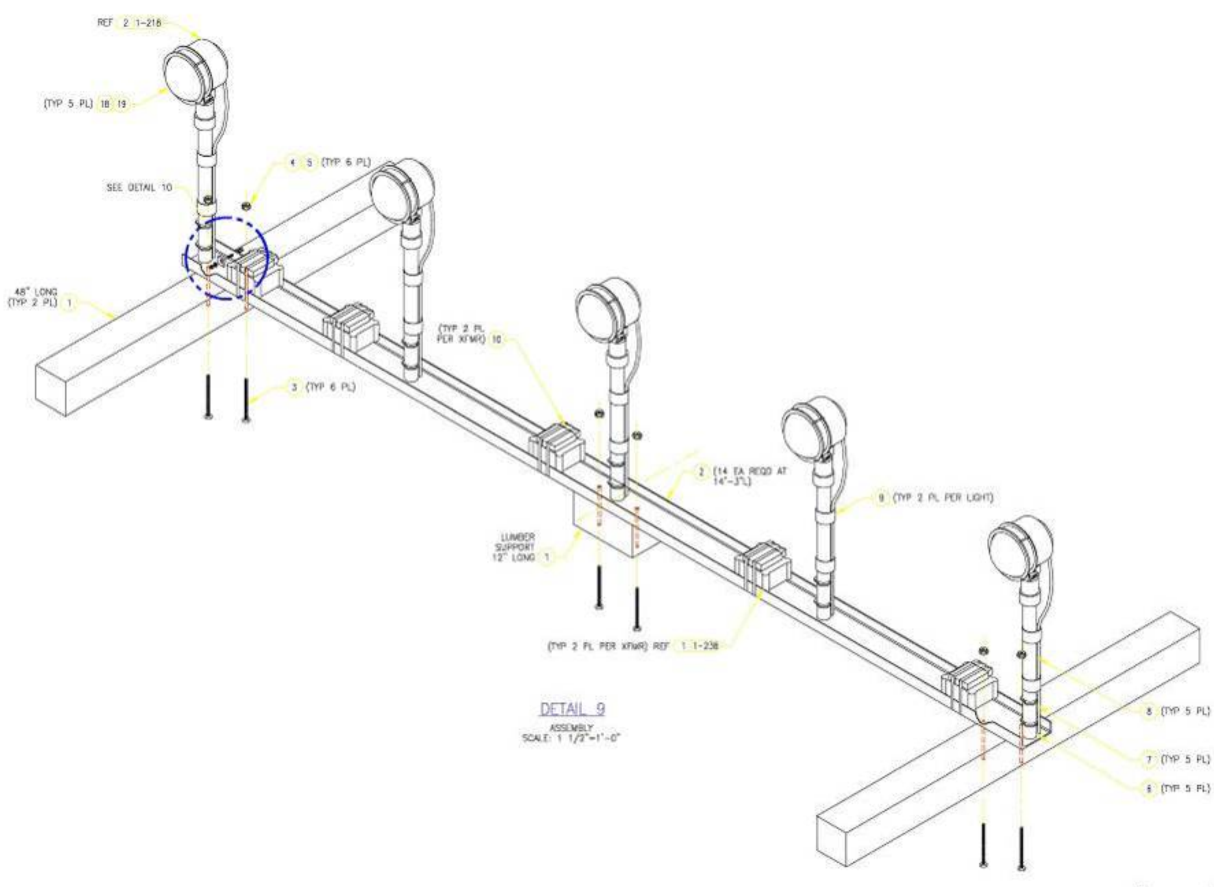
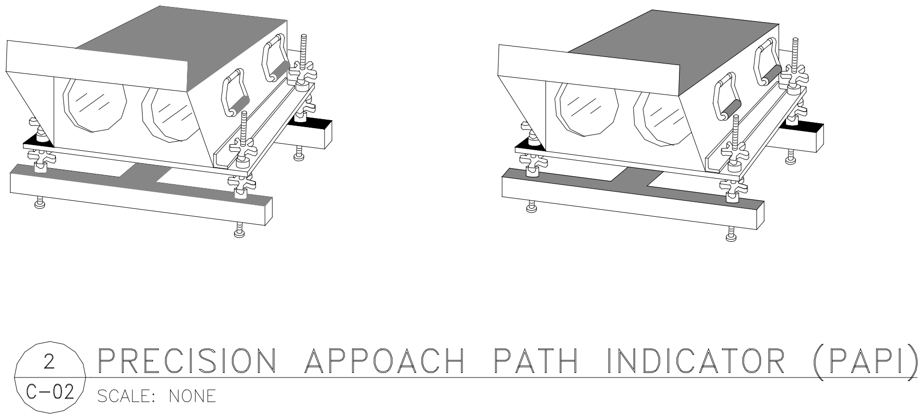
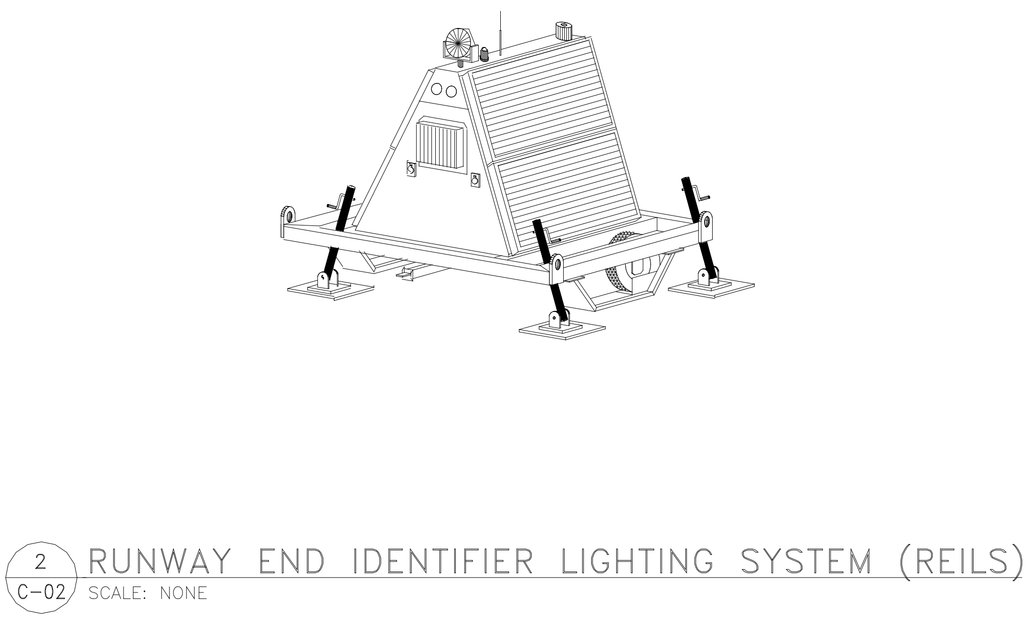


Figure 2-10 Typical Threshold Light Installation for Snow/Ice Airfields

Figure 2-11 Lighting Details for Snow/Ice Airfields





2-5 ELECTRONIC NAVIGATIONAL AID SYSTEMS (NAVAIDS).

2-5.1 NAVAIDS - General

Although some snow/ice runways are VFR-only facilities and operated solely during daylight (such as field science camps), it is still desirable to have a limited number of electronic NAVAIDS to help guide the aircraft to the airfield. In some locations such as Williams Field, NAVAIDS are required to fly the runway approaches defined by terminal instrument procedures (TERPS) due to significant terrain obstacles in close relation to the airfield. Whenever NAVAIDs are installed, they greatly increase aircraft operational safety, particularly when weather conditions are less than ideal.

2-5.2 NAVAIDS Siting Criteria

Adopting the full extent and type of NAVAIDS generally found at a conventional airport (e.g., ILS localizer and glideslope antennas) would be difficult to acquire and maintain in a snow/ice environment. Generally, it is not necessary for a snow/ice runway to have the full complement of available NAVAIDS, but in some cases terrain may dictate the need for NAVAIDS. Some snow/ice runways can be used without NAVAIDS as long as the field is properly marked and the airspace is controlled (such as field science camps). However, NAVAIDS are highly desirable and can significantly improve the safety of flying operations. The NAVAIDS listed below are optional (unless dictated by TERPS) but desirable and listed in the order of importance.

Table 2-5 NAVAIDS

System	Required?	Siting Criteria
Microwave landing system (MLS)	Optional	AFI 11-230, para. 6.11
Tactical air navigation (TACAN)	Optional	UFC 3-260-01, Appendix B, Section 13
Airport weather observation station (AWOS)	Optional	FAA Order 6560.20
Mobile air traffic control tower (MATCT)	Optional	UFC 3-260-01, Appendix B, Section 17 UFC 3-260-01, para. B13-2.12
Wind indicators (cones)	Optional	UFC 3-535-01, para. 10-2 FAA AC 150/5345-27E, Type L-806 (Frangible)

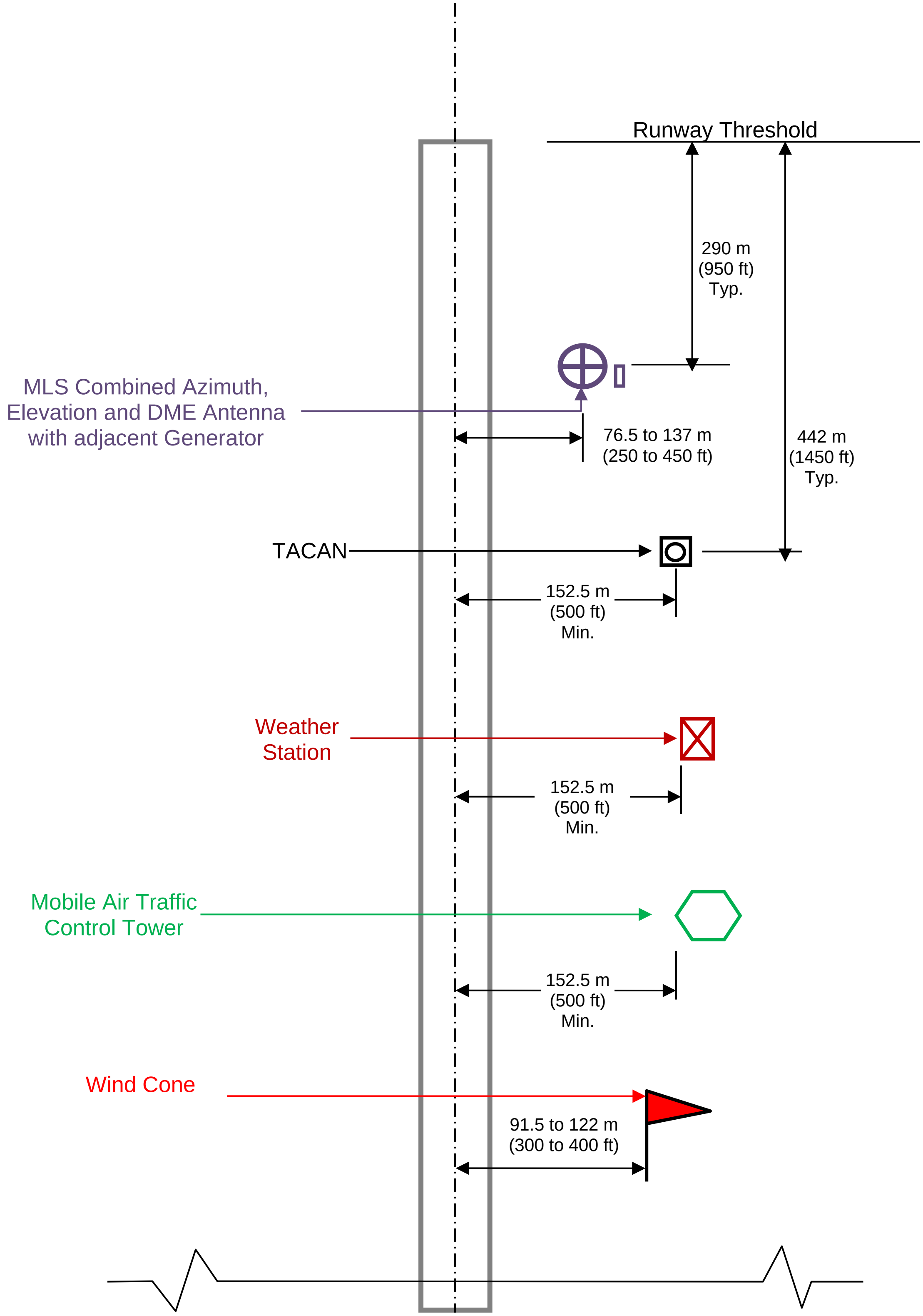
2-5.3 Positioning NAVAIDS

Figure 2-12 shows the positions for installing NAVAIDS (MLS, TACAN, AWOS, MATCT, and wind cone). These are strictly above-surface installations; however, subsurface wiring may be used for the NAVAIDS to allow central and displaced power generation.

2-5.4 NAVAIDS Implementation

Note that all NAVAIDS are generally only present at the site during the flying seasons. At most other times, all surface structures, including buildings and other support structures, are removed from the site to discourage progressive snow accumulation.

Figure 2-12 Snow/Ice Runway NAVAIDS Layout with Dimensions



2-6 AIRFIELD CERTIFICATION PROCESS.

2-6.1 Annual Certification.

2-6.1.1

The sea ice runway and white ice runway will be annually certified for operations by HQ AMC/A3. The airfield manager at McMurdo Station will initiate the request for certification by transmitting necessary information (dimensions, strength, cross-section, electronic NAVAIDS, lighting, markings) to HQ AMC/A7OI and HQ AMC/A3AS for review, comment, and to ensure all criteria are met. HQ AMC/A7OI provides the recommendation for certification for aircraft operations prior to the initial seasonal mission execution. The runway certification statement will be entered in the HQ AMC airfield suitability assessment maintained in the Global Decision Support System (GDSS) airfield database (AFD) in accordance with the Airfield Suitability and Restrictions Report (ASRR) and AMCI 11-211.

2-6.1.2

Due to the dynamic nature of the McMurdo airfields, environmental conditions change during a flying season or certification period, most often due to seasonal temperature fluctuations. The following changes to airfield conditions require notification to HQ AMC/A3AS for update to the GDSS AFD and, if applicable, waiver processing. Other changes to conditions (e.g., inoperable lighting system, missing edge marker flag) shall be issued as a Notice to Airmen (NOTAM) or airfield advisory by the airfield manager.

- Reductions in runway, shoulder, overrun, lateral clear area, or end clear area dimensions
- Reductions in allowable weight-bearing capacity (Sea Ice Monitoring Report)

2-6.2 Periodic Air Force Team Certification.

Although the primary responsibility for airfield data collection to verify design criteria falls with the on-site USAP airfield manager and staff, periodic evaluations by Air Force engineering personnel are needed for the reasons listed below. Evaluation of the Pegasus white ice runway by Air Force personnel will occur every third year.

2-6.2.1

Air Force engineers need to maintain an understanding of the extreme snow/ice runway environment and the challenges associated with building and maintaining a snow/ice airfield for use by Air Force aircraft.

2-6.2.2

HQ AMC/A7 is tasked to verify the interpretation of snow/ice runway airfield data and make a recommendation to certify the snow/ice runways for opening to aircraft traffic. The quality of the interpretation is substantially enhanced when the engineer has the on-site experience to understand how the data is collected and what it means.

2-6.2.3

The criteria established in this FC are currently only applied at McMurdo Station; therefore, updates to the FC are routinely needed to incorporate changes in equipment and airfield configurations.

2-6.3 Operational Waivers to Criteria.

The criteria in this FC are the minimum permissible for DOD aircraft (C-130, C-17, and C-5 operations). When deviations exist or occur, an operational waiver must be obtained before flight operations begin. The airfield manager or a designated representative will initiate a written waiver request through 13 AEG/CC and HQ PACAF/A3 to the Air Force component with operational control (OPCON) for Antarctic missions. The waiver must outline all criteria that do not meet the requirements of this FC. The appropriate airfield manager or airfield survey team will verify existing prepared landing zone (PLZ) dimensions and grades. HQ AMC/A7O and /A3V will assess the waiver request for viability and risk and make a recommendation to the Air Force component commander with OPCON for Antarctic missions. For Transportation Command (TRANSCOM)/AMC operational missions under OPCON of 18th Air Force, 18 AF/CC is the waiver authority in accordance with AFI 11-202V3.

Note: In addition to sending data and requests for deviations to HQ AMC/A3, data monitoring results shall be courtesy-copied to HQ PACAF/A7 and HQ AMC/A7.

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APPENDIX A REFERENCES

AIR FORCE

AFI 11-202, Vol. 3, *General Flight Rules*, http://www.e-publishing.af.mil

AFI 11-230, *Instrument Procedures*, http://www.e-publishing.af.mil

AFI 13-217, *Drop Zone and Landing Zone Operations*, http://www.e-publishing.af.mil

AMCI 11-211, *Destination Airfield Suitability Analysis*, http://www.e-publishing.af.mil

ARMY

CRREL Monograph 98-1, *Construction, Maintenance, and Operation of a Glacial Runway, McMurdo Station, Antarctica*, http://www.crrel.usace.army.mil/library/monographs/M98_01.pdf

CRREL Technical Report 153, *Study of the Rammsonde for Use in Hard Snow*

Waterways Experiment Station Instructional Report GL-92-3, *Description and Application of Dual Mass Dynamic Cone Penetrometer*, http://www.dtic.mil/dtic/tr/fulltext/u2/a251960.pdf

NAVY

Naval Civil Engineering Laboratory Report, *Nomographs for Operating Wheeled Aircraft on Sea-Ice Runways: McMurdo Station, Antarctica*, presented at the Third International Conference on Ice Technology, Cambridge, MA

Naval Facilities Engineering Service Center, *Landing and Parking Curves for the C-17 Globemaster on Sea Ice: McMurdo Station, Antarctica*, available in Proceedings of the Seventh (1997) International Offshore and Polar Engineering Conference

Vaudrey, K. 1977, *Ice Engineering – Study of Related Properties of Floating Sea-Ice Sheets and Summary of Elastic and Viscoelastic Analyses*, U.S. Naval Construction Battalion Center, Port Hueneme, CA, Civil Engineering Laboratory, Technical Report R-860

JOINT SERVICE

UFC 3-260-01, *Airfield and Heliport Planning and Design*, http://www.wbdg.org/ccb/browse_cat.php?o=29&c=4

UFC 3-535-01, *Visual Air Navigation Facilities*, http://www.wbdg.org/ccb/browse_cat.php?o=29&c=4

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM D1883, *Standard Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils*

ASTM D6951, *Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications*

AMERICAN SOCIETY OF MECHANICAL ENGINEERS (ASME)

Barthelemy, J., 1992, Nomographs for Operating Wheeled Aircraft on Sea-Ice Runways: McMurdo Station, Antarctica, 11th International Conference on Offshore Mechanics and Arctic Engineering, Calgary, Alberta, June 7–12, 2002, Proceedings, Vol. 4. Edited by Ayorinde, Sinha, Sodhi, and Nixon, p. 27-33, published by the American Society of Mechanical Engineers, New York.

FEDERAL AVIATION ADMINISTRATION (FAA)

FAA Order 6560.20B, *Siting Criteria for Automated Weather Observing Systems (AWOS)*, http://www.faa.gov/regulations_policies/orders_notices/index.cfm/go/document.information/documentID/9380

FAA Advisory Circular (AC) 150/5345-27E, *Specification for Wind Cone Assemblies*, http://www.faa.gov/documentlibrary/media/advisory_circular/150_5345_27e.pdf

FAA AC 150/5345-28G, *Precision Approach Path Indicator (PAPI) Systems*, http://www.faa.gov/airports/resources/advisory_circulars/index.cfm/go/document.current/documentNumber/150_5345-28

APPENDIX B BEST PRACTICES

B-1 DCP AND RSP OPERATING INSTRUCTIONS

B-1.1 Device Configuration.

For application on snow and ice airfields, the dynamic cone penetrometer (DCP) device shall be operated with a fixed 60°, 20-millimeter (0.8-inch) diameter cone, and an 8-kilogram (17.6-pound) drop hammer. The Russian snow penetrometer (RSP) shall be operated with the standard 30°, 11-millimeter (0.4-inch) diameter cone, and a 0.8-kilogram (1.75-pound) drop hammer.

B-1.2 Test Method.

Penetrometer measurements can be taken at any time of day, at any air temperature, and in any weather conditions (but environmental conditions at the time of testing must be documented). Take snow strength measurements at the locations noted in the field data sheet (see Figure B-63). **Note:** Ideally, two persons will work together to take measurements and record penetrometer data.

B-1.2.1

Verify that a measuring mechanism is available to accurately note every 25 millimeters (1 inch) of penetration of the penetrometer shaft (e.g., distance marks on the penetrometer shaft or an adjacent measuring rod). The “zero” penetration mark is located at the top of the cone’s pointed end (i.e., at the lowest point on the penetration tip where the maximum penetrometer width occurs).

B-1.2.2

Gently place the tip of the penetrometer onto the snow surface and keep the shaft in a vertical position.

B-1.2.3

Push the penetrometer vertically into the snow until the widest part of the tip cone is flush with the surface of the snow (i.e., at the “zero” depth mark).

B-1.2.4

Gently raise the hammer weight until light contact is made with the top handle. The hammer must not impact the handle when being raised.

B-1.2.5

Allow the hammer to freely fall down onto the anvil, thus forcing the cone into the snow/ice.

B-1.2.6

Record how many hammer blows (drops) are needed to drive the penetrometer cone 25 millimeters (1 inch) into the surface, as measured by the markings on the shaft or detached measuring device. This will complete Blow Set 1. Note: 25 millimeters (1 inch) is the penetration goal for each blow set, but if the snow properties suddenly change and the cone quickly penetrates further than 25 millimeters (1 inch), simply note the actual penetration depth and number of blows in that blow set.

B-1.2.7

In the penetrometer field data sheet for that location, write down the number of blows under Blow Set 1 and the penetration of the cone (in millimeters) for that blow set.

B-1.2.8

Without moving the penetrometer begin Blow Set 2, driving the penetrometer another 25 millimeters (1 inch) into the snow by dropping the hammer as many times as needed to achieve this penetration.

B-1.2.9

Record the Blow Set 2 data into the appropriate blocks on the field data sheet. Continue the penetration test, 25 millimeters (1 inch) at a time, until the penetrometer tip firmly contacts the supporting glacial ice surface and penetration effectively stops. In deep compacted snow the entire rod may advance until the anvil contacts the surface.

B-1.3 Errors.

If the test data are suspicious or erroneous due to problems attributable to operator or equipment error, fix the problem, move the penetrometer 1 meter (3 feet) away from the original test location, and start the test again. Note the event in the "Comments or Observations" block of the field data sheet.

B-1.4 Soft Snow.

If the penetrometer tests indicate an area of soft snow (only one or two blows gives 25 millimeters [1 inch] of penetration), note the area on the data sheet and mark the location with a pole or flag for further testing and repair. Move 1 meter (3 feet) down the runway and start the test over.

B-1.5 Strength Index.

The strength index can be determined from the DCP and RSP tests using the formulas given in Appendix C-2. Alternatively, the Ice Runway Strength Survey Tool program, a software analysis routine, is available by contacting the National Science Foundation POC in paragraph 1-3. This software will ultimately be available in the Pavement Computer Assisted Structural Engineering (PCASE) package of applications.

B-2 GLACIAL ICE AND WHITE ICE RUNWAY PATCHING PROCEDURE

B-2.1 Introduction.

Infrequently, there may be damage to the runway surface from equipment gouging, solar-induced subsurface melt pool formation, or surface melting instigated by windborne or spilled contaminants. These areas will require clean-out, repair, and re-certification. The following patching procedure shall be followed. Repair these areas by removing the damaged snow and ice and replacing it with a crushed ice and water "patch" (in the glacial ice) and a new snow pavement (on the surface) that provides the required hardness/strength. The repair procedure is based on information in CRREL Monograph 98-1, page 57.

B-2.2 Tools.

The following tools are needed:

- Long-handled chisel
- Welder's slag hammer or rock hammer
- Coal shovel
- Source of cold, fresh water

B-2.3 Patching Procedure.

Thoroughly remove all contaminants (including melted and/or refrozen snow and ice) at the site of the repair and dispose of in accordance with site regulations. Remove any loose (but clean) snow and ice from the damaged area and place it to the side for later use. Clear the faces and edges of the cavity to allow close inspection of the ice along the sides and bottom.

B-2.3.1 Glacial Ice.

B-2.3.1.1

Use the chisel to excavate the area surrounding the failure area to make certain that all of the weak ice has been dislodged. If a large area of the surrounding ice is weak, use one of the large-scale test methods (see CRREL Monograph 98-1, page 47) to break up the weak ice and identify its limits.

B-2.3.1.2

Glacial ice removed from the failed area shall be further broken up with a hammer into pieces roughly the size of a fist or smaller. The crushed ice shall be packed into the cavity to fill the hole slightly above its top (approximately 75 to 100 millimeters [3 to 4 inches] higher). Remove any excess ice from the runway.

B-2.3.1.3

Slowly fill the hole containing the crushed ice with cold water (ideally very near 0 °C [32 °F]) to approximately 75% full. Fill the hole by directing the water around the perimeter of the hole. Mix the ice-water slurry in the hole with the chisel and shovel by vigorous vertical probing to ensure that all pore spaces are filled with water and to encourage water to flow into any cracks radiating into the surrounding ice. After about an hour, proceed to add water to approximately 50 millimeters (2 inches) below the ice surface. Smooth the surface with the backside of a shovel. Allow it to cool for three to four hours, after which time the surface usually will be frozen over.

B-2.3.1.4

Using the chisel, break the top of the ice surface in a number of places (10% of total surface area). Slowly re-flood the patch area to fill the air gap under the ice surface with cold water.

B-2.3.1.5

Use a brightly colored flag (e.g., orange) to mark the location of the patch on the ice surface. A corner of the flag can be frozen into the surface using cold water. If the runway is not in use, a bamboo or plastic pole with a flag can be pushed into the ice-water slurry to mark the location.

B-2.3.1.6

Note the approximate location of the patched area using the runway markers as a guide for the long axis and the knowledge of the runway width for the other axis. If air operations are in effect, the airfield manager, the air traffic controller, and the flight crew coordinator shall be notified that a fresh patch is on the runway and that this area will be avoided for at least 48 hours.

B-2.3.1.7

Allow the area to freeze for at least 48 hours before allowing traffic to resume; the flag shall then be removed. If possible, the patched area shall be “dressed” with the chisel-tooth grader blade to blend its edges into the surrounding ice surface and to provide a uniform surface texture.

B-2.3.1.8

Following repair of the glacial ice, the site must be re-certified using the procedures given in paragraph B-4 if the repair area is greater than 0.4 square meter (4.3 square feet).

B-2.3.2 White Ice.

B-2.3.2.1

For a white ice surface requiring repair, whether or not the previous procedures (paragraph B-2.3.1 et seq.) were required to patch the underlying glacial ice, ensure that all weak, contaminated, or damaged pavement is stripped from the glacial ice surface.

B-2.3.2.2

Fill the area with clean, fresh (no more than one-year-old) snow using hand or mechanical equipment, depending on the volume of snow required.

B-2.3.2.3

Level the snow surface with a light drag or snow plane, or a wide-tire (1 meter), low-ground-pressure (tire inflation pressure of 100 kilopascals (kPa) [14.5 pounds per square inch (psi)] or less) wheeled vehicle.

B-2.3.2.4

Use a compaction roller (used to initially construct the white ice surface) to level the entire patched area using 85% of the final tire pressure and gross load used at initial construction. Allow the snow to “rest” for 24 hours and repeat compaction rolling at 95% of the final tire pressure and gross load. After another 24-hour rest, repeat compaction rolling at 100% of the final tire pressure and gross load used during initial construction. The patched area will be ready to accept routine aircraft traffic following another 24-hour rest period, but this must be verified with certification tests as given in Appendix B-5.

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B-3 SEA ICE RUNWAY PATCHING PROCEDURE

B-3.1 Introduction.

Infrequently, there may be damage to the runway surface from equipment gouging, solar-induced melt features, or surface melting caused by windborne or spilled contaminants. These areas will require clean-out, repair, and re-certification. The following patching procedure shall be followed. Repair these areas by removing the damaged snow and ice and replacing it with a crushed ice and water "patch" (in the sea ice) and a new snow pavement (on the surface) that provides the required hardness/strength. The repair procedure is based on information in CRREL Monograph 98-1, page 57. Note that this procedure is commonly used during runway construction, but when ice temperatures rise above about -6.5 °C (20 °F) this process is largely ineffective because of excessive freeze-up times.

B-3.2 Tools.

The following tools are needed:

- Long-handled chisel
- Welder's slag hammer or rock hammer
- Coal shovel
- Source of cold, fresh water

B-3.3 Patching Procedure.

Thoroughly remove all contaminants (including melted and/or refrozen snow and ice) at the site of the repair and dispose of in accordance with site regulations. Remove any loose (but clean) snow and ice from the damaged area and place it to the side for later use. Clear the faces and edges of the cavity to allow close inspection of the ice along the sides and bottom.

B-3.3.1 Sea Ice.

B-3.3.1.1

Use the chisel to excavate the area surrounding the failure area to make certain that all of the weak ice has been dislodged. If a large area of the surrounding ice is weak, use one of the large-scale test methods (see CRREL Monograph 98-1, page 47) to break up the weak ice and identify its limits.

B-3.3.1.2

Dispose of sea ice removed from the failed area. Pieces of glacial ice (not sea ice) roughly the size of a human fist or smaller shall be packed into the cavity to fill the hole slightly above its top (approximately 75 to 100 millimeters [3 to 4 inches] higher).

Packed snow may be used in the absence of sufficient glacial ice. Any excess material shall be removed from the runway.

B-3.3.1.3

Slowly fill the hole containing the crushed ice (or packed snow) with cold, fresh water (ideally, very near 0 °C [32 °F]) to approximately 75% full. Fill the hole by directing the water around the perimeter of the hole. Mix the ice-water slurry in the hole with the chisel and shovel by vigorous vertical probing to ensure that all pore spaces are filled with water and to encourage water to flow into any cracks radiating into the surrounding ice. If using packed snow, gently push down on the patch with the backside of a shovel only; do not probe and stir with a tool. After about an hour, add water to approximately 50 millimeters (2 inches) below the surrounding sea ice surface. Smooth the surface with the backside of a shovel. Allow it to cool for three to four hours, after which time the surface usually will be frozen over.

B-3.3.1.4

Using the chisel, break the top of the ice surface in a number of places (10% of total surface area). Slowly re-flood the patch area to fill the air gap under the ice surface with cold, **fresh** water.

B-3.3.1.5

Use a brightly colored flag (e.g., orange) to mark the location of the patch on the ice surface. A corner of the flag can be frozen into the surface using cold water. If the runway is not in use, a bamboo or plastic pole with a flag can be pushed into the ice-water slurry to mark the location.

B-3.3.1.6

Note the approximate location of the patched area, using the runway markers as a guide for the long axis and the knowledge of the runway width for the other axis. If air operations are in effect, the airfield manager, the air traffic controller, and the flight crew coordinator shall be notified that a fresh patch is on the runway and that this area must be avoided for at least 48 hours.

B-3.3.1.7

Allow the area to freeze for at least 48 hours before allowing traffic to resume; the flag shall then be removed. If possible, the patched area shall be “dressed” with the chisel-tooth grader blade to blend its edges into the surrounding ice surface and to provide a uniform surface texture.

B-3.3.1.8

Following the sea ice repair, the site must be re-certified using the procedures given in Appendix B-6 if the repair area is greater than 0.4 square meter (4.3 square feet).

B-3.3.2 Snow Cap.

B-3.3.2.1

For a runway surface operated with a snow cap, it is required to replace the cap after patching the sea ice.

B-3.3.2.2

Fill the area with clean, fresh (not more than one year old) snow using hand tools or mechanical equipment, depending on the volume of snow required.

B-3.3.2.3

Level the snow surface with a light drag or snow plane, or a wide-tire (1 meter), low-ground-pressure (tire inflation pressure of 100 kPa [14.5 psi] or less) wheeled vehicle.

B-3.3.2.4

If the snow cap being replaced was processed, use the same procedure originally applied to bring the snow patch to an equivalent level of strength. Allow the snow to “rest” for 24 hours before allowing routine aircraft traffic.

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B-4 GLACIAL ICE STRUCTURAL EVALUATION PROCEDURE

B-4.1 Glacial Ice Runway Surface Evaluation—Deformation Failure.

The glacial ice surface must be shown to be capable of supporting C-130 and C-17 contact pressure levels for heavy wheeled aircraft without compressive or shear failure. These capacities will be demonstrated by one of the two following methods, depending on the circumstances: proof rolling to detect zones of weakness, or the experience of past operations.

B-4.1.1 Proof Rolling.

B-4.1.1.1

The primary source of ice weakness at the Pegasus site is caused by melt and re-freeze features. When they occur, they commonly show no surface expression and may give the runway a deceptive appearance of strength. Rigorous adherence to prescribed maintenance procedures can avoid such melt/re-freeze problems (see CRREL Monograph 98-1 for maintenance procedures). If there is any doubt, or if the conditions described in paragraph B4.1.1.2 apply, then the runway must be tested for structural strength.

B-4.1.1.2

Proof rolling tests are required if the surface temperature in the ice (measured at a depth of 10 millimeters [0.5 inch]) rises to or above –4 °C (25 °F) (as confirmed by solar-shielded, continuously recording temperature probes buried in the ice). If ice temperatures reach or exceed –4 °C (25 °F), the potential exists for subsurface melt-pool formation and the runway surface must be inspected for such potential melt-damaged areas by proof rolling. The testing will be performed with pneumatic tire(s) having a minimum inflation pressure of 7.7 kilograms per square centimeter (760 kPa or 110 psi). The vehicle shall have a minimum individual tire load of 16,000 kilograms (35,000 pounds). Coverage shall be at no greater than 1-meter (3-foot) lateral spacing over the entire width of the runway and shoulder surface. Successful proof rolling will generate no ice cracking resulting in a removable ice piece greater in size than 0.3 meter by 0.3 meter by 0.05 meter deep (12 inches by 12 inches by 2 inches deep). Any defective areas discovered will be removed, repaired, and retested according to the process outlined in Appendix B-2.

B-4.1.2 Past Operations.

Previous aircraft operations at the Pegasus runway have demonstrated that the existing ice surface has sufficient compressive strength to support aircraft with tire pressures up to 13.7 kilograms per square centimeter (1350 kPa or 195 psi). If aircraft operations were successfully supported by the Pegasus runway in the immediately previous flight period (as confirmed by close visual inspection of the runway for damage), and as long as the near-surface ice temperature has not risen to or exceeded –4 °C (25 °F) since the last flight period (as confirmed by continuously recording temperature probes buried in the ice), the ice surface will be considered adequate for aircraft with tire pressures up to the magnitude of the maximum operated during the prior flight period. If previous aircraft operations were not successfully supported, needed repairs and re-certification of the runway must be accomplished before further aircraft operations.

B-4.2 Glacial Ice Runway Surface Evaluation—Creep Failure.

Long-term parking at warm ice temperatures can lead to creep deformation of the glacial ice. At ice temperatures below –4 °C (25 °F) creep deformation is relatively slow. Since the Pegasus PLZ is operated principally as a “turn-around” runway (i.e., arriving aircraft debark within a few hours, spending limited time onsite), it is expected that creep deformation will be negligible. However, if aircraft will be parked for extended time periods then they will have to be moved periodically to avoid any difficulty during the initial rollout. It is recommended that no more than 25 millimeters (1 inch) of deformation occur below a parked aircraft tire. In general, this limit will be reached in one hour at an ice temperature of -2.5 °C (27.5 °F), two hours at -5 °C (23 °F), and three hours at -10 °C (14 °F).

B-4.3 Glacial Ice Runway Surface Evaluation—Flexural Failure.

B-4.3.1

The ice sheet at the Pegasus site is approximately 30 meters (100 feet) thick. Depending on the temperature and crystallographic structure and impurities content of the ice, this ice has flexural strength on the order of 5 to 10 kilograms per square centimeter (490 to 980 kPa or 75 to 150 psi). The large thickness of the ice sheet reduces the bending stresses in response to heavy wheeled aircraft to levels that can easily be carried by the ice. A PCASE analysis routine for rigid portland cement concrete, modified for glacial ice, was used to determine the minimum thickness of glacial ice needed to support the heaviest aircraft load (a fully burdened C-17) without flexural cracking. To be conservative, a flexural strength of only 0.4 kilogram per square centimeter (39.2 kPa or 5.7 psi) was used (this value is based on the weakest ice found in the area). Also, the sub-base material for this analysis is water since the Pegasus runway is floating on the sea. The results indicate that a C-17 at 263,600 kilograms’ (580,000 pounds) gross load requires an ice thickness of 2.25 meters (7.4 feet) for a safety factor of 1.0. Given that impurities and closed cracks certainly exist in the ice, a factor of safety of 3.0 is recommended. Thus, the Pegasus runway shall have an ice thickness of at least 6.8 meters (22.3 feet) to support the anticipated aircraft and loads.

Note: Sea ice has a much greater flexural strength than glacial ice so a significantly thinner layer of sea ice is sufficient to support aircraft.

B-4.3.2

The present 30-meter (100-foot) thickness of ice at the site suffices for all anticipated aircraft operations. However, if the site experiences appreciable thinning, or if this FC is used for another site, or aircraft other than the C-130 or C-17 are operated, a new analysis is prudent.

B-5 WHITE ICE STRUCTURAL EVALUATION PROCEDURE

B-5.1 White Ice Pavement Thickness.

B-5.1.1

There is no limit on the thickness of the white ice pavement on top of the supporting glacial ice. However, the white ice strength profile must be verified using a DCP or RSP. The white ice strength profile must meet the following two requirements:

1. The strength of the white ice layer must be greater than or equal to the values listed in Table B-1 throughout the layer.

2. The strength profile must show that there is no weak zone beneath a strong surface. The strength of the white ice may not decrease by more than 25% from the overlying material.

B-5.1.2

If either of the above conditions are not satisfied, contact the person(s) listed in paragraph 1-3 for recommendations on how to proceed.

B-5.2 White Ice Runway Surface—Deformation Failure.

It is required that the glacial ice (surface and flexural characteristics) be evaluated according to Appendix B-4 as part of the certification of a thin processed snow operating surface at the Pegasus PLZ. Being a thin processed snow pavement overlying a thick and sufficiently strong base, the principal structural requirement of the white ice is its ability to support tire contact pressures.

B-5.3 White Ice Runway Surface—Snow Pavement Strength Determination.

B-5.3.1

A penetration resistance index will be used as the basis for evaluation of snow strength. Measurements may be taken with either a DCP or an RSP. See Appendix B-1 for test procedures for both devices. The correlation between RSP and DCP index strengths is shown in Figure B-1. The correlation between DCP and the traditional pavement strength index—CBR, developed in soils—is shown in Figure B-2. A correlation by calculation between the RSP and CBR indices is shown in Figure B-3.

Figure B-1 Correlation Between RSP and DCP

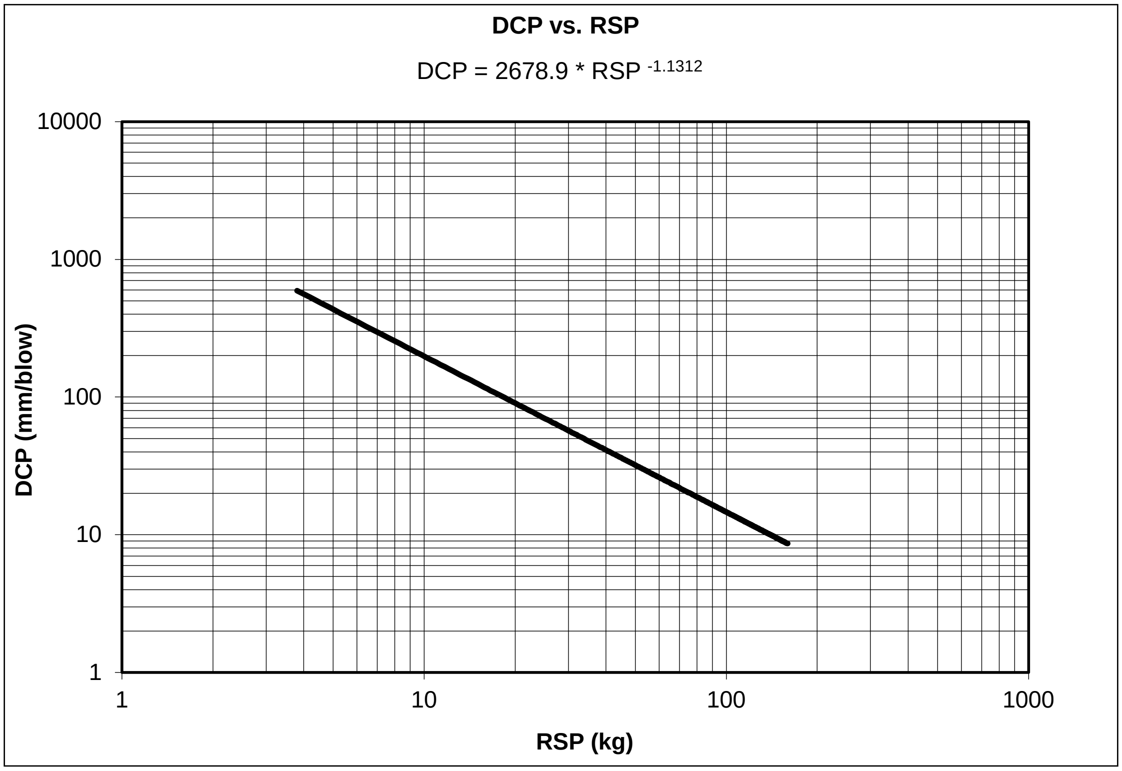


Figure B-2 Correlation Between DCP Index and CBR

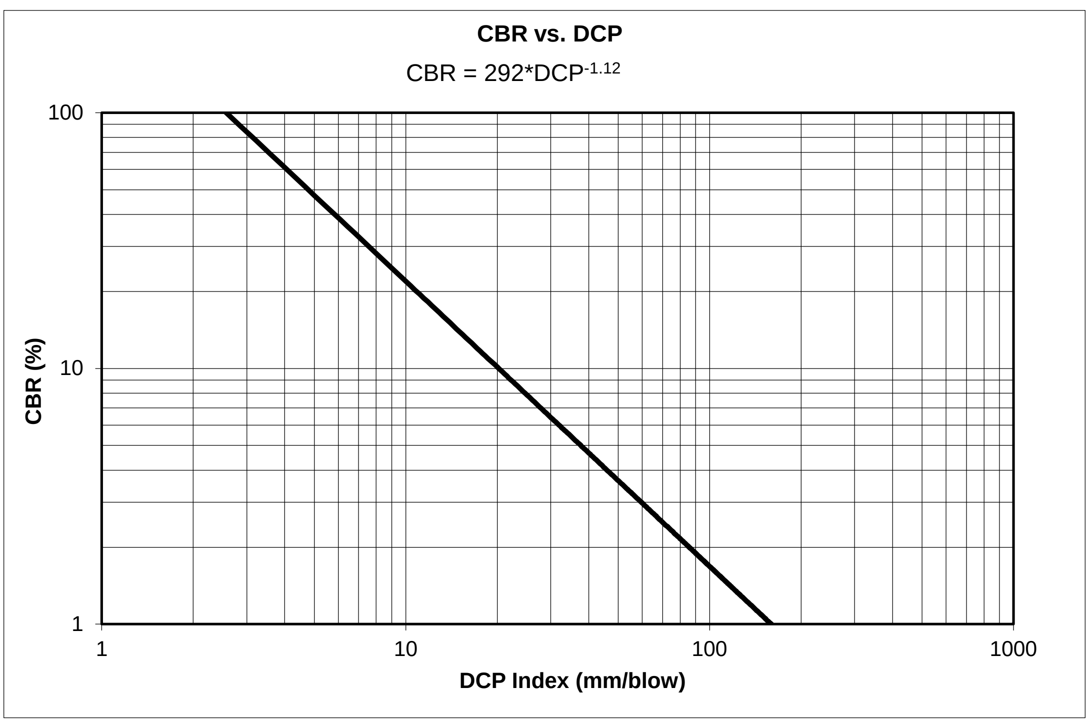
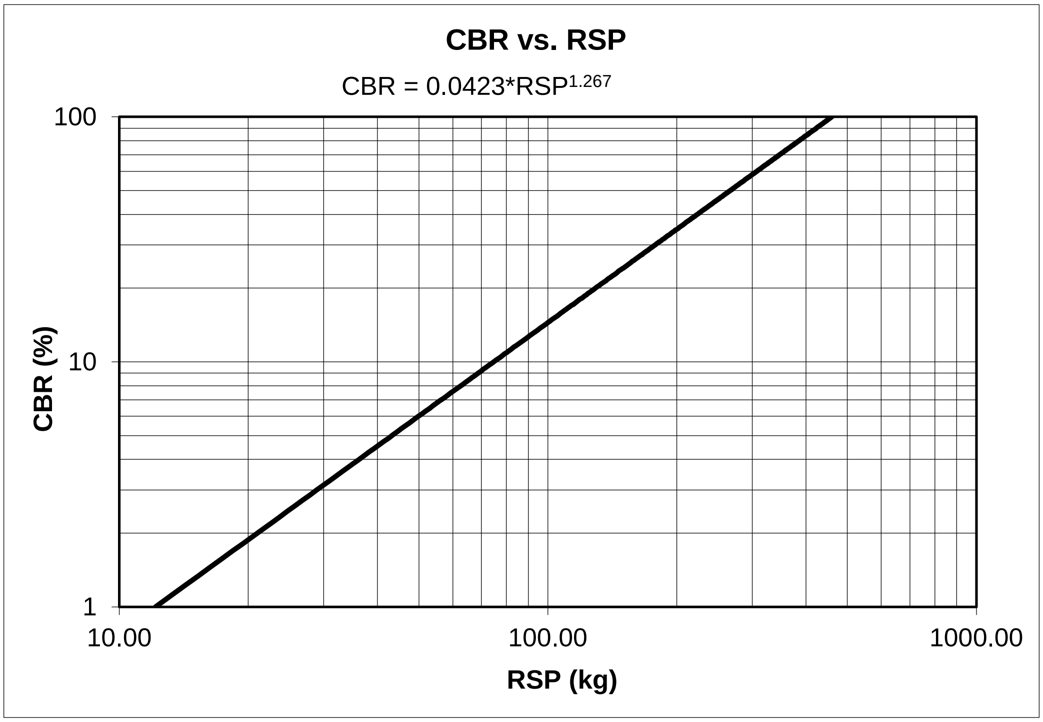


Figure B-3 Correlation Between RSP Index and CBR



B-5.3.2

Performance of a strength survey shall follow the procedure given in Appendix B-11. For the runway to be considered adequate for aircraft operations, two conditions must be met, as described in paragraphs B-5.3.2.1 and B-5.3.2.2.

B-5.3.2.1

All individual penetrometer test site values must be equal to or stronger than the required minimum strength value listed in Table B-1 and shown in Figure B-4.

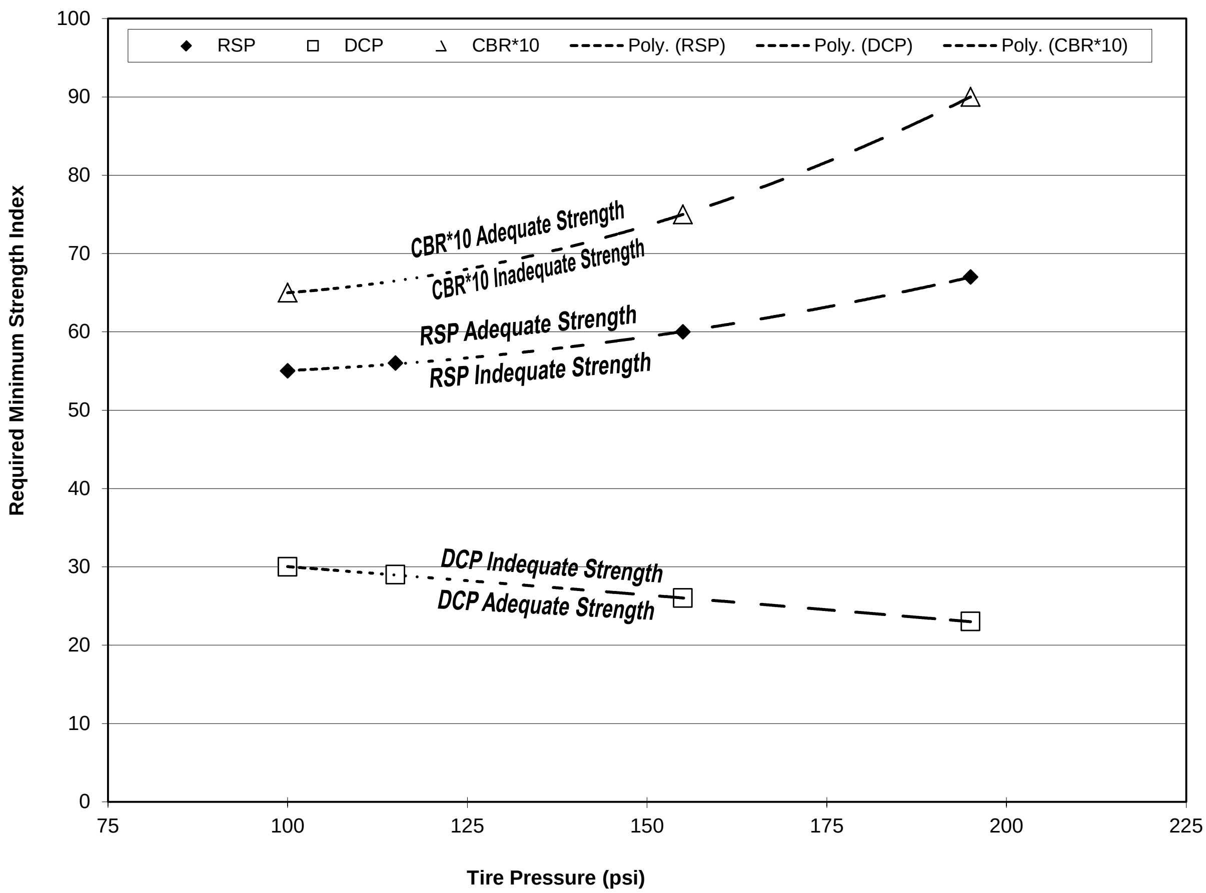
B-5.3.2.2

Maintenance (scarify and recompact) is required in areas that do not meet the minimum strength to increase the compacted snow strength. The area must be retested after maintenance is complete.

Table B-1 Minimum Snow Strength Required for White Ice Pavement

Aircraft	Tire Pressure (psi)	Minimum RSP Index	Maximum DCP Index	Minimum CBR Index
C-130	95	55	29	6.8
C-5A	111	56	28	6.9
C-17	155	61	26	7.7
757-200	180	65	24	8.4
P-3	200	69	22	9.1
767-300ER	205	70	22	9.3
A319	210	72	21	9.5

Figure B-4 Strength Criteria for White Ice Pavement



B-5.3.3

Appendix B-11 suggests a graphical method of quickly assessing the distribution of strength measurements using the White Ice Runway Strength Survey Tool program (contact the National Science Foundation operations manager [see paragraph 1-3] for a copy of this Microsoft® Excel-based program). **Note:** This approach makes it easier to locate regions of substandard snow strength so maintenance and repair activities can be quickly focused on trouble spots.

B-5.4 White Ice Runway Surface—Allowable Aircraft Loads/Contact Pressures.

B-5.4.1

Physical testing and aircraft validation activities at the Pegasus PLZ during the 2001–02 austral summer season (November to March) established the minimum thin snow pavement strength levels for C-130 and C-17 operations. These are shown in terms of several parameters in Table B-1. Note that with a thin processed snow pavement over a strong base material, white ice strength requirements are sensitive to aircraft contact pressure (tire pressure) but quite insensitive to aircraft gross load (since tire and gear load is being supported by the base material). Thus, Table B-1 values are for fully loaded or partially loaded aircraft operating at the noted tire pressures.

B-5.4.2

The allowable gross load and contact pressure will be applicable to aircraft both landing and taking off. These criteria are based on a condition of negligible surface deformation or rutting. Negligible is defined here as surface damage in isolated areas and not exceeding 25 millimeters (1 inch) in depth. The values in Table B-1 and Figure B-4 are conservative with respect to the vertical bearing load of wheeled aircraft; the values chosen ensure that surface deformations do not occur as a result of other aircraft loads, particularly shear loading of the white ice when aircraft brake or turn sharply.

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B-6 SEA ICE STRUCTURAL EVALUATION PROCEDURE

B-6.1 Introduction

B-6.1.1

Sea ice is often categorized as first-year or multi-year ice. This characterization of the ice indicates much about its nature, with multi-year ice having significantly greater complexity. However, for the purposes of a sea ice runway for heavy wheeled aircraft, this FC will treat both types the same, using overall ice thickness and ice temperature as governors for ice strength, which ultimately determines its ability to support a given aircraft operation.

B-6.1.2

Annually, before commencing aircraft operations (in Antarctica, flights on the sea ice runway usually begin in early October each season), the sea ice runway will be evaluated using the structural evaluation criteria in this FC. In addition, the airfield manager will conduct interim evaluations for quality assurance and validation of localized repairs.

B-6.2 Sea Ice Operating Surface.

The sea ice operating surface is an exposed, graded sea ice surface, or an ice surface overlain by either a moderately processed thin snow cap (less than 50 millimeters [2 inches]) or a thin layer (less than 75 millimeters [3 inches]) of fresh, loose snow.

B-6.2.1 Sea Ice Runway Evaluation—Deformation Failure.

A sea ice surface must be shown to be capable of supporting C-130, C-17, and C-5 aircraft contact pressure levels without compressive or shear failure. The primary sources of ice surface weakness at a sea ice runway site are melt-pockets and brine leaching features. When these occur, they may show minimal surface expression and may give the runway a deceptive appearance of strength. Rigorous maintenance, including the use of a reflective snow cap, can avoid melt problems. Brine leaching occurs as a function of time and such weak areas may become prevalent if the runway is sited on progressively older (multi-year) sea ice. Generally, brine leaching features will not reach a point of concern for a sea ice runway until the ice is four years of age or older. If there is any doubt, or if the conditions described in paragraph B-6.2.1.2 apply, the runway's structural strength must be certified daily. Adequate surface strength will generally be demonstrated by some form of proof rolling to detect zones of weakness.

B-6.2.1.1 Proof Rolling.

Full-scale proof rolling tests (see CRREL Monograph 98-1) are required before the first flight of the season following sea ice runway construction.

B-6.2.1.2 Inspection Requirements.

During runway operations, if the ice temperature exceeds –5 °C (23 °F) for an exposed sea ice surface, or –3 °C (26.5 °F) for a processed or loose snow surface, then a **rigorous daily visual inspection**, especially in the aircraft wheel tracks, is required. Any surface failure detected will require patching (Appendix B-3) and re-certification.

B-6.2.2 Sea Ice Runway Evaluation—Flexural Failure (Landing and Take-Off).

B-6.2.2.1 Flexural Strength.

Flexural strength of sea ice is a function of ice temperature, ice thickness, and salinity. Correspondingly, the maximum load capacity of sea ice under aircraft loads is a function of flexural strength and the landing-gear-assembly geometry of each aircraft. Determining the maximum allowable aircraft load from ice thickness and temperature measurements establishes the load capacities for landings and takeoffs on a sea ice runway.

B-6.2.2.2 Ice Temperature Measurement.

B-6.2.2.2.1

Collecting ice temperature measurements through the entire ice sheet at many locations on a frequent basis along a sea ice runway is onerous when using traditional technologies (drilling). At McMurdo Sound, seasonal time periods have been established to simplify the analytical process. The method combines ice surface temperatures into “bins,” such that each “bin” represents a period of the operational season. Each time period contains a maximum and minimum surface temperature. Current criteria divide the operational season (October to February) into four periods:

- Mid-October to late November (Period 1: -20 °C to -10 °C [-4 °F to 14 °F])
- Late November to mid-December (Period 2: -10 °C to -5 °C [14 °F to 23 °F])
- Mid-December to late December (Period 3: -5 °C to -2 °C [23 °F to 28 °F] with at least a small temperature gradient (minimum of 1 °C per meter [0.7 °F per foot] within a vertical column of ice, with the warmest temperatures at the ice surface and cooler temperatures at some depth)
- Late December through January (Period 4: -3 °C to -2 °C [26 °F to 28 °F] with ice temperature uniform throughout an entire vertical column; this is called an “isothermal condition”)

B-6.2.2.2.2

At McMurdo Sound, collect ice temperatures (measured at a depth of 150 millimeters [6 inches]) at a minimum of four locations on the runway proper and at two locations in the apron/parking area. Temperature data will be collected at a minimum of the following frequencies to verify that the calendar-suggested period is confirmed by ice temperatures. In all cases, actual ice temperatures will govern which period's standards to apply.

- Period 1: Once every two weeks
- Period 2: Once every week
- Period 3: Three times per week and 24 hours before each C-17 aircraft flight
- Period 4: Once every day

B-6.2.2.3 Ice Thickness Measurement.

B-6.2.2.3.1

Sea ice thickness is the most critical parameter to be established for calculating safe aircraft operations. Sea ice thickness—much more than ice temperature—tends to be slow to change and quite ubiquitous in the McMurdo Sound region. Its annual trend, irrespective of the initial ice thickness in late August, is well established from more than 20 years of data. However, under some circumstances, ice thickness can have considerable local variations. When this situation exists, and ice thicknesses are near the limits for desired aircraft operations, a statistical approach is used to establish sea ice thickness.

B-6.2.2.3.2

For initial certification, actual ice thickness must be measured at no less than 16 random locations spread throughout the runway surface, with no less than half located within a 15-meter (50-foot) -wide swath down the center of the runway. Since a statistical approach is used, more measurements will lead to greater confidence levels. Following the initial set of thicknesses used to certify opening the sea ice runway, it is acceptable to reduce the number of sea ice thickness measurements to a minimum five on the runway and one on the apron. When only five tests are completed on the runway, the minimum measured thickness will be the controlling thickness for strength evaluation purposes.

B-6.2.2.3.3

Thickness measurements must begin at least 10 days before the intended onset of flight operations. Measurements will continue throughout the entire duration of flight operations. Measurement frequency will be the same as for temperature measurements (see paragraph B-6.2.2.2).

B-6.2.2.3.4

Increased measurement density is only required during operating periods when the average thickness of the sea ice is nearing the point where it may limit gross aircraft weights and parking times for the aircraft type to be operated. For large aircraft, this will likely be the case any time first-year sea ice is encountered. Appendix B-7 describes the process for establishing the statistically sea ice thickness used for evaluation.

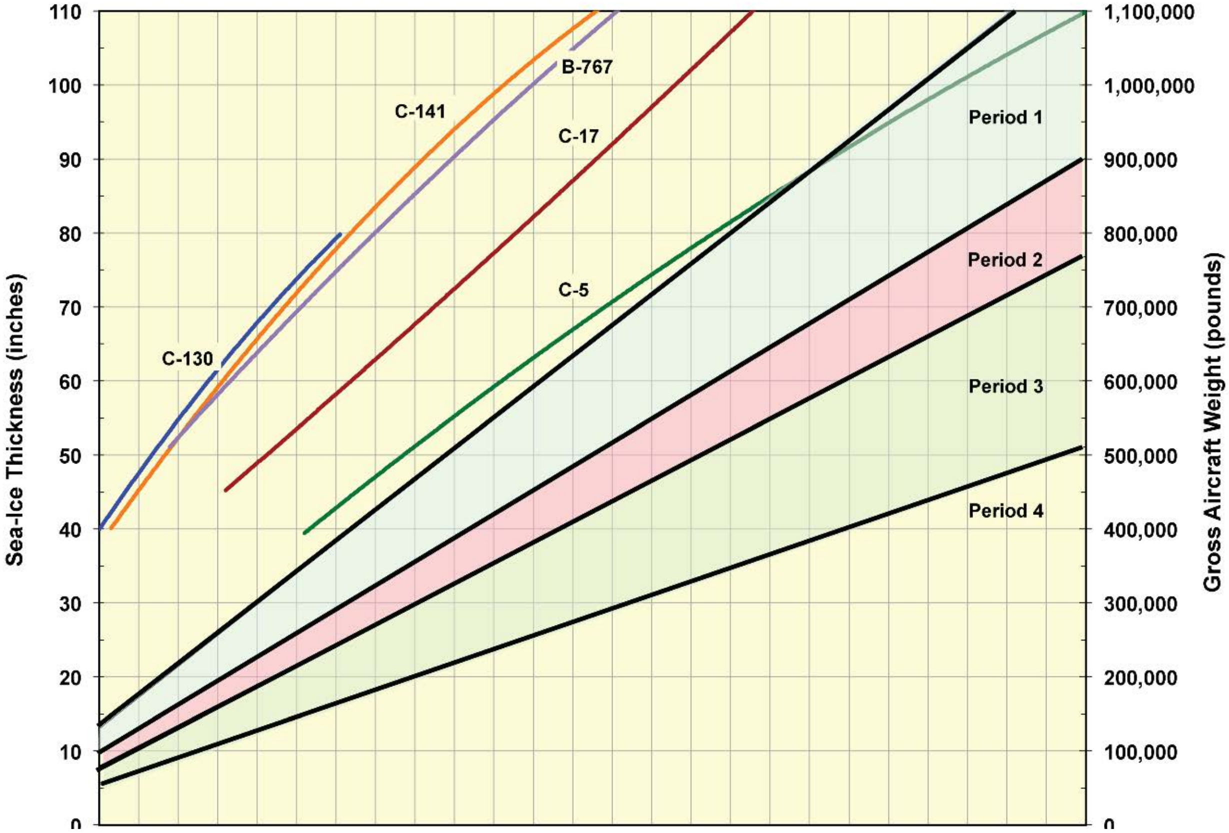
B-6.2.2.4 Factors of Safety.

Maximum allowable ice stresses have been determined for each of the four temperature-based operational periods using a computer program designed to calculate the flexural beam strength of sea ice. The allowable stresses have factors of safety between 1.3 and 1.4 (25% to 30% of flexural strength).

B-6.2.2.5 Maximum Allowable Stresses.

Maximum allowable stresses calculated for the four periods of the operational season at McMurdo Sound, combined with ice thickness and landing gear assembly geometry, were input to a model maintained by CRREL to predict the maximum allowable loads of C-130, C-17, and C-5 aircraft operating on the sea ice in McMurdo Sound. A range of sea ice thickness values experienced throughout the operational season were input and the model calculated the maximum allowable aircraft load given as a function of the sea ice runway thickness and the period of operation. Results from the model are presented in Figure B-5 and constitute the operational strength criteria for landing, taxiing, and take-off. The curves in Figure B-5 were developed based on the parameters described above, and each is specific to aircraft type and gear assembly geometry. The Figure B-5 nomograph may be worked from either direction; that is, if one knows the ice thickness and aircraft type to be operated, the maximum landing and take-off load may be calculated. Conversely, knowing what aircraft type and load are desired to be flown to/from the sea ice runway, the required ice thickness can be determined.

Figure B-5 Landing and Take-off Nomograph for the McMurdo Sound Sea Ice Runway



Notes:

(1) The relationship between ice thickness, temperature and aircraft load is specific to each aircraft and cannot be used for any other aircraft. Other aircraft of interest will require a new model run to develop allowable load/thickness curves (see FC paragraph 1-3 for contact information if a new analysis is needed).

(2) Examples of uses for this nomograph are provided in Appendix B-7. See Appendix B-14 for metric conversion factors.

(3) The nomograph has limited ability to provide a precise answer because of the thickness of lines on the chart, interpolation of temperature or load within bands on the chart, and an individual's technique. While time-consuming, the model used to develop the nomograph can be operated to produce tabulated results that provide a more user-independent solution. Examples of such tables were produced for the C-17 and are included in paragraph B-9.2.

B-6.2.3 Sea Ice Runway Surface Evaluation—Creep Failure (Parking).

B-6.2.3.1

Long-term parking at warm ice temperatures can lead to creep deformation of the sea ice. Long-term parking is defined here to mean any time an aircraft is stationary anywhere on sea ice for more than 30 minutes. At ice temperatures below –5 °C (23 °F), creep deformation is relatively slow. Since the sea ice runway at McMurdo Sound is operated principally as a "turn-around" runway (i.e., arriving aircraft debark within a few hours, spending limited time on site), it is expected that creep deformation will be negligible. However, if aircraft will be parked for extended time periods, or very heavy loads or thin ice conditions are present, aircraft may have to be periodically moved to avoid excessive creep deformation of the sea ice. A maximum allowable deflection limit of 10% of the ice thickness has been set for parked aircraft. Field tests indicate no major cracking or failures on sea ice until deflections are in excess of 25% of the ice thickness (Vaudrey, 1977). The 10% deflection value was selected because this is the freeboard limit for the ice sheet; although the ice is safe at this point (10% deflection), water could penetrate through existing cracks and holes to the runway surface, raising concern and causing operational difficulties (Barthelemy, 1992). Parking curves have been developed for each aircraft. The curves indicate the maximum time an aircraft can remain stationary as a function of the period (ice temperature), ice thickness, and aircraft type and load. The aircraft must change parking locations if it remains on the ice longer than indicated by the curves. The center of the new parking position must be at least 152.5 meters (500 feet) removed from the original location.

B-6.2.3.2

Care must also be exercised for other concentrated loads, such as fuel tanks. A similar analysis for the safe residence time for a given concentrated infrastructure load for the prevailing ice temperature and thickness will allow for decisions about total loads and placement geometry. Such infrastructure loads must also be taken into account when locating primary or secondary aircraft parking spots.

B-6.2.3.3

Operational strength criteria for aircraft parked on sea ice are presented in Figure B-6. Contact the person(s) listed in paragraph 13 for recommendations on how to analyze for infrastructure or long-term (12 or more hours) group aircraft parking loads.

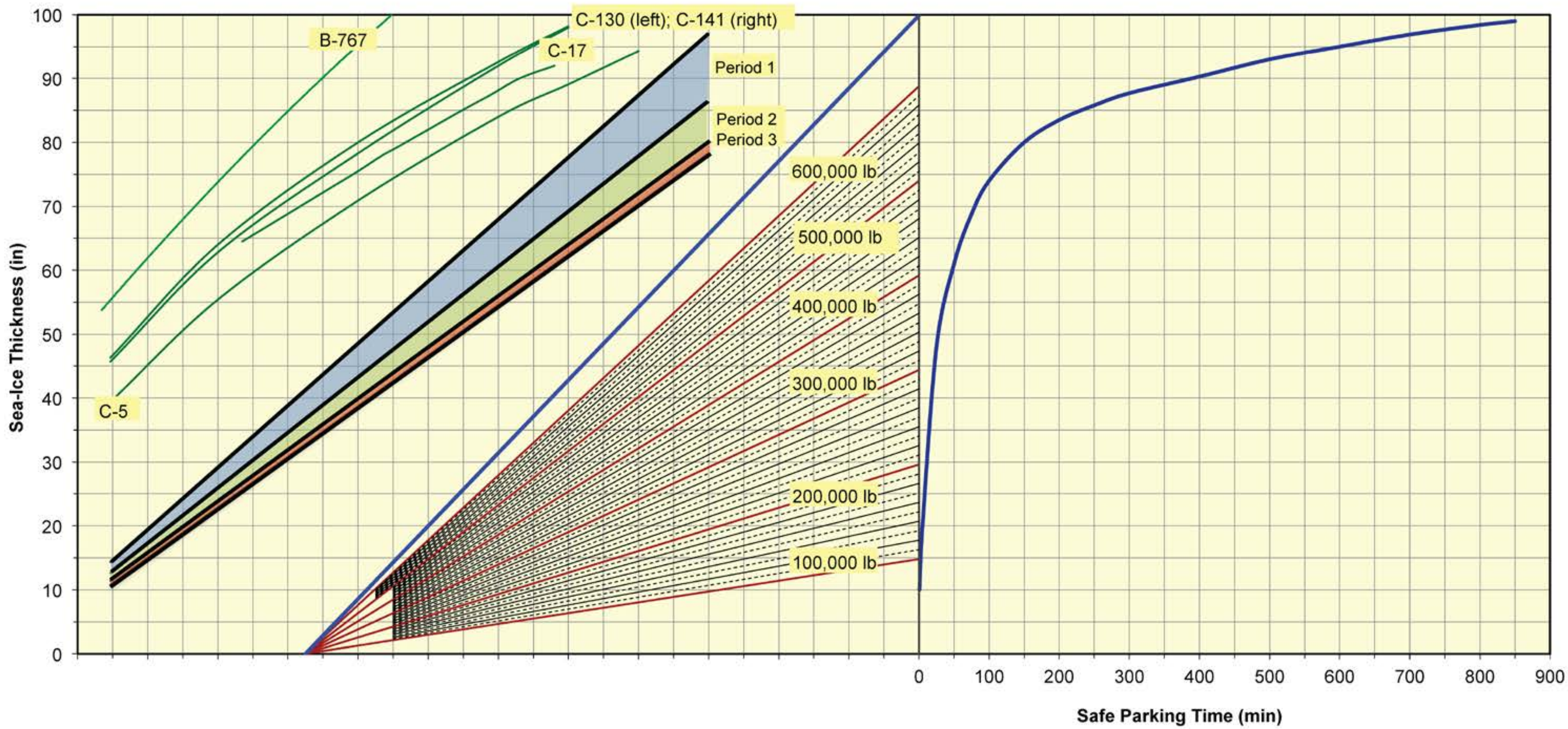
Figure B-6 Notes:

(1) Examples of nomograph use are provided in Appendix B-8. See Appendix B-14 for metric conversion factors.

(2) The nomograph has limited ability to provide a precise answer because of the thickness of lines on the chart, interpolation of temperature or load within bands on the chart, and an individual’s technique. While time-consuming, the model used to develop the nomograph can be operated to produce tabulated results which provide a more user-independent solution. Examples of such tables were produced for the C-17 and are included in paragraph B-9.2.

Figure B-6 Allowable Parking Times for the McMurdo Sound Sea Ice Runway

(See Appendix B-8 for Usage Directions, Appendix B-9 for an Example Conversion of the Nomograph to Solution Tables for the C-17, and Appendix B-14 for Metric Conversion Factors)



B-6.2.4

WARNING

Both landing/take-off and parking criteria must be determined and compared before each aircraft operation. In most cases, the minimum required sea ice thickness will be different for landing/take-off and for parking. The **GREATER** of the two calculated thicknesses must be used in planning for the aircraft mission. At times, adjustment of one or more controllable variables can allow performing an aircraft mission that, as initially planned, would not be allowed. See examples in Appendix B-8 for an illustration of this process.

B-6.2.5

The primary source of ice mass weakness at the sea ice runway site is weakening during mid- to late-season operations as sea and air temperatures rise. Cracks may also form in the sea ice sheet at any point during the operational season due to tidal and other ice forces active in the region. Though not unsafe, the cracks may limit mobility and must be repaired before aircraft operations. The sea ice crack-repair procedure is described in Appendix B-3.

B-6.2.6

A format for guiding sea ice runway certification is outlined in Appendix B-4. Recall that two conditions must be met for the runway to be considered structurally adequate for aircraft operations, as described in paragraphs B-5.3.2.1 and B-5.3.2.2.

B-6.2.7

This FC is written specifically for C-130, C-17, and C-5 aircraft. The load capacity of a sea ice runway changes according to aircraft landing-gear assemblies. Contact the person(s) listed in paragraph 1-3 for recommendations on how to proceed if operational needs are encountered when the ice thickness and temperature restrict necessary flight operations or if a different type of aircraft or landing gear configuration is proposed for operation on the McMurdo Sound sea ice runway.

B-7 EXAMPLE CALCULATIONS TO ESTABLISH THE STATISTICAL SEA ICE THICKNESS VALUE

B-7.1 Example Data

Twenty runway thickness measurements were made on the sea ice (all measurements in inches): 110, 74, 104, 77, 72, 74, 83, 79, 72, 77, 71, 72, 84, 78, 81, 78, 69, 88, 70, and 74.

B-7.2 Data Manipulation

Rank the measurements in ascending order on a spreadsheet and then calculate the percent of thickness measurements equal to or greater than each unique value.

B-7.3 Data Plotting

Plot thickness versus percent “equal to or greater than” as shown in Figure B-7.

B-7.4 Data Application

Enter Figure B-7 at 85%. Continue to the plotted curve then down to the evaluation thickness of 72 inches for this example.

B-7.5 Data Validation

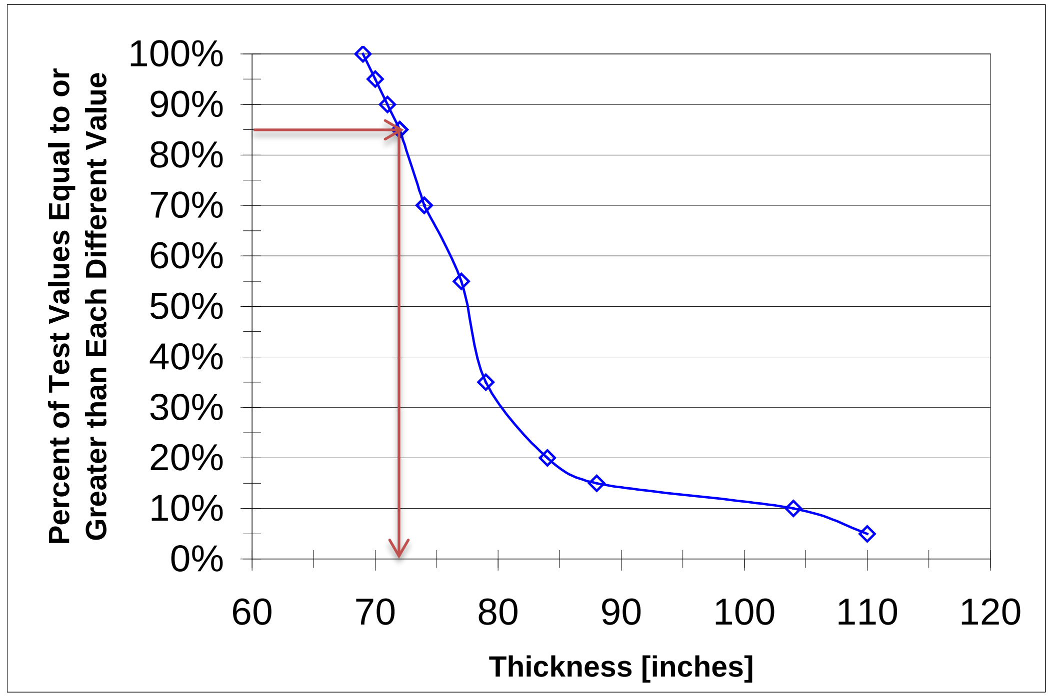
If a test measurement is so low that it is clearly an outlying data point (e.g., 10% less than the next lowest measurement) and therefore not representative of other tests on the runway, then additional tests must be completed to determine the extent of the thin area and whether special consideration is required. When the extent is determined, a separate structural analysis of the thin area may be appropriate, resulting in applying appropriate aircraft weight restrictions to the thin area.

Note: Sea ice thickness typically increases daily as the season progresses. Therefore, up-to-date thickness measurements are essential to determining the appropriate evaluation thickness.

Figure B-7 Tabular and Graphical Examples of Statistical Analysis of Sea Ice Thickness Data to Determine a Representative Value

(Defined as the thickness for which <u>less than 15%</u> of the samples are thinner)

Thickness Measurement [inches]	Number of Tests Equal to or Greater than Each Value	Percent of Tests Equal to or Greater Than Each Value
69	20	100%
70	19	95%
71	18	90%
72	17	85%
72	17	85%
72	17	85%
74	14	70%
74	14	
74	14	70%
77	11	
77	11	55%
78	9	
78	9	
79	7	35%
81	6	
83	5	
84	4	20%
88	3	15%
104	2	10%
110	1	5%



B-8 EXAMPLE CALCULATIONS USING LANDING AND TAKE-OFF AND PARKING NOMOGRAPHS

B-8.1 Example 1.

B-8.1.1

A measured mean sea ice thickness of 1.83 meters (72 inches) exists on McMurdo Sound. The date is 1 November and the measured mean sea ice temperature for the past week is –17 °C (1 °F). An oversize load, critical to USAP operations, is required in McMurdo Sound. Because of the cargo’s size and critical nature, it must be delivered by C-5. In planning for this flight operation, what is the maximum safe gross aircraft landing load given the current sea ice conditions?

B-8.1.2

On the landing and take-off nomograph (Figure B-8) locate 1.83 meters (72 inches) on the left-side vertical axis and draw a horizontal line intersecting the C-5 curve (a). Draw a vertical line from this intersection point to a position representing the scaled location of –17 °C (1 °F) (vertically between the Period 1 band limits of –20 °C (-4 °F) (upper line in band) and –10 °C (14 °F) (lower line in band) (b). From this position, draw a horizontal line to the right-side vertical axis where it can be seen that a maximum C-5 gross weight of 620,000 pounds can be safely supported for take-offs and landings (c).

B-8.2 Example 2.

B-8.2.1

Preliminary flight planning for the USAP field season favors operating C-17 aircraft well into Period 2 ice conditions. The final C-17 flight is desired for 12 December. The anticipated gross C-17 weight will be about 370,000 pounds for this final flight. What sea ice thickness will be required to support landing this planned flight?

B-8.2.2

On the landing and take-off nomograph (Figure B-9) locate 370,000 pounds on the right-side vertical axis and draw a horizontal line to a position representing the scaled location of 12 December vertically between the Period 2 band limits of about 25 November (upper line in band) and about 15 December (lower line in band) (a). Draw a vertical line from this point to the C-17 curve (b). From this intersection point, draw a horizontal line to intersect the left-side vertical axis, showing that about 78 inches of sea ice must be present for safe take-offs and landings.

B-8.2.3

Planners can use historical ice data to determine if there is a good likelihood of this ice thickness being present at a particular time. In any case, as the time nears 12 December, actual measured sea ice thicknesses will govern (via use of the nomograph as depicted in Example 1 [Figure B-8]) exactly what gross C-17 weight can safely be supported.

B-8.3 Example 3.

B-8.3.1

The C-5 operation presented in Example 1 (Figure B-8) determined that a maximum gross weight of 620,000 pounds for landing and take-off is dictated by the sea ice conditions. It is known that about 1.5 hours will be required after the C-5 is parked for off-loading, refueling, and pre-flight preparations. Can the C-5 at 620,000 pounds safely park on the sea ice for 1.5 hours?

B-8.3.2

On the parking nomograph (Figure B-10) locate 72 inches on the left-side vertical axis and draw a horizontal line to intersect with the C-5 curve (a). Then draw a vertical line from this intersection point to a position representing the scaled location of –17 °C (1 °F) vertically between the Period 1 band limits of –20 °C (-4 °F) (upper line in band) and –10 °C (14 °F) (lower line in band) (b). From this position, draw a horizontal line to a point representing the gross aircraft weight (vertically scaled location between provided weight curves) (c). Now draw a vertical line upward to the reflection surface (d). A horizontal line from the reflection surface is then drawn to intersect the parking curve (e). Lastly, a vertical line is then drawn to intersect the horizontal safe parking time axis where it can be seen that the C-5 mission considered will only allow about 25 minutes of parking time before creep failure of the sea ice.

B-8.3.3

Two possibilities exist for alleviating this situation. First, and easiest, is to minimize the gross weight of the C-5. While the landing nomograph (Figure B-8) indicates that a maximum gross weight of 620,000 pounds can be safely landed, a lesser weight is certainly also safe. If the C-5 gross arrival weight could be reduced to about 475,000 pounds, a parking time of about 75 minutes could be achieved. If the aircraft cannot be reduced to this load level, an alternative is to minimize the landing/parking weight as possible and plan for moving the parked aircraft one or more times during the off-loading process. This is quite inefficient and requires significant planning but has occasionally been necessary. The distance moved must be greater than two times the overall width of the aircraft (wingspan) and can be in any direction. As soon as the aircraft is parked in its new location the parking time clock restarts.

B-8.4 Example 4.

B-8.4.1

A two-hour parking time is required to achieve unloading and back-loading of a C-17 mission very late in the life of the annual McMurdo Sound sea ice runway (30 December). It is expected that the C-17 will have an average weight of 500,000 pounds during a large part of its parked time. What sea ice thickness will be necessary to support this flight?

B-8.4.2

On the parking nomograph (Figure B-11), locate 120 minutes on the horizontal safe parking time axis and draw a vertical line to intersect the parking curve (a). From this intersection point, draw a horizontal line to the reflection surface (b). From there, drop vertically to the 500,000 pounds aircraft load line (c). A horizontal line from this point to a temperature-representative point within Period 3 follows (d). Then draw a line vertically to intersect the C-17 curve (e). From here, a horizontal line can be seen to intersect the sea ice thickness axis at about 90 inches (f).

Figure B-8 Example 1

(See Attachment B-14 for Metric Conversion Factors)

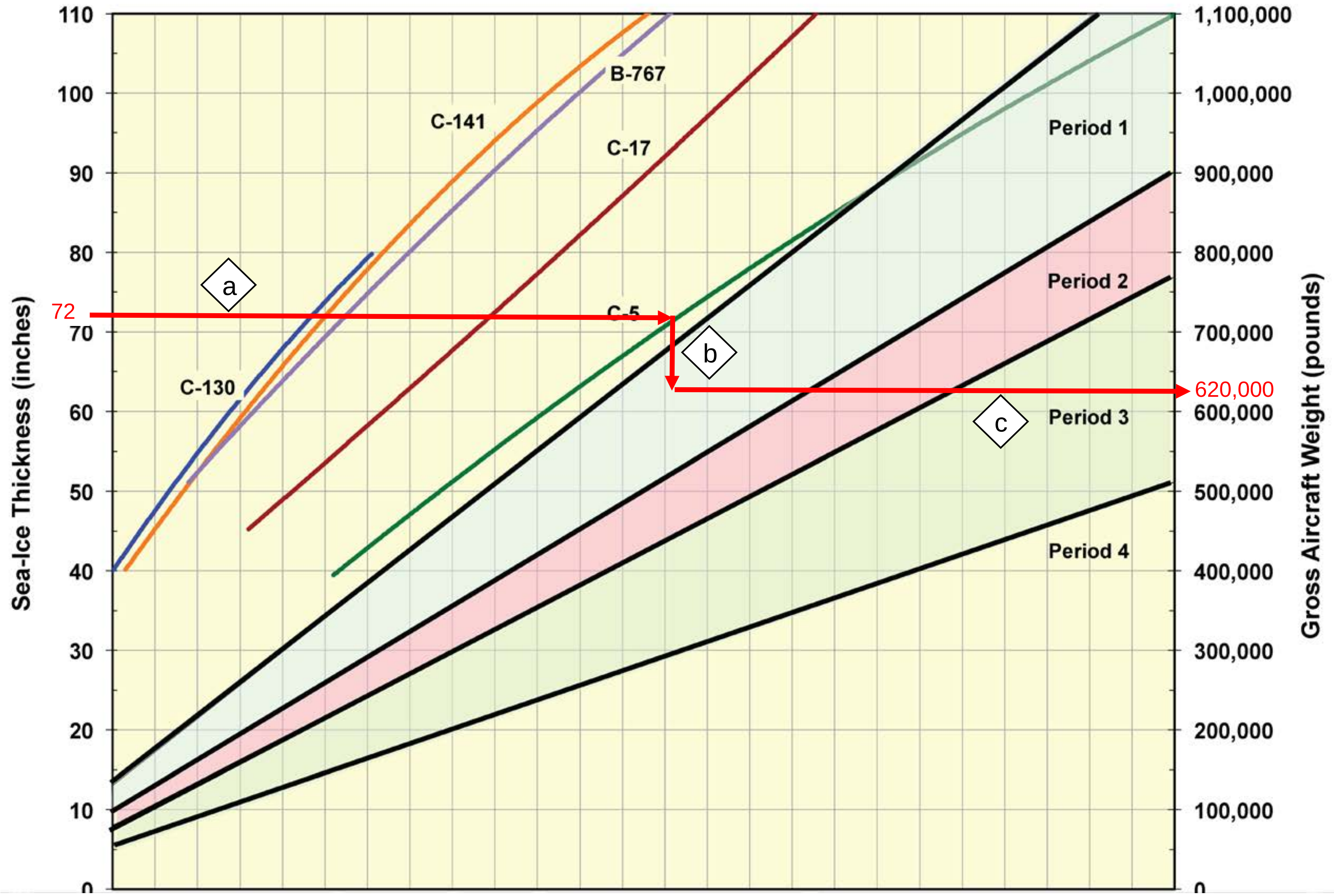


Figure B-9 Example 2

(See Attachment B-14 for Metric Conversion Factors)

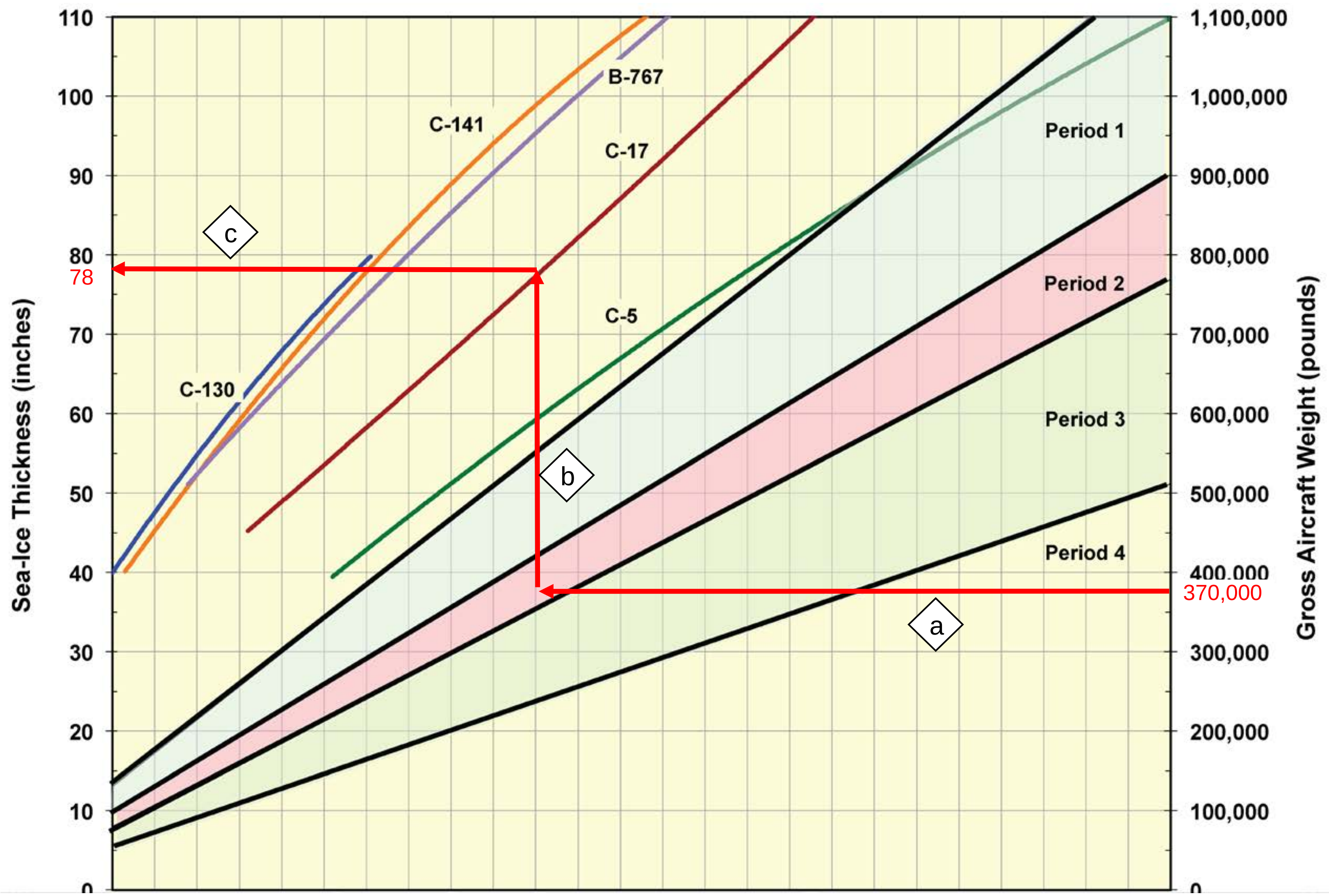


Figure B-10 Example 3

(See Attachment B-14 for Metric Conversion Factors)

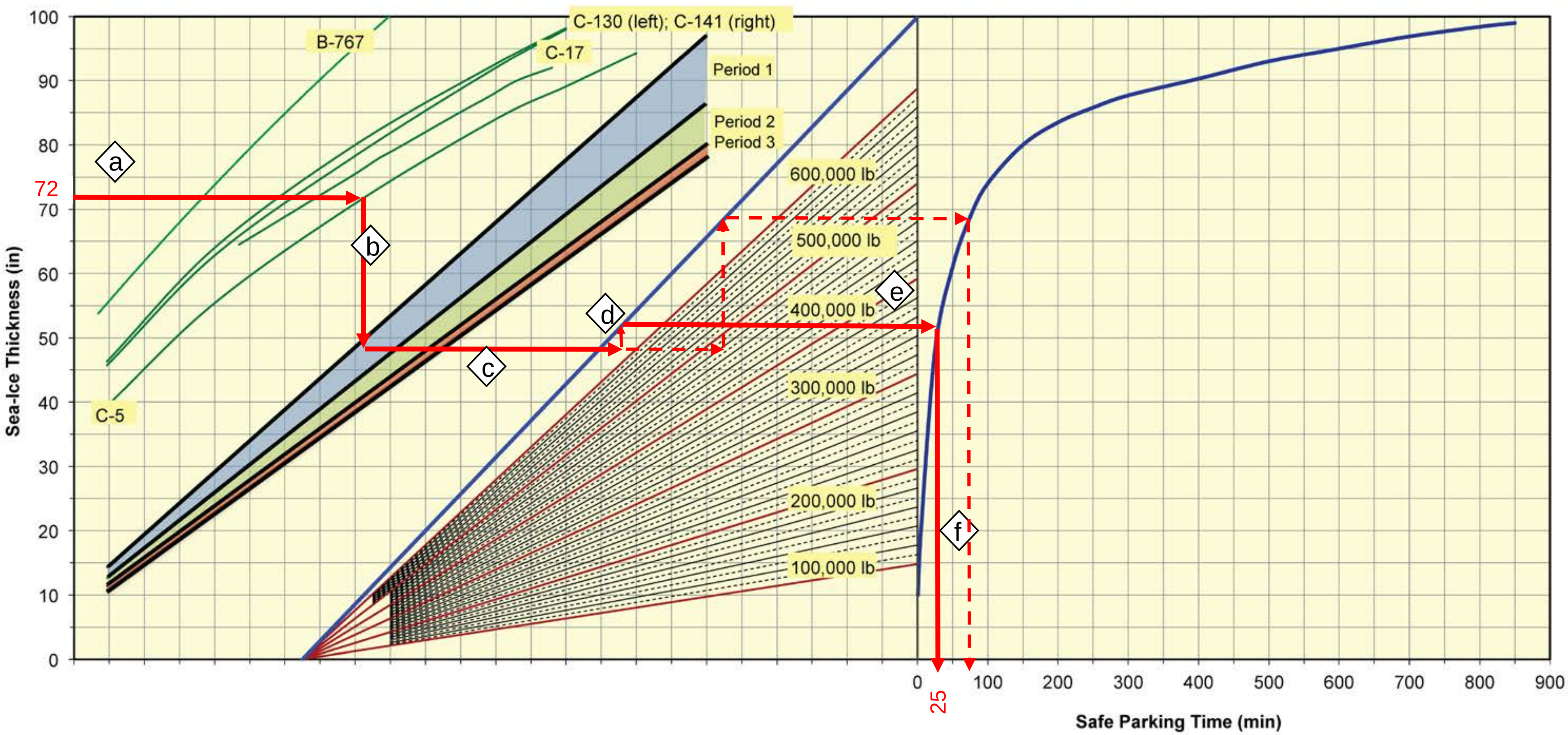
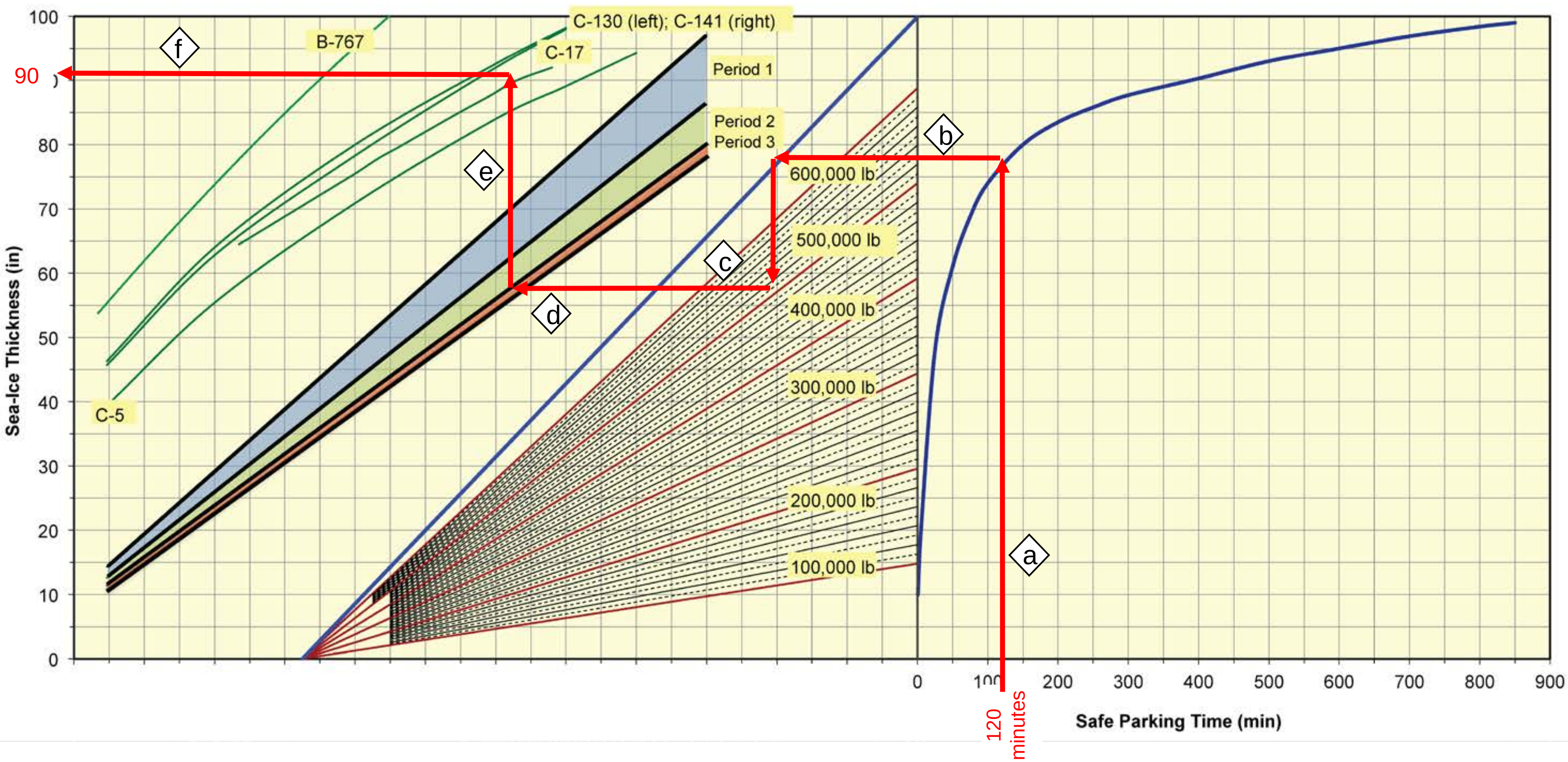


Figure B-11 Example 4

(See Attachment B-14 for Metric Conversion Factors)



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B-9 TABULATED RESULTS FROM APPLICATION OF LANDING/TAKE-OFF AND PARKING NOMOGRAPHS TO C-17 AND BOEING 767-300ER AIRCRAFT AT MCMURDO SOUND SEA ICE RUNWAY

B-9.1 Nomographs - General

The nomographs for safe landing/take-off (Figure B-5) and safe parking time (Figure B-6) have limited ability to provide a precise answer because of the thickness of lines on the chart, interpolation of temperature or load within bands on the chart, and an individual's technique. By applying the mathematical relationships used to generate the nomographs, tables of values for discrete temperatures and loads can be produced.

B-9.2 C-17 Nomographs

Figure B-12 depicts the safe landing and take-off loads (in pounds) for the C-17 aircraft between the temperature limits represented by McMurdo Sound Period 1 to Period 4. Figures B-14 to B-37 give safe parking times (in hours) for individual temperatures at 10,000-pound (4500-kilogram) increments of gross C-17 weight.

B-9.3 B767 Nomographs

Figure B-13 depicts the safe landing and take-off loads (in pounds) for the B767-300ER aircraft between the temperature limits represented by McMurdo Sound Period 1 to Period 4. Figures B-38 to B-61 give safe parking times (in hours) for individual temperatures at 10,000-pound (4500-kilogram) increments of gross B767-300ER weight.

Figure B-12 Tabular Representation of Landing/Take-Off Nomograph for C-17

(Values in Table are Gross Aircraft Weight in Pounds)

Ice Temperature (All Period 1, 2 and 3 ice for McMurdo Sound)

Sea Ice Thickness (inches)

(deg F)	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	12	10	8	6	4	2	0	-2	-4
(deg C)	-2.2	-2.8	-3.3	-3.9	-4.4	-5.0	-5.6	-6.1	-6.7	-7.2	-7.8	-8.3	-8.9	-9.4	-10.0	-11.1	-12.2	-13.3	-14.4	-15.6	-16.7	-17.8	-18.9	-20.0
44																								
45																								272,100
46																							269,100	280,700
47																						266,200	277,500	289,300
48																						274,400	285,900	297,900
49																					271,500	282,600	294,200	306,500
50																				268,800	279,500	290,800	302,600	315,100
51																			266,100	276,500	287,500	298,900	311,000	323,800
52																			273,700	284,300	295,400	307,100	319,400	332,400
53																		271,100	281,300	292,100	303,400	315,300	327,800	341,000
54																	268,500	278,500	288,900	299,900	311,400	323,500	336,200	349,600
55																266,100	275,800	285,900	296,500	307,700	319,400	331,600	344,600	358,200
56																273,200	283,000	293,300	304,100	315,400	327,300	339,800	353,000	366,800
57															270,700	280,300	290,300	300,700	311,700	323,200	335,300	348,000	361,400	375,500
58													270,500	274,000	277,600	287,400	297,500	308,200	319,300	331,000	343,300	356,200	369,800	384,100
59											270,400	273,600	277,100	280,700	284,600	294,400	304,800	315,600	326,900	338,800	351,200	364,400	378,200	392,700
60									270,300	273,400	276,600	280,000	283,600	287,500	291,500	301,500	312,000	323,000	334,500	346,600	359,200	372,500	386,500	401,300
61								273,100	276,200	279,400	282,800	286,400	290,200	294,200	298,400	308,600	319,300	330,400	342,100	354,300	367,200	380,700	394,900	409,900
62						273,000	275,900	278,900	282,100	285,500	289,000	292,800	296,800	300,900	305,400	315,700	326,500	337,800	349,700	362,100	375,200	388,900	403,300	418,500
63						278,500	281,500	284,700	288,000	291,600	295,300	299,200	303,300	307,700	312,300	322,800	333,800	345,300	357,300	369,900	383,100	397,100	411,700	427,200
64						284,000	287,100	290,500	293,900	297,600	301,500	305,600	309,900	314,400	319,200	329,900	341,000	352,700	364,900	377,700	391,100	405,200	420,100	435,800
65						289,500	292,800	296,200	299,900	303,700	307,700	311,900	316,400	321,200	326,200	337,000	348,300	360,100	372,500	385,500	399,100	413,400	428,500	444,400
66						295,000	298,400	302,000	305,800	309,700	313,900	318,300	323,000	327,900	333,100	344,100	355,500	367,500	380,100	393,200	407,100	421,600	436,900	453,000
67					274,200	300,500	304,000	307,800	311,700	315,800	320,100	324,700	329,500	334,600	340,000	351,200	362,800	374,900	387,700	401,000	415,000	429,800	445,300	461,600
68					279,100	306,000	309,700	313,500	317,600	321,900	326,400	331,100	336,100	341,400	347,000	358,200	370,000	382,300	395,300	408,800	423,000	437,900	453,700	470,200
69					284,000	311,500	315,300	319,300	323,500	327,900	332,600	337,500	342,700	348,100	353,900	365,300	377,300	389,800	402,800	416,600	431,000	446,100	462,100	478,900
70					288,900	317,000	320,900	325,100	329,400	334,000	338,800	343,900	349,200	354,900	360,900	372,400	384,500	397,200	410,400	424,400	439,000	454,300	470,500	487,500
71					293,800	322,500	326,600	330,800	335,300	340,100	345,000	350,300	355,800	361,600	367,800	379,500	391,800	404,600	418,000	432,100	446,900	462,500	478,800	496,100
72				275,300	298,700	328,000	332,200	336,600	341,200	346,100	351,200	356,600	362,300	368,400	374,700	386,600	399,000	412,000	425,600	439,900	454,900	470,700	487,200	504,700
73				279,700	303,600	333,500	337,800	342,400	347,200	352,200	357,500	363,000	368,900	375,100	381,700	393,700	406,300	419,400	433,200	447,700	462,900	478,800	495,600	513,300
74				284,100	308,500	339,000	343,500	348,200	353,100	358,200	363,700	369,400	375,500	381,800	388,600	400,800	413,500	426,900	440,800	455,500	470,800	487,000	504,000	521,900
75				288,500	313,400	344,500	349,100	353,900	359,000	364,300	369,900	375,800	382,000	388,600	395,500	407,900	420,800	434,300	448,400	463,200	478,800	495,200	512,400	530,600
76				292,900	318,300	350,000	354,700	359,700	364,900	370,400	376,100	382,200	388,600	395,300	402,500	415,000	428,000	441,700	456,000	471,000	486,800	503,400	520,800	539,200
77			276,100	297,300	323,200	355,500	360,400	365,500	370,800	376,400	382,300	388,600	395,100	402,100	409,400	422,000	435,300	449,100	463,600	478,800	494,800	511,500	529,200	547,800
78			280,100	301,700	328,100	361,000	366,000	371,200	376,700	382,500	388,600	394,900	401,700	408,800	416,300	429,100	442,500	456,500	471,200	486,600	502,700	519,700	537,600	556,400
79			284,200	306,200	333,000	366,500	371,600	377,000	382,600	388,500	394,800	401,300	408,200	415,500	423,300	436,200	449,800	463,900	478,800	494,400	510,700	527,900	546,000	565,000
80			288,200	310,600	337,900	372,000	377,300	382,800	388,500	394,600	401,000	407,700	414,800	422,300	430,200	443,300	457,000	471,400	486,400	502,100	518,700	536,100	554,400	573,600
81			292,200	315,000	342,800	377,500	382,900	388,500	394,500	400,700	407,200	414,100	421,400	429,000	437,100	450,400	464,300	478,800	494,000	509,900	526,700	544,200	562,800	582,200
82		276,800	296,200	319,400	347,700	383,000	388,500	394,300	400,400	406,700	413,400	420,500	427,900	435,800	444,100	457,500	471,500	486,200	501,600	517,700	534,600	552,400	571,100	590,900
83		280,500	300,200	323,800	352,600	388,500	394,200	400,100	406,300	412,800	419,600	426,900	434,500	442,500	451,000	464,600	478,800	493,600	509,200	525,500	542,600	560,600	579,500	599,500
84		284,200	304,200	328,200	357,500	394,000	399,800	405,800	412,200	418,900	425,900	433,200	441,000	449,300	457,900	471,700	486,000	501,000	516,800	533,300	550,600	568,800	587,900	
85		287,900	308,200	332,600	362,400	399,500	405,400	411,600	418,100	424,900	432,100	439,600	447,600	456,000	464,900	478,800	493,300	508,500	524,400	541,000	558,600	577,000	596,300	
86	274,100	291,600	312,300	337,100	367,300	405,000	411,100	417,400	424,000	431,000	438,300	446,000	454,100	462,700	471,800	485,800	500,500	515,900	532,000	548,800	566,500	585,100		
87	277,500	295,300	316,300	341,500	372,200	410,600	416,700	423,200	429,900	437,000	444,500	452,400	460,700	469,500	478,700	492,900	507,800	523,300	539,600	556,600	574,500	593,300		
88	280,900	298,900	320,300	345,900	377,100	416,100	422,300	428,900	435,800	443,100	450,700	458,800	467,300	476,200	485,700	500,000	515,000	530,700	547,100	564,400	582,500			
89	284,300	302,600	324,300	350,300	382,000	421,600	428,000	434,700	441,800	449,200	457,000	465,200	473,800	483,000	492,600	507,100	522,300	538,100	554,700	572,200	590,400			
90	287,700	306,300	328,300	354,700	386,900	427,100	433,600	440,500	447,700	455,200	463,200	471,600	480,400	489,700	499,600	514,200	529,500	545,500	562,300	579,900	598,400			
91	291,100	310,000	332,300	359,100	391,800	432,600	439,200	446,200	453,600	461,300	469,400	477,900	486,900	496,400	506,500	521,300	536,800	553,000	569,900	587,700				
92	294,500	313,700	336,400	363,500	396,700	438,100	444,900	452,000	459,500	467,300	475,600	484,300	493,500	503,200	513,400	528,400	544,000	560,400	577,500	595,500				
93	297,900	317,400	340,400	368,000	401,600	443,600	450,500	457,800	465,400	473,400	481,800	490,700	500,100	509,900	520,400	535,500	551,300	567,800	585,100					
94	301,300	321,000	344,400	372,400	406,500	449,100	456,100	463,500	471,300	479,500	488,100	497,100	506,600	516,700	527,300	542,600	558,500	575,200	592,700					
95	304,700	324,700	348,400	376,800	411,400	454,600	461,800	469,300	477,200	485,500	494,300	503,500	513,200	523,400	534,200	549,600	565,800	582,600						
96	308,100	328,400	352,400	381,200	416,300	460,100	467,400	475,100	483,100	491,600	500,500	509,900	519,700	530,100	541,200	556,700	573,000	590,100						
97	311,500	332,100	356,400	385,600	421,200	465,600	473,000	480,900	489,000	497,700	506,700	516,200	526,300	536,900	548,100	563,800	580,300	597,500						
98	314,900	335,800	360,400	390,000	426,100	471,100	478,700	486,600	495,000	503,700	512,900	522,600	532,800	543,600	555,000	570,900	587,500							
99	318,300	339,500	364,500	394,400	431,000	476,600	484,300	492,400	500,900	509,800	519,100	529,000	539,400	550,400	562,000	578,000	594,800							
100	321,700	343,100	368,500	398,800	435,900	482,100	489,900	498,200	506,800	515,800	525,400	535,400	546,000	557,100	568,900	585,100								
101	325,100	346,800	372,500	403,300	440,800	487,600	495,600	503,900	512,700	521,900	531,600	541,800	552,500	563,900	575,800	592,200								
102	328,500	350,500	376,500	407,700	445,700	493,100	501,200	509,700	518,600	528,000	537,800	548,200	559,100	570,600	582,800	599,300								
103	331,900	354,200	380,500	412,100	450,600	498,600	506,800	515,500	524,500	534,000	544,000	554,500	565,600	577,300	589,700									
104	335,300	357,900	384,500	416,500	455,500	504,100	512,500	521,200	530,400	540,100	550,200	560,900	572,200	584,100	596,600									
105	338,700	361,600	388,600	420,900	460,400	509,600	518,100	527,000	536,300	546,100	556,500	567,300	578,700	590,800										
106	342,100	365,200	392,600	425,300	465,300	515,100	523,700	532,800	542,300	552,200	562,700	573,700	585,300	597,600										
107	345,500	368,900	396,600	429,700	470,200	520,600	529,400	538,500	548,200	558,300	568,900	580,100	591,900											
108	348,900	372,600	400,600	434,200	475,100	526,100	535,000	544,300	554,100	564,300	575,100	586,500	598,400											
109	352,300	376,300	404,600	438,600	480,000	531,600	540,600	550,100	560,000	570,400	581,300	592,800												
110	355,700	380,000	408,600	443,000	484,900	537,100	546,300	555,900	565,900	576,500	587,600													
111	359,100	383,700	412,700	447,400	489,800	542,600	551,900	561,600	571,800	582,500	593,800													
112	362,500	387,300	416,700	451,800	494,700	548,100	557,500	567,400	577,700	588,600														
113	365,900	391,000	420,700	456,200	499,600	553,600	563,200	573,200	583,600	594,600														
114	369,300	394,700	424,700	460,600	504,500	559,200	568,800	578,900	589,600															
115	372,700	398,400	428,700	465,100	509,400	564,700	574,400	584,700	595,500															
116	376,100	402,100	432,700	469,500	514,300	570,200	580,100	590,500																
117	379,500	405,800	436,700	473,900	519,200	575,700	585,700	596,200																
118	382,900	409,400	440,800	478,300	524,100	581,200	591,300																	
119	386,300	413,100	444,800	482,700	529,000	586,700	597,000																	
120	389,700	416,800	448,800	487,100	533,900	592,200																		
121	393,100	420,500	452,800	491,500	538,800																			
122	396,500	424,200	456,800	496,000	543,700																			
123	399,900	427,900	460,800	500,400	548,600																			
124	403,300	431,500	464,900	504,800	553,500																			
125	406,700	435,200	468,900	509,200	558,400																			
126	410,100	438,900	472,900	513,600	563,300																			
127	413,500	442,600	476,900	518,000	568,200																			
128	416,900	446,300	480,900	522,400	573,100																			
129	420,300	450,000	484,900	526,800	578,000																			
130	423,700	453,600	488,900	531,300	582,900																			
131	427,100	457,300	493,000	535,700																				
132	430,500	461,000	497,000	540,100																				
133	433,900	464,700	501,000	544,500																				
134	437,300	468,400	505,000	548,900																				
135	440,700	472,100	509,000	553,300																				
136	444,100	475,700	513,000	557,700																				
137	447,500	479,400	517,100	562,200																				
138	450,900	483,100	521,100	566,600																				
139	454,300	486,800	525,100	571,000																				
140	457,700	490,500	529,100																					
141	461,100	494,200	533,100																					
142	464,500	497,800	537,100																					
143	467,900	501,500	541,200																					
144	471,300	505,200	545,200																					
145	474,700	508,900	549,200																					
146	478,200	512,600	553,200																					
147	481,600	516,300	557,200																					
148	485,000	519,900	561,200																					
149	488,400	523,600																						
150	491,800	527,300																						
151	495,200	531,000																						
152	498,600	534,700																						
153	502,000	538,400																						
154	505,400	542,000																						
155	508,800	545,700																						
156	512,200	549,400																						
157	515,600	553,100																						
158	519,000																							
159	522,400																							
160	525,800																							
161	529,200																							
162	532,600																							
163	536,000																							
164	539,400																							
165	542,800																							
166	546,200																							
167																								

Figure B-13 Tabular Representation of Landing/Take-Off Nomograph for B767-300ER

(Values in Table are Gross Aircraft Weight in Pounds)

Ice Thickness (inches)	Ice Temperature																						
deg F	28.0	27.0	26.1	25.0	24.1	23.0	21.9	21.0	19.9	19.0	17.1	16.0	15.1	14.0	12.0	10.0	8.1	6.1	3.9	1.9	0.0	-2.0	-4.0
deg C	-2.2	-2.8	-3.3	-3.9	-4.4	-5	-5.6	-6.1	-6.7	-7.2	-8.3	-8.9	-9.4	-10	-11.1	-12.2	-13.3	-14.4	-15.6	-16.7	-17.8	-18.9	-20
51																							207,280
52																						208,087	213,563
53																					208,614	214,254	219,894
54																				208,856	214,662	220,468	226,275
55																			208,810	214,783	220,757	226,730	232,704
56																		207,912	214,613	220,755	226,897	233,039	239,181
57																	207,262	213,574	220,460	226,772	233,084	239,396	245,708
58																206,312	212,795	219,278	226,350	232,834	239,317	245,800	252,283
59															205,057	211,713	218,368	225,024	232,285	238,940	245,596	252,251	258,907
60															210,324	217,154	223,983	230,812	238,262	245,092	251,921	258,750	265,579
61														208,626	215,630	222,634	229,639	236,643	244,284	251,288	258,292	265,296	272,301
62												205,889	209,482	213,794	220,974	228,155	235,335	242,516	250,349	257,529	264,710	271,890	279,071
63											206,535	210,934	214,600	218,999	226,357	233,715	241,073	248,431	256,458	263,816	271,173	278,531	285,889
64											211,528	216,015	219,754	224,241	231,778	239,315	246,851	254,388	262,610	270,147	277,683	285,220	292,757
65										208,167	216,556	221,132	224,945	229,521	237,237	244,954	252,671	260,388	268,806	276,523	284,239	291,956	299,673
66									209,179	213,066	221,619	226,284	230,172	234,837	242,735	250,633	258,531	266,429	275,045	282,944	290,842	298,740	306,638
67							205,320	209,283	214,038	218,000	226,718	231,473	235,436	240,191	248,272	256,352	264,433	272,514	281,329	289,409	297,490	305,571	313,651
68						205,201	210,047	214,085	218,931	222,969	231,853	236,698	240,736	245,582	253,846	262,111	270,375	278,640	287,656	295,920	304,184	312,449	320,713
69						209,869	214,806	218,920	223,857	227,971	237,022	241,959	246,073	251,010	259,460	267,909	276,359	284,808	294,026	302,476	310,925	319,375	327,824
70						214,570	219,598	223,789	228,818	233,008	242,228	247,256	251,447	256,476	265,111	273,747	282,383	291,019	300,440	309,076	317,712	326,348	334,984
71						219,302	224,423	228,691	233,812	238,079	247,468	252,589	256,857	261,978	270,802	279,625	288,449	297,272	306,898	315,722	324,545	333,369	342,192
72						224,066	229,280	233,625	238,840	243,185	252,744	257,958	262,304	267,518	276,530	285,543	294,555	303,568	313,399	322,412	331,424	340,437	349,449
73					205,160	228,862	234,170	238,593	243,901	248,324	258,056	263,363	267,787	273,095	282,297	291,500	300,703	309,905	319,944	329,147	338,350	347,552	356,755
74					209,463	233,690	239,092	243,594	248,997	253,498	263,402	268,805	273,306	278,709	288,103	297,497	306,891	316,285	326,533	335,927	345,321	354,715	364,109
75					213,794	238,550	244,047	248,628	254,126	258,707	268,785	274,282	278,863	284,360	293,947	303,534	313,120	322,707	333,165	342,752	352,339	361,926	371,513
76					218,154	243,442	249,035	253,696	259,288	263,949	274,202	279,795	284,456	290,048	299,829	309,610	319,391	329,171	339,841	349,622	359,403	369,184	378,964
77					222,542	248,366	254,055	258,796	264,485	269,226	279,655	285,344	290,085	295,774	305,750	315,726	325,702	335,678	346,561	356,537	366,513	376,489	386,465
78					226,958	253,322	259,108	263,930	269,715	274,537	285,144	290,930	295,751	301,537	311,709	321,882	332,054	342,227	353,324	363,497	373,669	383,842	
79				208,981	231,404	258,310	264,194	269,096	274,979	279,882	290,668	296,551	301,453	307,337	317,707	328,077	338,448	348,818	360,131	370,501	380,872		
80				212,999	235,877	263,330	269,312	274,296	280,277	285,261	296,227	302,208	307,193	313,174	323,743	334,312	344,882	355,451	366,981	377,551			
81				217,043	240,379	268,382	274,462	279,529	285,609	290,675	301,822	307,902	312,968	319,048	329,818	340,587	351,357	362,127	373,876	384,645			
82				221,113	244,910	273,466	279,645	284,795	290,974	296,123	307,452	313,631	318,780	324,960	335,931	346,902	357,873	368,845	380,813				
83				225,208	249,469	278,582	284,861	290,094	296,373	301,606	313,117	319,396	324,629	330,908	342,082	353,256	364,431	375,605	387,795				
84				229,329	254,056	283,730	290,110	295,426	301,806	307,122	318,818	325,198	330,514	336,894	348,272	359,651	371,029	382,407					
85				233,475	258,673	288,910	295,391	300,791	307,272	312,673	324,555	331,035	336,436	342,917	354,501	366,084	377,668						
86			206,842	237,647	263,317	294,122	300,704	306,190	312,773	318,258	330,326	336,909	342,395	348,977	360,768	372,558	384,348						
87			210,469	241,844	267,990	299,365	306,050	311,621	318,307	323,877	336,134	342,819	348,390	355,075	367,073	379,071							
88			214,118	246,067	272,692	304,641	311,429	317,086	323,874	329,531	341,976	348,764	354,421	361,209	373,417	385,624							
89			217,789	250,316	277,422	309,949	316,841	322,584	329,476	335,219	347,854	354,746	360,489	367,381	379,799								
90			221,482	254,590	282,180	315,289	322,285	328,115	335,111	340,941	353,767	360,764	366,594	373,590	386,219								
91			225,197	258,890	286,967	320,660	327,761	333,679	340,780	346,698	359,716	366,817	372,735	379,836									
92		206,899	228,934	263,215	291,783	326,064	333,270	339,276	346,483	352,438	365,700	372,907	378,913	386,119									
93		210,291	232,694	267,566	296,627	331,499	338,812	344,906	352,219	358,313	371,720	379,033	385,127										
94		213,703	236,475	271,943	301,499	336,967	344,387	350,570	357,989	364,172	377,775	385,195											
95		217,135	240,279	276,345	306,400	342,467	349,994	356,266	363,793	370,066	383,865												
96		220,587	244,105	280,773	311,330	347,998	355,633	361,996	369,631	375,994													
97		224,060	247,953	285,226	316,288	353,562	361,305	367,759	375,502	381,956													
98		227,552	251,823	289,705	321,274	359,157	367,010	373,555	381,408	387,952													
99		231,064	255,715	294,210	326,289	364,785	372,748	379,384	387,347														
100		234,596	259,629	298,740	331,333	370,444	378,518	385,246															
101		238,148	263,565	303,296	336,405	376,135	384,320																
102		241,720	267,524	307,877	341,505	381,859																	
103		245,311	271,504	312,484	346,634	387,614																	
104	207,539	248,923	275,507	317,117	351,792																		
105	210,495	252,555	279,532	321,775	356,978																		
106	213,468	256,207	283,579	326,459	362,192																		
107	216,457	259,878	287,648	331,168	367,435																		
108	219,461	263,570	291,739	335,903	372,706																		
109	222,483	267,282	295,852	340,663	378,006																		
110	225,520	271,013	299,987	345,450	383,335																		
111	228,574	274,765	304,145	350,261																			
112	231,643	278,536	308,324	355,099																			
113	234,730	282,327	312,526	359,962																			
114	237,832	286,139	316,750	364,850																			
115	240,951	289,970	320,996	369,764																			
116	244,085	293,821	325,264	374,704																			
117	247,236	297,692	329,554	379,669																			
118	250,404	301,584	333,866	384,660																			
119	253,587	305,495	338,201																				
120	256,787	309,426	342,557																				
121	260,003	313,377	346,936																				
122	263,236	317,348	351,337																				
123	266,484	321,339	355,759																				
124	269,749	325,350	360,204																				
125	273,030	329,381	364,672																				
126	276,327	333,431	369,161																				
127	279,641	337,502	373,672																				
128	282,970	341,593	378,205																				
129	286,316	345,704	382,761																				
130	289,679	349,834	387,339																				
131	293,057	353,985																					
132	296,452	358,155																					
133	299,863	362,346																					
134	303,290	366,556																					
135	306,734	370,787																					
136	310,193	375,037																					
137	313,669	379,307																					
138	317,161	383,597																					
139	320,670	387,908																					
140	324,194																						
141	327,735																						
142	331,292																						
143	334,866																						
144	338,456																						
145	342,061																						
146	345,684																						
147	349,322																						
148	352,976																						
149	356,647																						
150	360,334																						
151	364,038																						
152	367,757																						
153	371,493																						
154	375,245																						
155	379,014																						
156	382,798																						
157	386,599																						

Figure B-14 Tabular Representation of Parking Nomograph for C-17 on -4 °F (-20 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

Gross C-17 Weight (lb)

-4 F / Sea Ice Thickness (inches)	280,000	290,000	300,000	310,000	320,000	330,000	340,000	350,000	360,000	370,000	380,000	390,000	400,000	410,000	420,000	430,000	440,000	450,000	460,000	470,000	480,000	490,000	500,000	510,000	520,000	530,000	540,000	550,000	560,000	570,000	580,000	590,000	600,000
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0.8	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	1.3	1.2	1.0	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
63	1.7	1.5	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0
64	2.3	1.8	1.5	1.3	1.0	0.8	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0
65	2.8	2.3	2.0	1.7	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0
66	3.8	3.0	2.5	2.0	1.7	1.3	1.2	1.0	0.8	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0
67	4.8	3.8	3.2	2.5	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0
68	6.3	5.0	4.0	3.2	2.7	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
69	8.2	6.3	5.0	4.2	3.3	2.8	2.3	2.0	1.7	1.3	1.2	1.0	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
70	10.5	8.2	6.5	5.2	4.2	3.5	2.8	2.3	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
71	13.7	10.5	8.3	6.7	5.3	4.3	3.5	3.0	2.5	2.2	1.8	1.5	1.3	1.2	1.0	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
72	17.8	13.7	10.7	8.3	6.7	5.5	4.5	3.7	3.2	2.7	2.2	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2
73	23.3	17.7	13.7	10.7	8.5	6.8	5.5	4.7	3.8	3.2	2.7	2.3	2.0	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2
74	30.5	22.8	17.5	13.7	10.7	8.7	7.0	5.7	4.7	4.0	3.3	2.8	2.5	2.2	1.8	1.7	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3
75	40.0	29.7	22.5	17.3	13.7	10.8	8.7	7.2	5.8	4.8	4.2	3.5	3.0	2.5	2.2	2.0	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3
76	52.5	38.7	29.0	22.3	17.3	13.7	11.0	8.8	7.3	6.0	5.0	4.2	3.7	3.2	2.7	2.3	2.0	1.8	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.5	0.3
77	69.2	50.5	37.7	28.5	22.0	17.3	13.7	11.0	9.0	7.5	6.2	5.2	4.3	3.7	3.2	2.8	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5
78	91.3	66.0	48.8	36.7	28.2	21.8	17.3	13.8	11.2	9.2	7.7	6.3	5.3	4.5	3.8	3.3	2.8	2.5	2.2	2.0	1.7	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5
79	121.0	86.7	63.3	47.3	36.0	27.8	21.8	17.3	14.0	11.3	9.3	7.8	6.5	5.5	4.7	4.0	3.5	3.0	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7
80	160.7	114.0	82.7	61.2	46.2	35.3	27.7	21.8	17.5	14.2	11.5	9.5	8.0	6.7	5.7	4.8	4.2	3.7	3.2	2.8	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.2	1.0	1.0	0.8	0.8	0.7
81	>200	150.2	108.0	79.3	59.3	45.2	35.0	27.5	21.8	17.5	14.3	11.8	9.8	8.2	7.0	5.8	5.0	4.3	3.8	3.3	2.8	2.5	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8
82	>200	198.7	141.5	103.0	76.5	57.8	44.3	34.7	27.3	21.8	17.7	14.5	12.0	10.0	8.3	7.2	6.2	5.2	4.5	4.0	3.5	3.0	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.3	1.2	1.0	1.0
83	>200	>200	186.0	134.2	98.8	74.0	56.5	43.7	34.3	27.3	22.0	18.0	14.7	12.2	10.2	8.7	7.3	6.3	5.5	4.7	4.2	3.7	3.2	2.8	2.5	2.2	2.0	1.8	1.7	1.5	1.3	1.2	1.2
84	>200	>200	>200	175.3	128.0	95.2	72.2	55.5	43.3	34.2	27.3	22.2	18.2	15.0	12.5	10.5	8.8	7.7	6.5	5.7	4.8	4.3	3.8	3.3	3.0	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.3
85	>200	>200	>200	>200	166.3	122.8	92.3	70.5	54.7	43.0	34.2	27.5	22.3	18.3	15.3	12.8	10.8	9.2	7.8	6.7	5.8	5.2	4.5	3.8	3.5	3.0	2.7	2.5	2.2	2.0	1.8	1.7	1.5
86	>200	>200	>200	>200	>200	158.8	118.3	89.8	69.2	54.0	42.7	34.2	27.7	22.7	18.7	15.5	13.2	11.0	9.5	8.2	7.0	6.0	5.3	4.7	4.2	3.7	3.2	2.8	2.5	2.3	2.2	1.8	1.7
87	>200	>200	>200	>200	>200	>200	152.5	114.8	87.8	68.2	53.7	42.7	34.3	28.0	23.0	19.0	16.0	13.3	11.3	9.7	8.3	7.2	6.3	5.5	4.8	4.3	3.8	3.3	3.0	2.7	2.5	2.2	2.0
88	>200	>200	>200	>200	>200	>200	196.8	147.2	111.8	86.2	67.3	53.3	42.7	34.5	28.3	23.3	19.3	16.3	13.8	11.7	10.0	8.7	7.5	6.5	5.7	5.0	4.5	4.0	3.5	3.2	2.8	2.5	2.3
89	>200	>200	>200	>200	>200	>200	>200	189.2	142.7	109.3	85.0	66.8	53.2	42.8	34.8	28.7	23.7	19.8	16.7	14.2	12.0	10.3	9.0	7.8	6.8	6.0	5.3	4.7	4.2	3.7	3.3	3.0	2.7
90	>200	>200	>200	>200	>200	>200	>200	>200	182.8	139.2	107.3	84.0	66.5	53.3	43.2	35.2	29.0	24.2	20.3	17.2	14.5	12.5	10.7	9.3	8.2	7.0	6.2	5.5	4.8	4.3	3.8	3.5	3.2
91	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.5	136.2	105.8	83.3	66.3	53.5	43.5	35.7	29.5	24.7	20.8	17.5	15.0	12.8	11.2	9.7	8.3	7.3	6.5	5.7	5.2	4.5	4.0	3.7
92	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	173.3	133.8	104.8	83.0	66.5	53.8	44.0	36.2	30.2	25.2	21.3	18.2	15.5	13.3	11.5	10.0	8.7	7.7	6.8	6.0	5.3	4.8	4.3
93	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	169.8	132.2	104.2	83.0	66.8	54.3	44.5	36.8	30.7	25.8	21.8	18.7	16.0	13.8	12.0	10.3	9.2	8.0	7.0	6.3	5.7	5.0
94	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	167.2	131.0	103.8	83.2	67.3	55.0	45.2	37.5	31.5	26.5	22.5	19.2	16.5	14.3	12.3	10.8	9.5	8.3	7.3	6.5	5.8
95	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	165.3	130.3	103.8	83.5	67.8	55.7	46.0	38.3	32.2	27.3	23.2	19.8	17.2	14.8	12.8	11.3	9.8	8.7	7.7	6.8
96	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	164.2	130.0	104.2	84.3	68.8	56.7	47.0	39.3	33.2	28.0	24.0	20.5	17.7	15.3	13.3	11.8	10.3	9.2	8.2
97	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	163.5	130.3	104.8	85.2	69.8	57.7	48.0	40.3	34.0	29.0	24.8	21.3	18.5	16.0	14.0	12.3	10.8	9.5
98	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	163.5	131.0	105.8	86.3	71.2	59.0	49.3	41.5	35.2	30.0	25.7	22.2	19.2	16.7	14.7	12.8	11.3
99	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	164.2	132.2	107.3	87.8	72.5	60.3	50.7	42.7	36.3	31.0	26.7	23.0	20.0	17.3	15.3	13.5
100	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	165.5	133.7	109.0	89.7	74.3	62.0	52.2	44.2	37.5	32.2	27.7	24.0	20.8	18.2	16.0
101	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	167.3	135.8	111.2	91.7	76.3	63.8	53.8	45.7	39.0	33.3	28.8	25.0	21.8	19.0
102	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	169.8	138.3	113.7	94.2	78.5	65.8	55.7	47.3	40.5	34.8	30.0	26.2	22.8
103	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	173.0	141.5	116.7	96.8	81.0	68.2	57.8	49.2	42.2	36.3	31.5	27.3
104	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	176.8	145.2	120.0	100.0	83.8	70.8	60.2	51.3	44.0	38.0	33.0
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.5	149.5	124.0	103.5	87.0	73.7	62.7	53.7	46.2	39.8
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	187.0	154.5	128.5	107.7	90.7	76.8	65.5	56.2	48.5
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.3	160.2	133.7	112.2	94.8	80.5	68.8	59.0
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	166.8	139.5	117.3	99.3	84.5	72.3
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	174.3	146.2	123.3	104.5	89.2
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	183.0	153.8	130.0	110.5
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.0	162.5	137.5
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	172.5
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

Figure B-15 Tabular Representation of Parking Nomograph for C-17 on -2 °F (-19 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

-2 F	Gross C-17 Weight (lb)																																
Sea Ice Thickness (inches)	280,000	290,000	300,000	310,000	320,000	330,000	340,000	350,000	360,000	370,000	380,000	390,000	400,000	410,000	420,000	430,000	440,000	450,000	460,000	470,000	480,000	490,000	500,000	510,000	520,000	530,000	540,000	550,000	560,000	570,000	580,000	590,000	600,000
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	1.0	0.8	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	1.7	1.3	1.0	0.8	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0
64	2.0	1.7	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0
65	2.7	2.2	1.7	1.5	1.2	1.0	0.8	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0
66	3.3	2.7	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0
67	4.3	3.5	2.8	2.3	2.0	1.7	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0
68	5.7	4.5	3.7	3.0	2.3	2.0	1.7	1.5	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0
69	7.3	5.7	4.5	3.7	3.0	2.5	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
70	9.3	7.3	5.8	4.7	3.8	3.2	2.7	2.2	1.8	1.7	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
71	12.2	9.3	7.3	5.8	4.8	3.8	3.2	2.7	2.3	2.0	1.7	1.5	1.2	1.2	1.0	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
72	15.8	12.2	9.5	7.5	6.0	4.8	4.0	3.3	2.8	2.3	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2
73	20.5	15.5	12.0	9.5	7.5	6.2	5.0	4.2	3.5	2.8	2.5	2.2	1.8	1.7	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2
74	26.7	20.2	15.5	12.0	9.5	7.7	6.2	5.2	4.3	3.5	3.0	2.5	2.2	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3
75	34.8	26.0	19.8	15.3	12.0	9.7	7.8	6.3	5.3	4.3	3.7	3.2	2.7	2.3	2.0	1.8	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3
76	45.5	33.7	25.5	19.5	15.3	12.2	9.7	7.8	6.5	5.3	4.5	3.8	3.3	2.8	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3
77	59.8	43.8	32.8	25.0	19.3	15.3	12.2	9.8	8.0	6.7	5.5	4.7	4.0	3.3	2.8	2.5	2.2	2.0	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3
78	78.5	57.0	42.3	32.0	24.7	19.3	15.3	12.3	10.0	8.2	6.8	5.7	4.8	4.2	3.5	3.0	2.7	2.3	2.0	1.8	1.5	1.3	1.3	1.2	1.0	0.8	0.8	0.8	0.7	0.7	0.5	0.5	0.5
79	103.7	74.5	54.8	41.2	31.3	24.3	19.2	15.3	12.3	10.2	8.3	7.0	5.8	5.0	4.2	3.7	3.2	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7	0.5
80	137.0	97.7	71.2	53.0	40.2	30.8	24.2	19.2	15.3	12.5	10.3	8.5	7.2	6.0	5.2	4.3	3.8	3.3	2.8	2.5	2.2	2.0	1.7	1.5	1.3	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7
81	181.5	128.2	92.7	68.3	51.3	39.3	30.5	24.0	19.2	15.5	12.7	10.5	8.7	7.3	6.2	5.3	4.5	4.0	3.3	3.0	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.8
82	>200	168.8	120.8	88.3	65.8	50.0	38.7	30.2	24.0	19.3	15.7	12.8	10.7	8.8	7.5	6.3	5.5	4.7	4.0	3.5	3.2	2.7	2.5	2.2	2.0	1.7	1.5	1.3	1.3	1.2	1.0	1.0	0.8
83	>200	>200	158.2	114.7	84.8	63.8	49.0	38.0	30.0	24.0	19.3	15.8	13.0	10.8	9.2	7.7	6.5	5.7	4.8	4.2	3.7	3.2	2.8	2.5	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.2	1.0
84	>200	>200	>200	149.2	109.5	81.8	62.2	48.0	37.7	29.8	24.0	19.5	16.0	13.3	11.2	9.3	8.0	6.8	5.8	5.0	4.3	3.8	3.3	3.0	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.3	1.2
85	>200	>200	>200	194.7	141.7	105.2	79.3	60.8	47.3	37.3	29.8	24.2	19.7	16.2	13.5	11.3	9.7	8.2	7.0	6.0	5.2	4.5	4.0	3.5	3.2	2.8	2.5	2.2	2.0	1.8	1.7	1.5	1.3
86	>200	>200	>200	>200	183.8	135.3	101.5	77.3	59.8	46.8	37.2	29.8	24.3	20.0	16.5	13.8	11.7	9.8	8.3	7.2	6.2	5.5	4.8	4.2	3.7	3.3	2.8	2.7	2.3	2.2	1.8	1.7	1.5
87	>200	>200	>200	>200	>200	174.8	130.0	98.3	75.7	58.8	46.5	37.2	30.0	24.5	20.2	16.8	14.0	11.8	10.2	8.7	7.5	6.5	5.7	5.0	4.3	3.8	3.5	3.0	2.7	2.5	2.2	2.0	1.8
88	>200	>200	>200	>200	>200	>200	167.3	125.7	95.8	74.2	58.2	46.3	37.2	30.2	24.8	20.5	17.2	14.3	12.2	10.3	9.0	7.7	6.7	5.8	5.2	4.5	4.0	3.5	3.2	2.8	2.5	2.3	2.2
89	>200	>200	>200	>200	>200	>200	>200	160.8	122.0	93.8	73.2	57.8	46.2	37.3	30.5	25.2	20.8	17.5	14.7	12.5	10.7	9.2	8.0	7.0	6.2	5.3	4.7	4.2	3.7	3.3	3.0	2.7	2.5
90	>200	>200	>200	>200	>200	>200	>200	>200	155.5	118.8	92.2	72.3	57.5	46.2	37.5	30.8	25.5	21.2	17.8	15.2	12.8	11.0	9.5	8.3	7.2	6.3	5.5	5.0	4.3	3.8	3.5	3.2	2.8
91	>200	>200	>200	>200	>200	>200	>200	>200	199.2	151.2	116.5	90.8	71.8	57.5	46.3	37.8	31.2	25.8	21.7	18.3	15.5	13.3	11.3	9.8	8.7	7.5	6.7	5.8	5.2	4.7	4.2	3.7	3.3
92	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.8	147.7	114.5	90.0	71.5	57.5	46.7	38.3	31.7	26.3	22.2	18.7	16.0	13.7	11.8	10.2	8.8	7.8	6.8	6.0	5.3	4.8	4.3	3.8
93	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	187.7	144.8	113.2	89.3	71.5	57.8	47.2	38.8	32.2	27.0	22.7	19.2	16.5	14.2	12.2	10.7	9.3	8.2	7.2	6.3	5.7	5.0	4.5
94	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	183.5	142.5	112.2	89.2	71.7	58.2	47.7	39.3	32.8	27.5	23.3	19.8	17.0	14.7	12.7	11.0	9.7	8.5	7.5	6.7	5.8	5.3
95	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.3	141.0	111.5	89.2	72.0	58.7	48.3	40.0	33.5	28.2	23.8	20.3	17.5	15.2	13.2	11.5	10.0	8.8	7.8	7.0	6.2
96	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.8	140.0	111.3	89.5	72.7	59.5	49.2	40.8	34.3	29.0	24.7	21.0	18.2	15.7	13.7	11.8	10.5	9.2	8.2	7.2
97	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	176.3	139.5	111.5	90.0	73.5	60.3	50.0	41.8	35.2	29.8	25.3	21.8	18.8	16.3	14.2	12.3	10.8	9.7	8.5
98	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	175.3	139.5	112.2	91.0	74.5	61.5	51.2	42.8	36.2	30.7	26.2	22.5	19.5	16.8	14.7	13.0	11.3	10.0
99	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	175.2	140.0	113.2	92.2	75.7	62.7	52.3	44.0	37.2	31.7	27.2	23.3	20.2	17.7	15.3	13.5	11.8
100	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	175.7	141.2	114.5	93.7	77.2	64.2	53.7	45.3	38.3	32.8	28.2	24.3	21.0	18.3	16.0	14.2
101	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	176.8	142.7	116.2	95.5	79.0	65.8	55.3	46.7	39.7	34.0	29.2	25.3	22.0	19.2	16.8
102	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.7	144.8	118.3	97.5	81.0	67.7	57.0	48.3	41.2	35.3	30.5	26.3	23.0	20.0
103	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.2	147.5	121.0	100.0	83.3	69.8	59.0	50.2	42.8	36.8	31.7	27.5	24.0
104	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	184.5	150.7	124.2	103.0	86.0	72.3	61.2	52.0	44.5	38.3	33.2	28.8
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.7	154.7	127.7	106.3	89.0	75.0	63.7	54.3	46.5	40.2	34.8
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.5	159.2	131.8	110.0	92.5	78.2	66.3	56.7	48.8	42.2
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	199.5	164.5	136.7	114.3	96.3	81.5	69.5	59.5	51.2
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	170.8	142.3	119.3	100.7	85.5	73.0	62.5
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.0	148.7	125.0	105.7	89.8	76.8
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	186.2	156.0	131.3	111.3	94.8
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.8	164.3	138.7	117.7
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	174.0	147.2
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.2
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

Figure B-16 Tabular Representation of Parking Nomograph for C-17 on 0 °F (-17.5 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

0 F	Gross C-17 Weight (lb)																																
Sea Ice Thickness (inches)	280,000	290,000	300,000	310,000	320,000	330,000	340,000	350,000	360,000	370,000	380,000	390,000	400,000	410,000	420,000	430,000	440,000	450,000	460,000	470,000	480,000	490,000	500,000	510,000	520,000	530,000	540,000	550,000	560,000	570,000	580,000	590,000	600,000
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	1.2	1.0	0.8	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	1.5	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
64	1.8	1.5	1.3	1.0	0.8	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0
65	2.3	2.0	1.7	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0
66	3.0	2.5	2.0	1.7	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0
67	4.0	3.2	2.5	2.2	1.7	1.5	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0
68	5.0	4.0	3.2	2.7	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0
69	6.5	5.2	4.2	3.3	2.7	2.3	1.8	1.7	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
70	8.3	6.5	5.2	4.2	3.5	2.8	2.3	2.0	1.7	1.5	1.2	1.0	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
71	10.8	8.3	6.7	5.3	4.3	3.5	3.0	2.5	2.0	1.8	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
72	13.8	10.7	8.3	6.7	5.3	4.3	3.7	3.0	2.5	2.2	1.8	1.7	1.3	1.2	1.0	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
73	18.0	13.7	10.7	8.5	6.7	5.5	4.5	3.7	3.2	2.7	2.2	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2
74	23.3	17.7	13.7	10.7	8.5	6.8	5.5	4.7	3.8	3.2	2.7	2.3	2.0	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2
75	30.3	22.7	17.3	13.5	10.7	8.5	7.0	5.7	4.7	4.0	3.3	2.8	2.5	2.2	1.8	1.7	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3
76	39.5	29.3	22.3	17.2	13.5	10.7	8.7	7.0	5.8	4.8	4.0	3.5	3.0	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3
77	51.7	38.0	28.5	21.8	17.0	13.5	10.8	8.7	7.2	6.0	5.0	4.2	3.5	3.0	2.7	2.3	2.0	1.8	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3
78	67.5	49.3	36.8	28.0	21.5	17.0	13.5	10.8	8.8	7.3	6.0	5.2	4.3	3.7	3.2	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5
79	88.7	64.2	47.3	35.7	27.3	21.3	16.8	13.5	11.0	9.0	7.5	6.2	5.2	4.5	3.8	3.3	2.8	2.5	2.2	2.0	1.7	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5
80	116.7	83.7	61.3	45.8	34.8	27.0	21.2	16.8	13.7	11.0	9.2	7.7	6.3	5.3	4.7	4.0	3.3	3.0	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7
81	154.0	109.3	79.3	58.8	44.5	34.2	26.7	21.0	16.8	13.7	11.2	9.3	7.8	6.5	5.5	4.7	4.0	3.5	3.0	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.8	0.7
82	>200	143.3	103.2	75.8	56.8	43.3	33.5	26.3	21.0	17.0	13.8	11.3	9.5	8.0	6.7	5.7	4.8	4.2	3.7	3.2	2.8	2.5	2.2	2.0	1.7	1.5	1.3	1.3	1.2	1.0	1.0	0.8	0.8
83	>200	188.5	134.5	98.0	72.8	55.2	42.5	33.2	26.2	21.0	17.0	14.0	11.5	9.7	8.2	6.8	5.8	5.0	4.3	3.8	3.3	3.0	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.2	1.0	1.0
84	>200	>200	175.7	127.0	93.7	70.3	53.7	41.7	32.8	26.2	21.0	17.2	14.2	11.7	9.8	8.3	7.0	6.0	5.2	4.5	4.0	3.5	3.0	2.7	2.3	2.2	2.0	1.7	1.5	1.3	1.3	1.2	1.0
85	>200	>200	>200	165.0	120.7	90.0	68.2	52.5	41.2	32.5	26.2	21.2	17.3	14.3	12.0	10.0	8.5	7.3	6.3	5.3	4.7	4.2	3.7	3.2	2.8	2.5	2.3	2.0	1.8	1.7	1.5	1.3	1.2
86	>200	>200	>200	>200	156.0	115.5	86.8	66.5	51.7	40.7	32.3	26.2	21.3	17.5	14.5	12.2	10.3	8.7	7.5	6.5	5.7	4.8	4.3	3.8	3.3	3.0	2.7	2.3	2.2	1.8	1.7	1.5	1.5
87	>200	>200	>200	>200	>200	148.5	111.0	84.3	65.0	50.8	40.3	32.3	26.2	21.5	17.8	14.8	12.5	10.5	9.0	7.7	6.7	5.8	5.0	4.5	3.8	3.5	3.2	2.8	2.5	2.2	2.0	1.8	1.7
88	>200	>200	>200	>200	>200	191.7	142.2	107.3	82.2	64.0	50.3	40.2	32.3	26.3	21.7	18.0	15.0	12.7	10.8	9.2	8.0	6.8	6.0	5.3	4.7	4.0	3.7	3.2	2.8	2.7	2.3	2.2	1.8
89	>200	>200	>200	>200	>200	>200	182.7	136.8	104.2	80.5	63.0	50.0	40.0	32.5	26.7	22.0	18.3	15.3	13.0	11.2	9.5	8.2	7.2	6.2	5.5	4.8	4.3	3.8	3.3	3.0	2.7	2.5	2.2
90	>200	>200	>200	>200	>200	>200	>200	175.2	132.3	101.7	79.2	62.3	49.7	40.2	32.7	26.8	22.3	18.7	15.7	13.3	11.3	9.8	8.5	7.3	6.5	5.7	5.0	4.5	4.0	3.5	3.2	2.8	2.5
91	>200	>200	>200	>200	>200	>200	>200	>200	168.8	128.7	99.5	78.0	61.8	49.7	40.3	33.0	27.2	22.7	19.0	16.2	13.7	11.7	10.2	8.8	7.7	6.7	5.8	5.2	4.7	4.2	3.7	3.3	3.0
92	>200	>200	>200	>200	>200	>200	>200	>200	>200	163.5	125.7	98.0	77.3	61.7	49.7	40.5	33.3	27.7	23.2	19.5	16.5	14.2	12.2	10.5	9.2	8.0	7.0	6.2	5.5	4.8	4.3	3.8	3.5
93	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	159.3	123.3	96.8	76.8	61.7	50.0	40.8	33.7	28.2	23.5	19.8	17.0	14.5	12.5	10.8	9.5	8.2	7.2	6.3	5.7	5.0	4.5	4.0
94	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	155.8	121.5	96.0	76.5	61.8	50.3	41.3	34.3	28.7	24.2	20.3	17.3	15.0	12.8	11.2	9.8	8.5	7.5	6.7	6.0	5.3	4.7
95	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.5	153.2	120.2	95.5	76.7	62.0	50.8	41.8	34.8	29.2	24.7	21.0	18.0	15.5	13.3	11.7	10.2	8.8	7.8	7.0	6.2	5.5
96	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.7	151.2	119.3	95.3	76.8	62.5	51.3	42.7	35.5	29.8	25.3	21.5	18.5	16.0	13.8	12.0	10.5	9.3	8.2	7.3	6.5
97	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	190.7	149.8	119.0	95.5	77.3	63.3	52.2	43.3	36.3	30.7	26.0	22.2	19.2	16.5	14.3	12.5	11.0	9.7	8.5	7.7
98	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.7	149.0	119.0	96.0	78.2	64.2	53.2	44.3	37.2	31.5	26.8	23.0	19.8	17.2	14.8	13.0	11.5	10.2	9.0
99	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	187.3	148.8	119.5	96.8	79.2	65.2	54.2	45.3	38.2	32.3	27.7	23.7	20.5	17.8	15.5	13.5	12.0	10.5
100	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	187.0	149.3	120.3	98.0	80.3	66.5	55.5	46.5	39.3	33.5	28.7	24.7	21.3	18.5	16.2	14.2	12.5
101	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	187.3	150.3	121.7	99.5	81.8	68.0	56.8	47.8	40.5	34.5	29.7	25.5	22.2	19.3	16.8	14.8
102	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.3	151.8	123.5	101.3	83.7	69.7	58.5	49.3	42.0	35.8	30.8	26.7	23.0	20.2	17.7
103	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	190.2	154.0	125.7	103.5	85.8	71.7	60.3	51.0	43.5	37.2	32.0	27.7	24.2	21.0
104	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.8	156.7	128.5	106.0	88.3	74.0	62.3	52.8	45.2	38.7	33.3	29.0	25.2
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	196.3	160.2	131.7	109.2	91.0	76.5	64.7	55.0	47.0	40.5	35.0	30.3
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	164.3	135.5	112.7	94.3	79.3	67.3	57.3	49.2	42.3	36.7
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	169.2	140.0	116.7	97.8	82.7	70.2	60.0	51.5	44.3
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	175.0	145.2	121.3	102.0	86.3	73.5	62.8	54.0
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.8	151.3	126.7	106.8	90.5	77.2	66.2
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	189.7	158.2	132.8	112.2	95.3	81.3
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.7	166.2	139.8	118.3	100.7
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	175.5	148.0	125.5
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	186.2	157.3
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.7
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

Figure B-17 Tabular Representation of Parking Nomograph for C-17 on 2 °F (-16.5 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

Gross C-17 Weight (lb); Sea Ice Thickness (inches)

2 F	280,000	290,000	300,000	310,000	320,000	330,000	340,000	350,000	360,000	370,000	380,000	390,000	400,000	410,000	420,000	430,000	440,000	450,000	460,000	470,000	480,000	490,000	500,000	510,000	520,000	530,000	540,000	550,000	560,000	570,000	580,000	590,000	600,000
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	0.8	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	1.3	1.0	0.8	0.8	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
64	1.7	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0
65	2.2	1.8	1.5	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0
66	2.8	2.2	1.8	1.5	1.3	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0
67	3.5	2.8	2.3	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0
68	4.5	3.7	2.8	2.3	2.0	1.7	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0
69	5.8	4.5	3.7	3.0	2.5	2.0	1.7	1.5	1.2	1.0	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
70	7.3	5.8	4.7	3.8	3.0	2.5	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
71	9.5	7.3	5.8	4.7	3.8	3.2	2.7	2.2	1.8	1.7	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
72	12.2	9.5	7.5	6.0	4.8	4.0	3.3	2.7	2.3	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
73	15.8	12.2	9.5	7.5	6.0	4.8	4.0	3.3	2.8	2.3	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2
74	20.3	15.5	12.0	9.5	7.5	6.2	5.0	4.2	3.5	2.8	2.5	2.2	1.8	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2
75	26.3	19.8	15.3	12.0	9.5	7.7	6.2	5.2	4.2	3.5	3.0	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3
76	34.2	25.7	19.5	15.2	11.8	9.5	7.7	6.3	5.2	4.3	3.7	3.2	2.7	2.3	2.0	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3
77	44.5	33.0	24.8	19.2	15.0	11.8	9.5	7.8	6.3	5.3	4.5	3.8	3.2	2.8	2.3	2.0	1.8	1.7	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3
78	58.0	42.7	32.0	24.3	18.8	14.8	11.8	9.7	7.8	6.5	5.5	4.5	3.8	3.3	2.8	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3
79	75.8	55.2	41.0	31.0	23.8	18.7	14.8	12.0	9.7	8.0	6.7	5.5	4.7	4.0	3.5	3.0	2.5	2.2	2.0	1.7	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5
80	99.5	71.7	52.8	39.7	30.3	23.5	18.5	14.8	12.0	9.8	8.2	6.8	5.7	4.8	4.2	3.5	3.0	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7	0.5
81	130.7	93.3	68.2	50.7	38.5	29.7	23.3	18.5	14.8	12.0	10.0	8.2	6.8	5.8	5.0	4.3	3.7	3.2	2.8	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.8	0.7	0.7
82	172.2	121.8	88.2	65.2	49.0	37.5	29.2	23.0	18.3	14.8	12.2	10.0	8.3	7.0	6.0	5.2	4.3	3.8	3.3	2.8	2.5	2.2	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7
83	>200	159.5	114.3	83.8	62.7	47.7	36.8	28.8	22.8	18.3	15.0	12.3	10.2	8.5	7.2	6.2	5.3	4.5	4.0	3.5	3.0	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.2	1.2	1.0	1.0	0.8
84	>200	>200	148.8	108.2	80.2	60.5	46.3	36.2	28.5	22.8	18.5	15.2	12.5	10.3	8.7	7.3	6.3	5.3	4.7	4.0	3.5	3.2	2.8	2.5	2.2	2.0	1.7	1.5	1.5	1.3	1.2	1.0	1.0
85	>200	>200	194.2	139.8	102.8	77.0	58.7	45.3	35.7	28.3	22.8	18.5	15.2	12.7	10.5	8.8	7.5	6.5	5.7	4.8	4.2	3.7	3.3	2.8	2.5	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.2
86	>200	>200	>200	181.5	132.3	98.5	74.5	57.2	44.7	35.3	28.2	22.8	18.7	15.3	12.8	10.8	9.2	7.8	6.7	5.8	5.0	4.3	3.8	3.3	3.0	2.7	2.3	2.2	2.0	1.7	1.5	1.5	1.3
87	>200	>200	>200	>200	171.0	126.2	94.7	72.3	56.0	44.0	35.0	28.2	22.8	18.8	15.7	13.0	11.0	9.3	8.0	6.8	6.0	5.2	4.5	4.0	3.5	3.2	2.8	2.5	2.2	2.0	1.8	1.7	1.5
88	>200	>200	>200	>200	>200	162.2	120.8	91.7	70.5	55.0	43.5	34.8	28.2	23.0	19.0	15.8	13.3	11.2	9.5	8.2	7.2	6.2	5.3	4.7	4.2	3.7	3.3	2.8	2.7	2.3	2.2	1.8	1.7
89	>200	>200	>200	>200	>200	>200	154.7	116.3	89.0	69.0	54.3	43.2	34.8	28.3	23.2	19.3	16.2	13.5	11.5	9.8	8.5	7.3	6.3	5.5	4.8	4.3	3.8	3.3	3.0	2.7	2.5	2.2	2.0
90	>200	>200	>200	>200	>200	>200	198.5	148.3	112.7	86.8	67.8	53.7	43.0	34.8	28.5	23.5	19.5	16.3	13.8	11.8	10.2	8.7	7.5	6.5	5.8	5.0	4.5	4.0	3.5	3.2	2.8	2.5	2.3
91	>200	>200	>200	>200	>200	>200	>200	189.7	143.2	109.7	85.2	67.0	53.3	43.0	35.0	28.7	23.8	19.8	16.7	14.2	12.2	10.3	9.0	7.8	6.8	6.0	5.3	4.7	4.2	3.7	3.3	3.0	2.7
92	>200	>200	>200	>200	>200	>200	>200	>200	182.3	138.7	107.2	83.8	66.3	53.2	43.0	35.2	29.0	24.2	20.2	17.0	14.5	12.5	10.7	9.3	8.0	7.0	6.2	5.5	4.8	4.3	3.8	3.5	3.2
93	>200	>200	>200	>200	>200	>200	>200	>200	>200	176.2	135.2	105.2	82.8	66.0	53.2	43.2	35.5	29.3	24.5	20.7	17.5	14.8	12.8	11.0	9.7	8.3	7.3	6.5	5.7	5.0	4.5	4.0	3.7
94	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	171.2	132.3	103.7	82.0	65.8	53.2	43.5	35.8	29.8	25.0	21.0	17.8	15.3	13.2	11.3	10.0	8.7	7.7	6.7	6.0	5.3	4.7	4.2
95	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	167.0	130.0	102.5	81.7	65.8	53.5	43.8	36.3	30.3	25.5	21.5	18.3	15.8	13.7	11.8	10.3	9.0	8.0	7.0	6.2	5.5	5.0
96	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	163.8	128.3	101.8	81.5	66.0	54.0	44.5	37.0	31.0	26.0	22.2	18.8	16.3	14.0	12.2	10.7	9.3	8.2	7.3	6.5	5.8
97	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	161.3	127.3	101.5	81.7	66.5	54.5	45.2	37.7	31.7	26.7	22.7	19.5	16.8	14.5	12.7	11.0	9.7	8.7	7.7	6.8
98	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	159.7	126.7	101.5	82.2	67.2	55.3	45.8	38.3	32.3	27.5	23.5	20.2	17.3	15.0	13.2	11.5	10.2	9.0	8.0
99	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	158.7	126.5	101.8	82.8	68.0	56.2	46.8	39.3	33.2	28.2	24.2	20.8	18.0	15.7	13.7	12.0	10.5	9.3
100	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	199.5	158.3	126.8	102.7	83.8	69.0	57.3	47.8	40.3	34.2	29.2	25.0	21.5	18.7	16.3	14.2	12.5	11.0
101	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.8	158.5	127.7	103.8	85.0	70.3	58.5	49.0	41.5	35.2	30.2	25.8	22.3	19.3	17.0	14.8	13.0
102	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	199.0	159.5	129.0	105.3	86.7	71.8	60.0	50.5	42.7	36.3	31.2	26.8	23.2	20.2	17.7	15.5
103	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	161.0	130.8	107.2	88.5	73.7	61.7	52.0	44.2	37.7	32.3	27.8	24.2	21.2	18.5
104	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	163.2	133.2	109.5	90.7	75.7	63.5	53.7	45.7	39.2	33.7	29.2	25.3	22.0
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	166.2	136.0	112.2	93.2	78.0	65.7	55.7	47.5	40.7	35.2	30.3	26.5
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	169.8	139.5	115.3	96.2	80.7	68.2	58.0	49.5	42.5	36.7	31.8
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	174.2	143.5	119.2	99.7	83.8	71.0	60.3	51.7	44.5	38.5
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.5	148.3	123.5	103.5	87.3	74.0	63.2	54.2	46.7
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.8	154.0	128.5	108.0	91.3	77.7	66.3	57.0
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.2	160.7	134.3	113.2	95.8	81.7	69.8
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	168.2	141.0	119.0	101.0	86.2
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.0	148.8	125.8	107.0
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	187.3	157.8	133.7
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	199.3	168.2
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

Figure B-18 Tabular Representation of Parking Nomograph for C-17 on 4 °F (-15.5 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

4 F	Gross C-17 Weight (lb)																															
Sea Ice Thickness (inches)	280,000	290,000	300,000	310,000	320,000	330,000	340,000	350,000	360,000	370,000	380,000	390,000	400,000	410,000	420,000	430,000	440,000	450,000	460,000	470,000	480,000	490,000	500,000	510,000	520,000	530,000	540,000	550,000	560,000	570,000	580,000	590,000	600,000
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	1.0	0.8	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	1.5	1.3	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0
65	2.0	1.7	1.3	1.2	1.0	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0
66	2.5	2.0	1.7	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0
67	3.2	2.5	2.0	1.7	1.5	1.2	1.0	0.8	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0
68	4.0	3.2	2.7	2.2	1.8	1.5	1.3	1.0	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0
69	5.2	4.2	3.3	2.7	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0
70	6.5	5.2	4.2	3.3	2.8	2.3	2.0	1.7	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
71	8.5	6.7	5.2	4.2	3.5	2.8	2.3	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
72	10.8	8.3	6.7	5.3	4.3	3.5	3.0	2.5	2.0	1.8	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
73	13.8	10.7	8.3	6.7	5.3	4.3	3.7	3.0	2.5	2.2	1.8	1.7	1.3	1.2	1.0	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
74	17.8	13.7	10.5	8.3	6.7	5.5	4.5	3.7	3.2	2.7	2.2	1.8	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2
75	23.0	17.3	13.5	10.5	8.3	6.7	5.5	4.5	3.8	3.2	2.7	2.3	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2
76	29.7	22.3	17.0	13.3	10.5	8.3	6.8	5.7	4.7	3.8	3.3	2.8	2.3	2.0	1.8	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3
77	38.5	28.7	21.7	16.8	13.2	10.5	8.5	6.8	5.7	4.7	4.0	3.3	2.8	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3
78	49.8	36.8	27.7	21.2	16.5	13.2	10.5	8.5	7.0	5.8	4.8	4.2	3.5	3.0	2.5	2.2	2.0	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3
79	65.0	47.5	35.5	27.0	20.8	16.3	13.0	10.5	8.7	7.0	5.8	5.0	4.2	3.7	3.0	2.7	2.3	2.0	1.8	1.5	1.3	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.5
80	84.7	61.3	45.5	34.3	26.3	20.5	16.3	13.0	10.5	8.7	7.2	6.0	5.0	4.3	3.7	3.2	2.8	2.3	2.2	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5
81	110.8	79.5	58.3	43.7	33.3	25.8	20.3	16.2	13.0	10.7	8.8	7.3	6.2	5.2	4.5	3.8	3.3	2.8	2.5	2.2	2.0	1.7	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.8	0.7	0.7	0.5
82	145.3	103.5	75.3	55.8	42.3	32.5	25.3	20.2	16.2	13.2	10.7	8.8	7.5	6.3	5.3	4.5	4.0	3.3	3.0	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7
83	191.3	134.8	97.2	71.7	53.8	41.0	31.8	25.0	20.0	16.2	13.2	10.8	9.0	7.7	6.5	5.5	4.7	4.0	3.5	3.0	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.2	1.2	1.0	1.0	0.8	0.8
84	>200	176.2	126.0	92.0	68.5	52.0	40.0	31.3	24.8	20.0	16.2	13.3	11.0	9.2	7.7	6.5	5.7	4.8	4.2	3.7	3.2	2.8	2.5	2.2	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8
85	>200	>200	163.7	118.5	87.7	66.0	50.5	39.2	30.8	24.7	19.8	16.2	13.3	11.2	9.3	7.8	6.7	5.8	5.0	4.3	3.8	3.3	3.0	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.2	1.0
86	>200	>200	>200	153.2	112.3	84.0	63.8	49.2	38.5	30.5	24.5	20.0	16.3	13.5	11.3	9.5	8.2	6.8	6.0	5.2	4.5	4.0	3.5	3.0	2.7	2.3	2.2	2.0	1.7	1.5	1.5	1.3	1.2
87	>200	>200	>200	198.7	144.5	107.2	80.8	62.0	48.2	38.0	30.3	24.5	20.0	16.5	13.7	11.5	9.7	8.3	7.2	6.2	5.3	4.7	4.0	3.5	3.2	2.8	2.5	2.3	2.0	1.8	1.7	1.5	1.3
88	>200	>200	>200	>200	186.3	137.2	102.7	78.2	60.5	47.3	37.7	30.2	24.5	20.2	16.7	13.8	11.7	10.0	8.5	7.3	6.3	5.5	4.8	4.2	3.7	3.3	3.0	2.7	2.3	2.2	1.8	1.7	1.5
89	>200	>200	>200	>200	>200	176.0	130.8	99.0	76.0	59.2	46.8	37.3	30.2	24.7	20.3	16.8	14.2	12.0	10.2	8.7	7.5	6.5	5.7	5.0	4.3	3.8	3.5	3.0	2.7	2.5	2.2	2.0	1.8
90	>200	>200	>200	>200	>200	>200	167.3	125.7	95.8	74.2	58.3	46.3	37.2	30.2	24.8	20.5	17.2	14.3	12.2	10.3	9.0	7.7	6.7	5.8	5.2	4.5	4.0	3.5	3.2	2.8	2.5	2.3	2.2
91	>200	>200	>200	>200	>200	>200	>200	160.0	121.3	93.3	72.8	57.5	46.0	37.2	30.3	25.0	20.8	17.3	14.7	12.5	10.7	9.2	8.0	7.0	6.0	5.3	4.7	4.2	3.7	3.3	3.0	2.7	2.5
92	>200	>200	>200	>200	>200	>200	>200	>200	154.0	117.7	91.2	71.7	57.0	45.8	37.2	30.5	25.2	21.0	17.7	15.0	12.8	11.0	9.5	8.2	7.2	6.3	5.5	4.8	4.3	3.8	3.5	3.2	2.8
93	>200	>200	>200	>200	>200	>200	>200	>200	196.0	148.8	114.7	89.5	70.8	56.7	45.8	37.3	30.8	25.5	21.3	18.0	15.3	13.2	11.3	9.8	8.5	7.5	6.5	5.8	5.2	4.5	4.0	3.7	3.3
94	>200	>200	>200	>200	>200	>200	>200	>200	>200	189.0	144.7	112.3	88.3	70.2	56.5	45.8	37.7	31.2	26.0	21.8	18.5	15.7	13.5	11.7	10.0	8.8	7.7	6.8	6.0	5.3	4.7	4.2	3.8
95	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	183.2	141.3	110.5	87.3	69.8	56.5	46.2	38.0	31.5	26.3	22.2	18.8	16.2	13.8	12.0	10.3	9.2	8.0	7.0	6.2	5.5	5.0	4.5
96	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.3	138.7	109.0	86.8	69.8	56.7	46.5	38.5	32.0	26.8	22.7	19.3	16.5	14.3	12.3	10.8	9.5	8.3	7.3	6.5	5.8	5.2
97	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	174.7	136.7	108.2	86.5	70.0	57.0	47.0	39.0	32.7	27.5	23.3	19.8	17.0	14.7	12.8	11.2	9.8	8.7	7.7	6.8	6.0
98	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	171.7	135.2	107.7	86.5	70.3	57.7	47.7	39.7	33.3	28.2	23.8	20.5	17.7	15.2	13.3	11.7	10.2	9.0	8.0	7.0
99	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	169.7	134.3	107.5	86.8	70.8	58.3	48.3	40.5	34.0	28.8	24.7	21.2	18.2	15.8	13.8	12.0	10.7	9.3	8.3
100	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	168.3	134.0	107.8	87.5	71.7	59.2	49.3	41.3	34.8	29.7	25.3	21.8	18.8	16.3	14.3	12.5	11.0	9.8
101	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	167.8	134.3	108.5	88.5	72.8	60.3	50.3	42.3	35.8	30.5	26.2	22.5	19.5	17.0	14.8	13.0	11.5
102	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	167.8	135.0	109.7	89.7	74.0	61.7	51.7	43.5	37.0	31.5	27.2	23.3	20.3	17.7	15.5	13.7
103	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	168.7	136.3	111.2	91.3	75.7	63.2	53.0	44.8	38.2	32.7	28.2	24.3	21.2	18.5	16.2
104	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	170.3	138.2	113.0	93.3	77.5	64.8	54.7	46.3	39.5	33.8	29.2	25.3	22.0	19.3
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	172.7	140.7	115.5	95.5	79.7	66.8	56.5	48.0	41.0	35.3	30.5	26.5	23.0
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	175.7	143.7	118.3	98.3	82.2	69.2	58.5	49.8	42.7	36.8	31.8	27.7
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.5	147.3	121.8	101.5	85.0	71.7	60.8	52.0	44.7	38.5	33.3
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	184.3	151.7	125.8	105.0	88.3	74.7	63.5	54.3	46.7	40.3
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	190.0	157.0	130.5	109.3	92.0	78.0	66.5	57.0	49.2
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.0	163.2	136.0	114.2	96.3	81.8	69.8	60.0
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	170.3	142.3	119.7	101.3	86.2	73.8
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.7	149.7	126.2	107.0	91.2
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.5	158.2	133.7	113.5
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	168.2	142.3
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.0
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

Figure B-19 Tabular Representation of Parking Nomograph for C-17 on 6 °F (-14 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

6 F	Gross C-17 Weight (lb)																																
Sea Ice Thickness (inches)	280,000	290,000	300,000	310,000	320,000	330,000	340,000	350,000	360,000	370,000	380,000	390,000	400,000	410,000	420,000	430,000	440,000	450,000	460,000	470,000	480,000	490,000	500,000	510,000	520,000	530,000	540,000	550,000	560,000	570,000	580,000	590,000	600,000
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	1.3	1.2	1.0	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
65	1.8	1.5	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0
66	2.2	1.8	1.5	1.2	1.0	0.8	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0
67	2.8	2.3	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0
68	3.7	2.8	2.3	2.0	1.7	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0
69	4.7	3.7	3.0	2.5	2.0	1.7	1.5	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0
70	5.8	4.7	3.7	3.0	2.5	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
71	7.5	5.8	4.7	3.8	3.2	2.5	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
72	9.5	7.3	5.8	4.7	3.8	3.2	2.7	2.2	1.8	1.7	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
73	12.2	9.3	7.3	5.8	4.8	3.8	3.2	2.7	2.3	2.0	1.7	1.5	1.2	1.2	1.0	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
74	15.5	12.0	9.3	7.3	6.0	4.8	4.0	3.3	2.8	2.3	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2
75	20.0	15.2	11.8	9.3	7.3	6.0	4.8	4.0	3.3	2.8	2.5	2.2	1.8	1.5	1.3	1.2	1.0	1.0	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2
76	25.7	19.5	15.0	11.7	9.2	7.5	6.0	5.0	4.2	3.5	3.0	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3
77	33.2	24.8	19.0	14.7	11.5	9.2	7.5	6.2	5.0	4.2	3.5	3.0	2.7	2.2	2.0	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3
78	42.8	31.8	24.0	18.5	14.5	11.5	9.3	7.5	6.2	5.2	4.3	3.7	3.2	2.7	2.3	2.0	1.8	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3
79	55.5	40.8	30.7	23.3	18.2	14.3	11.5	9.3	7.7	6.3	5.3	4.5	3.8	3.2	2.8	2.3	2.2	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.5	0.3
80	72.2	52.7	39.2	29.7	22.8	18.0	14.2	11.5	9.3	7.7	6.3	5.3	4.5	3.8	3.3	2.8	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5
81	94.0	67.8	50.0	37.7	28.8	22.5	17.7	14.2	11.5	9.3	7.8	6.5	5.5	4.7	4.0	3.3	3.0	2.5	2.3	2.0	1.8	1.5	1.3	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5
82	122.8	87.8	64.3	48.0	36.5	28.2	22.2	17.5	14.2	11.5	9.5	7.8	6.7	5.5	4.8	4.0	3.5	3.0	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7
83	160.8	114.0	82.7	61.2	46.2	35.5	27.7	21.8	17.5	14.2	11.5	9.5	8.0	6.7	5.7	4.8	4.2	3.7	3.2	2.8	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.2	1.0	1.0	0.8	0.8	0.7
84	>200	148.3	106.7	78.3	58.7	44.7	34.5	27.2	21.7	17.3	14.2	11.7	9.7	8.2	6.8	5.8	5.0	4.3	3.8	3.3	2.8	2.5	2.2	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8
85	>200	193.7	138.0	100.5	74.7	56.5	43.3	33.8	26.8	21.5	17.3	14.2	11.8	9.8	8.3	7.0	6.0	5.2	4.5	3.8	3.3	3.0	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.2	1.0	1.0
86	>200	>200	179.0	129.3	95.3	71.5	54.7	42.3	33.3	26.5	21.3	17.3	14.3	11.8	10.0	8.5	7.2	6.2	5.3	4.7	4.0	3.5	3.2	2.7	2.5	2.2	2.0	1.7	1.5	1.5	1.3	1.2	1.0
87	>200	>200	>200	167.0	122.0	91.0	69.0	53.2	41.5	32.8	26.3	21.3	17.5	14.5	12.0	10.2	8.7	7.3	6.3	5.5	4.7	4.2	3.7	3.2	2.8	2.5	2.3	2.0	1.8	1.7	1.5	1.3	1.2
88	>200	>200	>200	>200	156.8	116.0	87.3	66.8	51.8	40.8	32.5	26.2	21.3	17.5	14.7	12.2	10.3	8.8	7.5	6.5	5.7	4.8	4.3	3.8	3.3	3.0	2.7	2.3	2.2	1.8	1.7	1.5	1.5
89	>200	>200	>200	>200	>200	148.2	110.8	84.2	65.0	50.8	40.3	32.3	26.2	21.5	17.7	14.8	12.5	10.5	9.0	7.7	6.7	5.8	5.0	4.5	3.8	3.5	3.0	2.8	2.5	2.2	2.0	1.8	1.7
90	>200	>200	>200	>200	>200	190.2	141.0	106.5	81.7	63.5	50.0	39.8	32.2	26.2	21.5	17.8	15.0	12.7	10.7	9.2	7.8	6.8	6.0	5.2	4.7	4.0	3.7	3.2	2.8	2.5	2.3	2.2	1.8
91	>200	>200	>200	>200	>200	>200	180.2	135.0	102.8	79.5	62.2	49.3	39.7	32.2	26.3	21.7	18.2	15.2	12.8	11.0	9.5	8.2	7.0	6.2	5.3	4.8	4.2	3.7	3.3	3.0	2.7	2.5	2.2
92	>200	>200	>200	>200	>200	>200	>200	171.8	130.0	99.8	77.7	61.3	49.0	39.5	32.2	26.5	22.0	18.3	15.5	13.2	11.3	9.7	8.3	7.3	6.3	5.7	5.0	4.3	3.8	3.5	3.2	2.8	2.5
93	>200	>200	>200	>200	>200	>200	>200	>200	164.8	125.8	97.3	76.3	60.7	48.7	39.5	32.3	26.7	22.2	18.7	15.8	13.5	11.5	10.0	8.7	7.5	6.7	5.8	5.2	4.5	4.0	3.7	3.3	3.0
94	>200	>200	>200	>200	>200	>200	>200	>200	>200	159.0	122.3	95.3	75.3	60.2	48.5	39.5	32.5	27.0	22.5	19.0	16.2	13.8	11.8	10.2	8.8	7.8	6.8	6.0	5.3	4.7	4.2	3.8	3.3
95	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	154.2	119.5	93.8	74.5	59.8	48.5	39.7	32.8	27.3	23.0	19.3	16.5	14.2	12.2	10.5	9.2	8.0	7.0	6.3	5.5	5.0	4.3	4.0
96	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.0	150.3	117.3	92.7	74.0	59.7	48.7	40.0	33.2	27.8	23.3	19.8	17.0	14.5	12.5	10.8	9.5	8.3	7.3	6.5	5.8	5.2	4.7
97	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	189.7	147.2	115.7	91.8	73.8	59.8	49.0	40.5	33.7	28.3	23.8	20.3	17.3	15.0	13.0	11.3	9.8	8.7	7.7	6.8	6.0	5.3
98	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.3	144.8	114.5	91.5	73.8	60.2	49.5	41.0	34.3	28.8	24.5	20.8	17.8	15.5	13.3	11.7	10.2	9.0	8.0	7.0	6.3
99	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.0	143.0	113.7	91.3	74.2	60.7	50.0	41.7	35.0	29.5	25.0	21.5	18.5	16.0	13.8	12.2	10.7	9.3	8.3	7.3
100	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.5	142.0	113.5	91.7	74.7	61.3	50.8	42.5	35.7	30.2	25.8	22.0	19.0	16.5	14.3	12.5	11.0	9.7	8.7
101	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.0	141.5	113.7	92.2	75.5	62.3	51.8	43.3	36.5	31.0	26.5	22.8	19.7	17.2	14.8	13.0	11.5	10.2
102	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.2	141.7	114.3	93.2	76.5	63.3	52.8	44.3	37.5	32.0	27.3	23.5	20.3	17.7	15.5	13.7	12.0
103	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.2	142.3	115.3	94.3	77.8	64.7	54.2	45.7	38.7	33.0	28.3	24.5	21.2	18.5	16.2	14.2
104	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.0	143.7	117.0	96.0	79.5	66.2	55.7	47.0	40.0	34.2	29.3	25.3	22.0	19.3	16.8
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.7	145.5	119.0	98.0	81.3	68.0	57.3	48.5	41.3	35.5	30.5	26.5	23.0	20.2
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.0	148.2	121.5	100.5	83.7	70.2	59.2	50.3	43.0	36.8	31.8	27.7	24.2
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.3	151.3	124.5	103.3	86.3	72.5	61.3	52.3	44.7	38.5	33.3	29.0
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	189.5	155.3	128.2	106.7	89.3	75.3	63.8	54.5	46.7	40.3	34.8
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	194.7	160.0	132.7	110.7	92.8	78.5	66.7	57.0	49.0	42.3
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	165.7	137.7	115.2	97.0	82.2	70.0	59.8	51.5
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	172.5	143.7	120.5	101.7	86.2	73.5	63.2
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.3	150.7	126.5	107.0	91.0	77.8
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	189.7	158.8	133.7	113.2	96.5
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	168.3	142.0	120.5
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.5	151.7
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.7
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

Figure B-20 Tabular Representation of Parking Nomograph for C-17 on 8 °F (-13 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

Gross C-17 Weight (lb)

8 F — Sea Ice Thickness (inches)	280,000	290,000	300,000	310,000	320,000	330,000	340,000	350,000	360,000	370,000	380,000
50	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0
55	0.2	0.2	0	0	0	0	0	0	0	0	0
56	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0
57	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0
58	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0
59	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0	0
60	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
61	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
62	0.8	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2
63	1.0	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.2	0.2
64	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3
65	1.7	1.3	1.0	0.8	0.8	0.7	0.5	0.5	0.5	0.3	0.3
66	2.0	1.7	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3
67	2.5	2.0	1.7	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5
68	3.2	2.7	2.2	1.8	1.5	1.2	1.0	0.8	0.8	0.7	0.5
69	4.2	3.3	2.7	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.7
70	5.2	4.2	3.3	2.7	2.2	1.8	1.5	1.3	1.2	1.0	0.8
71	6.7	5.2	4.2	3.3	2.8	2.3	2.0	1.7	1.3	1.2	1.0
72	8.3	6.5	5.2	4.2	3.5	2.8	2.3	2.0	1.7	1.5	1.2
73	10.7	8.3	6.5	5.2	4.3	3.5	2.8	2.5	2.0	1.8	1.5
74	13.7	10.5	8.2	6.5	5.3	4.3	3.5	3.0	2.5	2.2	1.8
75	17.3	13.3	10.3	8.2	6.5	5.3	4.3	3.7	3.0	2.5	2.2
76	22.3	16.8	13.0	10.2	8.2	6.5	5.3	4.5	3.7	3.2	2.7
77	28.7	21.5	16.5	12.8	10.2	8.2	6.7	5.5	4.5	3.8	3.2
78	36.8	27.5	20.8	16.2	12.7	10.2	8.2	6.7	5.5	4.7	3.8
79	47.5	35.2	26.5	20.3	15.8	12.5	10.0	8.2	6.7	5.5	4.7
80	61.5	45.0	33.7	25.7	19.8	15.7	12.5	10.0	8.2	6.8	5.7
81	79.8	57.8	43.0	32.5	25.0	19.5	15.5	12.3	10.2	8.3	6.8
82	103.7	74.7	54.8	41.2	31.5	24.3	19.2	15.3	12.3	10.2	8.3
83	135.2	96.3	70.3	52.3	39.7	30.5	23.8	19.0	15.2	12.3	10.2
84	176.8	124.8	90.3	66.7	50.2	38.3	29.8	23.5	18.8	15.2	12.5
85	>200	162.3	116.3	85.2	63.7	48.3	37.3	29.2	23.2	18.7	15.2
86	>200	>200	150.3	109.2	80.8	61.0	46.8	36.5	28.8	23.0	18.7
87	>200	>200	194.7	140.3	103.2	77.2	58.8	45.5	35.7	28.3	22.8
88	>200	>200	>200	180.8	131.8	98.0	74.2	57.0	44.5	35.2	28.2
89	>200	>200	>200	>200	169.2	124.8	93.8	71.7	55.5	43.7	34.7
90	>200	>200	>200	>200	>200	159.5	118.8	90.2	69.5	54.2	42.8
91	>200	>200	>200	>200	>200	>200	151.2	113.8	87.2	67.7	53.2
92	>200	>200	>200	>200	>200	>200	193.0	144.3	109.7	84.7	66.2
93	>200	>200	>200	>200	>200	>200	>200	183.5	138.7	106.3	82.7
94	>200	>200	>200	>200	>200	>200	>200	>200	175.7	133.8	103.3
95	>200	>200	>200	>200	>200	>200	>200	>200	>200	169.0	129.8
96	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	163.5
97	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
98	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
99	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
100	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
101	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
102	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
103	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
104	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

8 F — Sea Ice Thickness (inches)	390,000	400,000	410,000	420,000	430,000	440,000	450,000	460,000	470,000	480,000	490,000
50	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	0	0	0
56	0	0	0	0	0	0	0	0	0	0	0
57	0	0	0	0	0	0	0	0	0	0	0
58	0	0	0	0	0	0	0	0	0	0	0
59	0	0	0	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0	0	0	0
61	0.2	0.2	0	0	0	0	0	0	0	0	0
62	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0
63	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0
64	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0
65	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0
66	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
67	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
68	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
69	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2
70	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2
71	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3
72	1.0	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3
73	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3
74	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5
75	1.8	1.7	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.5
76	2.3	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7
77	2.7	2.3	2.0	1.8	1.5	1.3	1.2	1.0	1.0	0.8	0.8
78	3.3	2.8	2.3	2.2	1.8	1.7	1.3	1.2	1.2	1.0	0.8
79	4.0	3.3	2.8	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0
80	4.8	4.0	3.5	3.0	2.5	2.2	2.0	1.7	1.5	1.3	1.2
81	5.8	4.8	4.2	3.5	3.0	2.7	2.3	2.0	1.8	1.7	1.5
82	7.0	5.8	5.0	4.2	3.7	3.2	2.7	2.3	2.2	1.8	1.7
83	8.5	7.0	6.0	5.0	4.3	3.7	3.3	2.8	2.5	2.2	2.0
84	10.3	8.5	7.2	6.2	5.2	4.5	3.8	3.3	3.0	2.5	2.3
85	12.5	10.3	8.7	7.3	6.2	5.3	4.7	4.0	3.5	3.0	2.7
86	15.2	12.5	10.5	8.8	7.5	6.3	5.5	4.7	4.2	3.5	3.2
87	18.5	15.3	12.7	10.7	9.0	7.7	6.5	5.7	4.8	4.2	3.7
88	22.7	18.7	15.3	12.8	10.7	9.2	7.8	6.7	5.7	5.0	4.3
89	28.0	22.7	18.7	15.5	13.0	10.8	9.3	8.0	6.8	5.8	5.2
90	34.3	27.8	22.7	18.8	15.7	13.2	11.2	9.5	8.2	7.0	6.0
91	42.3	34.2	27.8	22.8	19.0	15.8	13.3	11.3	9.7	8.3	7.2
92	52.5	42.0	34.0	27.8	23.0	19.2	16.0	13.5	11.5	9.8	8.5
93	65.0	51.8	41.8	34.0	28.0	23.2	19.3	16.3	13.8	11.8	10.2
94	81.0	64.2	51.5	41.7	34.0	28.2	23.3	19.7	16.7	14.2	12.2
95	101.0	79.7	63.5	51.2	41.7	34.2	28.3	23.7	20.0	17.0	14.5
96	126.5	99.2	78.7	63.2	51.2	41.8	34.5	28.7	24.0	20.3	17.3
97	159.2	124.0	97.8	78.0	63.0	51.2	42.2	34.8	29.2	24.5	20.8
98	>200	155.5	122.0	96.8	77.7	63.0	51.5	42.5	35.3	29.7	25.0
99	>200	195.8	152.8	120.7	96.3	77.7	63.2	51.8	43.0	35.8	30.2
100	>200	>200	192.0	150.8	119.8	96.2	77.8	63.7	52.5	43.7	36.5
101	>200	>200	>200	189.3	149.5	119.3	96.3	78.3	64.3	53.3	44.5
102	>200	>200	>200	>200	187.5	148.8	119.5	96.8	79.2	65.2	54.2
103	>200	>200	>200	>200	>200	186.5	148.8	120.0	97.7	80.2	66.3
104	>200	>200	>200	>200	>200	>200	186.3	149.5	121.2	99.0	81.5
105	>200	>200	>200	>200	>200	>200	>200	187.2	150.8	122.7	100.7
106	>200	>200	>200	>200	>200	>200	>200	>200	188.8	152.8	124.8
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.3	155.7
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.0
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

8 F — Sea Ice Thickness (inches)	500,000	510,000	520,000	530,000	540,000	550,000	560,000	570,000	580,000	590,000	600,000
50	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	0	0	0
56	0	0	0	0	0	0	0	0	0	0	0
57	0	0	0	0	0	0	0	0	0	0	0
58	0	0	0	0	0	0	0	0	0	0	0
59	0	0	0	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0	0	0	0
61	0	0	0	0	0	0	0	0	0	0	0
62	0	0	0	0	0	0	0	0	0	0	0
63	0	0	0	0	0	0	0	0	0	0	0
64	0	0	0	0	0	0	0	0	0	0	0
65	0	0	0	0	0	0	0	0	0	0	0
66	0.2	0	0	0	0	0	0	0	0	0	0
67	0.2	0.2	0.2	0	0	0	0	0	0	0	0
68	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0
69	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0
70	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0
71	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
72	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
73	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
74	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
75	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2
76	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2
77	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3
78	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3
79	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3
80	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.5
81	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5
82	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7	0.5
83	1.7	1.5	1.3	1.2	1.2	1.0	1.0	0.8	0.8	0.7	0.7
84	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7
85	2.3	2.2	1.8	1.7	1.5	1.3	1.2	1.2	1.0	1.0	0.8
86	2.8	2.5	2.2	2.0	1.8	1.5	1.5	1.3	1.2	1.0	1.0
87	3.3	2.8	2.5	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.2
88	3.8	3.3	3.0	2.7	2.3	2.2	2.0	1.7	1.5	1.5	1.3
89	4.5	4.0	3.5	3.2	2.8	2.5	2.2	2.0	1.8	1.7	1.5
90	5.3	4.7	4.2	3.7	3.2	2.8	2.5	2.3	2.2	1.8	1.7
91	6.3	5.5	4.8	4.2	3.8	3.3	3.0	2.7	2.5	2.2	2.0
92	7.3	6.5	5.7	5.0	4.3	3.8	3.5	3.2	2.8	2.5	2.3
93	8.8	7.7	6.7	5.8	5.2	4.5	4.0	3.7	3.3	3.0	2.7
94	10.5	9.0	7.8	6.8	6.0	5.3	4.7	4.2	3.8	3.3	3.0
95	12.3	10.7	9.3	8.2	7.2	6.3	5.5	5.0	4.3	4.0	3.5
96	14.8	12.7	11.0	9.7	8.3	7.3	6.5	5.8	5.2	4.7	4.2
97	17.7	15.2	13.2	11.3	10.0	8.7	7.7	6.8	6.0	5.3	4.8
98	21.2	18.2	15.7	13.5	11.7	10.3	9.0	8.0	7.0	6.3	5.5
99	25.5	21.8	18.7	16.2	14.0	12.2	10.7	9.3	8.3	7.3	6.5
100	30.8	26.2	22.3	19.2	16.7	14.5	12.7	11.0	9.7	8.7	7.7
101	37.3	31.5	26.8	23.0	19.8	17.2	15.0	13.0	11.5	10.2	9.0
102	45.3	38.2	32.3	27.7	23.8	20.5	17.8	15.5	13.7	12.0	10.5
103	55.3	46.5	39.2	33.3	28.5	24.5	21.2	18.5	16.2	14.2	12.5
104	67.7	56.7	47.7	40.3	34.5	29.5	25.5	22.0	19.2	16.8	14.8
105	83.2	69.3	58.2	49.2	41.7	35.7	30.7	26.5	23.0	20.0	17.5
106	102.8	85.3	71.2	59.8	50.7	43.2	37.0	31.8	27.5	24.0	21.0
107	127.5	105.3	87.7	73.5	62.0	52.5	44.8	38.5	33.2	28.8	25.0
108	159.0	130.8	108.3	90.5	76.0	64.3	54.7	46.7	40.2	34.7	30.2
109	199.5	163.3	134.8	112.0	93.7	79.0	66.8	57.0	48.8	42.2	36.5
110	>200	>200	168.5	139.5	116.3	97.5	82.3	70.0	59.7	51.3	44.2
111	>200	>200	>200	174.8	145.0	121.2	102.0	86.2	73.3	62.8	54.0
112	>200	>200	>200	>200	182.2	151.7	127.0	107.0	90.7	77.3	66.3
113	>200	>200	>200	>200	>200	191.0	159.3	133.7	113.0	96.0	82.0
114	>200	>200	>200	>200	>200	>200	>200	168.3	141.7	119.8	102.0
115	>200	>200	>200	>200	>200	>200	>200	>200	179.0	150.8	127.8
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.7	161.8
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

Figure B-21 Tabular Representation of Parking Nomograph for C-17 on 10 °F (-12 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

Gross C-17 Weight (lb); rows: Sea Ice Thickness (inches)

10 F	280,000	290,000	300,000	310,000	320,000	330,000	340,000	350,000	360,000	370,000	380,000	390,000	400,000	410,000	420,000	430,000	440,000	450,000	460,000	470,000	480,000	490,000	500,000	510,000	520,000	530,000	540,000	550,000	560,000	570,000	580,000	590,000	600,000
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	1.2	1.0	0.8	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
65	1.5	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
66	1.8	1.5	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0
67	2.3	1.8	1.5	1.3	1.0	0.8	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0
68	2.8	2.3	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0
69	3.7	3.0	2.3	2.0	1.7	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0
70	4.7	3.7	3.0	2.5	2.0	1.7	1.5	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0
71	5.8	4.7	3.7	3.0	2.5	2.0	1.7	1.5	1.3	1.0	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
72	7.3	5.8	4.7	3.7	3.0	2.5	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
73	9.3	7.3	5.8	4.7	3.8	3.2	2.7	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
74	11.8	9.2	7.2	5.8	4.7	3.8	3.2	2.7	2.2	1.8	1.7	1.3	1.2	1.0	1.0	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
75	15.2	11.7	9.2	7.2	5.8	4.7	3.8	3.2	2.7	2.3	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2
76	19.3	14.7	11.5	9.0	7.2	5.8	4.8	4.0	3.3	2.8	2.3	2.0	1.8	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2
77	24.7	18.7	14.3	11.2	9.0	7.2	5.8	4.8	4.0	3.3	2.8	2.5	2.2	1.8	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2
78	31.7	23.7	18.2	14.0	11.2	8.8	7.2	5.8	4.8	4.2	3.5	3.0	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3
79	40.7	30.2	22.8	17.7	13.8	11.0	8.8	7.2	6.0	5.0	4.2	3.5	3.0	2.7	2.2	2.0	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3
80	52.3	38.7	29.0	22.2	17.3	13.7	11.0	8.8	7.3	6.0	5.0	4.2	3.7	3.2	2.7	2.3	2.0	1.8	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.5	0.3
81	67.7	49.3	36.8	28.0	21.7	17.0	13.5	10.8	8.8	7.3	6.0	5.2	4.3	3.7	3.2	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5
82	87.5	63.3	46.8	35.3	27.2	21.2	16.7	13.3	10.8	8.8	7.3	6.2	5.2	4.3	3.8	3.3	2.8	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5
83	113.7	81.5	59.8	44.7	34.0	26.3	20.7	16.5	13.3	10.8	9.0	7.5	6.3	5.3	4.5	3.8	3.3	2.8	2.5	2.2	2.0	1.8	1.5	1.3	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7
84	147.8	105.2	76.5	56.7	42.8	33.0	25.8	20.3	16.3	13.3	10.8	9.0	7.5	6.3	5.3	4.7	4.0	3.5	3.0	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7
85	193.0	136.0	98.0	72.2	54.2	41.3	32.2	25.3	20.2	16.2	13.3	11.0	9.2	7.7	6.5	5.5	4.7	4.0	3.5	3.2	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.2	1.2	1.0	1.0	0.8	0.8
86	>200	176.5	126.2	92.2	68.7	52.0	40.2	31.3	24.8	20.0	16.2	13.3	11.0	9.2	7.7	6.5	5.7	4.8	4.2	3.7	3.2	2.8	2.5	2.2	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8
87	>200	>200	162.7	117.8	87.2	65.7	50.2	39.0	30.7	24.5	19.8	16.2	13.3	11.2	9.3	7.8	6.7	5.8	5.0	4.3	3.8	3.3	2.8	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.2	1.0
88	>200	>200	>200	151.3	111.0	83.0	63.0	48.7	38.2	30.3	24.3	19.7	16.2	13.3	11.2	9.5	8.0	6.8	5.8	5.2	4.5	3.8	3.5	3.0	2.7	2.3	2.2	2.0	1.7	1.5	1.3	1.3	1.2
89	>200	>200	>200	194.7	141.7	105.2	79.3	60.8	47.3	37.3	29.8	24.2	19.7	16.2	13.5	11.3	9.7	8.2	7.0	6.0	5.2	4.5	4.0	3.5	3.2	2.8	2.5	2.2	2.0	1.8	1.7	1.5	1.3
90	>200	>200	>200	>200	181.5	133.7	100.2	76.3	59.2	46.3	36.8	29.7	24.0	19.7	16.3	13.7	11.5	9.8	8.3	7.2	6.2	5.3	4.7	4.2	3.7	3.2	2.8	2.5	2.3	2.2	1.8	1.7	1.5
91	>200	>200	>200	>200	>200	170.5	127.0	96.2	73.8	57.7	45.5	36.3	29.3	24.0	19.8	16.5	13.8	11.7	10.0	8.5	7.3	6.3	5.5	4.8	4.3	3.8	3.3	3.0	2.7	2.3	2.2	2.0	1.8
92	>200	>200	>200	>200	>200	>200	161.3	121.3	92.7	71.8	56.3	44.8	36.0	29.3	24.0	20.0	16.7	14.0	11.8	10.2	8.7	7.5	6.5	5.7	5.0	4.5	4.0	3.5	3.2	2.8	2.5	2.3	2.0
93	>200	>200	>200	>200	>200	>200	>200	153.5	116.5	89.8	70.2	55.5	44.3	35.8	29.3	24.2	20.2	16.8	14.2	12.2	10.3	9.0	7.7	6.7	5.8	5.2	4.7	4.0	3.7	3.2	2.8	2.7	2.3
94	>200	>200	>200	>200	>200	>200	>200	195.2	147.0	112.5	87.3	68.7	54.7	44.0	35.8	29.3	24.3	20.3	17.0	14.5	12.3	10.7	9.2	8.0	7.0	6.2	5.3	4.8	4.2	3.8	3.3	3.0	2.7
95	>200	>200	>200	>200	>200	>200	>200	>200	186.2	141.7	109.3	85.5	67.7	54.2	43.8	35.8	29.5	24.5	20.5	17.3	14.8	12.7	10.8	9.3	8.2	7.2	6.3	5.5	5.0	4.3	4.0	3.5	3.2
96	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.8	137.2	106.7	84.0	66.8	53.8	43.8	35.8	29.7	24.8	20.8	17.7	15.0	13.0	11.2	9.7	8.5	7.3	6.5	5.8	5.2	4.5	4.2	3.7
97	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	172.8	133.5	104.5	82.8	66.3	53.7	43.8	36.2	30.0	25.2	21.2	18.0	15.5	13.3	11.5	10.0	8.7	7.7	6.8	6.0	5.3	4.8	4.3
98	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	167.8	130.5	102.8	82.0	66.0	53.7	44.0	36.5	30.5	25.5	21.7	18.5	15.8	13.7	11.8	10.3	9.0	8.0	7.0	6.2	5.5	5.0
99	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	163.8	128.3	101.7	81.5	66.0	53.8	44.5	36.8	30.8	26.0	22.2	18.8	16.2	14.0	12.2	10.7	9.3	8.2	7.3	6.5	5.8
100	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	160.7	126.7	101.0	81.3	66.2	54.3	45.0	37.5	31.5	26.7	22.7	19.3	16.7	14.5	12.7	11.0	9.7	8.5	7.7	6.8
101	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	158.3	125.7	100.7	81.5	66.5	54.8	45.5	38.2	32.2	27.3	23.3	20.0	17.2	15.0	13.0	11.5	10.0	8.8	7.8
102	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.8	156.8	125.2	100.8	82.0	67.2	55.7	46.3	38.8	32.8	28.0	24.0	20.7	17.8	15.5	13.5	11.8	10.5	9.3
103	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	196.7	156.2	125.2	101.3	82.7	68.2	56.5	47.3	39.8	33.7	28.8	24.7	21.3	18.5	16.2	14.0	12.3	11.0
104	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.7	156.0	125.7	102.2	83.8	69.3	57.7	48.3	40.8	34.7	29.7	25.5	22.0	19.2	16.7	14.7	12.8
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.5	156.7	126.8	103.5	85.2	70.7	59.0	49.7	42.0	35.8	30.7	26.5	22.8	20.0	17.5	15.3
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	196.3	158.0	128.5	105.3	87.0	72.3	60.7	51.2	43.5	37.0	31.8	27.5	23.8	20.8	18.2
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.0	160.2	130.7	107.5	89.0	74.3	62.5	52.8	45.0	38.5	33.2	28.7	24.8	21.7
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	163.0	133.5	110.2	91.7	76.7	64.7	54.8	46.7	40.2	34.5	30.0	26.0
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	166.8	137.0	113.5	94.7	79.5	67.2	57.0	48.7	41.8	36.2	31.3
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	171.5	141.3	117.3	98.2	82.7	70.0	59.5	51.0	43.8	38.0
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.2	146.5	122.0	102.3	86.3	73.2	62.5	53.7	46.2
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	184.0	152.7	127.3	107.0	90.5	77.0	65.8	56.5
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.2	159.8	133.8	112.7	95.3	81.3	69.7
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	168.3	141.2	119.2	101.2	86.3
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.5	150.0	126.8	107.8
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	190.5	160.5	135.8
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	172.8
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

Figure B-22 Tabular Representation of Parking Nomograph for C-17 on 12 °F (-11 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

12 F	Gross C-17 Weight (lb)																															
Sea Ice Thickness (inches)	280,000	290,000	300,000	310,000	320,000	330,000	340,000	350,000	360,000	370,000	380,000	390,000	400,000	410,000	420,000	430,000	440,000	450,000	460,000	470,000	480,000	490,000	500,000	510,000	520,000	530,000	540,000	550,000	560,000	570,000	580,000	590,000	600,000
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
65	1.3	1.2	1.0	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
66	1.7	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0
67	2.2	1.8	1.5	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0
68	2.7	2.2	1.8	1.5	1.3	1.0	0.8	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0
69	3.5	2.8	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0
70	4.3	3.5	2.8	2.3	1.8	1.7	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0
71	5.5	4.3	3.5	2.8	2.3	2.0	1.7	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0
72	7.0	5.5	4.3	3.5	2.8	2.3	2.0	1.7	1.5	1.2	1.0	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
73	8.8	6.8	5.5	4.3	3.5	3.0	2.5	2.0	1.8	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
74	11.2	8.7	6.8	5.5	4.3	3.7	3.0	2.5	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
75	14.2	10.8	8.5	6.8	5.5	4.5	3.7	3.0	2.5	2.2	1.8	1.7	1.3	1.2	1.0	1.0	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
76	18.0	13.7	10.7	8.5	6.8	5.5	4.5	3.7	3.2	2.7	2.2	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2
77	23.0	17.3	13.5	10.5	8.3	6.7	5.5	4.5	3.8	3.2	2.7	2.3	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2
78	29.3	22.0	16.8	13.2	10.3	8.3	6.8	5.5	4.7	3.8	3.3	2.8	2.3	2.0	1.8	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3
79	37.7	28.0	21.3	16.5	13.0	10.3	8.3	6.8	5.7	4.7	4.0	3.3	2.8	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3
80	48.5	35.8	27.0	20.7	16.2	12.8	10.2	8.3	6.8	5.7	4.7	4.0	3.3	3.0	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3
81	62.3	45.7	34.2	26.0	20.2	15.8	12.7	10.2	8.3	6.8	5.7	4.8	4.0	3.5	3.0	2.7	2.3	2.0	1.7	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.5
82	80.5	58.5	43.3	32.8	25.2	19.7	15.7	12.5	10.2	8.3	7.0	5.8	4.8	4.2	3.5	3.0	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5
83	104.3	75.0	55.2	41.3	31.7	24.5	19.3	15.3	12.5	10.2	8.3	7.0	5.8	5.0	4.3	3.7	3.2	2.8	2.3	2.2	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7	0.5
84	135.5	96.7	70.5	52.5	39.7	30.7	24.0	19.0	15.3	12.3	10.2	8.5	7.0	6.0	5.0	4.3	3.8	3.3	2.8	2.5	2.2	2.0	1.7	1.5	1.3	1.2	1.2	1.0	1.0	0.8	0.8	0.7	0.7
85	176.5	124.7	90.2	66.5	50.2	38.3	29.8	23.5	18.8	15.2	12.3	10.2	8.5	7.2	6.0	5.2	4.5	3.8	3.3	3.0	2.5	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7
86	>200	161.5	115.7	84.8	63.3	48.2	37.2	29.2	23.2	18.7	15.2	12.5	10.3	8.7	7.3	6.2	5.3	4.5	4.0	3.5	3.0	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.2	1.2	1.0	1.0	0.8
87	>200	>200	149.0	108.3	80.2	60.5	46.5	36.2	28.5	22.8	18.5	15.2	12.5	10.3	8.7	7.3	6.3	5.5	4.7	4.0	3.5	3.2	2.8	2.5	2.2	2.0	1.7	1.5	1.5	1.3	1.2	1.0	1.0
88	>200	>200	192.5	138.7	102.0	76.3	58.2	45.0	35.3	28.2	22.7	18.3	15.2	12.5	10.5	8.8	7.5	6.5	5.5	4.8	4.2	3.7	3.2	2.8	2.5	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.2
89	>200	>200	>200	178.2	130.0	96.7	73.2	56.3	43.8	34.7	27.8	22.5	18.3	15.2	12.7	10.7	9.0	7.7	6.7	5.7	5.0	4.3	3.8	3.3	3.0	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.3
90	>200	>200	>200	>200	166.2	122.7	92.2	70.5	54.7	43.0	34.2	27.5	22.3	18.3	15.3	12.8	10.8	9.2	7.8	6.7	5.8	5.0	4.5	3.8	3.5	3.0	2.7	2.5	2.2	2.0	1.8	1.7	1.5
91	>200	>200	>200	>200	>200	156.2	116.7	88.5	68.2	53.3	42.2	33.8	27.3	22.3	18.5	15.3	13.0	11.0	9.3	8.0	6.8	6.0	5.2	4.7	4.0	3.7	3.2	2.8	2.5	2.3	2.0	1.8	1.7
92	>200	>200	>200	>200	>200	199.5	147.8	111.5	85.3	66.3	52.2	41.5	33.5	27.3	22.3	18.7	15.5	13.2	11.2	9.5	8.2	7.2	6.2	5.3	4.7	4.2	3.7	3.3	3.0	2.7	2.3	2.2	2.0
93	>200	>200	>200	>200	>200	>200	188.2	140.8	107.2	82.7	64.7	51.3	41.2	33.3	27.3	22.5	18.7	15.7	13.3	11.3	9.7	8.3	7.3	6.3	5.5	4.8	4.3	3.8	3.5	3.0	2.8	2.5	2.3
94	>200	>200	>200	>200	>200	>200	>200	178.7	135.0	103.5	80.5	63.5	50.7	40.8	33.2	27.3	22.7	19.0	16.0	13.5	11.5	10.0	8.7	7.5	6.5	5.7	5.0	4.5	4.0	3.5	3.2	2.8	2.7
95	>200	>200	>200	>200	>200	>200	>200	>200	170.5	130.0	100.5	78.8	62.5	50.2	40.7	33.2	27.5	22.8	19.2	16.2	13.8	11.8	10.2	8.8	7.7	6.7	6.0	5.3	4.7	4.2	3.7	3.3	3.0
96	>200	>200	>200	>200	>200	>200	>200	>200	>200	163.8	126.0	98.2	77.5	61.8	49.8	40.7	33.3	27.7	23.2	19.5	16.5	14.2	12.2	10.5	9.2	8.0	7.0	6.2	5.5	4.8	4.3	3.8	3.5
97	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	158.3	122.7	96.2	76.3	61.3	49.7	40.7	33.5	28.0	23.5	19.8	16.8	14.5	12.5	10.8	9.3	8.2	7.2	6.3	5.7	5.0	4.5	4.0
98	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	199.8	153.8	120.0	94.7	75.7	61.0	49.7	40.8	33.8	28.3	23.8	20.2	17.2	14.8	12.8	11.2	9.7	8.5	7.5	6.7	5.8	5.2	4.7
99	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.7	150.2	118.0	93.7	75.2	61.0	50.0	41.2	34.3	28.8	24.3	20.7	17.7	15.2	13.2	11.5	10.0	8.8	7.8	6.8	6.2	5.5
100	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.8	147.3	116.5	93.0	75.2	61.2	50.3	41.7	34.8	29.3	24.8	21.2	18.2	15.7	13.5	11.8	10.3	9.2	8.0	7.2	6.3
101	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.0	145.3	115.5	92.8	75.2	61.5	50.8	42.3	35.3	29.8	25.3	21.7	18.7	16.2	14.0	12.2	10.7	9.5	8.3	7.5
102	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.2	144.0	115.0	92.8	75.7	62.2	51.5	43.0	36.2	30.7	26.0	22.3	19.2	16.7	14.5	12.7	11.2	9.8	8.7
103	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.3	143.3	115.2	93.3	76.3	63.0	52.3	43.8	37.0	31.3	26.8	23.0	19.8	17.3	15.0	13.2	11.7	10.3
104	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.3	143.3	115.7	94.2	77.3	64.0	53.3	44.8	38.0	32.3	27.7	23.8	20.7	17.8	15.7	13.7	12.2
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.2	143.8	116.7	95.3	78.7	65.3	54.7	46.0	39.0	33.3	28.7	24.7	21.3	18.7	16.3	14.3
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.8	145.2	118.2	97.0	80.2	66.8	56.2	47.5	40.3	34.5	29.7	25.7	22.3	19.5	17.0
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.5	147.2	120.2	99.0	82.2	68.7	57.8	49.0	41.7	35.8	30.8	26.7	23.2	20.3
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	184.0	149.7	122.8	101.5	84.5	70.8	59.8	50.8	43.3	37.2	32.2	27.8	24.3
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	187.5	153.2	126.0	104.5	87.3	73.3	62.0	52.8	45.2	38.8	33.7	29.2
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.2	157.3	130.0	108.2	90.5	76.3	64.7	55.2	47.3	40.8	35.3
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.8	162.7	134.7	112.3	94.3	79.7	67.7	57.8	49.7	42.8
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	168.8	140.2	117.3	98.7	83.5	71.2	60.8	52.3
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	176.3	146.8	123.0	103.8	88.0	75.2	64.3
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.3	154.7	129.8	109.8	93.3	79.7
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.8	163.8	138.0	116.8	99.3
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	174.8	147.5	125.0
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.0	158.8
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

Figure B-23 Tabular Representation of Parking Nomograph for C-17 on 14 °F (-10 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

14 F	Gross C-17 Weight (lb)																																
Sea Ice Thickness (inches)	280,000	290,000	300,000	310,000	320,000	330,000	340,000	350,000	360,000	370,000	380,000	390,000	400,000	410,000	420,000	430,000	440,000	450,000	460,000	470,000	480,000	490,000	500,000	510,000	520,000	530,000	540,000	550,000	560,000	570,000	580,000	590,000	600,000
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	0.8	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
65	1.3	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
66	1.7	1.3	1.2	1.0	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0
67	2.0	1.7	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0
68	2.5	2.0	1.7	1.5	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0
69	3.2	2.7	2.2	1.8	1.5	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0
70	4.0	3.3	2.7	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0
71	5.2	4.2	3.3	2.7	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0
72	6.5	5.2	4.2	3.3	2.7	2.3	1.8	1.7	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
73	8.2	6.5	5.2	4.2	3.3	2.8	2.3	2.0	1.7	1.5	1.2	1.0	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
74	10.3	8.0	6.3	5.2	4.2	3.3	2.8	2.3	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
75	13.2	10.2	8.0	6.3	5.2	4.2	3.5	2.8	2.5	2.0	1.8	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
76	16.8	12.8	10.0	7.8	6.3	5.2	4.2	3.5	3.0	2.5	2.2	1.8	1.5	1.3	1.2	1.0	1.0	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2
77	21.3	16.2	12.5	9.8	7.8	6.3	5.2	4.3	3.5	3.0	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2
78	27.3	20.5	15.7	12.3	9.7	7.8	6.3	5.2	4.3	3.7	3.0	2.7	2.3	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3
79	34.8	26.0	19.8	15.3	12.0	9.7	7.8	6.3	5.3	4.3	3.7	3.2	2.7	2.3	2.0	1.8	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3
80	44.7	33.2	25.0	19.2	15.0	12.0	9.5	7.8	6.3	5.3	4.5	3.8	3.2	2.8	2.3	2.0	1.8	1.7	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3
81	57.5	42.2	31.7	24.2	18.7	14.8	11.8	9.5	7.8	6.5	5.3	4.5	3.8	3.3	2.8	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3
82	74.2	54.0	40.2	30.3	23.3	18.3	14.5	11.7	9.5	7.8	6.5	5.5	4.7	4.0	3.3	2.8	2.5	2.2	2.0	1.7	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5
83	95.8	69.2	51.0	38.3	29.3	22.8	18.0	14.3	11.7	9.5	7.8	6.5	5.5	4.7	4.0	3.5	3.0	2.7	2.3	2.0	1.8	1.5	1.3	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7	0.5
84	124.2	88.8	65.0	48.5	36.8	28.5	22.3	17.7	14.3	11.7	9.5	8.0	6.7	5.7	4.8	4.2	3.5	3.0	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7
85	161.3	114.3	83.0	61.3	46.3	35.5	27.7	21.8	17.5	14.2	11.7	9.7	8.0	6.7	5.7	4.8	4.2	3.7	3.2	2.8	2.5	2.2	2.0	1.7	1.5	1.3	1.2	1.2	1.0	1.0	0.8	0.8	0.7
86	>200	147.7	106.2	78.0	58.3	44.5	34.5	27.0	21.5	17.3	14.2	11.7	9.7	8.2	6.8	5.8	5.0	4.3	3.7	3.3	2.8	2.5	2.2	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8
87	>200	191.5	136.5	99.5	73.8	55.8	43.0	33.5	26.5	21.3	17.2	14.2	11.7	9.7	8.2	7.0	6.0	5.2	4.5	3.8	3.3	3.0	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.2	1.0	1.0
88	>200	>200	175.8	127.2	93.7	70.3	53.8	41.7	32.8	26.2	21.0	17.2	14.2	11.7	9.8	8.3	7.0	6.0	5.2	4.5	4.0	3.5	3.0	2.7	2.3	2.2	2.0	1.7	1.5	1.3	1.3	1.2	1.0
89	>200	>200	>200	163.0	119.2	89.0	67.5	52.0	40.7	32.2	25.8	21.0	17.2	14.2	11.8	10.0	8.5	7.2	6.2	5.3	4.7	4.0	3.5	3.2	2.8	2.5	2.2	2.0	1.8	1.7	1.5	1.3	1.2
90	>200	>200	>200	>200	152.2	112.7	84.8	65.0	50.5	39.8	31.7	25.7	20.8	17.2	14.3	12.0	10.2	8.7	7.3	6.3	5.5	4.8	4.2	3.7	3.3	2.8	2.7	2.3	2.2	1.8	1.7	1.5	1.3
91	>200	>200	>200	>200	194.8	143.2	107.2	81.5	62.8	49.3	39.0	31.3	25.5	20.8	17.2	14.3	12.2	10.3	8.8	7.5	6.5	5.7	5.0	4.3	3.8	3.3	3.0	2.7	2.3	2.2	2.0	1.8	1.7
92	>200	>200	>200	>200	>200	182.5	135.5	102.5	78.7	61.2	48.2	38.5	31.2	25.3	20.8	17.3	14.5	12.3	10.5	9.0	7.7	6.7	5.8	5.2	4.5	4.0	3.5	3.2	2.8	2.5	2.3	2.0	1.8
93	>200	>200	>200	>200	>200	>200	172.2	129.2	98.5	76.2	59.8	47.5	38.2	31.0	25.3	21.0	17.5	14.7	12.5	10.7	9.2	7.8	6.8	6.0	5.2	4.7	4.2	3.7	3.2	2.8	2.7	2.3	2.2
94	>200	>200	>200	>200	>200	>200	>200	163.5	123.8	95.2	74.2	58.7	46.8	37.8	30.8	25.3	21.2	17.7	15.0	12.7	10.8	9.3	8.2	7.0	6.2	5.3	4.8	4.2	3.8	3.3	3.0	2.7	2.5
95	>200	>200	>200	>200	>200	>200	>200	>200	156.2	119.3	92.5	72.7	57.7	46.3	37.7	30.8	25.5	21.3	17.8	15.2	13.0	11.2	9.5	8.3	7.2	6.3	5.7	5.0	4.3	4.0	3.5	3.2	2.8
96	>200	>200	>200	>200	>200	>200	>200	>200	197.8	150.2	115.7	90.3	71.3	57.2	46.2	37.7	31.0	25.7	21.5	18.2	15.5	13.2	11.3	9.8	8.5	7.5	6.5	5.8	5.2	4.5	4.0	3.7	3.3
97	>200	>200	>200	>200	>200	>200	>200	>200	>200	189.5	145.2	112.7	88.7	70.5	56.7	46.0	37.7	31.2	26.0	21.8	18.5	15.8	13.5	11.7	10.2	8.8	7.7	6.8	6.0	5.3	4.7	4.2	3.8
98	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.8	141.0	110.3	87.3	69.8	56.5	46.0	37.8	31.5	26.3	22.2	18.8	16.2	13.8	12.0	10.3	9.2	8.0	7.0	6.2	5.5	5.0	4.5
99	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.3	137.8	108.5	86.3	69.5	56.3	46.2	38.2	31.8	26.8	22.7	19.3	16.5	14.2	12.3	10.7	9.3	8.3	7.3	6.5	5.8	5.2
100	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	172.8	135.3	107.2	85.7	69.3	56.5	46.5	38.7	32.3	27.2	23.2	19.7	17.0	14.7	12.7	11.2	9.7	8.5	7.5	6.7	6.0
101	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	169.3	133.3	106.2	85.5	69.5	56.8	47.0	39.2	32.8	27.8	23.7	20.2	17.5	15.2	13.2	11.5	10.0	8.8	7.8	7.0
102	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	166.8	132.2	105.8	85.5	69.8	57.5	47.7	39.8	33.5	28.5	24.3	20.8	18.0	15.7	13.7	11.8	10.5	9.2	8.2
103	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	165.2	131.5	105.8	86.0	70.5	58.2	48.5	40.7	34.3	29.2	25.0	21.5	18.5	16.2	14.2	12.3	10.8	9.7
104	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	164.3	131.5	106.3	86.8	71.3	59.2	49.5	41.7	35.2	30.0	25.7	22.2	19.2	16.7	14.7	12.8	11.3
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	164.2	132.2	107.3	87.8	72.5	60.3	50.7	42.7	36.3	31.0	26.7	23.0	20.0	17.3	15.3	13.5
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	164.8	133.3	108.7	89.3	74.0	61.8	52.0	44.0	37.5	32.0	27.7	23.8	20.8	18.2	16.0
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	166.3	135.0	110.5	91.2	75.8	63.5	53.5	45.3	38.7	33.2	28.7	24.8	21.7	19.0
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	168.7	137.5	113.0	93.5	78.0	65.5	55.3	47.0	40.2	34.7	29.8	26.0	22.7
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	171.8	140.7	116.0	96.3	80.5	67.8	57.5	49.0	42.0	36.2	31.3	27.2
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	176.0	144.5	119.5	99.5	83.5	70.5	59.8	51.2	43.8	37.8	32.8
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.2	149.2	123.8	103.3	87.0	73.5	62.5	53.5	46.0	39.8
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	187.7	155.0	128.8	108.0	91.0	77.2	65.7	56.3	48.5
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.3	161.8	134.8	113.2	95.7	81.2	69.3	59.5
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	169.8	142.0	119.5	101.2	86.0	73.7
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.5	150.5	126.8	107.5	91.7
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.2	160.5	135.5	115.0
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	172.5	145.8
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	186.8
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

Figure B-24 Tabular Representation of Parking Nomograph for C-17 on 15 °F (-9.5 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

15 F	Gross C-17 Weight (lb)																																
Sea Ice Thickness (inches)	280,000	290,000	300,000	310,000	320,000	330,000	340,000	350,000	360,000	370,000	380,000	390,000	400,000	410,000	420,000	430,000	440,000	450,000	460,000	470,000	480,000	490,000	500,000	510,000	520,000	530,000	540,000	550,000	560,000	570,000	580,000	590,000	600,000
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	0.8	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	1.0	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
65	1.3	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66	1.5	1.3	1.0	0.8	0.8	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0
67	2.0	1.7	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0
68	2.5	2.0	1.7	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0
69	3.2	2.5	2.0	1.7	1.5	1.2	1.0	0.8	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0
70	4.0	3.2	2.5	2.2	1.8	1.5	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0
71	5.0	4.0	3.2	2.7	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0
72	6.3	5.0	4.0	3.2	2.7	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
73	8.0	6.2	5.0	4.0	3.3	2.7	2.3	1.8	1.7	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
74	10.0	7.8	6.2	5.0	4.0	3.3	2.8	2.3	2.0	1.7	1.5	1.2	1.0	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
75	12.7	9.8	7.7	6.2	5.0	4.0	3.3	2.8	2.3	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
76	16.2	12.3	9.7	7.7	6.2	5.0	4.2	3.3	2.8	2.5	2.0	1.8	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2
77	20.7	15.7	12.2	9.5	7.7	6.2	5.0	4.2	3.5	3.0	2.5	2.2	1.8	1.7	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2
78	26.3	19.8	15.2	11.8	9.3	7.5	6.2	5.0	4.2	3.5	3.0	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3
79	33.5	25.2	19.2	14.8	11.7	9.3	7.5	6.2	5.2	4.3	3.7	3.0	2.7	2.3	2.0	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3
80	43.0	31.8	24.2	18.5	14.5	11.5	9.3	7.5	6.2	5.2	4.3	3.7	3.2	2.7	2.3	2.0	1.8	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3
81	55.2	40.7	30.5	23.3	18.0	14.3	11.3	9.2	7.5	6.3	5.2	4.3	3.7	3.2	2.8	2.3	2.2	1.8	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.5	0.3
82	71.2	51.8	38.5	29.3	22.5	17.7	14.0	11.3	9.2	7.7	6.3	5.3	4.5	3.8	3.3	2.8	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5
83	91.8	66.3	49.0	36.8	28.2	22.0	17.3	13.8	11.3	9.2	7.7	6.3	5.3	4.5	3.8	3.3	2.8	2.5	2.2	2.0	1.7	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5
84	118.8	85.2	62.3	46.5	35.3	27.3	21.5	17.2	13.8	11.2	9.2	7.7	6.5	5.5	4.7	4.0	3.5	3.0	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7
85	154.3	109.5	79.5	59.0	44.5	34.2	26.7	21.2	16.8	13.7	11.2	9.3	7.8	6.5	5.5	4.7	4.2	3.5	3.2	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.8	0.7
86	>200	141.3	101.8	74.8	56.2	42.8	33.2	26.0	20.8	16.7	13.7	11.2	9.3	7.8	6.7	5.7	4.8	4.2	3.7	3.2	2.8	2.5	2.2	2.0	1.7	1.5	1.3	1.3	1.2	1.0	1.0	0.8	0.8
87	>200	183.0	130.7	95.3	70.8	53.7	41.3	32.3	25.7	20.5	16.7	13.7	11.3	9.5	8.0	6.7	5.8	5.0	4.3	3.7	3.3	2.8	2.5	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.2	1.0	0.8
88	>200	>200	168.2	121.7	89.8	67.5	51.7	40.2	31.7	25.2	20.3	16.7	13.7	11.3	9.5	8.0	6.8	5.8	5.0	4.3	3.8	3.3	3.0	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.3	1.2	1.0
89	>200	>200	>200	155.8	114.2	85.3	64.8	50.0	39.2	31.0	24.8	20.2	16.5	13.7	11.5	9.7	8.2	7.0	6.0	5.2	4.5	4.0	3.5	3.0	2.7	2.5	2.2	2.0	1.8	1.7	1.5	1.3	1.2
90	>200	>200	>200	>200	145.5	107.8	81.3	62.3	48.5	38.3	30.5	24.7	20.2	16.7	13.8	11.5	9.8	8.3	7.2	6.2	5.3	4.7	4.0	3.7	3.2	2.8	2.5	2.3	2.0	1.8	1.7	1.5	1.3
91	>200	>200	>200	>200	186.2	137.0	102.7	78.2	60.5	47.3	37.7	30.2	24.5	20.2	16.7	13.8	11.7	10.0	8.5	7.3	6.3	5.5	4.8	4.2	3.7	3.3	3.0	2.7	2.3	2.2	1.8	1.7	1.5
92	>200	>200	>200	>200	>200	174.5	129.8	98.2	75.5	58.8	46.3	37.0	30.0	24.5	20.2	16.8	14.0	11.8	10.2	8.7	7.5	6.5	5.7	5.0	4.3	3.8	3.3	3.0	2.7	2.5	2.2	2.0	1.8
93	>200	>200	>200	>200	>200	>200	164.7	123.7	94.5	73.2	57.5	45.7	36.7	29.8	24.5	20.2	16.8	14.2	12.0	10.3	8.8	7.7	6.7	5.8	5.2	4.5	4.0	3.5	3.2	2.8	2.5	2.3	2.0
94	>200	>200	>200	>200	>200	>200	>200	156.3	118.7	91.3	71.3	56.3	45.0	36.5	29.7	24.5	20.3	17.0	14.5	12.3	10.5	9.0	7.8	6.8	6.0	5.3	4.7	4.2	3.7	3.3	3.0	2.7	2.3
95	>200	>200	>200	>200	>200	>200	>200	198.3	149.5	114.3	88.8	69.8	55.5	44.7	36.3	29.8	24.7	20.5	17.3	14.7	12.5	10.7	9.3	8.0	7.0	6.2	5.5	4.8	4.3	3.8	3.3	3.0	2.8
96	>200	>200	>200	>200	>200	>200	>200	>200	189.0	143.7	110.8	86.7	68.5	54.8	44.3	36.2	29.8	24.8	20.8	17.5	15.0	12.8	11.0	9.5	8.3	7.2	6.3	5.7	5.0	4.5	4.0	3.5	3.2
97	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.3	139.0	108.0	85.0	67.7	54.5	44.3	36.3	30.0	25.2	21.2	17.8	15.2	13.0	11.3	9.8	8.5	7.5	6.7	5.8	5.2	4.7	4.2	3.7
98	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	174.8	135.2	105.7	83.7	67.0	54.2	44.3	36.5	30.3	25.3	21.5	18.2	15.5	13.3	11.7	10.0	8.8	7.7	6.8	6.0	5.3	4.8	4.3
99	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	169.7	132.0	104.0	82.8	66.7	54.2	44.5	36.8	30.7	25.8	21.8	18.7	16.0	13.8	12.0	10.3	9.2	8.0	7.0	6.3	5.7	5.0
100	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	165.3	129.5	102.7	82.3	66.5	54.3	44.8	37.2	31.2	26.3	22.3	19.0	16.3	14.2	12.3	10.7	9.3	8.3	7.3	6.5	5.8
101	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	162.2	127.8	101.8	82.0	66.7	54.7	45.3	37.7	31.7	26.8	22.8	19.5	16.8	14.7	12.7	11.2	9.8	8.7	7.7	6.8
102	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	159.7	126.7	101.5	82.2	67.0	55.3	45.8	38.3	32.3	27.5	23.5	20.2	17.3	15.0	13.2	11.5	10.2	9.0	8.0
103	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	158.2	126.0	101.5	82.5	67.7	56.0	46.7	39.2	33.2	28.2	24.2	20.7	18.0	15.7	13.7	12.0	10.5	9.3
104	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.2	157.3	126.0	102.0	83.3	68.5	57.0	47.7	40.0	34.0	29.0	24.8	21.5	18.5	16.2	14.2	12.5	11.0
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.2	157.2	126.7	102.8	84.3	69.7	58.0	48.7	41.2	35.0	29.8	25.7	22.2	19.3	16.8	14.7	13.0
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.0	157.8	127.7	104.2	85.8	71.2	59.5	50.0	42.3	36.0	30.8	26.7	23.0	20.0	17.5	15.3
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.8	159.3	129.5	106.0	87.5	72.8	61.0	51.5	43.7	37.3	32.0	27.7	24.0	21.0	18.3
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	199.7	161.5	131.7	108.3	89.8	75.0	63.0	53.2	45.3	38.8	33.3	28.8	25.0	21.8
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	164.5	134.7	111.2	92.3	77.3	65.2	55.2	47.2	40.3	34.8	30.2	26.3
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	168.5	138.5	114.7	95.5	80.2	67.7	57.5	49.2	42.2	36.5	31.7
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	173.5	143.0	118.7	99.2	83.5	70.7	60.2	51.5	44.3	38.3
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.5	148.5	123.5	103.5	87.3	74.2	63.2	54.2	46.7
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	186.8	155.0	129.3	108.7	91.8	78.0	66.7	57.3
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.7	162.7	136.2	114.5	97.0	82.7	70.7
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	172.0	144.2	121.7	103.2	88.0
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	183.0	153.7	129.8	110.3
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	196.2	165.2	139.8
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.8
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

Figure B-25 Tabular Representation of Parking Nomograph for C-17 on 16 °F (-9 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

16 F	Gross C-17 Weight (lb)																																
Sea Ice Thickness (inches)	280,000	290,000	300,000	310,000	320,000	330,000	340,000	350,000	360,000	370,000	380,000	390,000	400,000	410,000	420,000	430,000	440,000	450,000	460,000	470,000	480,000	490,000	500,000	510,000	520,000	530,000	540,000	550,000	560,000	570,000	580,000	590,000	600,000
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	0.8	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	1.0	0.8	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
65	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66	1.5	1.3	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0
67	2.0	1.5	1.3	1.2	1.0	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0
68	2.5	2.0	1.7	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0
69	3.0	2.5	2.0	1.7	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0
70	3.8	3.0	2.5	2.0	1.7	1.5	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0
71	4.8	3.8	3.2	2.5	2.2	1.8	1.5	1.3	1.0	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0
72	6.2	4.8	3.8	3.2	2.7	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
73	7.7	6.0	4.8	3.8	3.2	2.7	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
74	9.7	7.5	6.0	4.8	3.8	3.2	2.7	2.3	1.8	1.7	1.3	1.2	1.0	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
75	12.3	9.5	7.5	6.0	4.8	4.0	3.3	2.7	2.3	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
76	15.7	12.0	9.3	7.3	6.0	4.8	4.0	3.3	2.8	2.3	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2
77	19.8	15.2	11.7	9.2	7.3	6.0	4.8	4.0	3.3	2.8	2.5	2.0	1.8	1.5	1.3	1.2	1.0	1.0	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2
78	25.3	19.2	14.7	11.5	9.2	7.3	6.0	4.8	4.2	3.5	2.8	2.5	2.2	1.8	1.7	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2
79	32.3	24.2	18.5	14.3	11.3	9.0	7.3	6.0	5.0	4.2	3.5	3.0	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3
80	41.3	30.7	23.2	17.8	14.0	11.2	9.0	7.3	6.0	5.0	4.2	3.5	3.0	2.7	2.3	2.0	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3
81	53.0	39.0	29.3	22.5	17.5	13.8	11.0	9.0	7.3	6.0	5.0	4.3	3.7	3.2	2.7	2.3	2.0	1.8	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.5	0.3
82	68.2	49.8	37.2	28.2	21.8	17.0	13.5	11.0	9.0	7.3	6.2	5.2	4.3	3.7	3.2	2.8	2.3	2.2	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5
83	88.0	63.7	47.0	35.5	27.2	21.2	16.8	13.5	10.8	9.0	7.3	6.2	5.2	4.5	3.8	3.3	2.8	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5
84	113.7	81.5	59.8	44.7	34.0	26.3	20.7	16.5	13.3	10.8	9.0	7.5	6.3	5.3	4.5	3.8	3.3	2.8	2.5	2.2	2.0	1.8	1.5	1.3	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7
85	147.5	104.8	76.3	56.7	42.8	32.8	25.7	20.3	16.3	13.2	10.8	9.0	7.5	6.3	5.3	4.7	4.0	3.5	3.0	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7
86	191.8	135.2	97.5	71.8	53.8	41.2	32.0	25.2	20.0	16.2	13.2	10.8	9.0	7.7	6.5	5.5	4.7	4.0	3.5	3.2	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.2	1.2	1.0	1.0	0.8	0.8
87	>200	174.8	125.0	91.3	68.0	51.7	39.8	31.2	24.7	19.8	16.0	13.2	11.0	9.2	7.7	6.5	5.7	4.8	4.2	3.7	3.2	2.8	2.5	2.2	2.0	1.8	1.5	1.5	1.3	1.2	1.0	1.0	0.8
88	>200	>200	160.7	116.5	86.2	64.8	49.7	38.7	30.5	24.3	19.7	16.0	13.2	11.0	9.2	7.8	6.7	5.7	5.0	4.3	3.7	3.3	2.8	2.5	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.2	1.0
89	>200	>200	>200	149.0	109.3	81.8	62.2	48.0	37.7	29.8	24.0	19.5	16.0	13.3	11.0	9.3	8.0	6.8	5.8	5.0	4.3	3.8	3.3	3.0	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.3	1.2
90	>200	>200	>200	191.3	139.3	103.3	78.2	60.0	46.7	36.8	29.5	23.8	19.5	16.0	13.3	11.2	9.5	8.0	6.8	6.0	5.2	4.5	4.0	3.5	3.2	2.8	2.5	2.2	2.0	1.8	1.7	1.5	1.3
91	>200	>200	>200	>200	178.0	131.2	98.3	75.0	58.0	45.5	36.2	29.2	23.7	19.5	16.2	13.5	11.3	9.7	8.2	7.0	6.2	5.3	4.7	4.2	3.7	3.2	2.8	2.5	2.3	2.0	1.8	1.7	1.5
92	>200	>200	>200	>200	>200	166.8	124.2	94.2	72.3	56.5	44.7	35.7	28.8	23.7	19.5	16.2	13.5	11.5	9.8	8.3	7.2	6.3	5.5	4.8	4.2	3.7	3.3	3.0	2.7	2.3	2.2	2.0	1.8
93	>200	>200	>200	>200	>200	>200	157.5	118.5	90.5	70.2	55.2	43.8	35.3	28.7	23.7	19.5	16.3	13.7	11.7	10.0	8.5	7.3	6.5	5.7	5.0	4.3	3.8	3.5	3.0	2.8	2.5	2.2	2.0
94	>200	>200	>200	>200	>200	>200	>200	149.7	113.7	87.7	68.5	54.2	43.3	35.0	28.7	23.7	19.7	16.5	14.0	11.8	10.2	8.8	7.7	6.7	5.8	5.2	4.5	4.0	3.5	3.2	2.8	2.7	2.3
95	>200	>200	>200	>200	>200	>200	>200	189.7	143.0	109.7	85.2	67.0	53.3	43.0	35.0	28.7	23.8	19.8	16.7	14.2	12.2	10.3	9.0	7.8	6.8	6.0	5.3	4.7	4.2	3.7	3.3	3.0	2.7
96	>200	>200	>200	>200	>200	>200	>200	>200	180.8	137.7	106.3	83.2	65.8	52.7	42.7	34.8	28.8	24.0	20.2	17.0	14.5	12.3	10.7	9.2	8.0	7.0	6.2	5.5	4.8	4.3	3.8	3.5	3.2
97	>200	>200	>200	>200	>200	>200	>200	>200	>200	173.3	133.0	103.5	81.5	65.0	52.3	42.7	35.0	29.0	24.2	20.3	17.3	14.7	12.7	10.8	9.5	8.3	7.3	6.3	5.7	5.0	4.5	4.0	3.7
98	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	167.3	129.3	101.3	80.3	64.3	52.2	42.7	35.2	29.2	24.5	20.7	17.7	15.0	13.0	11.2	9.8	8.5	7.5	6.7	5.8	5.2	4.7	4.2
99	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	162.3	126.3	99.7	79.5	64.0	52.2	42.8	35.5	29.7	24.8	21.2	18.0	15.5	13.3	11.5	10.0	8.8	7.8	6.8	6.2	5.5	4.8
100	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	158.2	124.2	98.5	79.0	64.0	52.3	43.2	35.8	30.0	25.3	21.5	18.3	15.8	13.7	11.8	10.3	9.2	8.0	7.2	6.3	5.7
101	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.8	155.2	122.5	97.7	78.7	64.2	52.7	43.5	36.3	30.5	25.8	22.0	18.8	16.3	14.2	12.3	10.8	9.5	8.3	7.3	6.7
102	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	194.7	152.8	121.3	97.3	78.8	64.5	53.2	44.2	37.0	31.2	26.5	22.7	19.5	16.8	14.5	12.7	11.2	9.8	8.7	7.7
103	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.7	151.3	120.8	97.3	79.2	65.0	53.8	44.8	37.7	31.8	27.2	23.2	20.0	17.3	15.0	13.2	11.5	10.2	9.0
104	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	189.7	150.5	120.8	97.8	80.0	65.8	54.7	45.8	38.7	32.7	28.0	24.0	20.7	18.0	15.7	13.7	12.0	10.7
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.5	150.5	121.3	98.7	81.0	67.0	55.8	46.8	39.7	33.7	28.8	24.8	21.5	18.7	16.3	14.3	12.5
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.3	151.2	122.3	100.0	82.3	68.3	57.2	48.2	40.8	34.7	29.8	25.7	22.2	19.3	17.0	14.8
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	189.2	152.5	124.0	101.7	84.0	70.0	58.7	49.5	42.2	36.0	30.8	26.7	23.2	20.2	17.7
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.0	154.7	126.2	103.8	86.2	72.0	60.5	51.2	43.7	37.3	32.2	27.8	24.2	21.2
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.8	157.5	129.2	106.7	88.7	74.3	62.7	53.2	45.3	38.8	33.5	29.2	25.3
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.8	161.3	132.7	109.8	91.7	77.0	65.0	55.3	47.3	40.7	35.2	30.5
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	166.0	137.0	113.8	95.2	80.2	67.8	57.8	49.5	42.7	37.0
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	171.8	142.2	118.5	99.3	83.8	71.2	60.8	52.2	45.0
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.8	148.3	124.0	104.2	88.2	75.0	64.2	55.2
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	187.3	155.8	130.5	109.8	93.2	79.3	68.0
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.5	164.7	138.2	116.5	99.0	84.5
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	175.2	147.2	124.5	105.8
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	187.8	158.2	134.0
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	171.3
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

Figure B-26 Tabular Representation of Parking Nomograph for C-17 on 17 °F (-8 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

17 F	Gross C-17 Weight (lb)																																
Sea Ice Thickness (inches)	280,000	290,000	300,000	310,000	320,000	330,000	340,000	350,000	360,000	370,000	380,000	390,000	400,000	410,000	420,000	430,000	440,000	450,000	460,000	470,000	480,000	490,000	500,000	510,000	520,000	530,000	540,000	550,000	560,000	570,000	580,000	590,000	600,000
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	0.7	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	1.0	0.8	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
65	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66	1.5	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0
67	1.8	1.5	1.3	1.0	0.8	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0
68	2.3	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0
69	3.0	2.3	2.0	1.7	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0
70	3.7	3.0	2.5	2.0	1.7	1.3	1.2	1.0	0.8	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0
71	4.7	3.7	3.0	2.5	2.0	1.7	1.5	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0
72	5.8	4.7	3.7	3.0	2.5	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
73	7.5	5.8	4.7	3.8	3.2	2.5	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
74	9.3	7.3	5.8	4.7	3.8	3.2	2.7	2.2	1.8	1.7	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
75	11.8	9.2	7.2	5.8	4.7	3.8	3.2	2.7	2.2	1.8	1.7	1.3	1.2	1.0	1.0	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
76	15.0	11.5	9.0	7.2	5.8	4.7	3.8	3.2	2.7	2.3	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2
77	19.2	14.5	11.3	8.8	7.2	5.8	4.7	3.8	3.3	2.8	2.3	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2
78	24.3	18.3	14.2	11.2	8.8	7.2	5.8	4.8	4.0	3.3	2.8	2.3	2.0	1.8	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2
79	31.0	23.3	17.8	13.8	10.8	8.7	7.0	5.8	4.8	4.0	3.3	2.8	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3
80	39.7	29.5	22.3	17.3	13.5	10.8	8.7	7.0	5.8	4.8	4.0	3.5	3.0	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3
81	50.8	37.5	28.2	21.7	16.8	13.3	10.7	8.7	7.2	5.8	4.8	4.2	3.5	3.0	2.7	2.3	2.0	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3
82	65.3	47.8	35.7	27.2	21.0	16.5	13.2	10.5	8.7	7.2	6.0	5.0	4.2	3.7	3.2	2.7	2.3	2.0	1.8	1.7	1.3	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.5
83	84.3	61.0	45.2	34.2	26.2	20.5	16.2	13.0	10.5	8.7	7.2	6.0	5.0	4.3	3.7	3.2	2.8	2.3	2.2	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5
84	108.8	78.2	57.5	43.0	32.8	25.5	20.0	16.0	12.8	10.5	8.7	7.2	6.0	5.2	4.3	3.8	3.3	2.8	2.5	2.2	2.0	1.7	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5
85	141.0	100.3	73.2	54.3	41.2	31.7	24.8	19.7	15.8	12.8	10.5	8.7	7.3	6.2	5.2	4.5	3.8	3.3	2.8	2.5	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7
86	183.2	129.3	93.3	68.8	51.8	39.5	30.7	24.2	19.3	15.7	12.8	10.5	8.8	7.3	6.2	5.3	4.5	4.0	3.5	3.0	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.8
87	>200	167.0	119.7	87.5	65.3	49.5	38.3	30.0	23.8	19.2	15.5	12.7	10.5	8.8	7.5	6.3	5.5	4.7	4.0	3.5	3.2	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.3	1.2	1.0	1.0	0.8
88	>200	>200	153.7	111.5	82.5	62.3	47.7	37.2	29.3	23.5	19.0	15.5	12.8	10.7	9.0	7.5	6.5	5.5	4.8	4.2	3.7	3.2	2.8	2.5	2.2	2.0	1.8	1.7	1.5	1.3	1.2	1.2	1.0
89	>200	>200	198.0	142.5	104.7	78.5	59.7	46.2	36.2	28.8	23.2	18.8	15.5	12.8	10.7	9.0	7.7	6.5	5.7	4.8	4.3	3.7	3.3	2.8	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.2
90	>200	>200	>200	182.8	133.3	99.0	74.8	57.5	44.8	35.5	28.3	23.0	18.8	15.5	12.8	10.8	9.2	7.8	6.7	5.8	5.0	4.3	3.8	3.3	3.0	2.7	2.3	2.2	2.0	1.7	1.5	1.5	1.3
91	>200	>200	>200	>200	170.2	125.5	94.3	72.0	55.8	43.8	34.8	28.0	22.8	18.7	15.5	13.0	11.0	9.3	8.0	6.8	6.0	5.2	4.5	4.0	3.5	3.2	2.8	2.5	2.2	2.0	1.8	1.7	1.5
92	>200	>200	>200	>200	>200	159.5	119.0	90.2	69.5	54.3	43.0	34.3	27.8	22.7	18.8	15.7	13.2	11.2	9.5	8.2	7.0	6.0	5.3	4.7	4.2	3.7	3.2	2.8	2.5	2.3	2.2	1.8	1.7
93	>200	>200	>200	>200	>200	>200	150.7	113.5	86.8	67.3	53.0	42.2	34.0	27.7	22.7	18.8	15.8	13.3	11.3	9.7	8.3	7.2	6.2	5.5	4.8	4.2	3.8	3.3	3.0	2.7	2.3	2.2	2.0
94	>200	>200	>200	>200	>200	>200	191.3	143.2	108.8	84.0	65.7	52.0	41.7	33.8	27.7	22.8	19.0	16.0	13.5	11.5	9.8	8.5	7.3	6.5	5.7	5.0	4.3	3.8	3.5	3.2	2.8	2.5	2.3
95	>200	>200	>200	>200	>200	>200	>200	181.3	137.0	105.0	81.7	64.3	51.3	41.3	33.7	27.7	23.0	19.2	16.2	13.7	11.7	10.0	8.7	7.5	6.7	5.8	5.2	4.5	4.0	3.7	3.2	2.8	2.7
96	>200	>200	>200	>200	>200	>200	>200	>200	172.8	131.7	101.8	79.8	63.2	50.7	41.2	33.7	27.8	23.2	19.3	16.3	14.0	12.0	10.3	9.0	7.8	6.8	6.0	5.3	4.7	4.2	3.7	3.3	3.0
97	>200	>200	>200	>200	>200	>200	>200	>200	>200	165.8	127.3	99.2	78.3	62.5	50.3	41.0	33.7	28.0	23.3	19.7	16.7	14.2	12.2	10.5	9.2	8.0	7.0	6.2	5.5	4.8	4.3	3.8	3.5
98	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	160.0	123.8	97.2	77.2	61.8	50.2	41.0	33.8	28.2	23.7	20.0	17.0	14.5	12.5	10.8	9.5	8.3	7.3	6.3	5.7	5.0	4.5	4.0
99	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	155.2	121.0	95.5	76.3	61.5	50.2	41.2	34.2	28.5	24.0	20.3	17.3	14.8	12.8	11.2	9.7	8.5	7.5	6.7	5.8	5.3	4.7
100	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.3	151.5	118.8	94.3	75.8	61.5	50.3	41.5	34.5	29.0	24.5	20.8	17.8	15.3	13.2	11.5	10.0	8.8	7.8	6.8	6.2	5.5
101	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	190.2	148.5	117.3	93.7	75.7	61.5	50.7	42.0	35.0	29.5	25.0	21.3	18.2	15.7	13.7	11.8	10.3	9.2	8.2	7.2	6.3
102	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	186.2	146.3	116.3	93.3	75.7	62.0	51.2	42.5	35.7	30.0	25.5	21.8	18.8	16.2	14.2	12.3	10.8	9.5	8.3	7.5
103	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	183.3	144.8	115.7	93.3	76.0	62.5	51.8	43.2	36.3	30.7	26.2	22.5	19.3	16.7	14.5	12.8	11.2	9.8	8.8
104	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.3	144.2	115.7	93.8	76.7	63.3	52.7	44.0	37.2	31.5	27.0	23.2	20.0	17.3	15.2	13.3	11.7	10.3
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.3	144.0	116.2	94.7	77.7	64.3	53.7	45.2	38.2	32.5	27.8	23.8	20.7	18.0	15.7	13.8	12.2
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.2	144.7	117.3	95.8	79.0	65.7	55.0	46.3	39.2	33.5	28.7	24.8	21.5	18.7	16.3	14.3
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.0	146.0	118.8	97.5	80.7	67.2	56.5	47.7	40.5	34.7	29.8	25.7	22.3	19.5	17.2
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.7	148.0	121.0	99.7	82.7	69.2	58.2	49.3	42.0	36.0	31.0	26.8	23.3	20.3
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.5	150.8	123.7	102.2	85.2	71.3	60.2	51.2	43.7	37.5	32.3	28.0	24.5
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	189.2	154.5	127.0	105.3	88.0	74.0	62.5	53.2	45.5	39.2	33.8	29.5
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	194.0	159.0	131.2	109.2	91.3	77.0	65.3	55.7	47.7	41.2	35.7
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	164.5	136.2	113.5	95.3	80.5	68.3	58.5	50.2	43.3
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	171.2	142.2	118.8	100.0	84.7	72.0	61.7	53.0
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.2	149.2	125.0	105.3	89.3	76.2	65.3
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.8	157.7	132.3	111.8	95.0	81.2
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	167.7	141.0	119.3	101.5
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.7	151.5	128.3
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	194.3	164.0
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

Figure B-27 Tabular Representation of Parking Nomograph for C-17 on 18 °F (-7.5 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

Gross C-17 Weight (lb)

18 F / Sea Ice Thickness (inches)	280,000	290,000	300,000	310,000	320,000	330,000	340,000	350,000	360,000	370,000	380,000	390,000	400,000	410,000	420,000	430,000	440,000	450,000	460,000	470,000	480,000	490,000	500,000	510,000	520,000	530,000	540,000	550,000	560,000	570,000	580,000	590,000	600,000
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	0.8	0.8	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
65	1.2	1.0	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66	1.5	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0
67	1.8	1.5	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0
68	2.3	1.8	1.5	1.3	1.0	0.8	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0
69	2.8	2.3	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0
70	3.7	2.8	2.3	2.0	1.7	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0
71	4.5	3.7	3.0	2.3	2.0	1.7	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0
72	5.7	4.5	3.7	3.0	2.5	2.0	1.7	1.5	1.2	1.0	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
73	7.2	5.7	4.5	3.7	3.0	2.5	2.0	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
74	9.0	7.2	5.7	4.5	3.7	3.0	2.5	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
75	11.5	8.8	7.0	5.7	4.5	3.7	3.0	2.5	2.2	1.8	1.7	1.3	1.2	1.0	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
76	14.5	11.2	8.7	7.0	5.7	4.5	3.8	3.2	2.7	2.2	1.8	1.7	1.5	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
77	18.5	14.0	11.0	8.7	6.8	5.7	4.7	3.8	3.2	2.7	2.3	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2
78	23.5	17.7	13.7	10.7	8.5	6.8	5.7	4.7	3.8	3.2	2.7	2.3	2.0	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2
79	29.8	22.5	17.2	13.3	10.5	8.5	6.8	5.7	4.7	3.8	3.3	2.8	2.3	2.0	1.8	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3
80	38.2	28.5	21.5	16.7	13.0	10.3	8.3	6.8	5.7	4.7	4.0	3.3	2.8	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3
81	48.8	36.0	27.2	20.8	16.2	12.8	10.3	8.3	6.8	5.7	4.8	4.0	3.5	3.0	2.5	2.2	2.0	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3
82	62.7	46.0	34.3	26.2	20.2	15.8	12.7	10.2	8.3	6.8	5.7	4.8	4.2	3.5	3.0	2.7	2.3	2.0	1.7	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.5
83	80.7	58.7	43.5	32.8	25.2	19.7	15.7	12.5	10.2	8.3	7.0	5.8	4.8	4.2	3.5	3.2	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5
84	104.2	75.0	55.2	41.3	31.5	24.5	19.3	15.3	12.5	10.2	8.3	7.0	5.8	5.0	4.3	3.7	3.2	2.8	2.3	2.2	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7	0.5
85	134.8	96.2	70.2	52.2	39.5	30.5	23.8	19.0	15.2	12.3	10.2	8.5	7.0	6.0	5.0	4.3	3.7	3.2	2.8	2.5	2.2	2.0	1.7	1.5	1.3	1.2	1.2	1.0	1.0	0.8	0.8	0.7	0.7
86	175.0	123.7	89.5	66.0	49.7	38.0	29.7	23.3	18.7	15.0	12.3	10.2	8.5	7.2	6.0	5.2	4.5	3.8	3.3	3.0	2.5	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7
87	>200	159.7	114.5	83.8	62.7	47.7	36.8	28.8	22.8	18.5	15.0	12.3	10.2	8.5	7.2	6.2	5.3	4.5	4.0	3.5	3.0	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.2	1.2	1.0	1.0	0.8
88	>200	>200	146.8	106.8	79.2	59.8	45.8	35.7	28.2	22.5	18.3	15.0	12.3	10.3	8.7	7.3	6.2	5.3	4.7	4.0	3.5	3.2	2.7	2.5	2.2	2.0	1.7	1.5	1.3	1.3	1.2	1.0	1.0
89	>200	>200	189.2	136.3	100.3	75.2	57.3	44.3	34.8	27.7	22.3	18.2	15.0	12.3	10.3	8.7	7.5	6.3	5.5	4.8	4.2	3.7	3.2	2.8	2.5	2.2	2.0	1.8	1.7	1.5	1.3	1.2	1.2
90	>200	>200	>200	174.7	127.5	94.8	71.8	55.3	43.2	34.2	27.3	22.2	18.2	15.0	12.5	10.5	8.8	7.5	6.5	5.7	4.8	4.3	3.7	3.3	3.0	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.3
91	>200	>200	>200	>200	162.5	120.2	90.3	69.0	53.5	42.2	33.5	27.0	22.0	18.2	15.0	12.5	10.7	9.0	7.7	6.7	5.7	5.0	4.3	3.8	3.3	3.0	2.7	2.5	2.2	2.0	1.8	1.7	1.5
92	>200	>200	>200	>200	>200	152.5	113.8	86.5	66.7	52.2	41.3	33.0	26.8	22.0	18.2	15.2	12.7	10.7	9.2	7.8	6.8	5.8	5.2	4.5	4.0	3.5	3.2	2.8	2.5	2.3	2.0	1.8	1.7
93	>200	>200	>200	>200	>200	194.3	144.0	108.7	83.2	64.7	51.0	40.7	32.7	26.7	22.0	18.2	15.2	12.8	10.8	9.3	8.0	7.0	6.0	5.3	4.7	4.2	3.7	3.3	2.8	2.7	2.3	2.2	2.0
94	>200	>200	>200	>200	>200	>200	182.8	137.0	104.3	80.5	63.0	50.0	40.2	32.5	26.7	22.0	18.3	15.3	13.0	11.2	9.5	8.2	7.2	6.2	5.5	4.8	4.3	3.8	3.3	3.0	2.7	2.5	2.2
95	>200	>200	>200	>200	>200	>200	>200	173.2	131.0	100.7	78.3	61.8	49.3	39.8	32.3	26.7	22.2	18.5	15.7	13.2	11.3	9.7	8.5	7.3	6.3	5.7	5.0	4.3	4.0	3.5	3.2	2.8	2.5
96	>200	>200	>200	>200	>200	>200	>200	>200	165.2	126.0	97.5	76.5	60.7	48.7	39.5	32.3	26.7	22.3	18.7	15.8	13.5	11.5	10.0	8.7	7.5	6.7	5.8	5.2	4.5	4.0	3.7	3.3	3.0
97	>200	>200	>200	>200	>200	>200	>200	>200	>200	158.5	122.0	95.2	75.0	60.0	48.3	39.5	32.5	27.0	22.5	19.0	16.2	13.8	11.8	10.2	8.8	7.8	6.8	6.0	5.3	4.7	4.2	3.8	3.3
98	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	153.0	118.7	93.2	74.0	59.5	48.2	39.5	32.7	27.2	22.8	19.3	16.5	14.0	12.2	10.5	9.2	8.0	7.0	6.2	5.5	4.8	4.3	4.0
99	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.7	148.5	116.0	91.7	73.2	59.2	48.2	39.7	32.8	27.5	23.2	19.7	16.8	14.3	12.5	10.8	9.5	8.3	7.3	6.5	5.7	5.2	4.5
100	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	186.7	144.8	113.8	90.5	72.7	59.0	48.3	40.0	33.3	27.8	23.5	20.0	17.2	14.8	12.8	11.2	9.7	8.5	7.5	6.7	6.0	5.3
101	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.8	142.2	112.3	89.8	72.5	59.2	48.7	40.3	33.7	28.3	24.0	20.5	17.7	15.2	13.2	11.5	10.0	8.8	7.8	7.0	6.2
102	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.0	140.0	111.3	89.5	72.7	59.5	49.2	40.8	34.3	29.0	24.7	21.0	18.2	15.7	13.7	11.8	10.5	9.2	8.2	7.2
103	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	175.2	138.7	110.8	89.5	73.0	60.0	49.8	41.5	35.0	29.7	25.3	21.7	18.7	16.2	14.2	12.3	10.8	9.5	8.5
104	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	173.3	138.0	110.8	90.0	73.7	60.8	50.7	42.3	35.8	30.3	26.0	22.3	19.3	16.7	14.7	12.8	11.3	10.0
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	172.5	138.0	111.3	90.8	74.7	61.8	51.7	43.3	36.7	31.3	26.8	23.0	20.0	17.3	15.2	13.3	11.8
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	172.3	138.5	112.3	92.0	75.8	63.0	52.8	44.5	37.8	32.3	27.7	23.8	20.7	18.0	15.8	14.0
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	173.2	139.8	113.8	93.5	77.5	64.7	54.3	45.8	39.0	33.3	28.7	24.8	21.5	18.8	16.5
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	174.8	141.7	115.8	95.5	79.3	66.3	56.0	47.3	40.3	34.7	29.8	25.8	22.5	19.7
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.3	144.3	118.5	98.0	81.7	68.5	57.8	49.2	42.0	36.2	31.2	27.0	23.7
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.8	147.8	121.8	101.0	84.5	71.0	60.2	51.2	43.8	37.7	32.7	28.3
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.5	152.2	125.7	104.7	87.7	73.8	62.7	53.5	45.8	39.5	34.3
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.3	157.3	130.5	108.8	91.5	77.3	65.7	56.2	48.3	41.7
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.5	163.8	136.2	113.8	95.8	81.2	69.2	59.2	51.0
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	171.5	142.8	119.8	101.0	85.8	73.2	62.8
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.7	150.8	126.8	107.2	91.2	77.8
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.7	160.5	135.2	114.3	97.5
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	172.0	145.0	123.0
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.8	157.0
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

Figure B-28 Tabular Representation of Parking Nomograph for C-17 on 19 °F (-7 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

Gross C-17 Weight (lb)

Sea Ice Thickness (inches)

19 F	280,000	290,000	300,000	310,000	320,000	330,000	340,000	350,000	360,000	370,000	380,000	390,000	400,000	410,000	420,000	430,000	440,000	450,000	460,000	470,000	480,000	490,000	500,000	510,000	520,000	530,000	540,000	550,000	560,000	570,000	580,000	590,000	600,000
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
65	1.2	1.0	0.8	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
67	1.8	1.5	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0
68	2.2	1.8	1.5	1.2	1.0	0.8	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0
69	2.8	2.3	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0
70	3.5	2.8	2.3	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0
71	4.3	3.5	2.8	2.3	2.0	1.7	1.3	1.2	1.0	0.8	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0
72	5.5	4.3	3.5	2.8	2.3	2.0	1.7	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0
73	7.0	5.5	4.3	3.5	2.8	2.3	2.0	1.7	1.5	1.2	1.0	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
74	8.8	6.8	5.5	4.3	3.5	3.0	2.5	2.0	1.8	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
75	11.2	8.7	6.8	5.5	4.3	3.7	3.0	2.5	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
76	14.0	10.8	8.5	6.7	5.3	4.5	3.7	3.0	2.5	2.2	1.8	1.7	1.3	1.2	1.0	1.0	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
77	17.8	13.5	10.5	8.3	6.7	5.5	4.5	3.7	3.2	2.7	2.2	1.8	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2
78	22.7	17.2	13.2	10.3	8.2	6.7	5.5	4.5	3.7	3.2	2.7	2.3	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2
79	28.8	21.7	16.5	12.8	10.2	8.2	6.7	5.5	4.5	3.8	3.2	2.7	2.3	2.0	1.8	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3
80	36.7	27.3	20.8	16.0	12.7	10.0	8.2	6.7	5.5	4.5	3.8	3.3	2.8	2.3	2.0	1.8	1.7	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3
81	47.0	34.7	26.2	20.2	15.7	12.3	10.0	8.2	6.7	5.5	4.7	3.8	3.3	2.8	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3
82	60.2	44.2	33.0	25.2	19.5	15.3	12.2	9.8	8.2	6.7	5.5	4.7	4.0	3.3	3.0	2.5	2.2	2.0	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3
83	77.3	56.2	41.7	31.5	24.3	19.0	15.0	12.2	9.8	8.2	6.7	5.7	4.8	4.0	3.5	3.0	2.7	2.3	2.0	1.8	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5
84	99.7	71.8	52.8	39.7	30.3	23.7	18.7	14.8	12.0	9.8	8.2	6.8	5.7	4.8	4.2	3.5	3.0	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7	0.5
85	128.8	92.0	67.2	50.2	38.0	29.3	23.0	18.3	14.7	12.0	9.8	8.2	6.8	5.8	4.8	4.2	3.7	3.2	2.8	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.7
86	167.2	118.3	85.7	63.3	47.8	36.7	28.5	22.5	18.0	14.5	11.8	9.8	8.2	6.8	5.8	5.0	4.3	3.7	3.2	2.8	2.5	2.2	2.0	1.7	1.5	1.3	1.3	1.2	1.0	1.0	0.8	0.8	0.7
87	>200	152.5	109.5	80.3	60.2	45.8	35.3	27.8	22.2	17.8	14.5	11.8	9.8	8.3	7.0	6.0	5.2	4.3	3.8	3.3	3.0	2.5	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.2	1.0	0.8	0.8
88	>200	197.2	140.5	102.2	75.8	57.3	44.0	34.3	27.2	21.8	17.7	14.5	12.0	10.0	8.3	7.2	6.0	5.2	4.5	4.0	3.5	3.0	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.2	1.2	1.0	1.0
89	>200	>200	180.5	130.3	96.0	72.2	55.0	42.7	33.5	26.7	21.5	17.5	14.5	12.0	10.0	8.5	7.2	6.2	5.3	4.7	4.0	3.5	3.2	2.8	2.5	2.2	2.0	1.8	1.7	1.5	1.3	1.2	1.0
90	>200	>200	>200	166.8	122.0	90.8	69.0	53.2	41.5	32.8	26.3	21.3	17.5	14.5	12.0	10.2	8.7	7.3	6.3	5.5	4.7	4.2	3.7	3.2	2.8	2.5	2.3	2.0	1.8	1.7	1.5	1.3	1.2
91	>200	>200	>200	>200	155.3	115.0	86.5	66.2	51.5	40.5	32.3	26.0	21.2	17.5	14.5	12.2	10.3	8.7	7.5	6.5	5.5	4.8	4.3	3.7	3.3	3.0	2.7	2.3	2.2	1.8	1.7	1.5	1.5
92	>200	>200	>200	>200	198.5	145.8	109.0	82.8	64.0	50.0	39.7	31.8	25.8	21.2	17.5	14.7	12.3	10.3	8.8	7.7	6.5	5.7	5.0	4.3	3.8	3.5	3.0	2.7	2.5	2.2	2.0	1.8	1.7
93	>200	>200	>200	>200	>200	185.5	137.8	104.0	79.8	62.2	49.0	39.0	31.5	25.7	21.2	17.5	14.7	12.5	10.5	9.0	7.8	6.7	5.8	5.2	4.5	4.0	3.5	3.2	2.8	2.5	2.3	2.0	1.8
94	>200	>200	>200	>200	>200	>200	174.7	131.0	99.8	77.3	60.5	48.0	38.7	31.3	25.7	21.2	17.7	14.8	12.7	10.7	9.2	8.0	6.8	6.0	5.3	4.7	4.2	3.7	3.3	3.0	2.7	2.3	2.2
95	>200	>200	>200	>200	>200	>200	>200	165.7	125.3	96.3	75.2	59.3	47.3	38.2	31.2	25.7	21.3	17.8	15.0	12.8	11.0	9.5	8.2	7.2	6.2	5.5	4.8	4.3	3.8	3.3	3.0	2.7	2.5
96	>200	>200	>200	>200	>200	>200	>200	>200	158.0	120.7	93.5	73.3	58.3	46.8	38.0	31.2	25.8	21.5	18.0	15.3	13.0	11.2	9.7	8.3	7.3	6.3	5.7	5.0	4.5	4.0	3.5	3.2	2.8
97	>200	>200	>200	>200	>200	>200	>200	>200	199.7	151.7	116.8	91.2	72.0	57.7	46.5	38.0	31.2	26.0	21.7	18.3	15.5	13.3	11.5	9.8	8.7	7.5	6.7	5.8	5.2	4.7	4.2	3.7	3.3
98	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.2	146.3	113.7	89.3	71.0	57.0	46.3	38.0	31.3	26.2	22.0	18.7	15.8	13.7	11.7	10.2	8.8	7.8	6.8	6.0	5.3	4.8	4.3	3.8
99	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	184.2	142.0	111.0	87.8	70.3	56.8	46.3	38.2	31.7	26.5	22.3	19.0	16.2	14.0	12.0	10.5	9.2	8.0	7.0	6.3	5.5	5.0	4.5
100	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.3	138.7	109.0	86.8	69.8	56.7	46.5	38.5	32.0	26.8	22.7	19.3	16.5	14.3	12.3	10.8	9.5	8.3	7.3	6.5	5.8	5.2
101	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	173.8	136.0	107.7	86.2	69.7	56.8	46.8	38.8	32.5	27.3	23.2	19.8	17.0	14.7	12.8	11.2	9.8	8.7	7.7	6.7	6.0
102	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	170.2	134.0	106.7	85.8	69.7	57.2	47.2	39.3	33.0	27.8	23.7	20.3	17.5	15.2	13.2	11.5	10.2	9.0	7.8	7.0
103	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	167.5	132.7	106.3	85.8	70.2	57.7	47.8	40.0	33.7	28.5	24.3	20.8	18.0	15.7	13.7	12.0	10.5	9.3	8.2
104	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	165.8	132.0	106.3	86.3	70.7	58.5	48.7	40.8	34.5	29.3	25.0	21.5	18.7	16.2	14.2	12.3	11.0	9.7
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	164.8	132.0	106.7	87.0	71.7	59.3	49.7	41.7	35.3	30.2	25.8	22.3	19.3	16.8	14.7	12.8	11.3
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	164.8	132.7	107.7	88.2	72.8	60.7	50.8	42.8	36.3	31.0	26.7	23.0	20.0	17.5	15.3	13.5
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	165.5	133.8	109.2	89.7	74.3	62.0	52.2	44.2	37.5	32.2	27.7	24.0	20.8	18.2	16.0
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	167.2	135.7	111.0	91.7	76.2	63.8	53.8	45.7	38.8	33.3	28.8	25.0	21.7	19.0
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	169.7	138.2	113.5	94.0	78.3	65.8	55.7	47.3	40.5	34.8	30.0	26.2	22.8
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	173.0	141.5	116.7	96.8	81.0	68.2	57.8	49.2	42.2	36.3	31.5	27.3
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.5	145.7	120.5	100.3	84.2	71.0	60.3	51.5	44.2	38.2	33.0
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	183.0	150.7	125.0	104.3	87.7	74.2	63.2	54.0	46.5	40.2
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	189.8	156.7	130.3	109.2	92.0	78.0	66.5	57.0	49.0
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.2	164.0	136.8	114.8	97.0	82.3	70.3	60.3
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	172.8	144.5	121.5	102.8	87.5	74.8
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	183.3	153.5	129.3	109.7	93.5
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	196.2	164.5	138.8	117.8
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.8	150.3
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	194.0
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

Figure B-29 Tabular Representation of Parking Nomograph for C-17 on 20 °F (-6.5 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

20 F	Gross C-17 Weight (lb)																															
Sea Ice Thickness (inches)	280,000	290,000	300,000	310,000	320,000	330,000	340,000	350,000	360,000	370,000	380,000	390,000	400,000	410,000	420,000	430,000	440,000	450,000	460,000	470,000	480,000	490,000	500,000	510,000	520,000	530,000	540,000	550,000	560,000	570,000	580,000	590,000	600,000
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
65	1.2	0.8	0.8	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66	1.3	1.2	1.0	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
67	1.7	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0
68	2.2	1.8	1.5	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0
69	2.7	2.2	1.8	1.5	1.2	1.0	0.8	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0
70	3.3	2.7	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0
71	4.3	3.3	2.8	2.3	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0
72	5.3	4.3	3.5	2.8	2.3	2.0	1.7	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0
73	6.7	5.3	4.2	3.5	2.8	2.3	2.0	1.7	1.5	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
74	8.5	6.7	5.3	4.3	3.5	2.8	2.3	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
75	10.7	8.3	6.5	5.3	4.3	3.5	2.8	2.5	2.0	1.8	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
76	13.5	10.5	8.2	6.5	5.2	4.3	3.5	3.0	2.5	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
77	17.2	13.2	10.2	8.0	6.5	5.2	4.3	3.5	3.0	2.5	2.2	1.8	1.7	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2
78	21.8	16.5	12.7	10.0	8.0	6.5	5.3	4.3	3.7	3.0	2.7	2.2	1.8	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2
79	27.7	20.8	16.0	12.5	9.8	7.8	6.5	5.3	4.3	3.7	3.2	2.7	2.3	2.0	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3
80	35.3	26.3	20.0	15.5	12.2	9.7	7.8	6.5	5.3	4.5	3.7	3.2	2.7	2.3	2.0	1.8	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3
81	45.0	33.3	25.2	19.3	15.2	12.0	9.7	7.8	6.5	5.3	4.5	3.8	3.2	2.8	2.3	2.2	1.8	1.7	1.3	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3
82	57.7	42.3	31.7	24.2	18.8	14.8	11.8	9.5	7.8	6.5	5.3	4.5	3.8	3.3	2.8	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3
83	74.2	54.0	40.2	30.3	23.3	18.3	14.5	11.7	9.5	7.8	6.5	5.5	4.7	4.0	3.3	2.8	2.5	2.2	2.0	1.7	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5
84	95.5	68.8	50.8	38.2	29.2	22.7	18.0	14.3	11.7	9.5	7.8	6.5	5.5	4.7	4.0	3.5	3.0	2.7	2.3	2.0	1.8	1.5	1.3	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5
85	123.3	88.2	64.5	48.2	36.5	28.3	22.2	17.7	14.2	11.5	9.5	7.8	6.7	5.7	4.8	4.2	3.5	3.0	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7
86	159.7	113.2	82.2	60.8	45.8	35.2	27.5	21.7	17.3	14.0	11.5	9.5	8.0	6.7	5.7	4.8	4.2	3.7	3.2	2.8	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.2	1.0	1.0	0.8	0.8	0.7
87	>200	145.7	104.8	77.0	57.7	44.0	34.0	26.7	21.3	17.2	14.0	11.5	9.5	8.0	6.8	5.8	5.0	4.3	3.7	3.2	2.8	2.5	2.2	2.0	1.8	1.5	1.5	1.3	1.2	1.0	1.0	0.8	0.8
88	>200	188.2	134.3	97.8	72.8	55.0	42.3	33.0	26.2	21.0	17.0	14.0	11.5	9.7	8.2	6.8	5.8	5.0	4.3	3.8	3.3	3.0	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.2	1.0	1.0
89	>200	>200	172.5	124.7	92.0	69.2	52.8	41.0	32.3	25.7	20.7	16.8	14.0	11.5	9.7	8.2	7.0	6.0	5.2	4.5	3.8	3.5	3.0	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.3	1.2	1.0
90	>200	>200	>200	159.3	116.7	87.2	66.2	51.0	39.8	31.7	25.3	20.5	16.8	14.0	11.7	9.8	8.3	7.2	6.2	5.3	4.7	4.0	3.5	3.2	2.8	2.5	2.2	2.0	1.8	1.7	1.5	1.3	1.2
91	>200	>200	>200	>200	148.5	110.0	83.0	63.5	49.3	39.0	31.0	25.0	20.5	16.8	14.0	11.7	10.0	8.5	7.2	6.2	5.3	4.7	4.2	3.7	3.2	2.8	2.5	2.3	2.0	1.8	1.7	1.5	1.3
92	>200	>200	>200	>200	189.5	139.3	104.3	79.5	61.3	48.2	38.2	30.7	24.8	20.3	16.8	14.2	11.8	10.0	8.7	7.3	6.3	5.5	4.8	4.3	3.8	3.3	3.0	2.7	2.3	2.2	2.0	1.7	1.7
93	>200	>200	>200	>200	>200	177.2	131.8	99.7	76.5	59.7	47.0	37.5	30.3	24.8	20.3	17.0	14.2	12.0	10.2	8.7	7.5	6.5	5.7	5.0	4.3	3.8	3.5	3.0	2.8	2.5	2.2	2.0	1.8
94	>200	>200	>200	>200	>200	>200	166.8	125.3	95.7	74.2	58.2	46.2	37.2	30.2	24.7	20.5	17.0	14.3	12.2	10.3	9.0	7.7	6.7	5.8	5.2	4.5	4.0	3.5	3.2	2.8	2.5	2.3	2.2
95	>200	>200	>200	>200	>200	>200	>200	158.3	120.0	92.3	72.0	57.0	45.5	36.8	30.0	24.8	20.5	17.2	14.5	12.3	10.7	9.2	7.8	6.8	6.0	5.3	4.7	4.2	3.7	3.3	3.0	2.7	2.3
96	>200	>200	>200	>200	>200	>200	>200	>200	151.0	115.5	89.7	70.5	56.0	45.0	36.7	30.0	24.8	20.7	17.5	14.8	12.7	10.8	9.3	8.2	7.0	6.2	5.5	4.8	4.3	3.8	3.5	3.2	2.8
97	>200	>200	>200	>200	>200	>200	>200	>200	190.8	145.0	111.8	87.3	69.2	55.3	44.7	36.5	30.2	25.0	21.0	17.7	15.0	12.8	11.0	9.5	8.3	7.3	6.3	5.7	5.0	4.5	4.0	3.5	3.2
98	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.7	140.0	108.8	85.7	68.2	54.8	44.5	36.5	30.3	25.2	21.2	18.0	15.3	13.2	11.3	9.8	8.5	7.5	6.7	5.8	5.2	4.7	4.2	3.7
99	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	176.0	136.0	106.3	84.2	67.5	54.5	44.5	36.7	30.5	25.5	21.5	18.3	15.7	13.5	11.7	10.2	8.8	7.8	6.8	6.0	5.3	4.8	4.3
100	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	170.5	132.7	104.5	83.2	67.0	54.5	44.7	37.0	30.8	26.0	22.0	18.7	16.0	13.8	12.0	10.5	9.2	8.0	7.2	6.3	5.7	5.0
101	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	166.2	130.2	103.2	82.7	66.8	54.7	45.0	37.3	31.3	26.3	22.3	19.2	16.5	14.2	12.3	10.8	9.5	8.3	7.3	6.5	5.8
102	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	162.7	128.3	102.2	82.3	67.0	54.8	45.5	37.8	31.8	26.8	22.8	19.7	16.8	14.7	12.7	11.2	9.8	8.7	7.7	6.8
103	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	160.2	127.0	101.8	82.3	67.3	55.5	46.0	38.5	32.5	27.5	23.5	20.2	17.3	15.2	13.2	11.5	10.2	9.0	8.0
104	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	158.5	126.5	101.8	82.8	67.8	56.2	46.8	39.3	33.2	28.2	24.2	20.8	18.0	15.7	13.7	12.0	10.5	9.3
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.8	157.7	126.3	102.3	83.5	68.8	57.0	47.7	40.2	34.0	29.0	24.8	21.5	18.7	16.2	14.2	12.5	11.0
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.7	157.7	127.0	103.2	84.7	69.8	58.2	48.8	41.2	35.0	30.0	25.7	22.2	19.3	16.8	14.8	13.0
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.7	158.3	128.2	104.5	86.0	71.3	59.7	50.2	42.5	36.2	31.0	26.7	23.2	20.2	17.5	15.5
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.7	159.8	129.8	106.5	87.8	73.2	61.3	51.7	43.8	37.5	32.2	27.8	24.0	21.0	18.3
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	162.2	132.3	108.8	90.2	75.2	63.2	53.5	45.5	38.8	33.5	29.0	25.2	22.0
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	165.5	135.5	111.8	92.8	77.7	65.5	55.5	47.3	40.7	35.0	30.3	26.3
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	169.7	139.3	115.3	96.2	80.7	68.2	57.8	49.5	42.5	36.7	31.8
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	175.0	144.2	119.7	100.0	84.2	71.2	60.7	52.0	44.7	38.7
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.5	150.0	124.8	104.7	88.2	74.8	63.8	54.7	47.2
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	189.3	157.0	131.0	110.0	93.0	79.0	67.5	58.0
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	199.0	165.3	138.3	116.3	98.5	83.8	71.8
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	175.3	147.0	124.0	105.2	89.7
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	187.5	157.5	133.0	113.0
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	170.0	143.8
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.5
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

Figure B-30 Tabular Representation of Parking Nomograph for C-17 on 21 °F (-6 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

21 F	Gross C-17 Weight (lb)																																
Sea Ice Thickness (inches)	280,000	290,000	300,000	310,000	320,000	330,000	340,000	350,000	360,000	370,000	380,000	390,000	400,000	410,000	420,000	430,000	440,000	450,000	460,000	470,000	480,000	490,000	500,000	510,000	520,000	530,000	540,000	550,000	560,000	570,000	580,000	590,000	600,000
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
65	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66	1.3	1.2	1.0	0.8	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
67	1.7	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0
68	2.2	1.7	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0
69	2.7	2.2	1.7	1.5	1.2	1.0	0.8	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0
70	3.3	2.7	2.2	1.8	1.5	1.3	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0
71	4.2	3.3	2.7	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0
72	5.2	4.2	3.3	2.7	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0
73	6.5	5.2	4.2	3.3	2.7	2.3	1.8	1.7	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
74	8.2	6.5	5.2	4.2	3.3	2.8	2.3	2.0	1.7	1.5	1.2	1.0	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
75	10.3	8.0	6.3	5.2	4.2	3.3	2.8	2.3	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
76	13.0	10.0	7.8	6.3	5.2	4.2	3.5	2.8	2.5	2.0	1.8	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
77	16.5	12.7	9.8	7.8	6.3	5.2	4.2	3.5	2.8	2.5	2.2	1.8	1.5	1.3	1.2	1.0	1.0	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2
78	21.0	15.8	12.3	9.7	7.7	6.2	5.2	4.2	3.5	3.0	2.5	2.2	1.8	1.7	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2
79	26.7	20.0	15.3	12.0	9.5	7.7	6.2	5.2	4.3	3.5	3.0	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3
80	33.8	25.3	19.3	15.0	11.8	9.3	7.7	6.2	5.2	4.3	3.7	3.0	2.7	2.3	2.0	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3
81	43.3	32.0	24.2	18.7	14.7	11.7	9.3	7.5	6.2	5.2	4.3	3.7	3.2	2.7	2.3	2.0	1.8	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3
82	55.3	40.7	30.5	23.3	18.2	14.3	11.5	9.3	7.5	6.3	5.2	4.3	3.7	3.2	2.8	2.3	2.2	1.8	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.5	0.3
83	71.0	51.8	38.5	29.2	22.5	17.7	14.0	11.3	9.2	7.5	6.3	5.3	4.5	3.8	3.3	2.8	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5
84	91.3	66.0	48.8	36.7	28.2	21.8	17.3	13.8	11.2	9.2	7.7	6.3	5.3	4.5	3.8	3.3	2.8	2.5	2.2	2.0	1.7	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5
85	117.8	84.5	61.8	46.2	35.2	27.2	21.3	17.0	13.7	11.2	9.2	7.7	6.3	5.5	4.7	4.0	3.5	3.0	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7
86	152.5	108.3	78.7	58.3	44.0	33.8	26.3	20.8	16.7	13.5	11.2	9.2	7.7	6.5	5.5	4.7	4.0	3.5	3.0	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7
87	197.8	139.3	100.3	73.8	55.3	42.2	32.7	25.8	20.5	16.5	13.5	11.2	9.3	7.8	6.5	5.7	4.8	4.2	3.7	3.2	2.8	2.5	2.2	2.0	1.7	1.5	1.3	1.3	1.2	1.0	1.0	0.8	0.8
88	>200	179.7	128.3	93.7	69.7	52.8	40.7	31.8	25.2	20.2	16.3	13.5	11.2	9.3	7.8	6.7	5.7	4.8	4.2	3.7	3.2	2.8	2.5	2.2	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8
89	>200	>200	164.7	119.3	88.2	66.3	50.7	39.5	31.0	24.8	20.0	16.3	13.5	11.2	9.3	8.0	6.8	5.8	5.0	4.3	3.8	3.3	3.0	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.2	1.0
90	>200	>200	>200	152.3	111.7	83.5	63.5	49.0	38.3	30.5	24.5	19.8	16.3	13.5	11.3	9.5	8.0	6.8	6.0	5.2	4.5	3.8	3.5	3.0	2.7	2.3	2.2	2.0	1.7	1.5	1.5	1.3	1.2
91	>200	>200	>200	195.0	142.0	105.3	79.5	61.0	47.5	37.5	29.8	24.2	19.7	16.3	13.5	11.3	9.7	8.2	7.0	6.0	5.2	4.5	4.0	3.5	3.2	2.8	2.5	2.2	2.0	1.8	1.7	1.5	1.3
92	>200	>200	>200	>200	181.0	133.3	100.0	76.2	59.0	46.2	36.7	29.5	24.0	19.7	16.3	13.7	11.5	9.7	8.3	7.2	6.2	5.3	4.7	4.2	3.7	3.2	2.8	2.5	2.3	2.0	1.8	1.7	1.5
93	>200	>200	>200	>200	>200	169.3	126.0	95.5	73.3	57.2	45.2	36.2	29.2	23.8	19.7	16.3	13.7	11.7	9.8	8.5	7.3	6.3	5.5	4.8	4.3	3.8	3.3	3.0	2.7	2.3	2.2	2.0	1.8
94	>200	>200	>200	>200	>200	>200	159.5	120.0	91.7	71.0	55.8	44.3	35.7	29.0	23.8	19.7	16.5	13.8	11.8	10.0	8.7	7.5	6.5	5.7	5.0	4.3	3.8	3.5	3.2	2.8	2.5	2.3	2.0
95	>200	>200	>200	>200	>200	>200	>200	151.3	114.8	88.5	69.2	54.7	43.8	35.3	29.0	23.8	19.8	16.7	14.0	12.0	10.2	8.8	7.7	6.7	5.8	5.2	4.5	4.0	3.7	3.2	2.8	2.7	2.3
96	>200	>200	>200	>200	>200	>200	>200	191.5	144.3	110.5	85.8	67.5	53.8	43.3	35.2	28.8	24.0	20.0	16.8	14.3	12.2	10.5	9.0	7.8	6.8	6.0	5.3	4.7	4.2	3.7	3.3	3.0	2.7
97	>200	>200	>200	>200	>200	>200	>200	>200	182.2	138.7	107.0	83.7	66.3	53.2	43.0	35.2	29.0	24.2	20.2	17.0	14.5	12.5	10.7	9.3	8.0	7.0	6.2	5.5	4.8	4.3	3.8	3.5	3.2
98	>200	>200	>200	>200	>200	>200	>200	>200	>200	174.5	134.0	104.2	82.0	65.3	52.7	42.8	35.2	29.2	24.3	20.5	17.3	14.8	12.7	11.0	9.5	8.3	7.3	6.3	5.7	5.0	4.5	4.0	3.7
99	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	168.2	130.0	101.8	80.7	64.7	52.3	42.8	35.3	29.3	24.7	20.8	17.7	15.2	13.0	11.3	9.8	8.5	7.5	6.7	5.8	5.2	4.7	4.2
100	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	163.0	127.0	100.2	79.8	64.3	52.3	43.0	35.7	29.7	25.0	21.2	18.0	15.5	13.3	11.5	10.2	8.8	7.8	6.8	6.2	5.5	4.8
101	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	158.8	124.5	98.8	79.2	64.2	52.5	43.3	36.0	30.2	25.3	21.7	18.5	15.8	13.7	12.0	10.5	9.2	8.0	7.2	6.3	5.7
102	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	199.5	155.5	122.8	98.0	79.0	64.3	52.8	43.7	36.5	30.7	26.0	22.2	19.0	16.3	14.2	12.3	10.8	9.5	8.3	7.5	6.7
103	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.2	153.2	121.7	97.5	79.0	64.7	53.2	44.2	37.0	31.2	26.5	22.7	19.5	16.8	14.7	12.7	11.2	9.8	8.7	7.7
104	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.0	151.7	121.0	97.5	79.3	65.2	54.0	45.0	37.8	32.0	27.2	23.3	20.0	17.3	15.2	13.2	11.7	10.2	9.0
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	190.0	150.8	121.0	98.0	80.2	66.0	54.8	45.8	38.7	32.8	28.0	24.0	20.7	18.0	15.7	13.7	12.0	10.7
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.8	150.8	121.5	98.8	81.2	67.2	56.0	47.0	39.7	33.7	28.8	24.8	21.5	18.7	16.3	14.3	12.7
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.8	151.5	122.7	100.2	82.5	68.5	57.3	48.2	40.8	34.8	29.8	25.7	22.3	19.3	17.0	14.8
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	189.8	153.0	124.3	102.0	84.3	70.2	58.8	49.7	42.2	36.0	31.0	26.7	23.2	20.2	17.7
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.7	155.2	126.7	104.2	86.5	72.2	60.7	51.3	43.7	37.5	32.2	27.8	24.3	21.2
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	194.8	158.3	129.7	107.0	89.0	74.7	62.8	53.3	45.5	39.0	33.7	29.2	25.5
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	199.0	162.3	133.5	110.5	92.2	77.5	65.5	55.7	47.5	40.8	35.3	30.7
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	167.3	138.0	114.7	95.8	80.7	68.3	58.3	49.8	43.0	37.2
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	173.5	143.5	119.5	100.3	84.7	71.8	61.3	52.7	45.3
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.0	150.2	125.5	105.5	89.2	75.8	64.8	55.7
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	190.2	158.2	132.3	111.5	94.5	80.5	69.0
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	167.7	140.7	118.7	100.8	86.0
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.3	150.7	127.3	108.3
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.3	162.7	137.7
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.3
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

Figure B-31 Tabular Representation of Parking Nomograph for C-17 on 22 °F (-5.5 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

22 F	Gross C-17 Weight (lb)																																
Sea Ice Thickness (inches)	280,000	290,000	300,000	310,000	320,000	330,000	340,000	350,000	360,000	370,000	380,000	390,000	400,000	410,000	420,000	430,000	440,000	450,000	460,000	470,000	480,000	490,000	500,000	510,000	520,000	530,000	540,000	550,000	560,000	570,000	580,000	590,000	600,000
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	0.8	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
65	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66	1.3	1.0	0.8	0.8	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
67	1.7	1.3	1.2	1.0	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0
68	2.0	1.7	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0
69	2.5	2.0	1.7	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0
70	3.2	2.5	2.2	1.7	1.5	1.2	1.0	0.8	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0
71	4.0	3.2	2.7	2.2	1.8	1.5	1.3	1.0	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0
72	5.0	4.0	3.2	2.7	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0
73	6.3	5.0	4.0	3.2	2.7	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
74	8.0	6.2	5.0	4.0	3.3	2.7	2.3	1.8	1.7	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
75	10.0	7.8	6.2	5.0	4.0	3.3	2.7	2.3	2.0	1.7	1.5	1.2	1.0	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
76	12.7	9.7	7.7	6.2	5.0	4.0	3.3	2.8	2.3	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
77	16.0	12.2	9.5	7.5	6.0	5.0	4.0	3.3	2.8	2.3	2.0	1.8	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2
78	20.2	15.3	11.8	9.3	7.5	6.0	5.0	4.2	3.3	2.8	2.5	2.2	1.8	1.5	1.3	1.2	1.0	1.0	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2
79	25.7	19.3	14.8	11.7	9.2	7.3	6.0	5.0	4.2	3.5	3.0	2.5	2.2	1.8	1.7	1.5	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3
80	32.5	24.3	18.7	14.5	11.3	9.2	7.3	6.0	5.0	4.2	3.5	3.0	2.5	2.2	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3
81	41.5	30.8	23.3	18.0	14.2	11.2	9.0	7.3	6.0	5.0	4.2	3.5	3.0	2.7	2.3	2.0	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3
82	53.2	39.2	29.3	22.5	17.5	13.8	11.0	9.0	7.3	6.0	5.0	4.3	3.7	3.2	2.7	2.3	2.0	1.8	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.5	0.3
83	68.0	49.7	37.0	28.2	21.7	17.0	13.5	11.0	8.8	7.3	6.2	5.2	4.3	3.7	3.2	2.8	2.3	2.2	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5
84	87.5	63.3	46.8	35.3	27.0	21.2	16.7	13.3	10.8	8.8	7.3	6.2	5.2	4.3	3.8	3.3	2.8	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5
85	112.7	80.8	59.3	44.3	33.8	26.2	20.5	16.3	13.2	10.8	8.8	7.3	6.2	5.3	4.5	3.8	3.3	2.8	2.5	2.2	2.0	1.7	1.5	1.3	1.2	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7
86	145.7	103.5	75.3	56.0	42.3	32.5	25.5	20.2	16.2	13.2	10.8	8.8	7.5	6.3	5.3	4.5	4.0	3.3	3.0	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7
87	188.8	133.0	96.0	70.7	53.2	40.7	31.5	24.8	19.8	16.0	13.0	10.8	9.0	7.5	6.3	5.5	4.7	4.0	3.5	3.0	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.8
88	>200	171.5	122.7	89.7	66.8	50.7	39.2	30.7	24.3	19.5	15.8	13.0	10.8	9.0	7.7	6.5	5.5	4.8	4.2	3.7	3.2	2.8	2.5	2.2	2.0	1.7	1.5	1.3	1.3	1.2	1.0	1.0	0.8
89	>200	>200	157.3	114.0	84.3	63.7	48.7	37.8	29.8	23.8	19.3	15.7	13.0	10.8	9.0	7.7	6.5	5.7	4.8	4.2	3.7	3.2	2.8	2.5	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.2	1.0
90	>200	>200	>200	145.5	106.8	80.0	60.8	47.0	36.8	29.3	23.5	19.2	15.7	13.0	10.8	9.2	7.8	6.7	5.7	5.0	4.3	3.8	3.3	3.0	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.3	1.2
91	>200	>200	>200	186.2	135.7	100.8	76.2	58.5	45.7	36.0	28.8	23.3	19.0	15.7	13.0	11.0	9.3	7.8	6.8	5.8	5.2	4.5	3.8	3.5	3.0	2.7	2.5	2.2	2.0	1.8	1.7	1.5	1.3
92	>200	>200	>200	>200	172.8	127.5	95.7	73.0	56.5	44.3	35.3	28.3	23.2	19.0	15.7	13.2	11.2	9.3	8.0	7.0	6.0	5.2	4.5	4.0	3.5	3.2	2.8	2.5	2.3	2.0	1.8	1.7	1.5
93	>200	>200	>200	>200	>200	161.7	120.5	91.3	70.3	55.0	43.5	34.8	28.2	23.0	19.0	15.8	13.3	11.2	9.5	8.2	7.0	6.2	5.3	4.7	4.2	3.7	3.3	2.8	2.7	2.3	2.2	1.8	1.7
94	>200	>200	>200	>200	>200	>200	152.3	114.8	87.8	68.2	53.7	42.7	34.3	28.0	23.0	19.0	15.8	13.3	11.3	9.7	8.3	7.2	6.3	5.5	4.8	4.3	3.8	3.3	3.0	2.7	2.5	2.2	2.0
95	>200	>200	>200	>200	>200	>200	193.3	144.7	109.8	84.8	66.3	52.5	42.0	34.0	27.8	23.0	19.2	16.0	13.5	11.5	9.8	8.5	7.3	6.5	5.7	5.0	4.3	4.0	3.5	3.2	2.8	2.5	2.3
96	>200	>200	>200	>200	>200	>200	>200	182.8	138.0	105.8	82.3	64.8	51.7	41.7	33.8	27.8	23.0	19.3	16.3	13.8	11.8	10.2	8.7	7.7	6.7	5.8	5.2	4.5	4.0	3.7	3.2	3.0	2.7
97	>200	>200	>200	>200	>200	>200	>200	>200	174.0	132.7	102.5	80.3	63.7	51.0	41.3	33.8	27.8	23.2	19.5	16.5	14.0	12.0	10.3	9.0	7.8	6.8	6.0	5.3	4.7	4.2	3.8	3.3	3.0
98	>200	>200	>200	>200	>200	>200	>200	>200	>200	166.7	128.2	99.8	78.7	62.7	50.5	41.2	33.8	28.0	23.5	19.7	16.7	14.3	12.3	10.7	9.2	8.0	7.0	6.2	5.5	4.8	4.3	3.8	3.5
99	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	160.7	124.3	97.5	77.3	62.2	50.3	41.2	34.0	28.3	23.7	20.0	17.0	14.7	12.5	10.8	9.5	8.3	7.3	6.5	5.7	5.0	4.5	4.0
100	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	155.8	121.5	95.8	76.5	61.7	50.3	41.3	34.2	28.7	24.0	20.3	17.3	15.0	12.8	11.2	9.8	8.5	7.5	6.7	6.0	5.3	4.7
101	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.8	151.8	119.2	94.7	76.0	61.5	50.3	41.7	34.7	29.0	24.5	20.8	17.8	15.3	13.3	11.5	10.0	8.8	7.8	6.8	6.2	5.5
102	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	190.5	148.7	117.5	93.8	75.7	61.7	50.7	42.0	35.0	29.5	25.0	21.3	18.3	15.8	13.7	11.8	10.5	9.2	8.2	7.2	6.3
103	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	186.5	146.5	116.3	93.5	75.8	62.0	51.2	42.5	35.7	30.2	25.5	21.8	18.8	16.2	14.2	12.3	10.8	9.5	8.5	7.5
104	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	183.5	145.0	115.8	93.5	76.2	62.5	51.8	43.2	36.3	30.8	26.2	22.5	19.3	16.8	14.7	12.8	11.2	9.8	8.8
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.5	144.3	115.8	93.8	76.8	63.3	52.7	44.2	37.2	31.5	27.0	23.2	20.0	17.3	15.2	13.3	11.7	10.3
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.5	144.2	116.3	94.7	77.8	64.3	53.7	45.2	38.2	32.5	27.8	24.0	20.7	18.0	15.7	13.8	12.2
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.5	144.8	117.5	96.0	79.2	65.7	55.0	46.3	39.3	33.5	28.8	24.8	21.5	18.7	16.3	14.3
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.3	146.3	119.0	97.7	80.8	67.3	56.5	47.7	40.7	34.7	29.8	25.8	22.3	19.5	17.2
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	183.2	148.5	121.3	99.8	82.8	69.3	58.3	49.3	42.0	36.0	31.0	26.8	23.3	20.5
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	186.2	151.3	124.2	102.7	85.3	71.7	60.3	51.3	43.8	37.7	32.5	28.2	24.5
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	190.2	155.2	127.7	105.8	88.3	74.3	62.8	53.5	45.7	39.3	34.0	29.5
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.3	160.0	132.0	109.8	92.0	77.5	65.7	56.0	48.0	41.3	35.8
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	166.0	137.3	114.5	96.2	81.2	69.0	58.8	50.5	43.7
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	173.2	143.7	120.2	101.0	85.5	72.8	62.3	53.5
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.8	151.3	126.8	106.8	90.7	77.2	66.2
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.3	160.5	134.7	113.7	96.7	82.5
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	171.5	144.2	122.0	103.8
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	184.8	155.7	131.8
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	169.7
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

Figure B-32 Tabular Representation of Parking Nomograph for C-17 on 23 °F (-5 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

23 F	Gross C-17 Weight (lb)																															
Sea Ice Thickness (inches)	280,000	290,000	300,000	310,000	320,000	330,000	340,000	350,000	360,000	370,000	380,000	390,000	400,000	410,000	420,000	430,000	440,000	450,000	460,000	470,000	480,000	490,000	500,000	510,000	520,000	530,000	540,000	550,000	560,000	570,000	580,000	590,000	600,000
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
65	0.8	0.8	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66	1.2	1.0	0.8	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
67	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
68	1.8	1.5	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0
69	2.2	1.8	1.5	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0
70	2.7	2.2	1.8	1.5	1.3	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0
71	3.5	2.8	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0
72	4.3	3.5	2.8	2.3	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0
73	5.3	4.2	3.5	2.8	2.3	2.0	1.7	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0
74	6.7	5.3	4.2	3.5	2.8	2.3	2.0	1.7	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
75	8.3	6.5	5.2	4.2	3.5	2.8	2.3	2.0	1.7	1.5	1.2	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
76	10.5	8.2	6.5	5.2	4.2	3.5	2.8	2.3	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
77	13.3	10.2	8.0	6.3	5.2	4.2	3.5	2.8	2.5	2.0	1.8	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
78	16.7	12.8	10.0	7.8	6.3	5.2	4.2	3.5	3.0	2.5	2.2	1.8	1.5	1.3	1.2	1.0	1.0	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2
79	21.2	16.0	12.3	9.7	7.8	6.3	5.2	4.2	3.5	3.0	2.5	2.2	1.8	1.7	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2
80	26.7	20.2	15.5	12.0	9.5	7.7	6.2	5.2	4.3	3.5	3.0	2.7	2.2	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3
81	33.8	25.3	19.3	15.0	11.8	9.3	7.7	6.2	5.2	4.3	3.7	3.0	2.7	2.3	2.0	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3
82	43.2	32.0	24.2	18.7	14.5	11.5	9.3	7.5	6.2	5.2	4.3	3.7	3.2	2.7	2.3	2.0	1.8	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3
83	55.0	40.3	30.3	23.2	18.0	14.2	11.3	9.2	7.5	6.2	5.2	4.3	3.7	3.2	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.5	0.3
84	70.2	51.2	38.2	29.0	22.3	17.5	14.0	11.2	9.2	7.5	6.3	5.2	4.5	3.8	3.3	2.8	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5
85	90.0	65.2	48.2	36.2	27.8	21.7	17.2	13.7	11.2	9.2	7.5	6.3	5.3	4.5	3.8	3.3	2.8	2.5	2.2	2.0	1.7	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5
86	115.7	83.0	60.8	45.5	34.7	26.8	21.0	16.7	13.5	11.0	9.0	7.5	6.3	5.3	4.5	4.0	3.3	3.0	2.5	2.3	2.0	1.8	1.5	1.3	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7
87	149.2	106.0	77.0	57.2	43.2	33.2	26.0	20.5	16.5	13.3	11.0	9.0	7.5	6.3	5.5	4.7	4.0	3.5	3.0	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7
88	192.8	135.8	98.0	72.2	54.2	41.3	32.0	25.2	20.2	16.2	13.2	11.0	9.2	7.7	6.5	5.5	4.7	4.0	3.5	3.2	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.2	1.2	1.0	1.0	0.8	0.8
89	>200	174.7	125.0	91.3	68.0	51.5	39.7	31.2	24.7	19.8	16.0	13.2	11.0	9.2	7.7	6.5	5.7	4.8	4.2	3.7	3.2	2.8	2.5	2.2	2.0	1.8	1.5	1.5	1.3	1.2	1.0	1.0	0.8
90	>200	>200	159.8	115.8	85.7	64.5	49.3	38.3	30.3	24.2	19.5	16.0	13.2	11.0	9.2	7.8	6.7	5.7	4.8	4.3	3.7	3.3	2.8	2.5	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.2	1.0
91	>200	>200	>200	147.5	108.2	81.0	61.5	47.5	37.3	29.7	23.8	19.3	15.8	13.2	11.0	9.3	7.8	6.7	5.8	5.0	4.3	3.8	3.3	3.0	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.3	1.2
92	>200	>200	>200	188.3	137.2	101.8	77.0	59.2	46.0	36.3	29.0	23.5	19.2	15.8	13.2	11.0	9.3	8.0	6.8	5.8	5.2	4.5	4.0	3.5	3.0	2.7	2.5	2.2	2.0	1.8	1.7	1.5	1.3
93	>200	>200	>200	>200	174.3	128.5	96.5	73.7	57.0	44.8	35.7	28.7	23.3	19.2	15.8	13.2	11.2	9.5	8.2	7.0	6.0	5.2	4.7	4.0	3.5	3.2	2.8	2.5	2.3	2.0	1.8	1.7	1.5
94	>200	>200	>200	>200	>200	162.8	121.3	92.0	70.8	55.3	43.7	35.0	28.3	23.2	19.2	15.8	13.3	11.3	9.7	8.2	7.2	6.2	5.3	4.7	4.2	3.7	3.3	3.0	2.7	2.3	2.2	1.8	1.7
95	>200	>200	>200	>200	>200	>200	153.2	115.3	88.2	68.5	53.8	42.8	34.5	28.0	23.0	19.2	16.0	13.5	11.5	9.8	8.3	7.3	6.3	5.5	4.8	4.3	3.8	3.3	3.0	2.7	2.5	2.2	2.0
96	>200	>200	>200	>200	>200	>200	194.0	145.2	110.3	85.0	66.5	52.7	42.2	34.2	28.0	23.0	19.2	16.2	13.7	11.7	10.0	8.5	7.5	6.5	5.7	5.0	4.5	4.0	3.5	3.2	2.8	2.5	2.3
97	>200	>200	>200	>200	>200	>200	>200	183.2	138.3	106.0	82.5	65.0	51.7	41.7	34.0	27.8	23.2	19.3	16.3	13.8	11.8	10.2	8.8	7.7	6.7	5.8	5.2	4.5	4.0	3.7	3.3	3.0	2.7
98	>200	>200	>200	>200	>200	>200	>200	>200	174.2	132.7	102.5	80.3	63.7	51.0	41.3	33.8	28.0	23.2	19.5	16.5	14.0	12.0	10.3	9.0	7.8	6.8	6.0	5.3	4.7	4.2	3.8	3.3	3.0
99	>200	>200	>200	>200	>200	>200	>200	>200	>200	166.7	128.0	99.7	78.7	62.7	50.5	41.2	33.8	28.0	23.5	19.7	16.7	14.3	12.3	10.7	9.2	8.0	7.0	6.2	5.5	4.8	4.3	3.8	3.5
100	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	160.5	124.2	97.5	77.3	62.0	50.3	41.2	34.0	28.3	23.7	20.0	17.0	14.5	12.5	10.8	9.5	8.3	7.3	6.5	5.7	5.0	4.5	4.0
101	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	155.3	121.2	95.7	76.3	61.7	50.2	41.2	34.2	28.5	24.0	20.3	17.3	14.8	12.8	11.2	9.7	8.5	7.5	6.7	5.8	5.3	4.7
102	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.2	151.3	118.8	94.3	75.8	61.5	50.3	41.5	34.5	29.0	24.5	20.8	17.8	15.3	13.2	11.5	10.0	8.8	7.8	6.8	6.2	5.5
103	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	189.8	148.2	117.2	93.5	75.5	61.5	50.5	41.8	35.0	29.3	24.8	21.2	18.2	15.7	13.7	11.8	10.3	9.2	8.0	7.2	6.3
104	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.7	146.0	116.0	93.2	75.5	61.8	51.0	42.3	35.5	30.0	25.5	21.8	18.7	16.2	14.0	12.3	10.8	9.5	8.3	7.5
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.7	144.5	115.5	93.2	75.8	62.3	51.7	43.2	36.2	30.7	26.2	22.3	19.3	16.7	14.5	12.7	11.2	9.8	8.7
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.8	143.7	115.5	93.5	76.5	63.2	52.5	44.0	37.0	31.5	26.8	23.0	20.0	17.3	15.2	13.2	11.7	10.3
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.8	143.7	116.0	94.5	77.5	64.2	53.5	45.0	38.0	32.3	27.7	23.8	20.7	18.0	15.7	13.8	12.2
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.8	144.5	117.2	95.7	79.0	65.5	54.8	46.2	39.2	33.5	28.7	24.7	21.5	18.7	16.3	14.3
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.0	146.0	118.8	97.5	80.7	67.2	56.3	47.7	40.5	34.7	29.8	25.7	22.3	19.5	17.2
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	183.0	148.3	121.2	99.8	82.8	69.2	58.3	49.3	42.0	36.0	31.0	26.8	23.3	20.5
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	186.2	151.3	124.2	102.7	85.5	71.7	60.3	51.3	43.8	37.7	32.5	28.2	24.5
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	190.5	155.5	128.0	106.0	88.5	74.5	63.0	53.5	45.8	39.3	34.0	29.7
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	196.2	160.7	132.7	110.2	92.3	77.7	65.8	56.2	48.2	41.5	36.0
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	167.0	138.3	115.2	96.7	81.7	69.3	59.2	50.8	43.8
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	174.8	145.2	121.2	102.0	86.3	73.3	62.8	54.0
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	184.3	153.3	128.3	108.2	91.7	78.2	67.0
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.8	163.3	137.0	115.7	98.2	83.8
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	175.5	147.5	124.7	106.0
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	190.3	160.2	135.7
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	176.0

Figure B-33 Tabular Representation of Parking Nomograph for C-17 on 24 °F (-4.5 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

Gross C-17 Weight (lb) — columns 280,000 to 430,000

24 F / Sea Ice Thickness (inches)	280,000	290,000	300,000	310,000	320,000	330,000	340,000	350,000	360,000	370,000	380,000	390,000	400,000	410,000	420,000	430,000
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0
59	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0
60	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0
61	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0
62	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0
63	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0
64	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0
65	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
66	1.2	0.8	0.8	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
67	1.3	1.2	1.0	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
68	1.7	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2
69	2.2	1.7	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2
70	2.7	2.2	1.7	1.5	1.2	1.0	0.8	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3
71	3.3	2.7	2.2	1.8	1.5	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3
72	4.2	3.3	2.7	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3
73	5.2	4.0	3.3	2.7	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5
74	6.3	5.0	4.0	3.3	2.7	2.2	1.8	1.7	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5
75	8.0	6.3	5.0	4.0	3.3	2.7	2.3	2.0	1.7	1.3	1.2	1.0	0.8	0.8	0.7	0.7
76	10.0	7.8	6.2	5.0	4.0	3.3	2.8	2.3	2.0	1.7	1.5	1.2	1.0	1.0	0.8	0.7
77	12.7	9.7	7.7	6.2	5.0	4.0	3.3	2.8	2.3	2.0	1.7	1.5	1.3	1.2	1.0	0.8
78	15.8	12.2	9.5	7.5	6.0	5.0	4.0	3.3	2.8	2.3	2.0	1.8	1.5	1.3	1.2	1.0
79	20.0	15.3	11.8	9.3	7.5	6.0	4.8	4.0	3.3	2.8	2.5	2.2	1.8	1.5	1.3	1.2
80	25.3	19.2	14.7	11.5	9.2	7.3	6.0	5.0	4.2	3.5	2.8	2.5	2.2	1.8	1.7	1.3
81	32.2	24.0	18.3	14.3	11.2	9.0	7.3	6.0	5.0	4.2	3.5	3.0	2.5	2.2	1.8	1.7
82	40.8	30.3	23.0	17.7	13.8	11.0	8.8	7.2	6.0	5.0	4.2	3.5	3.0	2.7	2.2	2.0
83	52.0	38.3	28.8	22.0	17.2	13.5	10.8	8.8	7.2	6.0	5.0	4.2	3.7	3.0	2.7	2.3
84	66.5	48.5	36.2	27.5	21.3	16.7	13.3	10.7	8.7	7.2	6.0	5.0	4.3	3.7	3.2	2.7
85	85.0	61.7	45.7	34.3	26.5	20.7	16.3	13.0	10.7	8.7	7.2	6.0	5.2	4.3	3.7	3.2
86	109.2	78.5	57.7	43.2	32.8	25.5	20.0	16.0	12.8	10.5	8.7	7.2	6.0	5.2	4.3	3.8
87	140.7	100.2	73.0	54.2	41.0	31.7	24.7	19.7	15.7	12.8	10.5	8.7	7.3	6.2	5.2	4.5
88	181.7	128.3	92.7	68.3	51.3	39.3	30.5	24.0	19.2	15.5	12.7	10.5	8.7	7.3	6.2	5.3
89	>200	164.7	118.0	86.3	64.5	49.0	37.8	29.7	23.5	18.8	15.3	12.7	10.5	8.8	7.3	6.3
90	>200	>200	150.8	109.5	81.2	61.2	47.0	36.5	28.8	23.0	18.7	15.2	12.7	10.5	8.8	7.5
91	>200	>200	193.3	139.3	102.5	76.7	58.5	45.2	35.5	28.2	22.7	18.5	15.2	12.7	10.5	8.8
92	>200	>200	>200	177.7	129.7	96.5	73.0	56.2	43.8	34.7	27.7	22.5	18.3	15.2	12.7	10.7
93	>200	>200	>200	>200	164.7	121.7	91.5	69.8	54.2	42.7	33.8	27.3	22.2	18.3	15.2	12.7
94	>200	>200	>200	>200	>200	154.0	115.0	87.2	67.2	52.5	41.7	33.3	27.0	22.2	18.3	15.2
95	>200	>200	>200	>200	>200	195.5	144.8	109.3	83.7	65.0	51.2	40.8	32.8	26.8	22.0	18.3
96	>200	>200	>200	>200	>200	>200	183.3	137.3	104.5	80.8	63.2	50.2	40.2	32.7	26.7	22.0
97	>200	>200	>200	>200	>200	>200	>200	173.2	131.0	100.7	78.3	61.8	49.3	39.8	32.3	26.7
98	>200	>200	>200	>200	>200	>200	>200	>200	164.8	125.8	97.3	76.3	60.7	48.7	39.5	32.3
99	>200	>200	>200	>200	>200	>200	>200	>200	>200	157.8	121.3	94.7	74.8	59.7	48.2	39.3
100	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.8	152.0	117.8	92.5	73.5	59.0	48.0
101	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.2	147.3	115.0	90.8	72.7	58.7
102	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	184.8	143.5	112.8	89.7	72.2
103	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.8	140.7	111.2	89.0
104	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	176.0	138.5	110.2
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	173.3	137.2
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	171.5
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

Gross C-17 Weight (lb) — columns 440,000 to 600,000

24 F / Sea Ice Thickness (inches)	440,000	450,000	460,000	470,000	480,000	490,000	500,000	510,000	520,000	530,000	540,000	550,000	560,000	570,000	580,000	590,000	600,000
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
67	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
68	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0
69	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0
70	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0
71	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0
72	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0
73	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0
74	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
75	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
76	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
77	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
78	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2
79	1.0	1.0	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2
80	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2
81	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3
82	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3
83	2.0	1.8	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3
84	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5
85	2.8	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5
86	3.3	2.8	2.5	2.2	2.0	1.7	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5
87	3.8	3.3	2.8	2.5	2.2	2.0	1.8	1.5	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7
88	4.5	4.0	3.3	3.0	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.8
89	5.3	4.7	4.0	3.5	3.0	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.2	1.2	1.0	1.0	0.8
90	6.3	5.5	4.7	4.2	3.7	3.2	2.8	2.5	2.2	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0
91	7.5	6.5	5.5	4.8	4.2	3.7	3.2	2.8	2.5	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.2
92	9.0	7.7	6.5	5.7	5.0	4.3	3.8	3.3	3.0	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.3
93	10.7	9.2	7.8	6.7	5.8	5.0	4.5	3.8	3.5	3.0	2.7	2.5	2.2	2.0	1.8	1.7	1.5
94	12.8	10.8	9.2	7.8	6.8	6.0	5.2	4.5	4.0	3.5	3.2	2.8	2.5	2.3	2.0	1.8	1.7
95	15.3	12.8	11.0	9.3	8.0	7.0	6.0	5.3	4.7	4.2	3.7	3.3	3.0	2.7	2.3	2.2	2.0
96	18.3	15.5	13.0	11.2	9.5	8.2	7.2	6.2	5.5	4.8	4.3	3.8	3.3	3.0	2.7	2.5	2.2
97	22.2	18.5	15.7	13.2	11.3	9.7	8.5	7.3	6.3	5.7	5.0	4.3	4.0	3.5	3.2	2.8	2.5
98	26.7	22.2	18.7	15.8	13.5	11.5	10.0	8.7	7.5	6.7	5.8	5.2	4.5	4.0	3.7	3.3	3.0
99	32.3	26.8	22.5	18.8	16.0	13.7	11.8	10.2	8.8	7.7	6.8	6.0	5.3	4.7	4.2	3.8	3.3
100	39.3	32.5	27.0	22.7	19.2	16.3	14.0	12.0	10.5	9.2	8.0	7.0	6.2	5.5	4.8	4.3	4.0
101	47.8	39.3	32.7	27.3	23.0	19.5	16.7	14.3	12.3	10.7	9.3	8.2	7.2	6.3	5.7	5.0	4.5
102	58.5	48.0	39.7	33.0	27.7	23.3	19.8	17.0	14.7	12.7	11.0	9.7	8.5	7.5	6.7	6.0	5.3
103	71.8	58.7	48.2	40.0	33.5	28.2	23.8	20.3	17.5	15.0	13.2	11.3	10.0	8.8	7.8	6.8	6.2
104	88.7	71.8	58.8	48.7	40.5	34.0	28.7	24.3	20.8	18.0	15.5	13.5	11.8	10.3	9.2	8.2	7.2
105	109.7	88.7	72.3	59.5	49.3	41.2	34.7	29.3	25.0	21.5	18.5	16.0	14.0	12.2	10.8	9.5	8.5
106	136.5	109.7	89.0	73.0	60.2	50.2	42.0	35.5	30.2	25.7	22.2	19.2	16.7	14.5	12.7	11.2	9.8
107	170.7	136.5	110.3	89.8	73.8	61.2	51.2	43.0	36.3	31.0	26.5	22.8	19.8	17.2	15.0	13.2	11.7
108	>200	170.7	137.3	111.3	91.2	75.2	62.5	52.3	44.2	37.5	32.0	27.5	23.7	20.5	18.0	15.7	13.8
109	>200	>200	171.8	138.7	113.0	92.8	76.8	64.2	53.8	45.5	38.8	33.2	28.5	24.7	21.5	18.7	16.5
110	>200	>200	>200	173.8	140.8	115.3	95.0	79.0	66.0	55.7	47.2	40.2	34.5	29.7	25.8	22.5	19.7
111	>200	>200	>200	>200	176.8	144.0	118.2	97.7	81.5	68.3	57.7	49.0	41.8	36.0	31.2	27.0	23.5
112	>200	>200	>200	>200	>200	181.0	147.8	121.8	101.0	84.5	71.0	60.2	51.2	43.8	37.7	32.7	28.3
113	>200	>200	>200	>200	>200	>200	186.3	152.8	126.2	105.0	88.0	74.2	63.0	53.7	46.0	39.7	34.5
114	>200	>200	>200	>200	>200	>200	>200	193.0	158.8	131.7	109.8	92.2	78.0	66.2	56.7	48.7	42.0
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	166.2	138.2	115.5	97.2	82.3	70.2	60.0	51.7
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	175.2	146.0	122.3	103.2	87.5	74.7	64.0
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	186.2	155.3	130.5	110.3	93.7	80.0
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	199.7	167.0	140.5	118.8	101.2
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.0	152.5	129.3
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.7	167.7

Figure B-34 Tabular Representation of Parking Nomograph for C-17 on 25 °F (-4 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

25 F	Gross C-17 Weight (lb)																																
Sea Ice Thickness (inches)	280,000	290,000	300,000	310,000	320,000	330,000	340,000	350,000	360,000	370,000	380,000	390,000	400,000	410,000	420,000	430,000	440,000	450,000	460,000	470,000	480,000	490,000	500,000	510,000	520,000	530,000	540,000	550,000	560,000	570,000	580,000	590,000	600,000
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
65	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
67	1.3	1.0	0.8	0.8	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
68	1.7	1.3	1.2	1.0	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0
69	2.0	1.7	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0
70	2.5	2.0	1.7	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0
71	3.2	2.5	2.0	1.7	1.5	1.2	1.0	0.8	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0
72	3.8	3.2	2.5	2.2	1.7	1.5	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0
73	4.8	3.8	3.2	2.5	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0
74	6.2	4.8	3.8	3.2	2.7	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
75	7.7	6.0	4.8	3.8	3.2	2.7	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
76	9.5	7.5	5.8	4.7	3.8	3.2	2.7	2.2	1.8	1.7	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
77	12.0	9.3	7.3	5.8	4.7	3.8	3.2	2.7	2.3	2.0	1.7	1.5	1.2	1.0	1.0	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
78	15.2	11.7	9.0	7.2	5.8	4.7	3.8	3.2	2.7	2.3	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2
79	19.0	14.5	11.3	8.8	7.2	5.7	4.7	3.8	3.3	2.8	2.3	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2
80	24.0	18.2	14.0	11.0	8.7	7.0	5.7	4.7	4.0	3.3	2.8	2.3	2.0	1.8	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2
81	30.5	22.8	17.5	13.7	10.7	8.7	7.0	5.7	4.7	4.0	3.3	2.8	2.5	2.2	1.8	1.7	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3
82	38.7	28.8	21.8	16.8	13.2	10.5	8.5	7.0	5.7	4.8	4.0	3.3	2.8	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3
83	49.2	36.3	27.3	21.0	16.3	13.0	10.3	8.5	6.8	5.7	4.8	4.0	3.5	3.0	2.5	2.2	2.0	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3
84	62.8	46.0	34.3	26.2	20.3	16.0	12.7	10.2	8.3	6.8	5.8	4.8	4.2	3.5	3.0	2.7	2.3	2.0	1.8	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.5
85	80.3	58.3	43.3	32.7	25.2	19.7	15.5	12.5	10.2	8.3	6.8	5.8	4.8	4.2	3.5	3.0	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5
86	103.2	74.2	54.5	41.0	31.3	24.3	19.2	15.3	12.3	10.0	8.3	7.0	5.8	5.0	4.2	3.7	3.2	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7	0.5
87	132.7	94.7	69.0	51.5	39.0	30.0	23.5	18.7	15.0	12.2	10.0	8.3	7.0	5.8	5.0	4.3	3.7	3.2	2.8	2.5	2.2	2.0	1.7	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.8	0.7	0.7
88	171.2	121.0	87.7	64.8	48.8	37.3	29.0	23.0	18.3	14.8	12.2	10.0	8.3	7.0	6.0	5.2	4.3	3.8	3.3	2.8	2.5	2.2	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7
89	>200	155.3	111.5	81.8	61.2	46.5	36.0	28.2	22.5	18.0	14.7	12.0	10.0	8.3	7.2	6.0	5.2	4.5	3.8	3.3	3.0	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.2	1.0	0.8	0.8
90	>200	>200	142.3	103.5	76.8	58.0	44.7	34.8	27.5	22.0	17.8	14.5	12.0	10.0	8.5	7.2	6.2	5.3	4.5	4.0	3.5	3.0	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.3	1.2	1.0	1.0
91	>200	>200	182.3	131.7	97.0	72.7	55.5	43.0	33.8	26.8	21.7	17.7	14.5	12.0	10.2	8.5	7.3	6.2	5.3	4.7	4.0	3.5	3.2	2.8	2.5	2.2	2.0	1.8	1.7	1.5	1.3	1.2	1.2
92	>200	>200	>200	167.7	122.7	91.3	69.3	53.3	41.7	33.0	26.5	21.5	17.5	14.5	12.2	10.2	8.7	7.3	6.3	5.5	4.8	4.2	3.7	3.2	2.8	2.5	2.3	2.0	1.8	1.7	1.5	1.3	1.2
93	>200	>200	>200	>200	155.7	115.2	86.7	66.3	51.5	40.5	32.3	26.0	21.2	17.5	14.5	12.2	10.3	8.7	7.5	6.5	5.5	4.8	4.3	3.8	3.3	3.0	2.7	2.3	2.2	1.8	1.7	1.5	1.5
94	>200	>200	>200	>200	198.2	145.5	108.8	82.7	63.8	50.0	39.7	31.8	25.8	21.2	17.5	14.5	12.3	10.3	8.8	7.7	6.5	5.7	5.0	4.3	3.8	3.5	3.0	2.7	2.5	2.2	2.0	1.8	1.7
95	>200	>200	>200	>200	>200	184.7	137.2	103.5	79.5	61.8	48.7	38.8	31.3	25.7	21.0	17.5	14.7	12.3	10.5	9.0	7.8	6.7	5.8	5.2	4.5	4.0	3.5	3.2	2.8	2.5	2.3	2.0	1.8
96	>200	>200	>200	>200	>200	>200	173.3	130.0	99.2	76.7	60.2	47.7	38.3	31.2	25.5	21.0	17.7	14.8	12.5	10.7	9.2	8.0	6.8	6.0	5.3	4.7	4.2	3.7	3.3	3.0	2.7	2.3	2.2
97	>200	>200	>200	>200	>200	>200	>200	163.8	124.2	95.5	74.3	58.7	47.0	37.8	31.0	25.5	21.2	17.7	15.0	12.7	10.8	9.3	8.2	7.0	6.2	5.5	4.8	4.2	3.8	3.3	3.0	2.7	2.5
98	>200	>200	>200	>200	>200	>200	>200	>200	156.0	119.2	92.3	72.5	57.7	46.3	37.7	30.8	25.5	21.3	17.8	15.2	12.8	11.0	9.5	8.3	7.2	6.3	5.7	5.0	4.3	4.0	3.5	3.2	2.8
99	>200	>200	>200	>200	>200	>200	>200	>200	196.7	149.5	115.2	89.8	71.0	56.8	46.0	37.5	30.8	25.7	21.5	18.2	15.3	13.2	11.3	9.8	8.5	7.5	6.5	5.8	5.2	4.5	4.0	3.7	3.3
100	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.0	144.0	111.8	88.0	70.0	56.2	45.7	37.5	31.0	25.8	21.7	18.3	15.7	13.5	11.5	10.0	8.8	7.7	6.8	6.0	5.3	4.7	4.2	3.8
101	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.8	139.7	109.2	86.3	69.2	55.8	45.7	37.5	31.2	26.2	22.0	18.7	16.0	13.7	11.8	10.3	9.0	7.8	7.0	6.2	5.5	4.8	4.3
102	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	175.0	136.2	107.2	85.3	68.7	55.8	45.7	37.8	31.5	26.5	22.3	19.0	16.3	14.2	12.2	10.7	9.3	8.2	7.2	6.3	5.7	5.2
103	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	170.5	133.5	105.7	84.7	68.5	55.8	46.0	38.2	32.0	27.0	22.8	19.5	16.8	14.5	12.5	11.0	9.7	8.5	7.5	6.7	6.0
104	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	166.8	131.5	104.7	84.3	68.5	56.2	46.5	38.7	32.5	27.5	23.3	20.0	17.2	14.8	13.0	11.3	10.0	8.8	7.8	7.0
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	164.3	130.2	104.3	84.3	68.8	56.7	47.0	39.3	33.2	28.2	24.0	20.5	17.8	15.3	13.5	11.8	10.3	9.2	8.2
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	162.7	129.7	104.3	84.8	69.5	57.5	47.8	40.2	33.8	28.8	24.7	21.2	18.3	16.0	14.0	12.2	10.8	9.5
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	161.8	129.7	104.8	85.7	70.5	58.5	48.8	41.2	34.8	29.7	25.5	22.0	19.0	16.5	14.5	12.7	11.2
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	162.0	130.3	106.0	86.8	71.7	59.7	50.0	42.2	35.8	30.7	26.3	22.7	19.7	17.2	15.2	13.3
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	163.0	131.8	107.5	88.5	73.3	61.2	51.5	43.5	37.0	31.7	27.3	23.7	20.5	18.0	15.8
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	165.0	134.0	109.7	90.5	75.3	63.0	53.2	45.0	38.5	33.0	28.5	24.7	21.5	18.8
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	167.8	136.8	112.5	93.2	77.7	65.2	55.2	46.8	40.0	34.5	29.8	25.8	22.5
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	171.8	140.5	115.8	96.2	80.5	67.8	57.5	49.0	42.0	36.2	31.3	27.2
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.0	145.2	120.2	100.0	83.8	70.8	60.2	51.3	44.0	38.0	33.0
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	183.3	151.0	125.2	104.7	87.8	74.3	63.3	54.2	46.5	40.2
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.3	158.0	131.5	110.0	92.7	78.5	67.0	57.3	49.3
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	166.7	138.8	116.5	98.3	83.5	71.3	61.2
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.0	147.8	124.3	105.2	89.3	76.5
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	189.8	158.8	133.8	113.3	96.5
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	172.3	145.3	123.2
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	189.0	159.5

Figure B-35 Tabular Representation of Parking Nomograph for C-17 on 26 °F (-3.5 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

Gross C-17 Weight (lb)

Sea Ice Thickness (inches)

26 F	280,000	290,000	300,000	310,000	320,000	330,000	340,000	350,000	360,000	370,000	380,000	390,000	400,000	410,000	420,000	430,000	440,000	450,000	460,000	470,000	480,000	490,000	500,000	510,000	520,000	530,000	540,000	550,000	560,000	570,000	580,000	590,000	600,000
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
65	0.8	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
67	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
68	1.5	1.3	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0
69	2.0	1.5	1.3	1.2	1.0	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0
70	2.3	2.0	1.7	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0
71	3.0	2.5	2.0	1.7	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0
72	3.7	3.0	2.5	2.0	1.7	1.3	1.2	1.0	0.8	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0
73	4.7	3.7	3.0	2.5	2.0	1.7	1.5	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0
74	5.8	4.7	3.7	3.0	2.5	2.0	1.7	1.5	1.3	1.0	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
75	7.3	5.7	4.5	3.7	3.0	2.5	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
76	9.2	7.2	5.7	4.5	3.7	3.0	2.5	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
77	11.5	8.8	7.0	5.5	4.5	3.7	3.0	2.5	2.2	1.8	1.7	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
78	14.3	11.0	8.7	6.8	5.5	4.5	3.7	3.2	2.7	2.2	1.8	1.7	1.3	1.2	1.0	1.0	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
79	18.2	13.8	10.7	8.5	6.8	5.5	4.5	3.7	3.2	2.7	2.3	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2
80	22.8	17.3	13.3	10.5	8.3	6.7	5.5	4.5	3.8	3.2	2.7	2.3	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2
81	29.0	21.7	16.7	13.0	10.2	8.2	6.7	5.5	4.5	3.8	3.2	2.7	2.3	2.0	1.8	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3
82	36.7	27.3	20.8	16.0	12.7	10.0	8.2	6.7	5.5	4.5	3.8	3.3	2.8	2.3	2.0	1.8	1.7	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3
83	46.7	34.5	26.0	20.0	15.7	12.3	9.8	8.0	6.7	5.5	4.7	3.8	3.3	2.8	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3
84	59.5	43.5	32.7	24.8	19.3	15.2	12.2	9.8	8.0	6.7	5.5	4.7	4.0	3.3	2.8	2.5	2.2	2.0	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3
85	76.0	55.2	41.0	31.0	23.8	18.7	14.8	12.0	9.7	8.0	6.7	5.5	4.7	4.0	3.5	3.0	2.5	2.2	2.0	1.7	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5
86	97.3	70.2	51.7	38.8	29.7	23.2	18.2	14.5	11.8	9.7	8.0	6.7	5.7	4.8	4.0	3.5	3.0	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7	0.5
87	125.0	89.5	65.3	48.8	37.0	28.7	22.5	17.8	14.3	11.7	9.7	8.0	6.7	5.7	4.8	4.2	3.5	3.2	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7
88	161.2	114.3	82.8	61.3	46.3	35.5	27.7	21.8	17.5	14.2	11.7	9.7	8.0	6.7	5.7	4.8	4.2	3.7	3.2	2.8	2.5	2.2	2.0	1.7	1.5	1.3	1.2	1.2	1.0	1.0	0.8	0.8	0.7
89	>200	146.5	105.3	77.3	58.0	44.2	34.2	26.8	21.3	17.2	14.0	11.5	9.7	8.0	6.8	5.8	5.0	4.3	3.7	3.2	2.8	2.5	2.2	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8
90	>200	188.3	134.3	98.0	72.8	55.2	42.3	33.2	26.2	21.0	17.0	14.0	11.5	9.7	8.2	6.8	5.8	5.0	4.3	3.8	3.3	3.0	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.2	1.0	1.0
91	>200	>200	171.8	124.3	91.7	69.0	52.7	40.8	32.2	25.7	20.7	16.8	13.8	11.5	9.7	8.2	7.0	6.0	5.2	4.5	3.8	3.5	3.0	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.3	1.2	1.0
92	>200	>200	>200	158.3	116.0	86.5	65.7	50.7	39.7	31.5	25.2	20.5	16.8	13.8	11.7	9.8	8.3	7.0	6.0	5.3	4.5	4.0	3.5	3.2	2.8	2.5	2.2	2.0	1.8	1.7	1.5	1.3	1.2
93	>200	>200	>200	>200	147.0	109.0	82.2	63.0	49.0	38.7	30.8	24.8	20.3	16.7	13.8	11.7	9.8	8.3	7.2	6.2	5.3	4.7	4.2	3.7	3.2	2.8	2.5	2.3	2.0	1.8	1.7	1.5	1.3
94	>200	>200	>200	>200	187.0	137.5	103.0	78.5	60.7	47.5	37.7	30.3	24.7	20.2	16.7	14.0	11.7	10.0	8.5	7.3	6.3	5.5	4.8	4.2	3.7	3.3	3.0	2.7	2.3	2.2	2.0	1.7	1.5
95	>200	>200	>200	>200	>200	174.3	129.7	98.2	75.3	58.7	46.3	37.0	30.0	24.5	20.2	16.8	14.0	11.8	10.2	8.7	7.5	6.5	5.7	5.0	4.3	3.8	3.3	3.0	2.7	2.5	2.2	2.0	1.8
96	>200	>200	>200	>200	>200	>200	163.8	123.2	94.0	72.8	57.2	45.5	36.5	29.7	24.3	20.2	16.8	14.2	12.0	10.3	8.8	7.7	6.7	5.8	5.0	4.5	4.0	3.5	3.2	2.8	2.5	2.3	2.0
97	>200	>200	>200	>200	>200	>200	>200	155.0	117.5	90.5	70.7	55.8	44.7	36.2	29.5	24.3	20.2	17.0	14.3	12.2	10.5	9.0	7.8	6.8	6.0	5.2	4.7	4.2	3.7	3.3	3.0	2.7	2.3
98	>200	>200	>200	>200	>200	>200	>200	195.8	147.7	113.0	87.7	69.0	54.8	44.2	35.8	29.5	24.3	20.3	17.2	14.5	12.3	10.7	9.2	8.0	7.0	6.2	5.3	4.8	4.2	3.8	3.3	3.0	2.7
99	>200	>200	>200	>200	>200	>200	>200	>200	186.0	141.5	109.2	85.3	67.5	54.2	43.8	35.8	29.5	24.5	20.5	17.3	14.7	12.7	10.8	9.3	8.2	7.2	6.3	5.5	5.0	4.3	4.0	3.5	3.2
100	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.8	136.5	106.2	83.5	66.5	53.5	43.5	35.8	29.7	24.7	20.8	17.7	15.0	12.8	11.2	9.7	8.5	7.3	6.5	5.8	5.2	4.5	4.0	3.7
101	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	171.2	132.3	103.7	82.2	65.8	53.2	43.5	35.8	29.8	25.0	21.2	18.0	15.3	13.2	11.3	10.0	8.7	7.7	6.7	6.0	5.3	4.7	4.2
102	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	165.8	129.2	101.7	81.2	65.3	53.2	43.7	36.2	30.2	25.3	21.5	18.3	15.7	13.5	11.7	10.2	9.0	7.8	7.0	6.2	5.5	5.0
103	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	161.5	126.5	100.3	80.5	65.2	53.2	43.8	36.5	30.5	25.8	21.8	18.7	16.0	13.8	12.0	10.5	9.3	8.2	7.2	6.3	5.7
104	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	158.2	124.8	99.5	80.2	65.2	53.5	44.3	37.0	31.0	26.3	22.3	19.2	16.5	14.3	12.5	10.8	9.7	8.5	7.5	6.7
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.5	155.8	123.7	99.2	80.3	65.5	54.0	44.8	37.7	31.7	26.8	23.0	19.7	17.0	14.8	12.8	11.3	10.0	8.8	7.8
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.5	154.3	123.2	99.2	80.7	66.2	54.8	45.7	38.3	32.5	27.7	23.7	20.3	17.7	15.3	13.3	11.7	10.3	9.2
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.5	153.7	123.2	99.7	81.5	67.2	55.7	46.7	39.3	33.3	28.3	24.3	21.0	18.2	15.8	13.8	12.2	10.8
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.7	153.8	123.8	100.8	82.7	68.3	57.0	47.8	40.3	34.3	29.3	25.2	21.8	19.0	16.5	14.5	12.8
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.0	154.8	125.3	102.3	84.2	69.8	58.3	49.2	41.7	35.5	30.3	26.2	22.7	19.7	17.3	15.2
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	194.5	156.7	127.3	104.3	86.2	71.7	60.2	50.7	43.2	36.8	31.7	27.3	23.7	20.7	18.0
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.2	159.5	130.0	107.0	88.7	74.0	62.2	52.7	44.8	38.3	33.0	28.5	24.8	21.7
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	163.2	133.7	110.3	91.7	76.8	64.7	54.8	46.8	40.2	34.5	30.0	26.0
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	168.2	138.2	114.3	95.3	80.0	67.5	57.3	49.0	42.2	36.3	31.7
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	174.2	143.7	119.2	99.7	83.8	71.0	60.3	51.7	44.5	38.5
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.8	150.3	125.0	104.8	88.3	75.0	64.0	54.8	47.3
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.2	158.5	132.2	111.0	93.8	79.7	68.0	58.5
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	168.3	140.7	118.3	100.2	85.3	73.0
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.3	151.2	127.3	108.0	92.0
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.3	163.8	138.3	117.5
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.7	151.8

Figure B-36 Tabular Representation of Parking Nomograph for C-17 on 27 °F (-2.5 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

Gross C-17 Weight (lb) — Sea Ice Thickness (inches) in first column

27 F	280,000	290,000	300,000	310,000	320,000	330,000	340,000	350,000	360,000	370,000	380,000	390,000	400,000	410,000	420,000	430,000	440,000
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0
61	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0
62	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0
63	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0
64	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0
65	0.8	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0
66	1.0	0.8	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
67	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
68	1.5	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
69	1.8	1.5	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2
70	2.3	1.8	1.5	1.3	1.0	0.8	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2
71	2.8	2.3	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.3
72	3.5	2.8	2.3	2.0	1.7	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3
73	4.5	3.5	2.8	2.3	2.0	1.7	1.3	1.2	1.0	0.8	0.8	0.7	0.5	0.5	0.5	0.3	0.3
74	5.5	4.3	3.5	2.8	2.3	2.0	1.7	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5
75	7.0	5.5	4.3	3.5	2.8	2.3	2.0	1.7	1.5	1.2	1.0	1.0	0.8	0.7	0.7	0.5	0.5
76	8.7	6.8	5.3	4.3	3.5	3.0	2.5	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.7
77	10.8	8.5	6.7	5.3	4.3	3.5	3.0	2.5	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.8	0.7
78	13.7	10.5	8.3	6.5	5.3	4.3	3.5	3.0	2.5	2.2	1.8	1.5	1.3	1.2	1.0	1.0	0.8
79	17.2	13.2	10.2	8.2	6.5	5.3	4.3	3.7	3.0	2.5	2.2	1.8	1.7	1.3	1.2	1.0	1.0
80	21.7	16.5	12.7	10.0	8.0	6.5	5.3	4.3	3.7	3.0	2.7	2.2	1.8	1.7	1.5	1.3	1.2
81	27.5	20.7	15.8	12.3	9.8	7.8	6.3	5.2	4.3	3.7	3.2	2.7	2.3	2.0	1.7	1.5	1.3
82	34.8	26.0	19.8	15.3	12.0	9.7	7.8	6.3	5.3	4.3	3.7	3.2	2.7	2.3	2.0	1.7	1.5
83	44.2	32.7	24.7	19.0	14.8	11.8	9.5	7.7	6.3	5.3	4.5	3.7	3.2	2.7	2.3	2.0	1.8
84	56.2	41.3	31.0	23.7	18.3	14.5	11.5	9.3	7.7	6.3	5.3	4.5	3.8	3.2	2.8	2.5	2.2
85	71.7	52.3	38.8	29.5	22.8	17.8	14.2	11.3	9.3	7.7	6.3	5.3	4.5	3.8	3.3	2.8	2.5
86	91.8	66.3	49.0	36.8	28.3	22.0	17.3	13.8	11.3	9.2	7.7	6.3	5.3	4.5	3.8	3.3	2.8
87	118.0	84.5	61.8	46.2	35.2	27.2	21.3	17.0	13.7	11.2	9.2	7.7	6.5	5.5	4.7	4.0	3.5
88	151.8	107.8	78.3	58.2	43.8	33.7	26.3	20.8	16.7	13.5	11.2	9.2	7.7	6.5	5.5	4.7	4.0
89	196.2	138.2	99.5	73.3	55.0	42.0	32.5	25.7	20.3	16.5	13.5	11.0	9.2	7.7	6.5	5.5	4.8
90	>200	177.5	126.8	92.7	69.0	52.3	40.3	31.5	25.0	20.0	16.3	13.3	11.0	9.2	7.8	6.7	5.7
91	>200	>200	162.2	117.5	86.8	65.3	50.0	38.8	30.7	24.5	19.8	16.2	13.3	11.0	9.3	7.8	6.7
92	>200	>200	>200	149.3	109.7	82.0	62.3	48.2	37.7	30.0	24.0	19.5	16.0	13.3	11.2	9.3	8.0
93	>200	>200	>200	190.7	138.8	103.0	77.8	59.8	46.5	36.7	29.3	23.7	19.3	16.0	13.3	11.2	9.5
94	>200	>200	>200	>200	176.5	130.0	97.5	74.5	57.7	45.2	36.0	28.8	23.5	19.3	16.0	13.3	11.3
95	>200	>200	>200	>200	>200	164.7	122.7	93.0	71.5	55.8	44.2	35.3	28.5	23.3	19.3	16.0	13.5
96	>200	>200	>200	>200	>200	>200	154.8	116.5	89.2	69.2	54.3	43.3	34.8	28.3	23.3	19.3	16.2
97	>200	>200	>200	>200	>200	>200	196.0	146.5	111.3	85.8	67.2	53.2	42.5	34.5	28.2	23.2	19.3
98	>200	>200	>200	>200	>200	>200	>200	185.0	139.7	107.0	83.2	65.5	52.2	42.0	34.2	28.2	23.3
99	>200	>200	>200	>200	>200	>200	>200	>200	175.8	134.0	103.5	81.0	64.2	51.5	41.7	34.2	28.2
100	>200	>200	>200	>200	>200	>200	>200	>200	>200	168.3	129.3	100.7	79.3	63.3	51.0	41.5	34.2
101	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	162.0	125.5	98.3	78.0	62.7	50.7	41.5
102	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	157.0	122.3	96.7	77.2	62.2	50.7
103	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.3	153.0	120.0	95.3	76.5	62.0
104	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.0	149.8	118.3	94.5	76.3
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.0	147.7	117.3	94.2
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.2	146.3	116.8
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	183.3	145.8
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.7
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

27 F	450,000	460,000	470,000	480,000	490,000	500,000	510,000	520,000	530,000	540,000	550,000	560,000	570,000	580,000	590,000	600,000
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
67	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
68	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0
69	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0
70	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0
71	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0
72	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0
73	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0
74	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0
75	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
76	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
77	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
78	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
79	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2
80	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2
81	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3
82	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3
83	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3
84	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3
85	2.2	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5
86	2.5	2.2	2.0	1.7	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5
87	3.0	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7
88	3.5	3.0	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7
89	4.2	3.5	3.2	2.7	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.2	1.0	1.0	0.8	0.8
90	4.8	4.2	3.7	3.2	2.8	2.5	2.2	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8
91	5.7	5.0	4.3	3.8	3.3	2.8	2.5	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.2	1.0
92	6.8	5.8	5.0	4.3	3.8	3.3	3.0	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.3	1.2
93	8.0	6.8	6.0	5.2	4.5	4.0	3.5	3.2	2.7	2.5	2.2	2.0	1.8	1.7	1.5	1.3
94	9.5	8.2	7.0	6.0	5.3	4.7	4.0	3.7	3.2	2.8	2.5	2.3	2.0	1.8	1.7	1.5
95	11.3	9.7	8.3	7.2	6.2	5.5	4.8	4.2	3.7	3.3	3.0	2.7	2.3	2.2	2.0	1.7
96	13.5	11.5	9.8	8.5	7.3	6.3	5.5	4.8	4.3	3.8	3.3	3.0	2.7	2.5	2.2	2.0
97	16.2	13.7	11.7	10.0	8.7	7.5	6.5	5.7	5.0	4.5	4.0	3.5	3.2	2.8	2.5	2.3
98	19.5	16.3	13.8	11.8	10.2	8.8	7.7	6.7	5.8	5.2	4.7	4.2	3.7	3.3	3.0	2.7
99	23.5	19.7	16.7	14.2	12.2	10.5	9.0	7.8	6.8	6.0	5.3	4.8	4.2	3.8	3.3	3.0
100	28.3	23.7	19.8	16.8	14.3	12.3	10.7	9.3	8.2	7.2	6.3	5.5	5.0	4.3	4.0	3.5
101	34.2	28.5	23.8	20.2	17.2	14.7	12.7	11.0	9.5	8.3	7.3	6.5	5.7	5.2	4.5	4.2
102	41.7	34.5	28.8	24.2	20.5	17.5	15.0	13.0	11.3	9.8	8.7	7.5	6.7	6.0	5.3	4.7
103	50.7	41.8	34.8	29.2	24.7	21.0	18.0	15.5	13.3	11.7	10.2	8.8	7.8	7.0	6.2	5.5
104	62.2	51.0	42.3	35.3	29.7	25.2	21.5	18.3	15.8	13.7	12.0	10.5	9.2	8.2	7.2	6.5
105	76.3	62.5	51.5	42.8	35.8	30.3	25.7	22.0	18.8	16.3	14.2	12.3	10.8	9.5	8.5	7.5
106	94.3	76.8	63.0	52.2	43.7	36.7	31.0	26.3	22.7	19.5	16.8	14.7	12.8	11.3	10.0	8.8
107	117.0	94.8	77.5	64.0	53.2	44.5	37.5	31.8	27.2	23.3	20.2	17.5	15.3	13.3	11.8	10.3
108	146.0	117.7	95.8	78.7	65.2	54.3	45.7	38.5	32.8	28.0	24.2	20.8	18.2	15.8	14.0	12.3
109	183.0	147.0	119.0	97.3	80.2	66.7	55.7	47.0	39.8	34.0	29.2	25.2	21.7	19.0	16.5	14.5
110	>200	184.5	148.7	121.0	99.3	82.2	68.3	57.3	48.5	41.2	35.2	30.3	26.2	22.7	19.8	17.3
111	>200	>200	187.0	151.3	123.7	101.8	84.5	70.5	59.3	50.3	42.8	36.7	31.5	27.3	23.8	20.8
112	>200	>200	>200	190.7	155.0	127.0	105.0	87.3	73.2	61.7	52.3	44.7	38.3	33.2	28.7	25.0
113	>200	>200	>200	>200	195.7	159.7	131.3	108.8	90.8	76.3	64.5	54.8	46.8	40.3	34.8	30.3
114	>200	>200	>200	>200	>200	>200	165.5	136.5	113.5	94.8	80.0	67.7	57.7	49.5	42.5	36.8
115	>200	>200	>200	>200	>200	>200	>200	172.7	142.8	119.0	99.8	84.2	71.5	61.0	52.3	45.2
116	>200	>200	>200	>200	>200	>200	>200	>200	181.7	150.7	125.8	105.7	89.3	76.0	65.0	55.8
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.5	160.0	134.0	112.8	95.5	81.3	69.7
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	171.5	143.8	121.3	103.0	87.8
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.7	155.8	131.7	111.8
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	171.0	144.7

Figure B-37 Tabular Representation of Parking Nomograph for C-17 on 28 °F (-2 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

28 F	Gross C-17 Weight (lb)																															
Sea Ice Thickness (inches)	280,000	290,000	300,000	310,000	320,000	330,000	340,000	350,000	360,000	370,000	380,000	390,000	400,000	410,000	420,000	430,000	440,000	450,000	460,000	470,000	480,000	490,000	500,000	510,000	520,000	530,000	540,000	550,000	560,000	570,000	580,000	590,000	600,000
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
65	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66	0.8	0.8	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
67	1.2	1.0	0.8	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
68	1.5	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
69	1.8	1.5	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0	0	0
70	2.2	1.8	1.5	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0	0	0
71	2.7	2.2	1.8	1.5	1.3	1.0	0.8	0.8	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0	0
72	3.3	2.7	2.2	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0
73	4.2	3.3	2.7	2.3	1.8	1.5	1.3	1.2	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0
74	5.3	4.2	3.3	2.8	2.3	1.8	1.7	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0
75	6.7	5.2	4.2	3.3	2.8	2.3	2.0	1.7	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
76	8.3	6.5	5.2	4.2	3.3	2.8	2.3	2.0	1.7	1.5	1.2	1.0	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
77	10.3	8.0	6.3	5.2	4.2	3.3	2.8	2.3	2.0	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
78	13.0	10.0	7.8	6.3	5.0	4.2	3.5	2.8	2.3	2.0	1.8	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
79	16.3	12.5	9.8	7.7	6.2	5.0	4.2	3.5	2.8	2.5	2.2	1.8	1.5	1.3	1.2	1.0	1.0	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2
80	20.7	15.7	12.2	9.5	7.7	6.2	5.0	4.2	3.5	3.0	2.5	2.2	1.8	1.7	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2
81	26.0	19.7	15.0	11.8	9.3	7.5	6.2	5.0	4.2	3.5	3.0	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3
82	33.0	24.7	18.8	14.5	11.5	9.2	7.5	6.0	5.0	4.2	3.5	3.0	2.5	2.2	2.0	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3
83	41.8	31.0	23.5	18.2	14.2	11.2	9.0	7.3	6.0	5.0	4.2	3.7	3.0	2.7	2.3	2.0	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3	0.3
84	53.2	39.2	29.3	22.5	17.5	13.8	11.0	9.0	7.3	6.0	5.0	4.3	3.7	3.2	2.7	2.3	2.0	1.8	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5	0.5	0.5	0.3
85	67.8	49.5	36.8	28.0	21.7	17.0	13.5	10.8	8.8	7.3	6.2	5.2	4.3	3.7	3.2	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.5	0.5	0.5	0.5
86	86.7	62.8	46.5	35.0	26.8	21.0	16.5	13.3	10.8	8.8	7.3	6.2	5.2	4.3	3.8	3.2	2.8	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7	0.5	0.5
87	111.2	79.8	58.7	43.8	33.5	25.8	20.3	16.2	13.2	10.7	8.8	7.3	6.2	5.2	4.5	3.8	3.3	2.8	2.5	2.2	2.0	1.7	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.8	0.7	0.7	0.5
88	143.0	101.8	74.2	55.0	41.7	32.0	25.0	19.8	16.0	13.0	10.7	8.8	7.3	6.2	5.3	4.5	3.8	3.3	3.0	2.5	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7
89	184.7	130.3	94.0	69.3	52.2	39.8	31.0	24.3	19.5	15.7	12.8	10.5	8.8	7.3	6.3	5.3	4.7	4.0	3.5	3.0	2.7	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.2	1.0	0.8	0.8	0.8
90	>200	167.2	119.7	87.7	65.3	49.7	38.3	30.0	23.8	19.2	15.5	12.8	10.5	8.8	7.5	6.3	5.5	4.7	4.0	3.5	3.2	2.7	2.3	2.2	1.8	1.7	1.5	1.3	1.3	1.2	1.0	1.0	0.8
91	>200	>200	152.8	111.0	82.2	62.0	47.5	37.0	29.2	23.3	18.8	15.3	12.7	10.7	8.8	7.5	6.5	5.5	4.8	4.2	3.7	3.2	2.8	2.5	2.2	2.0	1.8	1.7	1.5	1.3	1.2	1.0	1.0
92	>200	>200	195.8	141.0	103.7	77.7	59.2	45.7	35.8	28.5	23.0	18.7	15.3	12.7	10.7	9.0	7.7	6.5	5.7	4.8	4.2	3.7	3.3	2.8	2.5	2.3	2.0	1.8	1.7	1.5	1.3	1.2	1.2
93	>200	>200	>200	179.8	131.2	97.5	73.8	56.7	44.2	35.0	28.0	22.7	18.5	15.3	12.7	10.7	9.0	7.7	6.7	5.7	5.0	4.3	3.8	3.3	3.0	2.7	2.3	2.2	1.8	1.7	1.5	1.5	1.3
94	>200	>200	>200	>200	166.5	123.0	92.3	70.5	54.7	43.0	34.2	27.5	22.5	18.5	15.3	12.8	10.8	9.2	7.8	6.7	5.8	5.2	4.5	4.0	3.5	3.0	2.7	2.5	2.2	2.0	1.8	1.7	1.5
95	>200	>200	>200	>200	>200	155.5	116.0	88.2	67.8	53.0	42.0	33.7	27.2	22.3	18.3	15.3	12.8	10.8	9.3	8.0	6.8	6.0	5.2	4.5	4.0	3.5	3.2	2.8	2.5	2.3	2.0	1.8	1.7
96	>200	>200	>200	>200	>200	197.3	146.3	110.3	84.5	65.7	51.7	41.2	33.2	27.0	22.2	18.5	15.5	13.0	11.0	9.5	8.2	7.0	6.2	5.3	4.7	4.2	3.7	3.3	3.0	2.7	2.3	2.2	2.0
97	>200	>200	>200	>200	>200	>200	185.2	138.7	105.5	81.5	63.8	50.5	40.5	32.8	26.8	22.2	18.5	15.5	13.2	11.2	9.7	8.3	7.2	6.3	5.5	4.8	4.3	3.8	3.3	3.0	2.7	2.5	2.2
98	>200	>200	>200	>200	>200	>200	>200	174.8	132.2	101.5	79.0	62.3	49.7	40.0	32.7	26.8	22.3	18.7	15.7	13.3	11.3	9.8	8.5	7.3	6.5	5.7	5.0	4.5	4.0	3.5	3.2	2.8	2.5
99	>200	>200	>200	>200	>200	>200	>200	>200	166.3	126.8	98.2	77.0	61.2	49.0	39.8	32.5	26.8	22.3	18.8	15.8	13.5	11.7	10.0	8.7	7.5	6.7	5.8	5.2	4.5	4.2	3.7	3.3	3.0
100	>200	>200	>200	>200	>200	>200	>200	>200	>200	159.2	122.5	95.5	75.3	60.2	48.5	39.7	32.5	27.0	22.7	19.0	16.2	13.8	11.8	10.3	8.8	7.8	6.8	6.0	5.3	4.7	4.2	3.8	3.3
101	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	153.3	118.8	93.3	74.2	59.5	48.3	39.5	32.7	27.2	22.8	19.3	16.5	14.2	12.2	10.5	9.2	8.0	7.0	6.2	5.5	5.0	4.3	4.0
102	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.0	148.7	116.2	91.7	73.3	59.2	48.2	39.7	33.0	27.5	23.2	19.7	16.8	14.5	12.5	10.8	9.5	8.3	7.3	6.5	5.7	5.2	4.5
103	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	186.7	145.0	114.0	90.5	72.8	59.0	48.3	40.0	33.3	27.8	23.7	20.0	17.2	14.8	12.8	11.2	9.7	8.5	7.5	6.7	6.0	5.3
104	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.8	142.2	112.3	89.8	72.5	59.2	48.7	40.3	33.7	28.3	24.0	20.5	17.7	15.2	13.2	11.5	10.0	8.8	7.8	7.0	6.2
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.0	140.0	111.3	89.5	72.7	59.5	49.2	40.8	34.3	29.0	24.7	21.0	18.2	15.7	13.7	11.8	10.5	9.2	8.2	7.2
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	175.3	138.8	111.0	89.7	73.2	60.2	49.8	41.7	35.0	29.7	25.3	21.7	18.7	16.2	14.2	12.3	10.8	9.7	8.5
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	173.8	138.3	111.2	90.2	73.8	61.0	50.7	42.5	35.8	30.5	26.0	22.3	19.3	16.8	14.7	12.8	11.3	10.0
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	173.2	138.5	111.8	91.2	75.0	62.0	51.8	43.5	36.8	31.3	26.8	23.2	20.0	17.5	15.2	13.3	11.8
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	173.5	139.5	113.2	92.5	76.3	63.5	53.2	44.8	38.0	32.5	27.8	24.0	20.8	18.2	15.8	14.0
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	175.0	141.2	115.0	94.5	78.2	65.2	54.8	46.3	39.3	33.7	29.0	25.0	21.8	19.0	16.7
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.3	143.8	117.5	96.8	80.5	67.3	56.7	48.0	41.0	35.0	30.2	26.2	22.8	20.0
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.8	147.2	120.8	99.8	83.2	69.8	58.8	50.0	42.7	36.7	31.7	27.5	24.0
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.7	151.7	124.8	103.5	86.5	72.7	61.5	52.3	44.8	38.5	33.3	29.0
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.8	157.2	129.8	108.0	90.3	76.2	64.7	55.2	47.2	40.7	35.3
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	199.7	164.2	135.8	113.3	95.2	80.3	68.2	58.3	50.0	43.2
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	172.5	143.2	119.7	100.7	85.2	72.5	62.0	53.3
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.8	152.2	127.5	107.3	91.0	77.7	66.5
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.5	163.0	136.8	115.5	98.2	83.7
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	176.5	148.3	125.5	106.7
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.2	162.7	137.7

Figure B-38 Tabular Representation of Parking Nomograph for B767-300ER on -4 °F (-20 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

Gross B-767-300ER Weight (lbs)

-4 F / Ice Thickness (in)	205000	210000	215000	220000	225000	230000	235000	240000	245000	250000	255000	260000	265000	270000	275000	280000	285000	290000	295000	300000	305000	310000	315000	320000	325000	330000	335000	340000	345000	350000	355000	360000	365000	370000	375000	380000	385000	388000
52	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
53	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
54	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
55	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
56	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
57	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
58	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
59	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1
60	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
61	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
62	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
63	1.1	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
64	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2
65	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
66	1.4	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
67	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3
68	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3
69	2.4	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
70	3.1	2.5	1.7	1.6	1.5	1.5	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4
71	3.9	3.3	2.7	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4
72	5.0	4.1	3.4	2.9	2.4	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5
73	6.3	5.2	4.4	3.6	3.1	2.6	1.7	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5
74	7.9	6.6	5.5	4.6	3.8	3.2	2.7	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5
75	9.9	8.2	6.9	5.7	4.8	4.1	3.4	2.9	2.5	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6
76	12.4	10.3	8.6	7.2	6.0	5.1	4.3	3.6	3.1	2.7	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6
77	15.4	12.8	10.6	8.9	7.5	6.3	5.3	4.5	3.9	3.3	2.8	2.4	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.7
78	19.0	15.8	13.2	11.0	9.2	7.8	6.6	5.6	4.8	4.1	3.5	3.0	2.6	1.8	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7
79	23.5	19.5	16.2	13.6	11.4	9.6	8.1	6.9	5.9	5.0	4.3	3.7	3.2	2.8	2.4	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8
80	28.8	23.9	19.9	16.7	14.0	11.8	10.0	8.5	7.2	6.2	5.3	4.6	3.9	3.4	3.0	2.6	1.8	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8
81	35.3	29.3	24.4	20.4	17.1	14.5	12.2	10.4	8.9	7.6	6.5	5.6	4.8	4.2	3.6	3.1	2.7	2.4	1.7	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.9
82	43.0	35.7	29.7	24.9	20.9	17.6	14.9	12.7	10.8	9.2	7.9	6.8	5.9	5.1	4.4	3.8	3.3	2.9	2.6	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9
83	52.3	43.4	36.2	30.3	25.4	21.4	18.1	15.4	13.1	11.2	9.6	8.3	7.1	6.2	5.4	4.7	4.1	3.6	3.1	2.7	2.4	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0
84	63.4	52.6	43.8	36.7	30.8	26.0	22.0	18.7	15.9	13.6	11.7	10.0	8.7	7.5	6.5	5.7	4.9	4.3	3.8	3.3	2.9	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0
85	76.6	63.6	53.0	44.3	37.2	31.4	26.6	22.6	19.2	16.4	14.1	12.1	10.5	9.1	7.9	6.8	6.0	5.2	4.6	4.0	3.5	3.1	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.1	1.1
86	92.3	76.6	63.8	53.4	44.9	37.8	32.0	27.2	23.2	19.8	17.0	14.6	12.6	10.9	9.5	8.2	7.2	6.3	5.5	4.8	4.2	3.7	3.3	2.9	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2
87	110.9	92.0	76.7	64.1	53.9	45.4	38.5	32.7	27.8	23.8	20.4	17.6	15.2	13.1	11.4	9.9	8.6	7.5	6.6	5.8	5.1	4.5	4.0	3.5	3.1	2.8	2.5	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.3
88	132.9	110.2	91.8	76.9	64.6	54.5	46.1	39.1	33.4	28.5	24.5	21.0	18.2	15.7	13.6	11.8	10.3	9.0	7.9	6.9	6.1	5.4	4.8	4.2	3.7	3.3	2.9	2.6	1.8	1.7	1.7	1.6	1.6	1.5	1.4	1.4	1.4	1.3
89	158.8	131.7	109.8	91.8	77.2	65.1	55.1	46.8	39.9	34.1	29.2	25.2	21.7	18.8	16.3	14.2	12.3	10.8	9.4	8.3	7.3	6.4	5.7	5.0	4.5	4.0	3.5	3.1	2.8	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4
90	189.3	157.0	130.8	109.5	92.0	77.6	65.7	55.8	47.5	40.6	34.9	30.0	25.9	22.4	19.4	16.9	14.7	12.9	11.3	9.9	8.7	7.7	6.8	6.0	5.3	4.7	4.2	3.7	3.3	3.0	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5
91	>200	186.7	155.6	130.2	109.4	92.2	78.1	66.3	56.5	48.3	41.4	35.6	30.8	26.6	23.1	20.1	17.5	15.3	13.4	11.8	10.3	9.1	8.1	7.1	6.3	5.6	5.0	4.5	4.0	3.6	3.2	2.9	2.6	1.8	1.7	1.7	1.6	1.6
92	>200	>200	184.5	154.4	129.7	109.4	92.6	78.7	67.0	57.3	49.2	42.3	36.5	31.6	27.4	23.8	20.8	18.1	15.9	13.9	12.3	10.8	9.6	8.5	7.5	6.7	5.9	5.3	4.7	4.2	3.8	3.4	3.0	2.7	2.5	1.8	1.7	1.7
93	>200	>200	>200	182.7	153.5	129.5	109.6	93.1	79.3	67.8	58.2	50.0	43.2	37.4	32.4	28.2	24.6	21.5	18.8	16.5	14.5	12.8	11.3	10.0	8.9	7.9	7.0	6.3	5.6	5.0	4.5	4.0	3.6	3.2	2.9	2.6	2.4	1.8
94	>200	>200	>200	>200	181.3	152.9	129.4	109.9	93.7	80.1	68.7	59.1	51.0	44.1	38.3	33.3	29.0	25.3	22.2	19.5	17.1	15.1	13.3	11.8	10.5	9.3	8.3	7.4	6.6	5.9	5.3	4.7	4.3	3.8	3.5	3.1	2.8	2.7
95	>200	>200	>200	>200	>200	180.1	152.5	129.5	110.4	94.4	80.9	69.6	60.1	52.0	45.1	39.2	34.2	29.9	26.2	23.0	20.2	17.8	15.7	13.9	12.3	11.0	9.8	8.7	7.8	6.9	6.2	5.6	5.0	4.5	4.1	3.7	3.3	3.1
96	>200	>200	>200	>200	>200	>200	179.3	152.3	129.8	111.0	95.2	81.9	70.6	61.1	53.0	46.1	40.2	35.1	30.8	27.0	23.7	20.9	18.5	16.4	14.5	12.9	11.5	10.2	9.1	8.2	7.3	6.6	5.9	5.3	4.8	4.3	3.9	3.7
97	>200	>200	>200	>200	>200	>200	>200	178.6	152.3	130.2	111.7	96.1	82.9	71.7	62.2	54.1	47.1	41.2	36.1	31.7	27.9	24.6	21.7	19.2	17.0	15.1	13.5	12.0	10.7	9.6	8.6	7.7	6.9	6.2	5.6	5.1	4.6	4.3
98	>200	>200	>200	>200	>200	>200	>200	>200	178.3	152.4	130.7	112.5	97.0	83.9	72.8	63.3	55.2	48.2	42.2	37.1	32.6	28.8	25.4	22.5	19.9	17.7	15.8	14.1	12.5	11.2	10.1	9.0	8.1	7.3	6.6	5.9	5.4	5.0
99	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.2	152.8	131.4	113.4	98.1	85.1	74.0	64.5	56.4	49.4	43.3	38.1	33.6	29.7	26.3	23.3	20.7	18.4	16.4	14.7	13.1	11.8	10.5	9.5	8.5	7.7	6.9	6.3	5.9
100	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.2	153.3	132.3	114.4	99.3	86.3	75.3	65.8	57.6	50.6	44.5	39.2	34.6	30.7	27.2	24.1	21.5	19.2	17.1	15.3	13.7	12.3	11.1	9.9	9.0	8.1	7.3	6.9
101	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.5	154.0	133.7	115.6	100.5	87.6	76.6	67.1	58.9	51.8	45.7	40.3	35.7	31.7	28.1	25.0	22.3	19.9	17.8	16.0	14.3	12.9	11.6	10.4	9.4	8.5	8.0
102	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.0	154.9	134.3	116.8	101.8	89.0	77.9	68.4	60.2	53.1	46.9	41.5	36.8	32.7	29.1	25.9	23.2	20.7	18.6	16.6	15.0	13.5	12.1	10.9	9.9	9.3
103	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.7	155.8	135.5	118.2	103.2	90.4	79.4	69.8	61.6	54.4	48.1	42.7	37.9	33.7	30.1	26.9	24.0	21.5	19.3	17.4	15.6	14.1	12.7	11.5	10.8
104	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.5	157.0	136.8	119.6	104.7	91.9	80.9	71.3	63.0	55.7	49.4	43.9	39.1	34.8	31.1	27.8	24.9	22.4	20.1	18.1	16.3	14.7	13.3	12.5
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.5	158.2	138.3	121.1	106.3	93.5	82.5	72.8	64.5	57.2	50.8	45.2	40.3	36.0	32.2	28.8	25.9	23.2	20.9	18.8	17.0	15.4	14.5
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.7	159.6	139.8	122.7	108.0	95.2	84.1	74.4	66.0	58.6	52.2	46.5	41.5	37.1	33.3	29.9	26.8	24.1	21.8	19.6	17.7	16.7
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	184.0	161.2	141.5	124.5	109.7	96.9	85.8	76.1	67.6	60.1	53.6	47.9	42.8	38.4	34.4	30.9	27.8	25.1	22.6	20.5	19.3
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.5	162.8	143.2	126.3	111.5	98.7	87.5	77.8	69.2	61.7	55.1	49.3	44.1	39.6	35.6	32.0	28.9	26.0	23.5	22.2
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	187.1	164.6	145.1	128.2	113.4	100.6	89.4	79.5	70.9	63.3	56.6	50.7	45.5	40.9	36.8	33.2	29.9	27.0	25.5
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.8	166.5	147.1	130.2	115.4	102.5	91.3	81.4	72.6	65.0	58.2	52.2	46.9	42.2	38.1	34.3	31.0	29.2
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	190.7	168.5	149.1	132.2	117.5	104.6	93.2	83.2	74.4	66.7	59.8	53.8	48.4	43.6	39.4	35.6	33.5
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.8	170.6	151.3	134.4	119.6	106.6	95.2	85.2	76.3	68.5	61.5	55.4	49.9	45.0	40.7	38.3
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.0	172.9	153.6	136.7	121.9	108.8	97.3	87.2	78.2	70.3	63.3	57.0	51.4	46.5	43.8
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.3	175.3	156.0	139.0	124.2	111.1	99.5	89.3	80.2	72.2	65.1	58.7	53.0	49.9
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	199.7	177.7	158.5	141.5	126.6	113.4	101.7	91.4	82.3	74.1	66.9	60.5	56.9
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.3	161.0	144.0	129.0	115.8	104.0	93.6	84.4	76.1	68.8	64.8
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	183.1	163.7	146.7	131.6	118.3	106.4	95.9	86.5	78.2	73.6
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.9	166.5	149.4	134.3	120.8	108.9	98.3	88.8	83.6
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.8	169.4	152.2	137.0	123.5	111.4	100.7	94.8
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.9	172.4	155.2	139.8	126.2	114.0	107.4
121	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.1	175.5	158.2	142.8	129.0	121.5
122	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.4	178.8	161.3	145.8	137.3
123	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.1	164.5	154.9
124	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.5	174.7
125	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	196.7
126	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
127	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
128	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
129	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
130	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
131	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
132	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
133	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
134	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

Figure B-39 Tabular Representation of Parking Nomograph for B767-300ER on -2 °F (-19 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

Gross B-767-300ER Weight (lbs)

-2 F / Ice Thickness (in)	205000	210000	215000	220000	225000	230000	235000	240000	245000	250000	255000	260000	265000	270000	275000	280000	285000	290000	295000	300000	305000	310000	315000	320000	325000	330000	335000	340000	345000	350000	355000	360000	365000	370000	375000	380000	385000	388000
52	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
53	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
54	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
55	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
56	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
57	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
58	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
59	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1
60	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1
61	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
62	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
63	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
64	1.1	1.1	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2
65	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2
66	1.3	1.3	1.2	1.1	1.1	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
67	1.5	1.4	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3
68	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3
69	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3
70	2.7	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4
71	3.5	2.9	2.4	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4
72	4.4	3.7	3.1	2.6	1.7	1.6	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4
73	5.6	4.7	3.9	3.3	2.7	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5
74	7.1	5.9	4.9	4.1	3.4	2.9	2.5	1.7	1.6	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5
75	8.9	7.4	6.1	5.1	4.3	3.6	3.1	2.6	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5
76	11.1	9.2	7.7	6.4	5.4	4.5	3.8	3.3	2.8	2.4	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6
77	13.8	11.4	9.5	8.0	6.7	5.6	4.8	4.1	3.5	3.0	2.5	1.7	1.7	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6
78	17.0	14.1	11.8	9.9	8.3	7.0	5.9	5.0	4.3	3.7	3.1	2.7	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7
79	21.0	17.4	14.5	12.2	10.2	8.6	7.3	6.2	5.3	4.5	3.9	3.3	2.9	2.5	1.7	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7
80	25.8	21.4	17.9	14.9	12.5	10.6	9.0	7.6	6.5	5.5	4.8	4.1	3.5	3.1	2.6	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8
81	31.6	26.2	21.9	18.3	15.4	13.0	11.0	9.3	7.9	6.8	5.8	5.0	4.3	3.7	3.2	2.8	2.5	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8
82	38.6	32.0	26.7	22.3	18.7	15.8	13.4	11.4	9.7	8.3	7.1	6.1	5.3	4.6	4.0	3.4	3.0	2.6	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9
83	46.9	38.9	32.4	27.1	22.8	19.2	16.3	13.8	11.8	10.1	8.6	7.4	6.4	5.5	4.8	4.2	3.6	3.2	2.8	2.4	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9
84	56.9	47.2	39.3	32.9	27.6	23.3	19.7	16.8	14.3	12.2	10.5	9.0	7.8	6.7	5.8	5.1	4.4	3.9	3.4	3.0	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0
85	68.8	57.1	47.5	39.8	33.4	28.2	23.9	20.3	17.3	14.8	12.7	10.9	9.4	8.1	7.0	6.1	5.3	4.7	4.1	3.6	3.2	2.8	2.5	1.7	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.1	1.1	1.1
86	82.9	68.8	57.3	47.9	40.3	34.0	28.7	24.4	20.8	17.8	15.3	13.1	11.3	9.8	8.5	7.4	6.4	5.6	4.9	4.3	3.8	3.4	3.0	2.6	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1
87	99.6	82.6	68.9	57.6	48.4	40.8	34.5	29.3	25.0	21.4	18.3	15.8	13.6	11.8	10.2	8.9	7.7	6.8	5.9	5.2	4.6	4.0	3.6	3.2	2.8	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2
88	119.4	99.0	82.5	69.0	58.0	48.9	41.4	35.2	30.0	25.6	22.0	18.9	16.3	14.1	12.2	10.6	9.3	8.1	7.1	6.2	5.5	4.8	4.3	3.8	3.4	3.0	2.6	1.8	1.7	1.7	1.6	1.6	1.5	1.4	1.4	1.4	1.3	1.3
89	142.7	118.4	98.6	82.5	69.3	58.5	49.5	42.0	35.8	30.6	26.3	22.6	19.5	16.9	14.6	12.7	11.1	9.7	8.5	7.5	6.6	5.8	5.1	4.5	4.0	3.6	3.2	2.8	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.4
90	170.1	141.1	117.6	98.4	82.7	69.7	59.0	50.1	42.7	36.5	31.3	26.9	23.2	20.1	17.4	15.2	13.2	11.6	10.1	8.9	7.8	6.9	6.1	5.4	4.8	4.2	3.8	3.4	3.0	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5	1.4
91	>200	167.9	139.9	117.0	98.3	82.9	70.2	59.6	50.8	43.4	37.3	32.1	27.7	23.9	20.7	18.0	15.7	13.7	12.0	10.6	9.3	8.2	7.2	6.4	5.7	5.0	4.5	4.0	3.6	3.2	2.9	2.6	1.8	1.7	1.7	1.6	1.6	1.5
92	>200	199.2	166.0	138.9	116.7	98.4	83.3	70.7	60.3	51.5	44.2	38.0	32.8	28.4	24.6	21.4	18.7	16.3	14.3	12.5	11.0	9.7	8.6	7.6	6.7	6.0	5.3	4.7	4.2	3.8	3.4	3.0	2.7	2.5	1.8	1.7	1.6	1.6
93	>200	>200	196.4	164.4	138.1	116.5	98.6	83.7	71.4	61.0	52.3	45.0	38.8	33.6	29.1	25.3	22.1	19.3	16.9	14.8	13.1	11.5	10.2	9.0	8.0	7.1	6.3	5.6	5.0	4.5	4.0	3.6	3.2	2.9	2.6	2.4	1.7	1.7
94	>200	>200	>200	194.1	163.1	137.6	116.4	98.9	84.3	72.1	61.8	53.2	45.9	39.7	34.4	29.9	26.1	22.8	20.0	17.5	15.4	13.6	12.0	10.6	9.4	8.4	7.5	6.6	5.9	5.3	4.8	4.3	3.8	3.4	3.1	2.8	2.5	2.4
95	>200	>200	>200	>200	192.2	162.1	137.2	116.5	99.3	84.9	72.8	62.7	54.1	46.8	40.6	35.3	30.8	26.9	23.5	20.7	18.2	16.0	14.2	12.5	11.1	9.9	8.8	7.8	7.0	6.3	5.6	5.0	4.5	4.1	3.7	3.3	3.0	2.8
96	>200	>200	>200	>200	>200	190.6	161.3	137.1	116.8	99.9	85.7	73.7	63.6	55.0	47.7	41.5	36.2	31.6	27.7	24.3	21.4	18.8	16.6	14.7	13.1	11.6	10.3	9.2	8.2	7.4	6.6	5.9	5.3	4.8	4.3	3.9	3.5	3.3
97	>200	>200	>200	>200	>200	>200	189.3	160.8	137.1	117.2	100.5	86.5	74.6	64.5	56.0	48.7	42.4	37.1	32.5	28.5	25.1	22.1	19.5	17.3	15.3	13.6	12.1	10.8	9.6	8.6	7.7	6.9	6.2	5.6	5.1	4.6	4.1	3.9
98	>200	>200	>200	>200	>200	>200	>200	188.4	160.5	137.3	117.7	101.3	87.4	75.6	65.6	57.0	49.7	43.4	38.0	33.4	29.4	25.9	22.9	20.2	18.0	15.9	14.2	12.7	11.3	10.1	9.1	8.1	7.3	6.6	5.9	5.3	4.8	4.5
99	>200	>200	>200	>200	>200	>200	>200	>200	187.7	160.5	137.6	118.4	102.1	88.4	76.6	66.6	58.1	50.8	44.5	39.0	34.3	30.3	26.7	23.7	21.0	18.6	16.6	14.8	13.2	11.8	10.6	9.5	8.5	7.7	6.9	6.2	5.6	5.3
100	>200	>200	>200	>200	>200	>200	>200	>200	>200	187.2	160.6	138.1	119.2	103.1	89.4	77.8	67.8	59.2	51.9	45.5	40.1	35.3	31.2	27.6	24.5	21.8	19.4	17.3	15.4	13.8	12.3	11.1	10.0	9.0	8.1	7.3	6.6	6.2
101	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	187.0	160.8	138.8	120.0	104.1	90.6	78.9	69.0	60.4	53.0	46.7	41.1	36.3	32.2	28.5	25.3	22.5	20.1	17.9	16.1	14.4	12.9	11.6	10.4	9.4	8.5	7.7	7.2
102	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	187.0	161.3	139.5	121.0	105.3	91.8	80.2	70.2	61.7	54.2	47.8	42.2	37.4	33.1	29.4	26.2	23.4	20.9	18.7	16.7	15.0	13.5	12.1	10.9	9.9	8.9	8.4
103	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	187.2	161.9	140.5	122.1	106.5	93.1	81.5	71.5	62.9	55.5	49.0	43.4	38.5	34.7	30.4	27.1	24.2	21.7	19.4	17.4	15.6	14.1	12.7	11.4	10.3	9.7
104	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	187.6	162.7	141.5	123.4	107.8	94.4	82.9	72.9	64.3	56.8	50.3	44.6	39.6	35.2	31.4	28.0	25.1	22.5	20.2	18.1	16.3	14.7	13.3	12.0	11.3
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.2	163.6	142.7	124.7	109.2	95.8	84.3	74.3	65.7	58.1	51.5	45.8	40.7	36.3	32.4	29.0	26.0	23.3	21.0	18.9	17.0	15.3	13.9	13.0
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.9	164.7	143.9	126.1	110.7	97.4	85.8	75.8	67.1	59.5	52.9	47.0	41.9	37.4	33.5	30.0	26.9	24.2	21.8	19.6	17.7	16.0	15.1
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	189.9	165.9	145.3	127.6	112.2	98.9	87.4	77.4	68.6	60.9	54.2	48.3	43.2	38.6	34.6	31.0	27.9	25.1	22.6	20.4	18.4	17.4
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.0	167.3	146.8	129.2	113.9	100.6	89.0	79.0	70.1	62.4	55.6	49.7	44.4	39.8	35.7	32.1	28.9	26.0	23.5	21.2	20.0
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.2	168.8	148.5	130.9	115.6	102.3	90.7	80.6	71.7	64.0	57.1	51.1	45.8	41.1	36.9	33.2	29.9	27.0	24.4	23.0
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.7	170.4	150.2	132.7	117.4	104.1	92.5	82.3	73.4	65.5	58.6	52.5	47.1	42.3	38.1	34.3	31.0	28.0	26.4
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.2	172.1	152.0	134.6	119.3	106.0	94.3	84.1	75.1	67.2	60.2	54.0	48.5	43.7	39.3	35.5	32.1	30.2
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	196.9	174.0	154.0	136.5	121.3	108.0	96.2	85.9	76.9	68.9	61.8	55.5	50.0	45.0	40.6	36.7	34.6
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.8	176.0	156.0	138.6	123.4	110.0	98.2	87.8	78.7	70.6	63.4	57.1	51.5	46.4	42.0	39.5
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.1	158.2	140.8	125.5	112.1	100.2	89.8	80.6	72.4	65.2	58.7	53.0	47.9	45.1
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.3	160.4	143.0	127.7	114.3	102.4	91.8	82.5	74.3	66.9	60.4	54.6	51.4
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.6	162.8	145.4	130.0	116.5	104.5	93.9	84.5	76.2	68.7	62.1	58.5
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.1	165.3	147.8	132.4	118.8	106.8	96.1	86.6	78.1	70.6	66.5
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	187.7	167.9	150.4	134.9	121.2	109.1	98.3	88.7	80.2	75.5
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	190.4	170.5	153.0	137.5	123.7	111.5	100.6	90.9	85.6
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.2	173.3	155.7	140.2	126.3	114.0	103.0	97.0
121	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	196.1	176.7	158.6	142.9	128.9	116.5	109.7
122	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	199.1	179.2	161.5	145.7	131.7	124.0
123	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.3	164.5	148.7	140.0
124	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.5	167.6	157.8
125	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.8	177.8
126	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
127	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
128	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
129	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
130	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
131	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
132	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
133	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
134	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

Figure B-40 Tabular Representation of Parking Nomograph for B767-300ER on 0 °F (-17.5 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

0 F	Gross B-767-300ER Weight (lbs)																																					
Ice Thickness (in)	205000	210000	215000	220000	225000	230000	235000	240000	245000	250000	255000	260000	265000	270000	275000	280000	285000	290000	295000	300000	305000	310000	315000	320000	325000	330000	335000	340000	345000	350000	355000	360000	365000	370000	375000	380000	385000	388000
52	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
53	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
54	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
55	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
56	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
57	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
58	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
59	0.7	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1
60	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1
61	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
62	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
63	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
64	1.1	1.0	1.0	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
65	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2
66	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
67	1.4	1.3	1.2	1.2	1.1	1.1	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3
68	1.5	1.4	1.4	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3
69	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3
70	2.4	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4
71	3.1	2.6	1.7	1.6	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4
72	4.0	3.3	2.7	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4
73	5.0	4.2	3.5	2.9	2.4	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5
74	6.3	5.2	4.4	3.7	3.1	2.6	1.7	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5
75	7.9	6.6	5.5	4.6	3.9	3.2	2.7	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5
76	9.9	8.2	6.8	5.7	4.8	4.1	3.4	2.9	2.5	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6
77	12.3	10.2	8.5	7.1	6.0	5.0	4.3	3.6	3.1	2.6	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6
78	15.2	12.6	10.5	8.8	7.4	6.2	5.3	4.5	3.8	3.3	2.8	2.4	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.7
79	18.8	15.6	13.0	10.9	9.1	7.7	6.5	5.5	4.7	4.0	3.5	3.0	2.6	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7
80	23.1	19.2	16.0	13.4	11.2	9.5	8.0	6.8	5.8	5.0	4.3	3.7	3.2	2.7	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8
81	28.3	23.5	19.6	16.4	13.8	11.6	9.8	8.3	7.1	6.1	5.2	4.5	3.9	3.3	2.9	2.5	1.8	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8
82	34.5	28.7	23.9	20.0	16.8	14.2	12.0	10.2	8.7	7.4	6.4	5.5	4.7	4.1	3.5	3.1	2.7	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.9
83	42.0	34.9	29.1	24.3	20.4	17.2	14.6	12.4	10.6	9.0	7.7	6.7	5.7	5.0	4.3	3.7	3.3	2.9	2.5	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9
84	51.0	42.3	35.2	29.5	24.8	20.9	17.7	15.0	12.8	10.9	9.4	8.1	7.0	6.0	5.2	4.5	4.0	3.5	3.0	2.7	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0
85	61.6	51.1	42.6	35.7	29.9	25.3	21.4	18.2	15.5	13.2	11.3	9.8	8.4	7.3	6.3	5.5	4.8	4.2	3.7	3.2	2.8	2.5	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0
86	74.3	61.6	51.4	43.0	36.1	30.4	25.8	21.9	18.7	16.0	13.7	11.8	10.2	8.8	7.6	6.6	5.8	5.0	4.4	3.9	3.4	3.0	2.7	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1
87	89.3	74.1	61.7	51.7	43.4	36.6	31.0	26.3	22.4	19.2	16.4	14.1	12.2	10.6	9.2	8.0	6.9	6.1	5.3	4.7	4.1	3.6	3.2	2.8	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2
88	107.1	88.8	74.0	61.9	52.0	43.9	37.1	31.6	26.9	23.0	19.7	17.0	14.6	12.7	11.0	9.5	8.3	7.3	6.4	5.6	4.9	4.3	3.8	3.4	3.0	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.4	1.4	1.4	1.3	1.3	1.2
89	128.0	106.2	88.5	74.1	62.7	52.5	44.4	37.7	32.2	27.5	23.6	20.3	17.5	15.1	13.1	11.4	10.0	8.7	7.6	6.7	5.9	5.2	4.6	4.1	3.6	3.2	2.8	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3
90	152.7	126.7	105.6	88.3	74.2	62.6	53.0	45.0	38.3	32.8	28.1	24.2	20.9	18.1	15.7	13.6	11.9	10.4	9.1	8.0	7.0	6.2	5.5	4.8	4.3	3.8	3.4	3.0	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4
91	181.7	150.7	125.6	105.1	88.3	74.4	63.0	53.5	45.6	39.0	33.5	28.8	24.8	21.5	18.6	16.2	14.1	12.3	10.8	9.5	8.3	7.4	6.5	5.8	5.1	4.5	4.0	3.6	3.2	2.9	2.6	1.8	1.7	1.7	1.6	1.6	1.5	1.5
92	>200	178.9	149.0	124.7	104.8	88.4	74.8	63.5	54.1	46.3	39.7	34.2	29.5	25.5	22.1	19.2	16.8	14.6	12.8	11.3	9.9	8.7	7.7	6.8	6.1	5.4	4.8	4.3	3.8	3.4	3.1	2.7	2.5	1.8	1.7	1.6	1.6	1.6
93	>200	>200	176.5	147.6	124.0	104.6	88.5	75.2	64.1	54.8	47.0	40.4	34.9	30.2	26.2	22.8	19.8	17.3	15.2	13.3	11.7	10.3	9.1	8.1	7.2	6.4	5.7	5.1	4.5	4.0	3.6	3.2	2.9	2.6	1.8	1.7	1.7	1.6
94	>200	>200	>200	174.4	146.5	123.6	104.6	88.8	75.7	64.7	55.5	47.8	41.2	35.7	30.9	26.9	23.4	20.5	17.9	15.7	13.9	12.2	10.8	9.5	8.5	7.5	6.7	6.0	5.3	4.8	4.3	3.8	3.4	3.1	2.8	2.5	1.8	1.7
95	>200	>200	>200	>200	172.7	145.7	123.3	104.7	89.3	76.3	65.5	56.3	48.6	42.0	36.5	31.7	27.6	24.1	21.1	18.6	16.3	14.4	12.7	11.3	10.0	8.9	7.9	7.0	6.3	5.6	5.0	4.5	4.1	3.7	3.3	3.0	2.7	2.5
96	>200	>200	>200	>200	>200	171.3	145.0	123.2	105.0	89.8	77.0	66.2	57.1	49.4	42.9	37.3	32.5	28.4	24.9	21.8	19.2	16.9	15.0	13.2	11.7	10.4	9.3	8.3	7.4	6.6	5.9	5.3	4.8	4.3	3.9	3.5	3.2	3.0
97	>200	>200	>200	>200	>200	>200	170.2	144.6	123.2	105.4	90.4	77.7	67.1	58.0	50.3	43.8	38.2	33.3	29.2	25.6	22.5	19.9	17.6	15.5	13.8	12.2	10.9	9.7	8.7	7.8	6.9	6.2	5.6	5.0	4.5	4.1	3.7	3.5
98	>200	>200	>200	>200	>200	>200	199.4	169.4	144.4	123.4	105.9	91.1	78.6	68.0	59.0	51.3	44.7	39.1	34.2	30.0	26.4	23.3	20.6	18.2	16.1	14.3	12.8	11.4	10.2	9.1	8.1	7.3	6.6	5.9	5.3	4.8	4.3	4.1
99	>200	>200	>200	>200	>200	>200	>200	198.0	168.8	144.3	123.8	106.5	91.9	79.5	68.9	59.9	52.3	45.7	40.0	35.1	30.9	27.2	24.0	21.3	18.9	16.8	14.9	13.3	11.9	10.6	9.5	8.5	7.7	6.9	6.2	5.6	5.1	4.8
100	>200	>200	>200	>200	>200	>200	>200	>200	196.9	168.4	144.4	124.2	107.2	92.7	80.4	69.9	61.0	53.3	46.7	41.0	36.0	31.8	28.1	24.8	22.0	19.6	17.4	15.5	13.9	12.4	11.1	10.0	9.0	8.1	7.3	6.6	5.9	5.6
101	>200	>200	>200	>200	>200	>200	>200	>200	>200	196.1	168.2	144.7	124.8	108.0	93.7	81.5	71.0	62.1	54.4	47.7	42.0	37.0	32.7	28.9	25.7	22.8	20.3	18.1	16.1	14.4	12.9	11.6	10.4	9.4	8.5	7.6	6.9	6.5
102	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.6	168.2	145.1	125.6	108.9	94.7	82.6	72.2	63.2	55.5	48.8	43.0	38.0	33.6	29.8	26.5	23.6	21.0	18.8	16.8	15.0	13.5	12.1	10.9	9.8	8.9	8.0	7.5
103	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.3	168.5	145.7	126.4	109.9	95.8	83.7	73.3	64.4	56.6	49.9	44.1	39.0	34.6	30.8	27.4	24.4	21.8	19.5	17.5	15.7	14.1	12.7	11.4	10.3	9.3	8.8
104	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.2	168.8	146.5	127.4	111.0	97.0	85.0	74.6	65.6	57.9	51.1	45.2	40.1	35.6	31.7	28.3	25.2	22.6	20.2	18.1	16.3	14.7	13.2	11.9	10.8	10.2
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.3	169.4	147.3	128.4	112.2	98.3	86.3	75.9	66.9	59.1	52.3	46.4	41.2	36.7	32.7	29.2	26.1	23.4	21.0	18.9	17.0	15.3	13.8	12.5	11.7
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.6	170.1	148.3	129.6	113.5	99.6	87.7	77.3	68.3	60.4	53.6	47.6	42.4	37.8	33.7	30.2	27.0	24.2	21.8	19.6	17.7	15.9	14.4	13.6
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	196.1	171.0	149.4	130.9	114.9	101.1	89.1	78.7	69.7	61.8	54.9	48.8	43.5	38.9	34.8	31.2	28.0	25.1	22.6	20.4	18.4	16.6	15.6
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	196.8	172.0	150.7	132.3	116.4	102.6	90.6	80.2	71.1	63.2	56.2	50.1	44.8	40.0	35.9	32.2	28.9	26.0	23.4	21.2	19.1	18.0
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.7	173.2	152.0	133.7	117.9	104.1	92.2	81.7	72.6	64.6	57.6	51.4	46.0	41.2	37.0	33.2	29.9	27.0	24.3	22.0	20.7
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.8	174.5	153.5	135.3	119.5	105.8	93.8	83.3	74.2	66.1	59.0	52.8	47.3	42.4	38.1	34.3	30.9	27.9	25.2	23.7
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	200.0	175.9	155.1	137.0	121.2	107.5	95.5	85.0	75.8	67.7	60.5	54.2	48.7	43.7	39.3	35.5	32.0	28.9	27.2
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.5	156.8	138.8	123.0	109.3	97.3	86.7	77.4	69.3	62.1	55.7	50.0	45.0	40.6	36.6	33.1	31.2
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.2	158.6	140.6	124.9	111.2	99.1	88.5	79.2	70.9	63.6	57.2	51.5	46.4	41.8	37.8	35.6
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.0	160.5	142.6	126.9	113.1	101.0	90.4	81.0	72.6	65.3	58.7	52.9	47.8	43.2	40.6
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.9	162.5	144.6	128.9	115.2	103.0	92.3	82.8	74.4	66.9	60.3	54.4	49.2	46.3
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.0	164.7	146.8	131.1	117.2	105.0	94.2	84.7	76.2	68.7	62.0	56.0	52.7
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	187.2	166.9	149.0	133.3	119.4	107.2	96.3	86.6	78.1	70.5	63.7	60.0
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	189.5	169.2	151.4	135.6	121.7	109.3	98.4	88.7	80.0	72.3	68.1
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.9	171.7	153.8	138.0	124.0	111.6	100.6	90.7	82.0	77.2
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	194.5	174.2	156.3	140.5	126.4	113.9	102.8	92.9	87.5
121	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.1	176.9	158.9	143.0	128.9	116.3	105.1	99.0
122	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	199.9	179.6	161.7	145.7	131.5	118.8	111.9
123	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.5	164.5	148.4	134.1	126.3
124	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.5	167.4	151.3	142.4
125	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.6	170.4	160.4
126	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.8	180.6
127	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
128	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
129	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
130	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
131	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
132	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
133	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
134	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

Figure B-41 Tabular Representation of Parking Nomograph for B767-300ER on 2 °F (-16.5 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

2 F — Gross B-767-300ER Weight (lbs)

Ice Thickness (in)	205000	210000	215000	220000	225000	230000	235000	240000	245000	250000	255000	260000	265000	270000	275000	280000	285000	290000	295000
52	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
53	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1
54	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1
55	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
56	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
57	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
58	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2
59	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2
60	0.7	0.7	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3
61	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3
62	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3
63	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4
64	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4
65	1.1	1.1	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5
66	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5
67	1.4	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5
68	1.5	1.4	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6
69	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6
70	1.7	1.6	1.5	1.5	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7
71	2.8	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8
72	3.5	2.9	2.4	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8
73	4.5	3.7	3.1	2.6	1.7	1.6	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.0	1.0	1.0	0.9	0.9
74	5.6	4.7	3.9	3.3	2.7	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9
75	7.1	5.9	4.9	4.1	3.4	2.9	2.4	1.7	1.6	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0
76	8.8	7.3	6.1	5.1	4.3	3.6	3.1	2.6	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.1	1.1
77	11.0	9.1	7.6	6.3	5.3	4.5	3.8	3.2	2.8	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2
78	13.6	11.3	9.4	7.9	6.6	5.6	4.7	4.0	3.4	2.9	2.5	1.7	1.7	1.6	1.5	1.4	1.4	1.3	1.3
79	16.8	13.9	11.6	9.7	8.2	6.9	5.8	4.9	4.2	3.6	3.1	2.7	1.8	1.7	1.6	1.5	1.5	1.4	1.4
80	20.6	17.1	14.3	11.9	10.0	8.5	7.2	6.1	5.2	4.4	3.8	3.3	2.8	2.4	1.7	1.7	1.6	1.5	1.4
81	25.3	21.0	17.5	14.6	12.3	10.4	8.8	7.4	6.3	5.4	4.7	4.0	3.5	3.0	2.6	1.8	1.7	1.6	1.5
82	30.9	25.6	21.3	17.9	15.0	12.7	10.7	9.1	7.8	6.6	5.7	4.9	4.2	3.6	3.2	2.8	2.4	1.7	1.7
83	37.6	31.2	26.0	21.7	18.3	15.4	13.0	11.1	9.4	8.1	6.9	6.0	5.1	4.4	3.9	3.3	2.9	2.6	1.8
84	45.6	37.8	31.5	26.4	22.2	18.7	15.8	13.4	11.4	9.8	8.4	7.2	6.2	5.4	4.7	4.1	3.5	3.1	2.7
85	55.2	45.8	38.1	31.9	26.8	22.6	19.1	16.2	13.8	11.8	10.2	8.7	7.5	6.5	5.7	4.9	4.3	3.7	3.3
86	66.5	55.2	46.0	38.5	32.3	27.3	23.1	19.6	16.7	14.3	12.2	10.5	9.1	7.9	6.8	5.9	5.2	4.5	4.0
87	80.0	66.4	55.3	46.3	38.9	32.8	27.7	23.6	20.1	17.2	14.7	12.7	10.9	9.5	8.2	7.1	6.2	5.4	4.8
88	95.9	79.6	66.3	55.5	46.6	39.3	33.3	28.3	24.1	20.6	17.7	15.2	13.1	11.3	9.8	8.6	7.5	6.5	5.7
89	114.7	95.2	79.3	66.4	55.7	47.0	39.8	33.8	28.8	24.6	21.1	18.2	15.7	13.6	11.8	10.2	8.9	7.8	6.8
90	136.9	113.5	94.6	79.2	66.5	56.1	47.5	40.3	34.4	29.4	25.2	21.7	18.7	16.2	14.0	12.2	10.6	9.3	8.1
91	162.8	135.1	112.6	94.2	79.1	66.7	56.5	48.0	40.9	35.0	30.0	25.8	22.3	19.3	16.7	14.5	12.7	11.1	9.7
92	193.3	160.4	133.6	111.8	93.9	79.2	67.1	57.0	48.5	41.5	35.6	30.6	26.4	22.9	19.8	17.2	15.0	13.1	11.5
93	>200	189.9	158.3	132.4	111.2	93.8	79.4	67.5	57.5	49.2	42.2	36.3	31.3	27.1	23.5	20.4	17.8	15.6	13.6
94	>200	>200	187.0	156.5	131.5	110.9	93.8	79.7	67.9	58.1	49.8	42.9	37.0	32.0	27.7	24.1	21.0	18.4	16.1
95	>200	>200	>200	184.5	155.0	130.7	110.6	94.0	80.1	68.5	58.7	50.5	43.6	37.7	32.7	28.4	24.8	21.7	19.0
96	>200	>200	>200	>200	182.3	153.8	130.2	110.6	94.2	80.6	69.1	59.4	51.3	44.4	38.5	33.5	29.2	25.5	22.3
97	>200	>200	>200	>200	>200	180.5	152.8	129.8	110.6	94.6	81.1	69.8	60.2	52.1	45.2	39.3	34.2	29.9	26.2
98	>200	>200	>200	>200	>200	>200	179.0	152.1	129.6	110.8	95.0	81.8	70.5	61.0	52.9	46.0	40.1	35.1	30.7
99	>200	>200	>200	>200	>200	>200	>200	177.8	151.6	129.6	111.1	95.6	82.5	71.4	61.9	53.8	46.9	41.0	35.9
100	>200	>200	>200	>200	>200	>200	>200	>200	176.9	151.2	129.7	111.6	96.3	83.3	72.2	62.8	54.8	47.9	41.9
101	>200	>200	>200	>200	>200	>200	>200	>200	>200	176.2	151.1	130.0	112.2	97.0	84.2	73.2	63.8	55.8	48.8
102	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	175.7	151.2	130.4	112.8	97.9	85.1	74.2	64.8	56.8
103	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	175.5	151.4	131.0	113.6	98.8	86.1	75.3	65.9
104	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	175.4	151.8	131.6	114.5	99.8	87.2	76.4
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	175.6	152.3	132.4	115.5	100.9	88.4
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	175.9	153.0	133.3	116.5	102.1
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	176.4	153.8	134.4	117.7
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.0	154.7	135.5
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.8	155.8
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.8
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
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116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
121	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
122	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
123	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
124	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
125	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
126	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
127	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
128	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
129	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
130	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
131	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
132	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
133	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
134	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

Ice Thickness (in)	300000	305000	310000	315000	320000	325000	330000	335000	340000	345000	350000	355000	360000	365000	370000	375000	380000	385000	388000
52	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
53	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
54	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
55	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
56	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
57	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
58	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
59	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
60	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1
61	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
62	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
63	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
64	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
65	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2
66	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2
67	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
68	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3
69	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3
70	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3
71	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4
72	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4
73	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4
74	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5
75	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5
76	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5
77	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6
78	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6
79	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7
80	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7
81	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8
82	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8
83	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9
84	2.4	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9
85	2.9	2.5	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.1	1.0	1.0
86	3.5	3.1	2.7	2.4	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.1
87	4.2	3.7	3.2	2.9	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1
88	5.0	4.4	3.9	3.4	3.0	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.3	1.2	1.2
89	6.0	5.3	4.6	4.1	3.6	3.2	2.9	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.3
90	7.1	6.3	5.5	4.9	4.3	3.8	3.4	3.0	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3
91	8.5	7.5	6.6	5.8	5.2	4.6	4.1	3.6	3.2	2.9	2.6	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.4
92	10.1	8.9	7.8	6.9	6.1	5.4	4.8	4.3	3.8	3.4	3.1	2.7	2.5	1.8	1.7	1.6	1.6	1.5	1.5
93	12.0	10.5	9.3	8.2	7.2	6.4	5.7	5.1	4.5	4.0	3.6	3.2	2.9	2.6	1.8	1.7	1.7	1.6	1.6
94	14.1	12.4	11.0	9.7	8.6	7.6	6.7	6.0	5.4	4.8	4.3	3.8	3.4	3.1	2.8	2.5	1.8	1.7	1.7
95	16.7	14.7	12.9	11.4	10.1	9.0	8.0	7.1	6.3	5.6	5.0	4.5	4.1	3.6	3.3	3.0	2.7	2.4	1.8
96	19.6	17.2	15.2	13.4	11.9	10.5	9.4	8.3	7.4	6.6	5.9	5.3	4.8	4.3	3.9	3.5	3.1	2.8	2.7
97	23.0	20.2	17.8	15.8	13.9	12.4	11.0	9.8	8.7	7.8	7.0	6.2	5.6	5.0	4.5	4.1	3.7	3.3	3.1
98	27.0	23.7	20.9	18.5	16.3	14.5	12.9	11.5	10.2	9.1	8.2	7.3	6.6	5.9	5.3	4.8	4.3	3.9	3.7
99	31.5	27.7	24.4	21.6	19.1	16.9	15.1	13.4	11.9	10.7	9.5	8.5	7.7	6.9	6.2	5.6	5.0	4.6	4.3
100	36.8	32.4	28.5	25.2	22.3	19.8	17.6	15.6	13.9	12.4	11.1	10.0	8.9	8.0	7.2	6.5	5.9	5.3	5.0
101	42.9	37.7	33.2	29.4	26.0	23.0	20.5	18.2	16.2	14.5	13.0	11.6	10.4	9.4	8.4	7.6	6.9	6.2	5.8
102	49.8	43.9	38.7	34.1	30.2	26.8	23.8	21.2	18.9	16.9	15.1	13.5	12.1	10.9	9.8	8.8	8.0	7.2	6.8
103	57.9	50.9	44.9	39.6	35.1	31.1	27.6	24.6	21.9	19.6	17.5	15.7	14.1	12.6	11.4	10.3	9.3	8.4	7.9
104	67.1	59.0	52.0	45.9	40.7	36.0	32.0	28.5	25.4	22.7	20.3	18.2	16.3	14.7	13.2	11.9	10.7	9.7	9.1
105	77.6	68.2	60.2	53.1	47.0	41.7	37.0	33.0	29.4	26.2	23.5	21.0	18.9	17.0	15.3	13.7	12.4	11.2	10.6
106	89.6	78.8	69.5	61.4	54.3	48.2	42.8	38.1	33.9	30.3	27.1	24.3	21.8	19.6	17.6	15.9	14.3	12.9	12.2
107	103.3	90.9	80.1	70.8	62.6	55.5	49.3	43.9	39.1	35.0	31.3	28.0	25.1	22.6	20.3	18.3	16.5	14.9	14.1
108	118.9	104.6	92.2	81.5	72.1	64.0	56.8	50.6	45.1	40.3	36.0	32.3	28.9	26.0	23.4	21.1	19.0	17.2	16.2
109	136.7	120.3	106.1	93.7	82.9	73.5	65.3	58.1	51.8	46.3	41.4	37.1	33.3	29.9	26.9	24.2	21.9	19.8	18.6
110	157.0	138.1	121.7	107.5	95.2	84.4	75.0	66.7	59.5	53.1	47.5	42.6	38.2	34.3	30.9	27.8	25.1	22.7	21.4
111	179.9	158.3	139.5	123.3	109.1	96.7	85.9	76.5	68.2	60.9	54.5	48.8	43.8	39.3	35.4	31.9	28.8	26.0	24.5
112	>200	181.2	159.7	141.1	124.9	110.7	98.4	87.5	78.0	69.7	62.3	55.8	50.1	45.0	40.5	36.5	32.9	29.8	28.0
113	>200	>200	182.6	161.3	142.7	126.6	112.4	100.1	89.2	79.7	71.3	63.8	57.3	51.5	46.3	41.7	37.7	34.0	32.0
114	>200	>200	>200	184.1	162.9	144.5	128.3	114.2	101.8	90.9	81.3	72.9	65.4	58.7	52.9	47.6	43.0	38.8	36.6
115	>200	>200	>200	>200	185.7	164.7	146.3	130.2	116.1	103.7	92.7	83.1	74.5	67.0	60.3	54.3	49.0	44.3	41.7
116	>200	>200	>200	>200	>200	187.5	166.6	148.2	132.2	118.0	105.6	94.6	84.9	76.2	68.6	61.8	55.8	50.4	47.5
117	>200	>200	>200	>200	>200	>200	189.4	168.6	150.3	134.2	120.0	107.5	96.5	86.7	78.0	70.3	63.4	57.3	54.0
118	>200	>200	>200	>200	>200	>200	>200	191.4	170.7	152.4	136.3	122.1	109.6	98.5	88.6	79.8	72.1	65.1	61.3
119	>200	>200	>200	>200	>200	>200	>200	>200	193.6	172.9	154.6	138.5	124.3	111.7	100.5	90.6	81.7	73.9	69.5
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.8	175.2	156.9	140.8	126.5	113.9	102.6	92.6	83.7	78.8
121	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.2	177.6	159.3	143.2	128.9	116.1	104.8	94.7	89.2
122	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.1	161.8	145.6	131.3	118.4	107.0	100.8
123	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.7	164.4	148.2	133.7	120.8	113.8
124	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.5	167.1	150.8	136.3	128.3
125	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.3	169.9	153.6	144.6
126	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.3	172.8	162.7
127	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	194.3	183.0
128	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
129	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
130	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
131	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
132	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
133	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
134	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

Figure B-42 Tabular Representation of Parking Nomograph for B767-300ER on 4 °F (-15.5 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

4 F	Gross B-767-300ER Weight (lbs)																	
Ice Thickness (in)	205000	210000	215000	220000	225000	230000	235000	240000	245000	250000	255000	260000	265000	270000	275000	280000	285000	290000
52	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
53	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1
54	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1
55	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
56	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
57	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
58	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2
59	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2
60	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3
61	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3
62	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3
63	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4
64	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4
65	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5
66	1.2	1.1	1.1	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5
67	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5
68	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6
69	1.5	1.5	1.4	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6
70	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7
71	2.5	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8
72	3.1	2.6	1.7	1.6	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8
73	4.0	3.3	2.7	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9
74	5.0	4.2	3.5	2.9	2.4	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	1.0
75	6.3	5.2	4.3	3.6	3.1	2.6	1.7	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0
76	7.9	6.5	5.4	4.5	3.8	3.2	2.7	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1
77	9.8	8.1	6.8	5.7	4.7	4.0	3.4	2.9	2.5	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.2	1.2
78	12.1	10.1	8.4	7.0	5.9	5.0	4.2	3.6	3.0	2.6	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3
79	15.0	12.4	10.3	8.7	7.3	6.1	5.2	4.4	3.8	3.2	2.8	2.4	1.7	1.6	1.6	1.5	1.4	1.4
80	18.4	15.3	12.7	10.6	8.9	7.5	6.4	5.4	4.6	4.0	3.4	2.9	2.5	1.7	1.7	1.6	1.5	1.5
81	22.6	18.7	15.6	13.1	11.0	9.2	7.8	6.6	5.7	4.8	4.2	3.6	3.1	2.7	1.8	1.7	1.6	1.6
82	27.6	22.9	19.1	15.9	13.4	11.3	9.6	8.1	6.9	5.9	5.1	4.4	3.8	3.3	2.8	2.5	1.7	1.7
83	33.6	27.8	23.2	19.4	16.3	13.8	11.6	9.9	8.4	7.2	6.2	5.3	4.6	4.0	3.4	3.0	2.6	1.8
84	40.7	33.8	28.2	23.6	19.8	16.7	14.1	12.0	10.2	8.7	7.5	6.4	5.6	4.8	4.2	3.6	3.2	2.8
85	49.3	40.9	34.1	28.5	23.9	20.2	17.1	14.5	12.4	10.6	9.1	7.8	6.7	5.8	5.1	4.4	3.8	3.3
86	59.4	49.3	41.1	34.4	28.9	24.4	20.6	17.5	14.9	12.8	10.9	9.4	8.1	7.0	6.1	5.3	4.6	4.0
87	71.5	59.3	49.4	41.4	34.7	29.3	24.8	21.1	18.0	15.4	13.2	11.3	9.8	8.5	7.3	6.4	5.6	4.9
88	85.8	71.2	59.3	49.6	41.7	35.2	29.8	25.3	21.5	18.4	15.8	13.6	11.7	10.1	8.8	7.6	6.7	5.8
89	102.6	85.1	70.9	59.4	49.9	42.1	35.6	30.2	25.8	22.0	18.9	16.3	14.0	12.1	10.5	9.1	8.0	7.0
90	122.5	101.6	84.6	70.8	59.5	50.2	42.5	36.1	30.7	26.3	22.5	19.4	16.7	14.5	12.6	10.9	9.5	8.3
91	145.8	120.9	100.8	84.3	70.8	59.7	50.6	42.9	36.6	31.3	26.8	23.1	19.9	17.2	14.9	13.0	11.3	9.9
92	173.1	143.6	119.6	100.1	84.1	70.9	60.0	51.0	43.5	37.2	31.9	27.4	23.6	20.5	17.7	15.4	13.5	11.8
93	>200	170.1	141.7	118.6	99.6	84.0	71.1	60.4	51.5	44.0	37.8	32.5	28.0	24.2	21.0	18.3	15.9	13.9
94	>200	>200	167.5	140.1	117.7	99.3	84.0	71.4	60.8	52.0	44.6	38.4	33.1	28.6	24.8	21.6	18.8	16.5
95	>200	>200	197.5	165.3	138.8	117.1	99.1	84.2	71.8	61.3	52.6	45.3	39.0	33.8	29.3	25.5	22.2	19.4
96	>200	>200	>200	194.5	163.4	137.8	116.6	99.1	84.4	72.2	61.9	53.3	46.0	39.8	34.5	30.0	26.1	22.8
97	>200	>200	>200	>200	191.9	161.8	137.0	116.3	99.1	84.8	72.7	62.5	54.0	46.7	40.5	35.2	30.7	26.8
98	>200	>200	>200	>200	>200	189.6	160.5	136.3	116.2	99.3	85.2	73.3	63.2	54.7	47.5	41.3	36.0	31.4
99	>200	>200	>200	>200	>200	>200	187.7	159.5	135.9	116.2	99.7	85.7	74.0	64.0	55.5	48.3	42.1	36.8
100	>200	>200	>200	>200	>200	>200	>200	186.1	158.6	135.6	116.3	100.1	86.3	74.7	64.8	56.3	49.1	42.9
101	>200	>200	>200	>200	>200	>200	>200	>200	184.8	158.0	135.6	116.6	100.6	87.0	75.5	65.6	57.2	50.0
102	>200	>200	>200	>200	>200	>200	>200	>200	>200	183.8	157.7	135.6	117.0	101.2	87.8	76.4	66.6	58.2
103	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	183.0	157.5	135.8	117.5	101.9	88.6	77.3	67.5
104	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.5	157.4	136.2	118.1	102.7	89.6	78.3
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.2	157.6	136.7	118.9	103.6	90.6
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.0	157.9	137.3	119.7	104.6
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.1	158.4	138.1	120.7
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.4	159.0	138.9
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.8	159.7
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	183.4
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
121	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
122	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
123	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
124	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
125	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
126	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
127	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
128	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
129	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
130	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
131	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
132	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
133	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
134	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

4 F	Gross B-767-300ER Weight (lbs)																			
Ice Thickness (in)	295000	300000	305000	310000	315000	320000	325000	330000	335000	340000	345000	350000	355000	360000	365000	370000	375000	380000	385000	388000
52	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0
53	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
54	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
55	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
56	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
57	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
58	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
59	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
60	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1
61	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1
62	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
63	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
64	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
65	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
66	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2
67	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
68	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3
69	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3
70	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3
71	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4
72	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4
73	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4
74	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5
75	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5
76	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5
77	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6
78	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6
79	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.7
80	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7
81	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7
82	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8
83	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8
84	2.4	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9
85	2.9	2.6	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	1.0
86	3.5	3.1	2.7	2.4	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0
87	4.3	3.7	3.3	2.9	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1
88	5.1	4.5	3.9	3.5	3.1	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.2
89	6.1	5.4	4.7	4.2	3.7	3.2	2.9	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2
90	7.3	6.4	5.6	5.0	4.4	3.9	3.4	3.1	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3
91	8.7	7.6	6.7	5.9	5.2	4.6	4.1	3.6	3.2	2.9	2.6	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.4
92	10.3	9.0	8.0	7.0	6.2	5.5	4.9	4.3	3.8	3.4	3.1	2.7	2.4	1.8	1.7	1.6	1.6	1.5	1.5	1.4
93	12.2	10.7	9.4	8.3	7.3	6.5	5.8	5.1	4.5	4.1	3.6	3.2	2.9	2.6	1.8	1.7	1.7	1.6	1.6	1.5
94	14.4	12.7	11.1	9.8	8.7	7.7	6.8	6.0	5.4	4.8	4.3	3.8	3.4	3.1	2.8	2.5	1.8	1.7	1.6	1.6
95	17.0	14.9	13.1	11.6	10.2	9.0	8.0	7.1	6.3	5.7	5.0	4.5	4.0	3.6	3.3	2.9	2.6	2.4	1.7	1.7
96	20.0	17.6	15.4	13.6	12.0	10.6	9.4	8.4	7.5	6.7	5.9	5.3	4.8	4.3	3.8	3.5	3.1	2.8	2.5	2.4
97	23.5	20.6	18.1	16.0	14.1	12.5	11.1	9.8	8.8	7.8	7.0	6.2	5.6	5.0	4.5	4.1	3.7	3.3	3.0	2.8
98	27.5	24.2	21.3	18.7	16.6	14.7	13.0	11.5	10.3	9.2	8.2	7.3	6.6	5.9	5.3	4.8	4.3	3.9	3.5	3.3
99	32.7	28.3	24.9	21.9	19.4	17.1	15.2	13.5	12.0	10.7	9.6	8.6	7.7	6.9	6.2	5.6	5.0	4.5	4.1	3.8
100	37.6	33.0	29.0	25.6	22.6	20.0	17.7	15.8	14.0	12.5	11.2	10.0	8.9	8.0	7.2	6.5	5.8	5.3	4.8	4.5
101	43.8	38.5	33.8	29.8	26.3	23.3	20.7	18.4	16.3	14.6	13.0	11.6	10.4	9.4	8.4	7.6	6.8	6.1	5.6	5.2
102	50.9	44.7	39.3	34.7	30.6	27.1	24.0	21.4	19.0	16.9	15.1	13.5	12.1	10.9	9.8	8.8	7.9	7.2	6.5	6.1
103	59.1	51.9	45.7	40.3	35.6	31.5	27.9	24.8	22.1	19.7	17.6	15.7	14.1	12.6	11.3	10.2	9.2	8.3	7.5	7.1
104	68.6	60.2	52.9	46.7	41.2	36.5	32.4	28.7	25.6	22.8	20.4	18.2	16.3	14.6	13.2	11.8	10.7	9.6	8.7	8.2
105	79.3	69.6	61.3	54.0	47.7	42.2	37.4	33.3	29.6	26.4	23.6	21.1	18.9	16.9	15.2	13.7	12.3	11.1	10.1	9.5
106	91.6	80.4	70.8	62.4	55.1	48.8	43.2	38.4	34.2	30.5	27.2	24.3	21.8	19.6	17.6	15.8	14.3	12.9	11.6	10.9
107	105.7	92.8	81.6	71.9	63.6	56.2	49.9	44.3	39.4	35.2	31.4	28.1	25.2	22.6	20.3	18.2	16.4	14.8	13.4	12.6
108	121.7	106.8	94.0	82.8	73.2	64.8	57.4	51.0	45.4	40.5	36.1	32.3	29.0	26.0	23.4	21.0	18.9	17.1	15.4	14.5
109	139.9	122.8	108.1	95.3	84.1	74.5	66.0	58.7	52.2	46.5	41.6	37.2	33.3	29.9	26.8	24.2	21.8	19.6	17.8	16.7
110	160.6	141.0	124.0	109.4	96.6	85.5	75.8	67.4	59.9	53.4	47.7	42.7	38.2	34.3	30.8	27.7	25.0	22.6	20.4	19.2
111	184.1	161.7	142.2	125.4	110.7	98.0	86.9	77.2	68.7	61.3	54.7	48.9	43.8	39.3	35.3	31.8	28.7	25.9	23.4	22.0
112	>200	185.1	162.8	143.5	126.8	112.2	99.5	88.4	78.7	70.1	62.6	56.0	50.2	45.0	40.5	36.4	32.8	29.6	26.8	25.2
113	>200	>200	186.1	164.1	144.9	128.3	113.7	101.0	89.9	80.2	71.6	64.0	57.4	51.5	46.2	41.6	37.5	33.8	30.6	28.8
114	>200	>200	>200	187.3	165.5	146.4	129.9	115.4	102.7	91.5	81.7	73.1	65.5	58.8	52.8	47.5	42.8	38.6	34.9	32.9
115	>200	>200	>200	>200	188.6	167.0	148.0	131.5	117.1	104.3	93.2	83.3	74.7	67.0	60.2	54.2	48.8	44.1	39.8	37.5
116	>200	>200	>200	>200	>200	190.1	168.6	149.8	133.3	118.8	106.1	94.9	85.0	76.3	68.5	61.7	55.6	50.2	45.3	42.7
117	>200	>200	>200	>200	>200	>200	191.7	170.3	151.6	135.1	120.7	107.9	96.7	86.8	78.0	70.1	63.2	57.0	51.5	48.5
118	>200	>200	>200	>200	>200	>200	>200	193.4	172.1	153.5	137.0	122.6	109.8	98.5	88.5	79.7	71.8	64.8	58.5	55.1
119	>200	>200	>200	>200	>200	>200	>200	>200	195.3	174.1	155.5	139.1	124.6	111.8	100.4	90.4	81.5	73.5	66.4	62.5
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.3	176.2	157.6	141.2	126.7	113.8	102.4	92.3	83.3	75.3	70.9
121	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	199.4	178.3	159.8	143.3	128.8	115.9	104.5	94.3	85.2	80.2
122	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.6	162.0	145.6	131.0	118.1	106.6	96.3	90.7
123	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	183.0	164.4	148.0	133.3	120.3	108.7	102.4
124	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.5	166.9	150.4	135.7	122.6	115.5
125	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.0	169.5	152.9	138.2	130.1
126	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	190.7	172.1	155.5	146.5
127	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.5	174.9	164.7
128	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	196.4	185.0
129	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
130	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
131	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
132	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
133	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
134	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

Figure B-43 Tabular Representation of Parking Nomograph for B767-300ER on 6 °F (-14 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

6 F	Gross B-767-300ER Weight (lbs)																		
Ice Thickness (in)	205000	210000	215000	220000	225000	230000	235000	240000	245000	250000	255000	260000	265000	270000	275000	280000	285000	290000	295000
52	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
53	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
54	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1
55	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1
56	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
57	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
58	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
59	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2
60	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
61	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3
62	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3
63	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3
64	1.0	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4
65	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4
66	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5
67	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5
68	1.4	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5
69	1.5	1.4	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6
70	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6
71	1.7	1.6	1.5	1.5	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7
72	2.8	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8
73	3.5	2.9	2.4	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8
74	4.4	3.7	3.1	2.6	1.7	1.6	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.0	1.0	1.0	0.9	0.9
75	5.6	4.6	3.9	3.2	2.7	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9
76	7.0	5.8	4.8	4.0	3.4	2.9	2.4	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0
77	8.7	7.2	6.0	5.0	4.2	3.6	3.0	2.6	1.7	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1
78	10.8	8.9	7.5	6.2	5.2	4.4	3.7	3.2	2.7	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2
79	13.3	11.0	9.2	7.7	6.5	5.5	4.6	3.9	3.3	2.9	2.5	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3
80	16.4	13.6	11.3	9.5	8.0	6.7	5.7	4.8	4.1	3.5	3.0	2.6	1.8	1.7	1.6	1.5	1.5	1.4	1.3
81	20.1	16.7	13.9	11.6	9.8	8.2	7.0	5.9	5.0	4.3	3.7	3.2	2.7	2.4	1.7	1.6	1.6	1.5	1.4
82	24.6	20.4	17.0	14.2	11.9	10.1	8.5	7.2	6.2	5.3	4.5	3.9	3.4	2.9	2.5	1.7	1.7	1.6	1.5
83	29.9	24.8	20.7	17.3	14.5	12.3	10.4	8.8	7.5	6.4	5.5	4.7	4.1	3.5	3.1	2.7	1.8	1.7	1.6
84	36.3	30.1	25.1	21.0	17.6	14.9	12.6	10.7	9.1	7.8	6.7	5.8	5.0	4.3	3.7	3.2	2.8	2.5	1.7
85	44.0	36.5	30.4	25.4	21.4	18.0	15.2	12.9	11.0	9.4	8.1	7.0	6.0	5.2	4.5	3.9	3.4	3.0	2.6
86	53.0	44.0	36.7	30.7	25.8	21.7	18.4	15.6	13.3	11.4	9.8	8.4	7.2	6.3	5.4	4.7	4.1	3.6	3.2
87	63.8	52.9	44.1	36.9	31.0	26.2	22.1	18.8	16.0	13.7	11.8	10.1	8.7	7.5	6.5	5.7	5.0	4.3	3.8
88	76.6	63.5	52.9	44.3	37.2	31.4	26.6	22.6	19.2	16.4	14.1	12.1	10.5	9.1	7.9	6.8	6.0	5.2	4.6
89	91.7	76.0	63.4	53.0	44.5	37.6	31.8	27.0	23.0	19.7	16.9	14.5	12.5	10.8	9.4	8.2	7.1	6.2	5.5
90	109.4	90.8	75.6	63.3	53.2	44.8	37.9	32.2	27.5	23.5	20.1	17.3	14.9	12.9	11.2	9.8	8.5	7.4	6.5
91	130.2	108.0	90.0	75.3	63.3	53.4	45.2	38.4	32.7	28.0	24.0	20.6	17.8	15.4	13.4	11.6	10.1	8.8	7.7
92	154.7	128.3	106.9	89.5	75.2	63.4	53.7	45.6	38.8	33.2	28.5	24.5	21.1	18.3	15.9	13.8	12.0	10.5	9.2
93	183.3	152.1	126.7	106.0	89.1	75.1	63.6	54.0	46.0	39.4	33.8	29.0	25.0	21.7	18.8	16.3	14.2	12.4	10.9
94	>200	179.8	149.8	125.3	105.3	88.8	75.2	63.8	54.4	46.5	39.9	34.3	29.6	25.6	22.2	19.3	16.8	14.7	12.9
95	>200	>200	176.7	147.8	124.2	104.7	88.7	75.3	64.2	54.9	47.1	40.5	34.9	30.2	26.2	22.8	19.9	17.4	15.2
96	>200	>200	>200	174.0	146.2	123.3	104.3	88.6	75.5	64.6	55.4	47.7	41.1	35.6	30.8	26.8	23.4	20.4	17.9
97	>200	>200	>200	>200	171.7	144.8	122.6	104.1	88.7	75.9	65.1	56.0	48.3	41.8	36.2	31.5	27.5	24.0	21.0
98	>200	>200	>200	>200	>200	169.7	143.7	122.0	104.0	88.9	76.3	65.6	56.6	49.0	42.5	36.9	32.2	28.1	24.6
99	>200	>200	>200	>200	>200	198.5	168.1	142.8	121.7	104.0	89.2	76.8	66.2	57.3	49.7	43.2	37.7	32.9	28.8
100	>200	>200	>200	>200	>200	>200	196.2	166.7	142.1	121.5	104.2	89.6	77.3	66.9	58.0	50.4	44.0	38.4	33.7
101	>200	>200	>200	>200	>200	>200	>200	194.2	165.5	141.5	121.4	104.4	90.1	77.9	67.6	58.8	51.3	44.8	39.2
102	>200	>200	>200	>200	>200	>200	>200	>200	192.6	164.7	141.2	121.5	104.8	90.7	78.6	68.4	59.6	52.1	45.6
103	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.2	164.0	141.1	121.7	105.3	91.3	79.4	69.2	60.5	53.0
104	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	190.1	163.5	141.1	122.1	105.9	92.1	80.3	70.1	61.4
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	189.3	163.3	141.2	122.5	106.5	92.9	81.2	71.1
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.6	163.2	141.6	123.1	107.3	93.8	82.1
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.2	163.3	142.0	123.8	108.2	94.7
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.0	163.5	142.6	124.6	109.1
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.1	163.9	143.3	125.5
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.2	164.5	144.1
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.6	165.2
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	189.1
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
121	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
122	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
123	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
124	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
125	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
126	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
127	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
128	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
129	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
130	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
131	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
132	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
133	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
134	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

6 F	Gross B-767-300ER Weight (lbs)																		
Ice Thickness (in)	300000	305000	310000	315000	320000	325000	330000	335000	340000	345000	350000	355000	360000	365000	370000	375000	380000	385000	388000
52	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0
53	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
54	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
55	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
56	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
57	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
58	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
59	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
60	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
61	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1
62	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
63	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
64	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
65	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
66	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2
67	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2
68	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
69	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3
70	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3
71	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3
72	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4
73	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4
74	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4
75	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5
76	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5
77	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5
78	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6
79	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6
80	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7
81	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7
82	1.5	1.4	1.4	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8
83	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8
84	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.9
85	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9
86	2.8	2.4	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0
87	3.3	2.9	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0
88	4.0	3.5	3.1	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.1	1.1
89	4.8	4.2	3.7	3.3	2.9	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2
90	5.7	5.0	4.4	3.9	3.5	3.1	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2
91	6.8	6.0	5.3	4.7	4.1	3.7	3.2	2.9	2.6	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3
92	8.1	7.1	6.3	5.5	4.9	4.3	3.9	3.4	3.1	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4
93	9.6	8.4	7.4	6.6	5.8	5.1	4.6	4.1	3.6	3.2	2.9	2.6	1.8	1.7	1.7	1.6	1.6	1.5	1.5
94	11.3	10.0	8.8	7.8	6.9	6.1	5.4	4.8	4.3	3.8	3.4	3.1	2.8	2.5	1.8	1.7	1.6	1.6	1.6
95	13.3	11.7	10.4	9.1	8.1	7.2	6.4	5.7	5.1	4.5	4.0	3.6	3.2	2.9	2.6	1.8	1.7	1.7	1.6
96	15.7	13.8	12.2	10.8	9.5	8.4	7.5	6.7	6.0	5.3	4.8	4.3	3.8	3.4	3.1	2.8	2.5	1.8	1.7
97	18.5	16.2	14.3	12.6	11.2	9.9	8.8	7.8	7.0	6.2	5.6	5.0	4.5	4.0	3.6	3.3	3.0	2.7	2.5
98	21.6	19.0	16.8	14.8	13.1	11.6	10.3	9.2	8.2	7.3	6.5	5.9	5.3	4.7	4.3	3.8	3.5	3.1	2.9
99	25.3	22.3	19.6	17.3	15.3	13.6	12.1	10.8	9.6	8.6	7.7	6.9	6.2	5.5	5.0	4.5	4.0	3.7	3.4
100	29.5	26.0	22.9	20.2	17.9	15.9	14.1	12.6	11.2	10.0	8.9	8.0	7.2	6.5	5.8	5.2	4.7	4.3	4.0
101	34.4	30.3	26.7	23.6	20.9	18.5	16.4	14.6	13.0	11.7	10.4	9.3	8.4	7.5	6.8	6.1	5.5	5.0	4.7
102	40.1	35.2	31.1	27.4	24.3	21.5	19.1	17.0	15.2	13.6	12.1	10.9	9.7	8.8	7.9	7.1	6.4	5.8	5.5
103	46.5	40.9	36.1	31.9	28.2	25.0	22.2	19.8	17.6	15.7	14.1	12.6	11.3	10.2	9.1	8.2	7.4	6.7	6.3
104	53.9	47.4	41.8	36.9	32.7	29.0	25.8	22.9	20.4	18.2	16.3	14.6	13.1	11.8	10.6	9.6	8.6	7.8	7.3
105	62.4	54.9	48.4	42.8	37.8	33.6	29.8	26.5	23.6	21.1	18.9	16.9	15.2	13.6	12.3	11.1	10.0	9.0	8.5
106	72.1	63.4	55.9	49.4	43.7	38.8	34.4	30.6	27.3	24.4	21.8	19.5	17.5	15.8	14.2	12.8	11.5	10.4	9.8
107	83.2	73.2	64.5	57.0	50.4	44.7	39.7	35.4	31.5	28.1	25.2	22.6	20.2	18.2	16.4	14.7	13.3	12.0	11.3
108	95.8	84.3	74.3	65.6	58.1	51.5	45.8	40.7	36.3	32.4	29.0	26.0	23.3	20.9	18.8	17.0	15.3	13.8	13.0
109	110.2	96.9	85.4	75.5	66.8	59.2	52.6	46.8	41.7	37.3	33.3	29.9	26.8	24.1	21.7	19.5	17.6	15.9	15.0
110	126.5	111.3	98.1	86.6	76.7	68.0	60.4	53.8	47.9	42.8	38.3	34.3	30.8	27.6	24.9	22.4	20.2	18.3	17.2
111	145.0	127.6	112.5	99.3	87.9	78.0	69.3	61.6	55.0	49.1	43.9	39.3	35.3	31.7	28.5	25.7	23.2	21.0	19.7
112	166.0	146.1	128.8	113.7	100.7	89.3	79.3	70.6	62.9	56.2	50.3	45.0	40.4	36.3	32.7	29.4	26.6	24.0	22.6
113	189.8	167.0	147.2	130.0	115.1	102.1	90.7	80.7	71.9	64.2	57.5	51.5	46.2	41.5	37.3	33.7	30.4	27.4	25.8
114	>200	190.7	168.1	148.5	131.4	116.5	103.5	92.1	82.1	73.4	65.6	58.8	52.7	47.4	42.6	38.4	34.7	31.3	29.5
115	>200	>200	191.7	169.3	149.9	132.9	118.1	105.1	93.7	83.6	74.8	67.0	60.1	54.0	48.6	43.8	39.5	35.7	33.6
116	>200	>200	>200	192.8	170.7	151.3	134.4	119.6	106.7	95.2	85.2	76.3	68.5	61.5	55.4	49.9	45.0	40.7	38.3
117	>200	>200	>200	>200	194.1	172.1	152.9	136.1	121.3	108.3	96.9	86.8	77.9	70.0	63.0	56.8	51.2	46.3	43.6
118	>200	>200	>200	>200	>200	195.5	173.7	154.6	137.8	123.1	110.1	98.6	88.5	79.5	71.5	64.5	58.2	52.6	49.5
119	>200	>200	>200	>200	>200	>200	197.1	175.4	156.3	139.6	124.9	111.9	100.4	90.2	81.2	73.1	66.0	59.6	56.2
120	>200	>200	>200	>200	>200	>200	>200	198.7	177.2	158.2	141.5	126.8	113.7	102.2	92.0	82.9	74.8	67.6	63.6
121	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.1	160.2	143.5	128.8	115.7	104.1	93.8	84.7	76.5	72.0
122	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.1	162.2	145.6	130.8	117.7	106.1	95.7	86.5	81.4
123	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	183.2	164.4	147.7	132.9	119.8	108.1	97.7	92.0
124	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.4	166.6	150.0	135.1	121.9	110.2	103.8
125	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	187.8	169.0	152.3	137.4	124.2	116.9
126	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	190.2	171.4	154.7	139.8	131.6
127	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.8	173.9	157.2	148.0
128	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.4	176.6	166.3
129	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.2	186.6
130	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
131	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
132	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
133	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
134	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

Figure B-44 Tabular Representation of Parking Nomograph for B767-300ER on 8 °F (-13 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

8 F	Gross B-767-300ER Weight (lbs)																																				
Ice Thickness (in)	205000	210000	215000	220000	225000	230000	235000	240000	245000	250000	255000	260000	265000	270000	275000	280000	285000	290000	295000	300000	305000	310000	315000	320000	325000	330000	335000	340000	345000	350000	355000	360000	365000	370000	375000	380000	385000	388000
52	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0
53	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
54	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
55	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
56	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
57	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
58	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
59	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
60	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
61	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1
62	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1
63	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
64	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
65	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
66	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
67	1.2	1.1	1.1	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2
68	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
69	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3
70	1.5	1.5	1.4	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3
71	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3
72	2.5	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4
73	3.1	2.6	1.7	1.6	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4
74	3.9	3.3	2.7	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4
75	4.9	4.1	3.4	2.9	2.4	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5
76	6.2	5.1	4.3	3.6	3.0	2.5	1.7	1.6	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5
77	7.7	6.4	5.3	4.5	3.7	3.2	2.7	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5
78	9.6	7.9	6.6	5.5	4.6	3.9	3.3	2.8	2.4	1.7	1.6	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6
79	11.8	9.8	8.2	6.8	5.7	4.8	4.1	3.5	3.0	2.5	1.7	1.7	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6
80	14.6	12.1	10.1	8.4	7.1	6.0	5.1	4.3	3.7	3.1	2.7	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6
81	17.9	14.8	12.4	10.3	8.7	7.3	6.2	5.3	4.5	3.8	3.3	2.8	2.4	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7
82	21.8	18.1	15.1	12.6	10.6	8.9	7.6	6.4	5.5	4.7	4.0	3.5	3.0	2.6	1.8	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7
83	26.6	22.1	18.4	15.4	12.9	10.9	9.2	7.8	6.7	5.7	4.9	4.2	3.6	3.1	2.7	2.4	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8
84	32.3	26.8	22.3	18.7	15.7	13.2	11.2	9.5	8.1	6.9	6.0	5.1	4.4	3.8	3.3	2.9	2.5	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.8
85	39.1	32.5	27.1	22.6	19.0	16.0	13.6	11.5	9.8	8.4	7.2	6.2	5.3	4.6	4.0	3.5	3.0	2.7	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9
86	47.2	39.2	32.7	27.3	23.0	19.4	16.4	13.9	11.9	10.1	8.7	7.5	6.5	5.6	4.8	4.2	3.7	3.2	2.8	2.5	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9
87	56.9	47.2	39.3	32.9	27.6	23.3	19.7	16.8	14.3	12.2	10.5	9.0	7.8	6.7	5.8	5.1	4.4	3.9	3.4	3.0	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0
88	68.3	56.6	47.2	39.5	33.2	28.0	23.7	20.1	17.1	14.7	12.6	10.8	9.3	8.1	7.0	6.1	5.3	4.6	4.1	3.6	3.1	2.8	2.4	1.7	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.1
89	81.7	67.8	56.5	47.3	39.7	33.5	28.3	24.1	20.5	17.5	15.0	12.9	11.2	9.7	8.4	7.3	6.4	5.5	4.9	4.3	3.8	3.3	2.9	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1
90	97.6	80.9	67.4	56.4	47.4	40.0	33.8	28.7	24.5	20.9	18.0	15.5	13.3	11.5	10.0	8.7	7.6	6.6	5.8	5.1	4.5	3.9	3.5	3.1	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2
91	116.2	96.4	80.3	67.2	56.5	47.6	40.3	34.2	29.2	24.9	21.4	18.4	15.9	13.7	11.9	10.4	9.0	7.9	6.9	6.1	5.3	4.7	4.2	3.7	3.3	2.9	2.6	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.3
92	138.0	114.5	95.4	79.8	67.1	56.6	47.9	40.7	34.7	29.6	25.4	21.9	18.9	16.3	14.2	12.3	10.7	9.4	8.2	7.2	6.3	5.6	4.9	4.4	3.9	3.4	3.1	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3
93	163.6	135.7	113.1	94.6	79.5	67.0	56.7	48.2	41.1	35.1	30.1	25.9	22.4	19.3	16.8	14.6	12.7	11.1	9.7	8.5	7.5	6.6	5.9	5.2	4.6	4.1	3.6	3.2	2.9	2.6	1.8	1.7	1.7	1.6	1.6	1.5	1.5	1.4
94	193.5	160.5	133.7	111.9	94.0	79.3	67.1	57.0	48.6	41.5	35.6	30.6	26.4	22.9	19.8	17.2	15.0	13.1	11.5	10.1	8.9	7.8	6.9	6.1	5.4	4.8	4.3	3.8	3.4	3.1	2.7	2.5	1.8	1.7	1.6	1.6	1.5	1.5
95	>200	189.3	157.8	132.0	110.9	93.5	79.2	67.2	57.3	49.0	42.0	36.2	31.2	27.0	23.4	20.4	17.7	15.5	13.6	11.9	10.5	9.2	8.2	7.2	6.4	5.7	5.1	4.5	4.0	3.6	3.2	2.9	2.6	1.8	1.7	1.7	1.6	1.6
96	>200	>200	185.7	155.4	130.6	110.1	93.2	79.2	67.5	57.7	49.5	42.6	36.7	31.8	27.6	24.0	20.9	18.3	16.0	14.0	12.3	10.9	9.6	8.5	7.5	6.7	6.0	5.3	4.7	4.2	3.8	3.4	3.1	2.8	2.5	1.8	1.7	1.7
97	>200	>200	>200	182.6	153.4	129.4	109.5	93.0	79.3	67.8	58.1	50.0	43.1	37.3	32.4	28.2	24.5	21.4	18.8	16.5	14.5	12.8	11.3	10.0	8.9	7.9	7.0	6.2	5.6	5.0	4.5	4.0	3.6	3.2	2.9	2.6	2.4	1.8
98	>200	>200	>200	>200	179.8	151.7	128.4	109.0	92.9	79.5	68.2	58.6	50.6	43.8	38.0	33.0	28.8	25.1	22.0	19.3	17.0	15.0	13.2	11.7	10.4	9.2	8.2	7.3	6.5	5.8	5.2	4.7	4.2	3.8	3.4	3.1	2.8	2.6
99	>200	>200	>200	>200	>200	177.5	150.2	127.6	108.7	93.0	79.7	68.6	59.2	51.2	44.4	38.6	33.7	29.4	25.8	22.6	19.9	17.5	15.5	13.7	12.2	10.8	9.6	8.6	7.7	6.8	6.1	5.5	4.9	4.4	4.0	3.6	3.3	3.1
100	>200	>200	>200	>200	>200	>200	175.4	149.0	127.0	108.6	93.1	80.1	69.1	59.8	51.9	45.1	39.3	34.4	30.1	26.4	23.2	20.5	18.1	16.0	14.2	12.6	11.2	10.0	8.9	8.0	7.2	6.4	5.8	5.2	4.7	4.2	3.8	3.6
101	>200	>200	>200	>200	>200	>200	>200	173.7	148.0	126.6	108.6	93.4	80.6	69.7	60.5	52.6	45.8	40.1	35.1	30.8	27.1	23.9	21.1	18.7	16.6	14.7	13.1	11.7	10.4	9.3	8.3	7.5	6.7	6.1	5.5	4.9	4.4	4.2
102	>200	>200	>200	>200	>200	>200	>200	>200	172.2	147.3	126.3	108.7	93.7	81.1	70.3	61.2	53.3	46.6	40.8	35.8	31.5	27.8	24.5	21.7	19.3	17.1	15.2	13.6	12.1	10.8	9.7	8.7	7.8	7.0	6.3	5.7	5.2	4.9
103	>200	>200	>200	>200	>200	>200	>200	>200	>200	171.0	146.7	126.2	108.9	94.2	81.7	71.0	61.9	54.1	47.4	41.6	36.6	32.3	28.5	25.2	22.4	19.9	17.7	15.8	14.1	12.6	11.3	10.1	9.1	8.2	7.4	6.7	6.0	5.7
104	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.3	170.1	146.3	126.2	109.2	94.7	82.4	71.8	62.8	55.0	48.2	42.4	37.4	33.1	29.3	25.9	23.0	20.5	18.3	16.3	14.6	13.1	11.7	10.5	9.5	8.6	7.7	7.0	6.6
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	196.9	169.4	146.1	126.4	109.6	95.3	83.1	72.6	63.6	55.8	49.1	43.3	38.3	33.9	30.0	26.7	23.7	21.2	18.9	16.9	15.1	13.6	12.2	11.0	9.9	8.9	8.1	7.6
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.7	168.8	146.1	126.7	110.2	96.0	83.9	73.5	64.5	56.8	50.0	44.2	39.1	34.7	30.8	27.4	24.5	21.8	19.5	17.5	15.7	14.1	12.7	11.4	10.3	9.3	8.8
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	194.8	168.5	146.2	127.1	110.8	96.8	84.8	74.5	65.5	57.7	51.0	45.1	40.0	35.6	31.6	28.2	25.2	22.5	20.2	18.1	16.3	14.6	13.2	11.9	10.8	10.1
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	194.1	168.4	146.4	127.6	111.5	97.7	85.8	75.4	66.5	58.8	52.0	46.1	41.0	36.5	32.5	29.0	26.0	23.3	20.9	18.7	16.9	15.2	13.7	12.4	11.7
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.6	168.4	146.8	128.3	112.4	98.6	86.8	76.5	67.6	59.8	53.0	47.1	41.9	37.4	33.4	29.9	26.7	24.0	21.6	19.4	17.5	15.8	14.3	13.4
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.4	168.6	147.3	129.0	113.3	99.7	87.8	77.6	68.7	60.9	54.1	48.1	42.9	38.3	34.3	30.7	27.6	24.8	22.3	20.1	18.1	16.4	15.4
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.3	168.9	148.0	129.9	114.3	100.7	89.0	78.8	69.8	62.0	55.2	49.2	44.0	39.3	35.2	31.6	28.4	25.6	23.0	20.8	18.8	17.7
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.5	169.4	148.7	130.9	115.4	101.9	90.2	80.0	71.0	63.2	56.4	50.3	45.0	40.3	36.2	32.5	29.3	26.4	23.8	21.5	20.2
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.8	170.1	149.6	131.9	116.5	103.1	91.4	81.2	72.3	64.5	57.6	51.5	46.1	41.4	37.2	33.5	30.2	27.2	24.6	23.2
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	194.2	170.9	150.6	133.1	117.8	104.4	92.8	82.6	73.6	65.7	58.8	52.7	47.3	42.5	38.2	34.4	31.1	28.1	26.4
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	194.9	171.8	151.7	134.3	119.1	105.8	94.2	83.9	75.0	67.0	60.1	53.9	48.4	43.6	39.3	35.4	32.0	30.2
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.7	172.8	153.0	135.6	120.5	107.2	95.6	85.4	76.4	68.4	61.4	55.2	49.6	44.7	40.4	36.5	34.3
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	196.6	174.0	154.3	137.1	122.0	108.8	97.1	86.9	77.8	69.8	62.7	56.5	50.9	45.9	41.5	39.1
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.7	175.3	155.7	138.6	123.5	110.3	98.7	88.4	79.3	71.3	64.1	57.8	52.2	47.1	44.4
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.9	176.7	157.3	140.2	125.2	112.0	100.3	90.0	80.9	72.8	65.6	59.2	53.5	50.4
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.2	158.9	141.9	126.9	113.7	102.0	91.7	82.5	74.3	67.1	60.6	57.1
121	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.9	160.6	143.7	128.7	115.5	103.8	93.4	84.1	75.9	68.6	64.6
122	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.6	162.4	145.5	130.6	117.3	105.6	95.1	85.9	77.6	73.1
123	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	183.5	164.4	147.5	132.5	119.2	107.5	97.0	87.6	82.5
124	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.4	166.4	149.5	134.5	121.2	109.4	98.9	93.1
125	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	187.5	168.5	151.6	136.6	123.3	111.4	104.9
126	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	189.7	170.7	153.8	138.8	125.4	118.1
127	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.0	173.0	156.1	141.1	132.8
128	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	194.3	175.4	158.5	149.2
129	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	196.8	177.9	167.5
130	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	199.4	187.8
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133	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
134	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

Figure B-45 Tabular Representation of Parking Nomograph for B767-300ER on 10 °F (-12 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

Gross B-767-300ER Weight (lbs)

10 F / Ice Thickness (in)	205000	210000	215000	220000	225000	230000	235000	240000	245000	250000	255000	260000	265000	270000	275000	280000	285000	290000	295000	300000	305000	310000	315000	320000	325000	330000	335000	340000	345000	350000	355000	360000	365000	370000	375000	380000	385000	388000
52	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0
53	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0
54	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
55	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
56	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
57	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
58	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
59	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
60	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
61	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1
62	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1
63	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
64	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
65	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
66	1.1	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
67	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2
68	1.3	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2
69	1.4	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
70	1.5	1.4	1.3	1.2	1.2	1.1	1.1	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3
71	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3
72	1.7	1.6	1.5	1.5	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3
73	2.8	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4
74	3.5	2.9	2.4	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4
75	4.4	3.6	3.0	2.5	1.7	1.6	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4
76	5.5	4.5	3.8	3.2	2.7	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5
77	6.8	5.7	4.7	4.0	3.3	2.8	2.4	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5
78	8.5	7.0	5.9	4.9	4.1	3.5	2.9	2.5	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5
79	10.5	8.7	7.2	6.1	5.1	4.3	3.6	3.1	2.6	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6
80	12.9	10.7	8.9	7.5	6.3	5.3	4.5	3.8	3.2	2.8	2.4	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6
81	15.9	13.2	11.0	9.2	7.7	6.5	5.5	4.7	4.0	3.4	2.9	2.5	1.7	1.7	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.7
82	19.4	16.1	13.4	11.2	9.4	7.9	6.7	5.7	4.9	4.2	3.6	3.1	2.6	1.8	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7
83	23.6	19.6	16.3	13.7	11.5	9.7	8.2	7.0	5.9	5.1	4.4	3.7	3.2	2.8	2.4	1.7	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8
84	28.7	23.8	19.9	16.6	14.0	11.8	10.0	8.5	7.2	6.2	5.3	4.5	3.9	3.4	2.9	2.6	1.8	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8
85	34.8	28.9	24.0	20.1	16.9	14.3	12.1	10.2	8.7	7.5	6.4	5.5	4.8	4.1	3.6	3.1	2.7	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.9
86	42.0	34.9	29.0	24.3	20.4	17.2	14.6	12.4	10.5	9.0	7.7	6.7	5.7	5.0	4.3	3.7	3.3	2.9	2.5	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9
87	50.6	42.0	35.0	29.3	24.6	20.7	17.5	14.9	12.7	10.9	9.3	8.0	6.9	6.0	5.2	4.5	3.9	3.4	3.0	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0
88	60.7	50.4	42.0	35.1	29.5	24.9	21.1	17.9	15.2	13.0	11.2	9.6	8.3	7.2	6.2	5.4	4.7	4.1	3.6	3.2	2.8	2.5	1.7	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0
89	72.7	60.3	50.3	42.1	35.3	29.8	25.2	21.4	18.3	15.6	13.4	11.5	9.9	8.6	7.5	6.5	5.7	4.9	4.3	3.8	3.3	2.9	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1
90	86.9	72.1	60.0	50.2	42.2	35.6	30.1	25.6	21.8	18.6	16.0	13.8	11.9	10.3	8.9	7.7	6.8	5.9	5.2	4.5	4.0	3.5	3.1	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.4	1.4	1.4	1.3	1.3	1.2	1.2	1.2
91	103.5	85.8	71.5	59.9	50.3	42.4	35.9	30.5	26.0	22.2	19.1	16.4	14.1	12.2	10.6	9.2	8.0	7.0	6.2	5.4	4.8	4.2	3.7	3.3	2.9	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2
92	123.0	102.0	85.0	71.1	59.8	50.4	42.7	36.2	30.9	26.4	22.6	19.5	16.8	14.5	12.6	11.0	9.6	8.4	7.3	6.4	5.6	5.0	4.4	3.9	3.5	3.1	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3
93	145.8	120.9	100.8	84.3	70.8	59.7	50.6	43.0	36.6	31.3	26.8	23.1	19.9	17.2	14.9	13.0	11.3	9.9	8.7	7.6	6.7	5.9	5.2	4.6	4.1	3.6	3.2	2.9	2.6	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.4
94	172.4	143.0	119.2	99.7	83.8	70.7	59.8	50.8	43.3	37.0	31.7	27.3	23.6	20.4	17.7	15.4	13.4	11.7	10.3	9.0	7.9	7.0	6.2	5.5	4.8	4.3	3.8	3.4	3.0	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5	1.4
95	>200	168.8	140.7	117.7	98.9	83.4	70.6	60.0	51.1	43.7	37.5	32.2	27.8	24.1	20.9	18.1	15.8	13.8	12.1	10.6	9.3	8.2	7.3	6.4	5.7	5.1	4.5	4.0	3.6	3.2	2.9	2.6	1.8	1.7	1.7	1.6	1.6	1.5
96	>200	198.8	165.6	138.6	116.4	98.2	83.1	70.6	60.2	51.4	44.1	38.0	32.7	28.3	24.6	21.4	18.6	16.3	14.3	12.5	11.0	9.7	8.6	7.6	6.7	6.0	5.3	4.7	4.2	3.8	3.4	3.0	2.7	2.5	1.8	1.7	1.6	1.6
97	>200	>200	194.6	162.9	136.8	115.4	97.7	83.0	70.7	60.5	51.9	44.6	38.5	33.3	28.9	25.1	21.9	19.1	16.8	14.7	12.9	11.4	10.1	8.9	7.9	7.0	6.2	5.6	5.0	4.4	4.0	3.6	3.2	2.9	2.6	1.8	1.7	1.7
98	>200	>200	>200	191.0	160.5	135.3	114.5	97.3	82.9	70.9	60.8	52.3	45.1	39.0	33.9	29.4	25.7	22.4	19.6	17.2	15.2	13.4	11.8	10.5	9.3	8.2	7.3	6.5	5.8	5.2	4.7	4.2	3.8	3.4	3.1	2.8	2.5	1.8
99	>200	>200	>200	>200	187.8	158.4	134.0	113.9	97.0	83.0	71.2	61.2	52.8	45.7	39.6	34.5	30.0	26.3	23.0	20.2	17.8	15.7	13.8	12.2	10.9	9.6	8.6	7.6	6.8	6.1	5.5	4.9	4.4	4.0	3.6	3.2	2.9	2.7
100	>200	>200	>200	>200	>200	185.0	156.6	133.0	113.4	96.9	83.1	71.5	61.7	53.4	46.3	40.3	35.1	30.7	26.9	23.6	20.7	18.3	16.2	14.3	12.7	11.3	10.0	8.9	8.0	7.1	6.4	5.7	5.2	4.6	4.2	3.8	3.4	3.2
101	>200	>200	>200	>200	>200	>200	182.5	155.1	132.2	113.0	96.9	83.4	71.9	62.2	54.0	46.9	40.9	35.8	31.3	27.5	24.2	21.3	18.8	16.7	14.8	13.1	11.7	10.4	9.3	8.3	7.5	6.7	6.0	5.4	4.9	4.4	4.0	3.7
102	>200	>200	>200	>200	>200	>200	>200	180.4	153.8	131.5	112.8	97.0	83.7	72.4	62.8	54.6	47.6	41.6	36.4	32.0	28.1	24.8	21.9	19.4	17.2	15.3	13.6	12.1	10.8	9.7	8.7	7.8	7.0	6.3	5.7	5.1	4.6	4.4
103	>200	>200	>200	>200	>200	>200	>200	>200	178.7	152.8	131.0	112.7	97.2	84.1	73.0	63.4	55.3	48.3	42.3	37.2	32.7	28.8	25.5	22.5	20.0	17.7	15.8	14.1	12.6	11.2	10.1	9.0	8.1	7.3	6.6	5.9	5.4	5.1
104	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.1	151.9	130.7	112.8	97.5	84.6	73.6	64.1	56.1	49.1	43.1	37.9	33.4	29.5	26.1	23.2	20.6	18.3	16.3	14.6	13.0	11.7	10.5	9.4	8.5	7.6	6.9	6.2	5.9
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	175.9	151.3	130.5	112.9	98.0	85.2	74.3	64.9	56.8	49.9	43.9	38.7	34.2	30.2	26.8	23.8	21.2	18.9	16.9	15.1	13.5	12.1	10.9	9.8	8.8	8.0	7.2	6.8
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	174.9	150.9	130.5	113.2	98.4	85.8	75.0	65.7	57.7	50.7	44.7	39.5	35.0	31.0	27.5	24.5	21.8	19.5	17.5	15.6	14.0	12.6	11.3	10.2	9.2	8.3	7.8
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	174.1	150.6	130.6	113.6	99.0	86.5	75.8	66.5	58.5	51.6	45.6	40.3	35.8	31.8	28.3	25.2	22.5	20.1	18.0	16.2	14.5	13.1	11.8	10.6	9.6	9.1
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	173.5	150.5	130.9	114.1	99.7	87.3	76.7	67.4	59.5	52.5	46.5	41.2	36.6	32.6	29.0	25.9	23.2	20.8	18.6	16.8	15.1	13.6	12.3	11.1	10.4
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	199.6	173.1	150.5	131.2	114.7	100.5	88.2	77.6	68.4	60.4	53.5	47.4	42.1	37.5	33.4	29.8	26.7	23.9	21.5	19.3	17.3	15.6	14.1	12.7	12.0
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.8	172.9	150.7	131.7	115.4	101.3	89.1	78.6	69.4	61.4	54.5	48.4	43.1	38.4	34.3	30.7	27.5	24.6	22.1	19.9	18.0	16.2	14.6	13.8
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.3	172.9	151.1	132.3	116.2	102.2	90.1	79.6	70.4	62.5	55.5	49.4	44.0	39.3	35.2	31.5	28.3	25.4	22.9	20.6	18.6	16.8	15.8
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.0	173.0	151.6	133.0	117.0	103.2	91.1	80.7	71.5	63.5	56.6	50.4	45.0	40.3	36.1	32.4	29.1	26.2	23.6	21.3	19.2	18.1
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.9	173.3	152.2	133.9	118.0	104.2	92.3	81.8	72.7	64.7	57.7	51.5	46.1	41.3	37.0	33.3	29.9	27.0	24.3	22.0	20.7
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.0	173.8	152.9	134.8	119.0	105.4	93.4	83.0	73.9	65.9	58.8	52.6	47.1	42.3	38.0	34.2	30.8	27.8	25.1	23.7
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.2	174.4	153.7	135.8	120.2	106.6	94.7	84.3	75.1	67.1	60.0	53.7	48.2	43.3	39.0	35.1	31.7	28.7	27.0
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.6	175.1	154.7	136.9	121.4	107.8	96.0	85.6	76.4	68.3	61.2	54.9	49.4	44.4	40.0	36.1	32.6	30.7
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	199.2	176.0	155.7	138.1	122.7	109.2	97.3	86.9	77.7	69.6	62.5	56.2	50.5	45.5	41.1	37.1	35.0
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	199.9	176.9	156.9	139.4	124.1	110.6	98.8	88.3	79.1	71.0	63.8	57.4	51.7	46.7	42.2	39.7
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.1	158.2	140.8	125.5	112.1	100.2	89.8	80.6	72.4	65.2	58.7	53.0	47.9	45.1
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.3	159.6	142.3	127.0	113.6	101.8	91.3	82.1	73.9	66.6	60.1	54.3	51.1
121	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.7	161.1	143.8	128.6	115.2	103.4	92.9	83.6	75.4	68.0	61.4	57.9
122	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.1	162.6	145.5	130.3	116.9	105.1	94.6	85.2	76.9	69.5	65.4
123	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	183.7	164.3	147.2	132.1	118.7	106.8	96.3	86.9	78.5	73.9
124	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.4	166.1	149.0	133.9	120.5	108.6	98.0	88.6	83.4
125	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	187.2	168.0	150.9	135.8	122.4	110.5	99.8	94.0
126	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	189.1	169.9	152.9	137.8	124.4	112.4	105.8
127	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.1	172.0	155.0	139.9	126.4	119.0
128	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.3	174.2	157.2	142.0	133.7
129	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.5	176.4	159.4	150.1
130	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.8	178.8	168.3
131	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.6
132	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
133	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
134	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

Figure B-46 Tabular Representation of Parking Nomograph for B767-300ER on 12 °F (-11 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

12 F	Gross B-767-300ER Weight (lbs)																																					
Ice Thickness (in)	205000	210000	215000	220000	225000	230000	235000	240000	245000	250000	255000	260000	265000	270000	275000	280000	285000	290000	295000	300000	305000	310000	315000	320000	325000	330000	335000	340000	345000	350000	355000	360000	365000	370000	375000	380000	385000	388000
52	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
53	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0
54	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
55	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
56	0.4	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
57	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
58	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
59	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
60	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
61	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
62	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1
63	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
64	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
65	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
66	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
67	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
68	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2
69	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
70	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3
71	1.5	1.5	1.4	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3
72	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3
73	2.4	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4
74	3.1	2.5	1.7	1.6	1.5	1.5	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4
75	3.9	3.2	2.7	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4
76	4.8	4.0	3.3	2.8	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5
77	6.0	5.0	4.2	3.5	2.9	2.5	1.7	1.6	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5
78	7.5	6.2	5.2	4.3	3.6	3.1	2.6	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5
79	9.3	7.7	6.4	5.4	4.5	3.8	3.2	2.7	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6
80	11.4	9.5	7.9	6.6	5.6	4.7	4.0	3.4	2.9	2.5	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.6	0.6	0.6
81	14.0	11.7	9.7	8.1	6.8	5.8	4.9	4.1	3.5	3.0	2.6	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.6
82	17.2	14.3	11.9	9.9	8.3	7.0	6.0	5.1	4.3	3.7	3.2	2.7	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7
83	21.0	17.4	14.5	12.1	10.2	8.6	7.3	6.2	5.3	4.5	3.9	3.3	2.9	2.5	1.7	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7
84	25.5	21.1	17.6	14.7	12.4	10.4	8.8	7.5	6.4	5.5	4.7	4.0	3.5	3.0	2.6	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8
85	30.9	25.6	21.3	17.9	15.0	12.6	10.7	9.1	7.7	6.6	5.7	4.9	4.2	3.6	3.2	2.8	2.4	1.7	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8
86	37.3	30.9	25.8	21.6	18.1	15.3	12.9	11.0	9.4	8.0	6.9	5.9	5.1	4.4	3.8	3.3	2.9	2.5	1.8	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9
87	44.9	37.3	31.0	26.0	21.8	18.4	15.6	13.2	11.3	9.6	8.3	7.1	6.1	5.3	4.6	4.0	3.5	3.0	2.7	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9
88	53.9	44.8	37.3	31.2	26.2	22.1	18.7	15.9	13.5	11.6	9.9	8.5	7.4	6.4	5.5	4.8	4.2	3.7	3.2	2.8	2.5	1.7	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0
89	64.6	53.6	44.7	37.4	31.4	26.5	22.4	19.0	16.2	13.9	11.9	10.2	8.8	7.6	6.6	5.8	5.0	4.4	3.8	3.4	3.0	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.1
90	77.2	64.0	53.4	44.7	37.5	31.6	26.8	22.7	19.4	16.6	14.2	12.2	10.5	9.1	7.9	6.9	6.0	5.2	4.6	4.0	3.5	3.1	2.8	2.4	1.7	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.1	1.1
91	92.0	76.3	63.6	53.2	44.7	37.7	31.9	27.1	23.1	19.7	16.9	14.6	12.6	10.9	9.4	8.2	7.1	6.2	5.5	4.8	4.2	3.7	3.3	2.9	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2
92	109.4	90.7	75.6	63.3	53.1	44.8	37.9	32.2	27.5	23.5	20.1	17.3	14.9	12.9	11.2	9.7	8.5	7.4	6.5	5.7	5.0	4.4	3.9	3.5	3.1	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2
93	129.7	107.6	89.6	75.0	63.0	53.1	45.0	38.2	32.6	27.8	23.9	20.5	17.7	15.3	13.3	11.6	10.1	8.8	7.7	6.8	6.0	5.3	4.6	4.1	3.6	3.2	2.9	2.6	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3
94	153.4	127.3	106.1	88.7	74.6	62.9	53.2	45.2	38.5	32.9	28.2	24.3	21.0	18.1	15.7	13.7	11.9	10.4	9.1	8.0	7.0	6.2	5.5	4.9	4.3	3.8	3.4	3.0	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4
95	181.1	150.2	125.2	104.8	88.0	74.2	62.8	53.4	45.5	38.9	33.3	28.7	24.7	21.4	18.6	16.1	14.1	12.3	10.8	9.5	8.3	7.3	6.5	5.7	5.1	4.5	4.0	3.6	3.2	2.9	2.6	1.8	1.7	1.7	1.6	1.5	1.5	1.5
96	>200	177.0	147.5	123.4	103.7	87.4	74.0	62.8	53.6	45.8	39.3	33.8	29.2	25.2	21.9	19.0	16.6	14.5	12.7	11.1	9.8	8.6	7.6	6.8	6.0	5.3	4.7	4.2	3.8	3.4	3.0	2.7	2.4	1.7	1.7	1.6	1.6	1.6
97	>200	>200	173.3	145.0	121.8	102.7	87.0	73.9	63.0	53.8	46.2	39.7	34.3	29.6	25.7	22.4	19.5	17.0	14.9	13.1	11.5	10.2	9.0	7.9	7.0	6.3	5.6	5.0	4.4	4.0	3.5	3.2	2.9	2.6	1.8	1.7	1.7	1.6
98	>200	>200	>200	170.1	142.9	120.5	102.0	86.6	73.8	63.1	54.2	46.6	40.2	34.8	30.2	26.2	22.9	20.0	17.5	15.4	13.5	11.9	10.5	9.3	8.3	7.3	6.5	5.8	5.2	4.6	4.2	3.7	3.4	3.0	2.7	2.5	1.8	1.7
99	>200	>200	>200	199.1	167.3	141.1	119.4	101.4	86.4	73.9	63.4	54.5	47.0	40.7	35.3	30.7	26.8	23.4	20.5	18.0	15.8	13.9	12.3	10.9	9.7	8.6	7.6	6.8	6.1	5.4	4.9	4.4	3.9	3.5	3.2	2.9	2.6	2.4
100	>200	>200	>200	>200	195.4	164.8	139.5	118.5	101.0	86.4	74.1	63.7	55.0	47.6	41.2	35.9	31.3	27.3	23.9	21.0	18.5	16.3	14.4	12.7	11.3	10.0	8.9	8.0	7.1	6.4	5.7	5.1	4.6	4.1	3.7	3.4	3.0	2.9
101	>200	>200	>200	>200	>200	192.2	162.7	138.2	117.8	100.7	86.4	74.3	64.1	55.5	48.1	41.8	36.5	31.9	27.9	24.5	21.6	19.0	16.8	14.9	13.2	11.7	10.4	9.3	8.3	7.4	6.6	6.0	5.4	4.8	4.3	3.9	3.5	3.3
102	>200	>200	>200	>200	>200	>200	189.4	160.9	137.1	117.2	100.5	86.5	74.6	64.5	56.0	48.7	42.4	37.1	32.5	28.5	25.1	22.1	19.5	17.3	15.3	13.6	12.1	10.8	9.6	8.6	7.7	6.9	6.2	5.6	5.1	4.6	4.1	3.9
103	>200	>200	>200	>200	>200	>200	>200	186.9	159.3	136.2	116.8	100.5	86.7	75.0	65.1	56.6	49.3	43.1	37.7	33.1	29.1	25.7	22.7	20.1	17.8	15.8	14.1	12.6	11.2	10.0	9.0	8.1	7.2	6.5	5.9	5.3	4.8	4.5
104	>200	>200	>200	>200	>200	>200	>200	>200	184.7	158.0	135.5	116.6	100.6	87.0	75.5	65.6	57.2	50.0	43.8	38.4	33.8	29.8	26.3	23.3	20.7	18.4	16.3	14.6	13.0	11.6	10.4	9.3	8.4	7.6	6.8	6.1	5.6	5.2
105	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.9	156.9	135.0	116.4	100.7	87.4	76.0	66.2	57.9	50.7	44.5	39.1	34.5	30.5	27.0	23.9	21.3	18.9	16.9	15.1	13.5	12.1	10.8	9.7	8.8	7.9	7.1	6.4	6.1
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.3	156.0	134.6	116.4	101.0	87.8	76.6	66.9	58.6	51.4	45.3	39.9	35.2	31.2	27.7	24.6	21.9	19.5	17.4	15.6	13.9	12.5	11.2	10.1	9.1	8.2	7.4	7.0
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.0	155.3	134.4	116.6	101.4	88.4	77.2	67.6	59.4	52.2	46.0	40.7	36.0	31.9	28.4	25.2	22.5	20.1	18.0	16.1	14.4	13.0	11.7	10.5	9.5	8.6	8.1
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.0	154.8	134.3	116.8	101.8	89.0	77.9	68.4	60.2	53.1	46.9	41.5	36.8	32.7	29.1	25.9	23.1	20.7	18.5	16.6	15.0	13.5	12.1	10.9	9.9	9.3
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.1	154.5	134.4	117.1	102.4	89.7	78.7	69.2	61.0	53.9	47.7	42.3	37.6	33.5	29.8	26.6	23.8	21.3	19.1	17.2	15.5	14.0	12.6	11.4	10.7
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.5	154.4	134.6	117.6	103.0	90.4	79.5	70.1	61.9	54.8	48.6	43.2	38.4	34.3	30.6	27.4	24.5	22.0	19.8	17.8	16.0	14.5	13.1	12.3
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.1	154.4	134.9	118.2	103.7	91.2	80.4	71.1	62.9	55.8	49.5	44.1	39.3	35.1	31.4	28.1	25.2	22.7	20.4	18.4	16.6	15.0	14.1
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	176.8	154.5	135.3	118.8	104.5	92.1	81.4	72.0	63.9	56.7	50.5	45.0	40.2	36.0	32.2	28.9	26.0	23.4	21.1	19.0	17.2	16.2
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	176.7	154.8	135.9	119.5	105.4	93.1	82.4	73.1	64.9	57.8	51.5	46.0	41.1	36.8	33.1	29.7	26.7	24.1	21.7	19.6	18.5
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	176.8	155.2	136.6	120.4	106.3	94.1	83.5	74.1	66.0	58.8	52.5	47.0	42.1	37.8	33.9	30.5	27.5	24.8	22.4	21.1
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.1	155.8	137.3	121.3	107.4	95.2	84.6	75.3	67.1	59.9	53.6	48.0	43.1	38.7	34.8	31.4	28.3	25.6	24.1
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.5	156.4	138.2	122.3	108.5	96.4	85.8	76.4	68.3	61.1	54.7	49.1	44.1	39.7	35.8	32.3	29.2	27.5
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.0	157.2	139.2	123.4	109.6	97.6	87.0	77.7	69.5	62.2	55.8	50.2	45.2	40.7	36.7	33.2	31.2
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.7	158.1	140.2	124.6	110.9	98.8	88.3	78.9	70.7	63.5	57.0	51.3	46.2	41.7	37.7	35.5
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.5	159.2	141.4	125.8	112.2	100.2	89.6	80.3	72.0	64.7	58.2	52.5	47.4	42.8	40.3
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.4	160.3	142.7	127.2	113.6	101.6	91.0	81.6	73.4	66.0	59.5	53.7	48.5	45.7
121	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.5	161.5	144.0	128.6	115.0	103.0	92.4	83.1	74.8	67.4	60.8	54.9	51.7
122	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.7	162.9	145.4	130.1	116.5	104.6	94.0	84.5	76.2	68.8	62.1	58.5
123	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	184.0	164.3	146.9	131.6	118.1	106.1	95.5	86.1	77.7	70.2	66.1
124	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.4	165.8	148.6	133.3	119.8	107.8	97.1	87.7	79.2	74.6
125	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	186.9	167.5	150.2	135.0	121.5	109.5	98.8	89.3	84.1
126	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.6	169.2	152.0	136.8	123.3	111.3	100.5	94.7
127	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	190.3	171.0	153.9	138.7	125.1	113.1	106.5
128	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.2	172.9	155.8	140.6	127.1	119.7
129	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	194.1	174.9	157.9	142.6	134.3
130	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	196.7	177.0	160.0	150.6
131	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.3	179.2	168.8
132	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.9
133	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
134	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

Figure B-47 Tabular Representation of Parking Nomograph for B767-300ER on 14 °F (-10 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

14 F	Gross B-767-300ER Weight (lbs)																		
Ice Thickness (in)	205000	210000	215000	220000	225000	230000	235000	240000	245000	250000	255000	260000	265000	270000	275000	280000	285000	290000	295000
52	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
53	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
54	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
55	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
56	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1
57	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
58	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
59	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
60	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2
61	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2
62	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3
63	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3
64	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3
65	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4
66	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4
67	1.1	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4
68	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5
69	1.3	1.2	1.1	1.1	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5
70	1.4	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5
71	1.5	1.4	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6
72	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6
73	1.7	1.6	1.5	1.5	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7
74	2.7	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.7
75	3.4	2.8	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8
76	4.3	3.5	3.0	2.5	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9
77	5.3	4.4	3.7	3.1	2.6	1.7	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9
78	6.6	5.5	4.6	3.8	3.2	2.7	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0
79	8.2	6.8	5.7	4.7	4.0	3.4	2.8	2.4	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1
80	10.1	8.4	7.0	5.8	4.9	4.1	3.5	3.0	2.5	1.7	1.7	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.1
81	12.4	10.3	8.6	7.2	6.0	5.1	4.3	3.7	3.1	2.7	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2
82	15.2	12.6	10.5	8.8	7.4	6.2	5.3	4.5	3.8	3.3	2.8	2.4	1.7	1.6	1.6	1.5	1.4	1.4	1.3
83	18.5	15.4	12.8	10.7	9.0	7.6	6.4	5.5	4.7	4.0	3.4	2.9	2.5	1.7	1.7	1.6	1.5	1.5	1.4
84	22.6	18.7	15.6	13.0	11.0	9.2	7.8	6.6	5.7	4.8	4.2	3.6	3.1	2.7	1.8	1.7	1.6	1.6	1.5
85	27.3	22.7	18.9	15.8	13.3	11.2	9.5	8.1	6.9	5.9	5.0	4.3	3.7	3.2	2.8	2.4	1.7	1.7	1.6
86	33.0	27.4	22.8	19.1	16.1	13.5	11.5	9.7	8.3	7.1	6.1	5.2	4.5	3.9	3.4	2.9	2.6	1.8	1.7
87	39.8	33.0	27.5	23.0	19.3	16.3	13.8	11.7	10.0	8.5	7.3	6.3	5.4	4.7	4.1	3.5	3.1	2.7	1.8
88	47.8	39.7	33.1	27.7	23.2	19.6	16.6	14.1	12.0	10.3	8.8	7.6	6.5	5.7	4.9	4.3	3.7	3.2	2.8
89	57.3	47.5	39.6	33.1	27.8	23.5	19.9	16.9	14.4	12.3	10.5	9.1	7.8	6.8	5.9	5.1	4.5	3.9	3.4
90	68.5	56.8	47.3	39.6	33.3	28.1	23.8	20.2	17.2	14.7	12.6	10.8	9.4	8.1	7.0	6.1	5.3	4.7	4.1
91	81.6	67.7	56.4	47.2	39.7	33.5	28.3	24.0	20.5	17.5	15.0	12.9	11.2	9.6	8.4	7.3	6.3	5.5	4.9
92	97.1	80.5	67.1	56.1	47.2	39.8	33.7	28.6	24.4	20.8	17.9	15.4	13.3	11.5	10.0	8.7	7.5	6.6	5.8
93	115.1	95.5	79.6	66.6	56.0	47.2	39.9	33.9	28.9	24.7	21.2	18.2	15.7	13.6	11.8	10.3	8.9	7.8	6.8
94	136.3	113.0	94.2	78.8	66.2	55.8	47.3	40.1	34.2	29.3	25.1	21.6	18.6	16.1	14.0	12.1	10.6	9.3	8.1
95	160.9	133.5	111.2	93.1	78.2	65.9	55.8	47.4	40.4	34.5	29.6	25.5	22.0	19.0	16.5	14.3	12.5	10.9	9.6
96	189.6	157.3	131.0	109.6	92.1	77.7	65.8	55.9	47.6	40.7	34.9	30.0	25.9	22.4	19.4	16.9	14.7	12.9	11.3
97	>200	184.9	154.1	128.9	108.3	91.3	77.3	65.7	56.0	47.8	41.0	35.3	30.5	26.3	22.9	19.9	17.3	15.1	13.3
98	>200	>200	180.7	151.2	127.1	107.2	90.7	77.0	65.7	56.1	48.1	41.4	35.7	30.9	26.8	23.3	20.3	17.8	15.6
99	>200	>200	>200	177.1	148.8	125.5	106.2	90.2	76.9	65.7	56.4	48.5	41.8	36.2	31.4	27.3	23.8	20.8	18.2
100	>200	>200	>200	>200	173.9	146.6	124.1	105.4	89.8	76.8	65.9	56.7	48.9	42.3	36.7	31.9	27.8	24.3	21.3
101	>200	>200	>200	>200	>200	171.0	144.7	123.0	104.8	89.6	76.8	66.1	57.0	49.3	42.8	37.2	32.4	28.3	24.8
102	>200	>200	>200	>200	>200	199.1	168.5	143.1	122.0	104.3	89.5	77.0	66.4	57.4	49.8	43.3	37.8	33.0	28.9
103	>200	>200	>200	>200	>200	>200	195.8	166.3	141.8	121.2	104.0	89.4	77.2	66.8	57.9	50.4	43.9	38.4	33.6
104	>200	>200	>200	>200	>200	>200	>200	193.0	164.5	140.6	120.6	103.8	89.5	77.4	67.2	58.4	50.9	44.5	39.0
105	>200	>200	>200	>200	>200	>200	>200	>200	190.5	162.9	139.7	120.2	103.7	89.7	77.8	67.6	59.0	51.5	45.1
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.3	161.5	138.9	119.9	103.7	89.9	78.2	68.2	59.6	52.2
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	186.4	160.4	138.4	119.7	103.8	90.3	78.7	68.8	60.2
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	184.8	159.4	137.9	119.6	104.1	90.7	79.3	69.4
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	183.5	158.7	137.7	119.7	104.4	91.2	79.9
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.4	158.2	137.6	119.9	104.8	91.8
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.5	157.8	137.6	120.2	105.3
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.8	157.6	137.7	120.6
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.3	157.6	138.0
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.0	157.7
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.9
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
121	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
122	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
123	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
124	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
125	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
126	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
127	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
128	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
129	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
130	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
131	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
132	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
133	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
134	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

14 F	Gross B-767-300ER Weight (lbs)																		
Ice Thickness (in)	300000	305000	310000	315000	320000	325000	330000	335000	340000	345000	350000	355000	360000	365000	370000	375000	380000	385000	388000
52	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
53	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0
54	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
55	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
56	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
57	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
58	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
59	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
60	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
61	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
62	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1
63	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1
64	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
65	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
66	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
67	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
68	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2
69	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
70	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
71	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3
72	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3
73	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3
74	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4
75	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4
76	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4
77	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5
78	1.0	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5
79	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5
80	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6
81	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6
82	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.7
83	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7
84	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7
85	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8
86	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8
87	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9
88	2.5	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	1.0
89	3.0	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0
90	3.6	3.1	2.8	2.4	1.7	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.1
91	4.3	3.7	3.3	2.9	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1
92	5.1	4.5	3.9	3.5	3.1	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.4	1.4	1.4	1.3	1.3	1.2	1.2
93	6.0	5.3	4.7	4.1	3.6	3.2	2.9	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.3
94	7.1	6.3	5.5	4.9	4.3	3.8	3.4	3.0	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3
95	8.4	7.4	6.5	5.8	5.1	4.5	4.0	3.6	3.2	2.8	2.5	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.4
96	9.9	8.7	7.7	6.8	6.0	5.3	4.7	4.2	3.7	3.3	3.0	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5
97	11.6	10.2	9.0	8.0	7.1	6.3	5.6	4.9	4.4	3.9	3.5	3.2	2.8	2.5	1.8	1.7	1.7	1.6	1.6
98	13.7	12.0	10.6	9.4	8.3	7.3	6.5	5.8	5.2	4.6	4.1	3.7	3.3	3.0	2.7	2.4	1.7	1.7	1.7
99	16.0	14.1	12.4	11.0	9.7	8.6	7.6	6.8	6.1	5.4	4.8	4.3	3.9	3.5	3.1	2.8	2.6	1.8	1.7
100	18.7	16.4	14.5	12.8	11.3	10.0	8.9	7.9	7.1	6.3	5.7	5.1	4.5	4.1	3.7	3.3	3.0	2.7	2.5
101	21.8	19.2	16.9	14.9	13.2	11.7	10.4	9.3	8.3	7.4	6.6	5.9	5.3	4.8	4.3	3.9	3.5	3.1	3.0
102	25.4	22.3	19.7	17.4	15.4	13.6	12.1	10.8	9.6	8.6	7.7	6.9	6.2	5.5	5.0	4.5	4.1	3.7	3.5
103	29.5	25.9	22.9	20.2	17.9	15.9	14.1	12.5	11.2	10.0	8.9	8.0	7.2	6.4	5.8	5.2	4.7	4.3	4.0
104	34.2	30.1	26.5	23.4	20.7	18.4	16.3	14.5	13.0	11.6	10.4	9.3	8.3	7.5	6.7	6.1	5.5	4.9	4.7
105	39.6	34.9	30.7	27.1	24.0	21.3	18.9	16.8	15.0	13.4	12.0	10.7	9.6	8.7	7.8	7.0	6.3	5.7	5.4
106	45.8	40.3	35.5	31.4	27.8	24.6	21.9	19.5	17.4	15.5	13.9	12.4	11.1	10.0	9.0	8.1	7.3	6.6	6.2
107	52.9	46.5	41.0	36.2	32.1	28.4	25.3	22.5	20.0	17.9	16.0	14.3	12.9	11.6	10.4	9.4	8.5	7.6	7.2
108	60.9	53.6	47.3	41.8	37.0	32.8	29.1	25.9	23.1	20.6	18.4	16.5	14.8	13.3	12.0	10.8	9.7	8.8	8.3
109	70.1	61.7	54.4	48.0	42.5	37.7	33.5	29.8	26.6	23.7	21.2	19.0	17.1	15.3	13.8	12.4	11.2	10.1	9.5
110	80.6	70.9	62.5	55.2	48.9	43.3	38.5	34.3	30.5	27.3	24.4	21.8	19.6	17.6	15.9	14.3	12.9	11.6	11.0
111	92.4	81.3	71.7	63.3	56.1	49.7	44.2	39.3	35.0	31.3	28.0	25.1	22.5	20.2	18.2	16.4	14.8	13.4	12.6
112	105.9	93.2	82.1	72.6	64.2	56.9	50.6	45.0	40.1	35.8	32.1	28.7	25.8	23.2	20.8	18.8	16.9	15.3	14.4
113	121.2	106.6	94.0	83.0	73.5	65.1	57.9	51.5	45.9	41.0	36.7	32.9	29.5	26.5	23.8	21.5	19.4	17.5	16.5
114	138.4	121.8	107.4	94.8	83.9	74.4	66.1	58.8	52.5	46.8	41.9	37.5	33.7	30.3	27.2	24.5	22.1	20.0	18.8
115	157.9	138.9	122.5	108.2	95.8	84.9	75.4	67.1	59.8	53.4	47.8	42.8	38.4	34.5	31.1	28.0	25.3	22.8	21.5
116	179.9	158.3	139.6	123.3	109.1	96.7	85.9	76.5	68.2	60.9	54.5	48.8	43.8	39.3	35.4	31.9	28.8	26.0	24.5
117	>200	180.1	158.8	140.3	124.2	110.1	97.8	87.0	77.6	69.3	62.0	55.5	49.8	44.8	40.3	36.3	32.8	29.6	27.9
118	>200	>200	180.5	159.4	141.1	125.1	111.2	98.9	88.2	78.8	70.4	63.1	56.6	50.9	45.8	41.3	37.2	33.6	31.7
119	>200	>200	>200	181.0	160.2	142.0	126.2	112.3	100.1	89.4	80.0	71.6	64.3	57.8	52.0	46.8	42.3	38.2	36.0
120	>200	>200	>200	>200	181.6	161.0	143.1	127.3	113.5	101.4	90.7	81.2	72.9	65.5	58.9	53.1	47.9	43.3	40.8
121	>200	>200	>200	>200	>200	182.4	162.0	144.2	128.5	114.8	102.7	92.0	82.5	74.1	66.7	60.1	54.3	49.0	46.2
122	>200	>200	>200	>200	>200	>200	183.2	163.1	145.4	129.8	116.1	104.0	93.3	83.9	75.5	68.0	61.4	55.5	52.2
123	>200	>200	>200	>200	>200	>200	>200	184.2	164.3	146.7	131.2	117.5	105.5	94.8	85.3	76.8	69.3	62.7	59.0
124	>200	>200	>200	>200	>200	>200	>200	>200	185.4	165.5	148.1	132.6	119.0	106.9	96.2	86.7	78.3	70.7	66.6
125	>200	>200	>200	>200	>200	>200	>200	>200	>200	186.6	166.9	149.5	134.2	120.6	108.5	97.8	88.2	79.7	75.1
126	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.0	168.4	151.1	135.8	122.2	110.1	99.4	89.8	84.5
127	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	189.4	170.0	152.7	137.5	123.9	111.8	101.0	95.1
128	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.0	171.7	154.5	139.2	125.6	113.5	106.9
129	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.7	173.4	156.3	141.0	127.4	120.0
130	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	194.5	175.3	158.7	142.9	134.6
131	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	196.4	177.2	160.2	150.8
132	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.4	179.3	168.8
133	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.8
134	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

Figure B-48 Tabular Representation of Parking Nomograph for B767-300ER on 15 °F (-9.5 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

15 F	Gross B-767-300ER Weight (lbs)																																					
Ice Thickness (in)	205000	210000	215000	220000	225000	230000	235000	240000	245000	250000	255000	260000	265000	270000	275000	280000	285000	290000	295000	300000	305000	310000	315000	320000	325000	330000	335000	340000	345000	350000	355000	360000	365000	370000	375000	380000	385000	388000
52	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
53	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0
54	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
55	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
56	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
57	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
58	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
59	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
60	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
61	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
62	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
63	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1
64	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
65	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
66	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
67	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
68	1.1	1.1	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2
69	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2
70	1.3	1.3	1.2	1.1	1.1	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
71	1.4	1.4	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3
72	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.1	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3
73	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3
74	2.5	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4
75	3.2	2.6	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4
76	4.0	3.3	2.8	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4
77	5.0	4.1	3.4	2.9	2.4	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5
78	6.2	5.1	4.3	3.6	3.0	2.5	1.7	1.6	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5
79	7.7	6.3	5.3	4.4	3.7	3.1	2.7	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5
80	9.4	7.8	6.5	5.5	4.6	3.9	3.3	2.8	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6
81	11.6	9.6	8.0	6.7	5.6	4.7	4.0	3.4	2.9	2.5	1.7	1.7	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6
82	14.2	11.8	9.8	8.2	6.9	5.8	4.9	4.2	3.6	3.0	2.6	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.6
83	17.3	14.4	12.0	10.0	8.4	7.1	6.0	5.1	4.3	3.7	3.2	2.7	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7
84	21.1	17.5	14.6	12.2	10.2	8.6	7.3	6.2	5.3	4.5	3.9	3.3	2.9	2.5	1.7	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7
85	25.5	21.2	17.7	14.8	12.4	10.5	8.9	7.5	6.4	5.5	4.7	4.0	3.5	3.0	2.6	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8
86	30.9	25.6	21.3	17.9	15.0	12.6	10.7	9.1	7.7	6.6	5.7	4.9	4.2	3.6	3.2	2.8	2.4	1.7	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8
87	37.2	30.9	25.7	21.5	18.1	15.2	12.9	11.0	9.3	8.0	6.8	5.9	5.1	4.4	3.8	3.3	2.9	2.5	1.8	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9
88	44.7	37.1	30.9	25.9	21.7	18.3	15.5	13.2	11.2	9.6	8.2	7.1	6.1	5.3	4.6	4.0	3.5	3.0	2.7	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9
89	53.6	44.5	37.0	31.0	26.0	22.0	18.6	15.8	13.5	11.5	9.9	8.5	7.3	6.3	5.5	4.8	4.2	3.6	3.2	2.8	2.5	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0
90	64.0	53.1	44.3	37.0	31.1	26.2	22.2	18.9	16.1	13.7	11.8	10.1	8.7	7.6	6.6	5.7	5.0	4.3	3.8	3.3	2.9	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0
91	76.4	63.3	52.8	44.2	37.1	31.3	26.5	22.5	19.2	16.4	14.1	12.1	10.4	9.0	7.8	6.8	5.9	5.2	4.5	4.0	3.5	3.1	2.7	2.4	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.1	1.1
92	90.8	75.3	62.8	52.5	44.1	37.2	31.5	26.8	22.8	19.5	16.7	14.4	12.4	10.7	9.3	8.1	7.1	6.2	5.4	4.7	4.2	3.7	3.2	2.9	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2
93	107.7	89.4	74.5	62.3	52.3	44.1	37.4	31.7	27.0	23.1	19.8	17.1	14.7	12.7	11.0	9.6	8.4	7.3	6.4	5.6	4.9	4.4	3.9	3.4	3.0	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.4	1.4	1.4	1.3	1.3	1.2
94	127.5	105.8	88.1	73.8	62.0	52.3	44.2	37.6	32.0	27.4	23.5	20.2	17.4	15.1	13.1	11.4	9.9	8.7	7.6	6.7	5.9	5.2	4.6	4.0	3.6	3.2	2.8	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3
95	150.6	124.9	104.1	87.1	73.2	61.7	52.2	44.4	37.8	32.3	27.7	23.8	20.6	17.8	15.4	13.4	11.7	10.2	9.0	7.9	6.9	6.1	5.4	4.8	4.2	3.8	3.3	3.0	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4
96	177.4	147.2	122.6	102.6	86.2	72.7	61.5	52.3	44.6	38.1	32.7	28.1	24.2	21.0	18.2	15.8	13.8	12.1	10.6	9.3	8.2	7.2	6.3	5.6	5.0	4.4	3.9	3.5	3.1	2.8	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.5
97	>200	173.1	144.2	120.7	101.4	85.5	72.4	61.5	52.4	44.8	38.4	33.0	28.5	24.7	21.4	18.6	16.2	14.2	12.4	10.9	9.6	8.4	7.5	6.6	5.9	5.2	4.6	4.1	3.7	3.3	3.0	2.6	2.4	1.7	1.7	1.6	1.6	1.5
98	>200	>200	169.2	141.6	119.0	100.3	84.9	72.1	61.5	52.6	45.1	38.8	33.5	28.9	25.1	21.8	19.0	16.6	14.6	12.8	11.2	9.9	8.8	7.8	6.9	6.1	5.4	4.8	4.3	3.9	3.5	3.1	2.8	2.5	1.8	1.7	1.7	1.6
99	>200	>200	198.7	165.8	139.3	117.5	99.4	84.5	72.0	61.5	52.8	45.4	39.2	33.9	29.4	25.6	22.3	19.5	17.1	15.0	13.2	11.6	10.3	9.1	8.0	7.1	6.4	5.7	5.1	4.5	4.1	3.6	3.3	2.9	2.7	2.4	1.7	1.7
100	>200	>200	>200	193.8	162.8	137.3	116.2	98.7	84.1	71.9	61.7	53.1	45.8	39.6	34.4	29.9	26.0	22.8	19.9	17.5	15.4	13.6	12.0	10.6	9.4	8.4	7.4	6.6	5.9	5.3	4.7	4.3	3.8	3.4	3.1	2.8	2.5	2.4
101	>200	>200	>200	>200	189.9	160.2	135.6	115.1	98.1	83.9	72.0	61.9	53.4	46.2	40.1	34.9	30.4	26.5	23.3	20.4	18.0	15.8	14.0	12.4	11.0	9.7	8.7	7.7	6.9	6.2	5.5	5.0	4.5	4.0	3.6	3.3	2.9	2.8
102	>200	>200	>200	>200	>200	186.5	157.8	134.1	114.3	97.7	83.8	72.1	62.2	53.8	46.7	40.6	35.4	30.9	27.1	23.8	20.9	18.4	16.3	14.4	12.8	11.4	10.1	9.0	8.0	7.2	6.4	5.8	5.2	4.7	4.2	3.8	3.4	3.2
103	>200	>200	>200	>200	>200	>200	183.4	155.8	132.8	113.6	97.4	83.8	72.3	62.5	54.2	47.2	41.1	35.9	31.5	27.6	24.3	21.4	18.9	16.7	14.9	13.2	11.7	10.5	9.3	8.4	7.5	6.7	6.0	5.4	4.9	4.4	4.0	3.8
104	>200	>200	>200	>200	>200	>200	>200	180.8	154.1	131.7	113.0	97.2	83.9	72.5	62.9	54.7	47.7	41.7	36.5	32.1	28.2	24.9	22.0	19.4	17.2	15.3	13.6	12.1	10.8	9.7	8.7	7.8	7.0	6.3	5.7	5.1	4.6	4.4
105	>200	>200	>200	>200	>200	>200	>200	>200	178.5	152.6	130.9	112.6	97.1	84.0	72.9	63.4	55.3	48.3	42.3	37.1	32.7	28.8	25.4	22.5	20.0	17.7	15.8	14.1	12.6	11.2	10.1	9.0	8.1	7.3	6.6	5.9	5.4	5.1
106	>200	>200	>200	>200	>200	>200	>200	>200	>200	176.4	151.3	130.2	112.3	97.2	84.3	73.3	63.9	55.8	48.9	42.9	37.8	33.3	29.4	26.0	23.1	20.5	18.2	16.3	14.5	13.0	11.6	10.4	9.4	8.4	7.6	6.9	6.2	5.8
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	174.7	150.3	129.7	112.2	97.3	84.6	73.8	64.5	56.5	49.6	43.6	38.4	33.9	30.0	26.6	23.7	21.1	18.8	16.8	15.0	13.4	12.1	10.8	9.7	8.8	7.9	7.2	6.7
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	173.2	149.4	129.3	112.1	97.5	85.0	74.3	65.1	57.1	50.2	44.3	39.1	34.6	30.7	27.3	24.3	21.6	19.3	17.3	15.5	13.9	12.5	11.2	10.1	9.1	8.3	7.8
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	199.3	172.0	148.8	129.0	112.2	97.8	85.5	74.9	65.7	57.8	51.0	45.0	39.9	35.3	31.4	27.9	24.9	22.2	19.9	17.8	16.0	14.4	12.9	11.7	10.5	9.5	8.9
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.6	170.9	148.3	128.9	112.4	98.2	86.0	75.5	66.4	58.6	51.7	45.8	40.6	36.1	32.1	28.6	25.6	22.9	20.5	18.4	16.5	14.9	13.4	12.1	10.9	10.3
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	196.1	170.1	148.0	129.0	112.7	98.7	86.7	76.2	67.2	59.4	52.5	46.6	41.4	36.8	32.8	29.3	26.2	23.5	21.1	18.9	17.0	15.4	13.9	12.5	11.8
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	194.9	169.5	147.8	129.1	113.1	99.3	87.3	77.0	68.0	60.2	53.4	47.4	42.2	37.6	33.6	30.1	26.9	24.2	21.7	19.5	17.6	15.9	14.4	13.5
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.9	169.1	147.7	129.4	113.6	99.9	88.1	77.8	68.9	61.1	54.3	48.3	43.0	38.4	34.4	30.8	27.6	24.8	22.3	20.1	18.2	16.4	15.5
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.2	168.8	147.9	129.8	114.2	100.7	88.9	78.7	69.8	62.0	55.2	49.2	43.9	39.3	35.2	31.6	28.4	25.5	23.0	20.8	18.8	17.7
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.6	168.7	148.1	130.3	114.8	101.5	89.8	79.6	70.7	62.9	56.1	50.1	44.8	40.2	36.0	32.4	29.1	26.3	23.7	21.4	20.2
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.2	168.7	148.4	130.9	115.6	102.3	90.7	80.6	71.7	63.9	57.1	51.1	45.8	41.1	36.9	33.2	29.9	27.0	24.4	23.0
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.0	168.9	148.9	131.6	116.4	103.3	91.7	81.6	72.8	65.0	58.1	52.1	46.7	42.0	37.8	34.0	30.7	27.8	26.1
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.0	169.3	149.5	132.3	117.4	104.3	92.8	82.7	73.9	66.1	59.2	53.1	47.7	42.9	38.7	34.9	31.6	29.7
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.2	169.7	150.2	133.2	118.3	105.3	93.9	83.9	75.0	67.2	60.3	54.2	48.7	43.9	39.6	35.8	33.7
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.5	170.3	151.0	134.2	119.4	106.5	95.1	85.0	76.2	68.4	61.4	55.3	49.8	44.9	40.6	38.2
121	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.9	171.1	152.0	135.2	120.6	107.7	96.3	86.3	77.4	69.6	62.6	56.4	50.9	46.0	43.3
122	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.5	171.9	153.0	136.4	121.8	108.9	97.6	87.6	78.7	70.8	63.8	57.6	52.0	49.0
123	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	194.2	172.9	154.1	137.6	123.1	110.3	98.9	88.9	80.0	72.1	65.1	58.8	55.4
124	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.1	173.9	155.3	138.9	124.5	111.7	100.3	90.3	81.4	73.4	66.4	62.5
125	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	196.1	175.1	156.6	140.3	125.9	113.1	101.8	91.7	82.8	74.8	70.4
126	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.2	176.4	158.0	141.8	127.4	114.6	103.3	93.2	84.3	79.3
127	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.4	177.8	159.5	143.3	129.0	116.2	104.9	94.8	89.2
128	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	199.8	179.3	161.1	145.0	130.6	117.9	106.5	100.3
129	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.9	162.8	146.7	132.4	119.6	112.6
130	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	187.6	164.5	148.5	134.1	126.3
131	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	184.3	166.4	150.3	141.5
132	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	186.2	168.3	158.5
133	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.2	177.2
134	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.0

Figure B-49 Tabular Representation of Parking Nomograph for B767-300ER on 16 °F (-9 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

16 F	Gross B-767-300ER Weight (lbs)																																					
Ice Thickness (in)	205000	210000	215000	220000	225000	230000	235000	240000	245000	250000	255000	260000	265000	270000	275000	280000	285000	290000	295000	300000	305000	310000	315000	320000	325000	330000	335000	340000	345000	350000	355000	360000	365000	370000	375000	380000	385000	388000
52	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
53	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
54	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0
55	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
56	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
57	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
58	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
59	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
60	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
61	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
62	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
63	0.7	0.7	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1
64	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
65	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
66	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
67	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
68	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
69	1.2	1.1	1.1	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2
70	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
71	1.4	1.3	1.3	1.2	1.1	1.1	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3
72	1.5	1.4	1.4	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3
73	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3
74	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
75	3.0	2.5	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4
76	3.7	3.1	2.6	1.7	1.6	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4
77	4.6	3.8	3.2	2.7	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4
78	5.8	4.8	4.0	3.3	2.8	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5
79	7.1	5.9	4.9	4.1	3.5	2.9	2.5	1.7	1.6	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5
80	8.8	7.3	6.1	5.1	4.3	3.6	3.1	2.6	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5
81	10.8	9.0	7.5	6.3	5.3	4.4	3.8	3.2	2.7	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6
82	13.2	11.0	9.2	7.7	6.4	5.4	4.6	3.9	3.3	2.8	2.4	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6
83	16.2	13.4	11.2	9.4	7.9	6.6	5.6	4.8	4.1	3.5	3.0	2.6	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7
84	19.7	16.3	13.6	11.4	9.6	8.1	6.8	5.8	4.9	4.2	3.6	3.1	2.7	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7
85	23.9	19.8	16.5	13.8	11.6	9.8	8.3	7.0	6.0	5.1	4.4	3.8	3.3	2.8	2.4	1.7	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8
86	28.8	23.9	19.9	16.7	14.0	11.8	10.0	8.5	7.2	6.2	5.3	4.6	3.9	3.4	3.0	2.6	1.8	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8
87	34.8	28.8	24.0	20.1	16.9	14.2	12.1	10.2	8.7	7.5	6.4	5.5	4.7	4.1	3.6	3.1	2.7	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.9
88	41.8	34.7	28.9	24.2	20.3	17.1	14.5	12.3	10.5	9.0	7.7	6.6	5.7	4.9	4.3	3.7	3.2	2.8	2.5	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9
89	50.1	41.5	34.6	29.0	24.3	20.5	17.4	14.8	12.6	10.7	9.2	7.9	6.8	5.9	5.1	4.5	3.9	3.4	3.0	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.3	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0
90	59.9	49.7	41.4	34.6	29.1	24.5	20.8	17.6	15.0	12.8	11.0	9.5	8.2	7.1	6.1	5.3	4.7	4.1	3.6	3.1	2.7	2.4	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0
91	71.4	59.2	49.3	41.3	34.7	29.2	24.8	21.0	17.9	15.3	13.1	11.3	9.8	8.4	7.3	6.4	5.5	4.8	4.2	3.7	3.3	2.9	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1
92	84.9	70.4	58.7	49.1	41.3	34.8	29.4	25.0	21.3	18.2	15.6	13.4	11.6	10.0	8.7	7.6	6.6	5.8	5.0	4.4	3.9	3.4	3.0	2.7	2.4	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.1
93	100.7	83.6	69.6	58.3	48.9	41.3	34.9	29.7	25.3	21.6	18.5	16.0	13.8	11.9	10.3	9.0	7.8	6.8	6.0	5.3	4.6	4.1	3.6	3.2	2.8	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2
94	119.2	98.9	82.4	69.0	57.9	48.9	41.4	35.1	29.9	25.6	22.0	18.9	16.3	14.1	12.2	10.6	9.3	8.1	7.1	6.2	5.5	4.8	4.3	3.8	3.3	3.0	2.6	1.8	1.7	1.7	1.6	1.6	1.5	1.4	1.4	1.4	1.3	1.3
95	140.8	116.8	97.4	81.5	68.4	57.7	48.9	41.5	35.4	30.2	25.9	22.3	19.2	16.6	14.4	12.6	10.9	9.6	8.4	7.4	6.5	5.7	5.0	4.5	4.0	3.5	3.1	2.8	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.4
96	166.0	137.7	114.7	96.0	80.7	68.0	57.6	48.9	41.7	35.6	30.6	26.3	22.7	19.6	17.0	14.8	12.9	11.3	9.9	8.7	7.6	6.7	5.9	5.3	4.7	4.1	3.7	3.3	2.9	2.6	1.8	1.7	1.7	1.6	1.6	1.5	1.5	1.4
97	195.2	161.9	134.9	112.9	94.8	80.0	67.7	57.5	49.0	41.9	35.9	30.9	26.7	23.1	20.0	17.4	15.2	13.3	11.6	10.2	9.0	7.9	7.0	6.2	5.5	4.9	4.3	3.9	3.4	3.1	2.8	2.5	1.8	1.7	1.6	1.6	1.5	1.5
98	>200	190.0	158.3	132.5	111.3	93.9	79.5	67.5	57.5	49.2	42.2	36.3	31.3	27.1	23.5	20.4	17.8	15.6	13.6	12.0	10.5	9.3	8.2	7.3	6.4	5.7	5.1	4.5	4.0	3.6	3.2	2.9	2.6	1.8	1.7	1.7	1.6	1.6
99	>200	>200	185.4	155.2	130.4	109.9	93.1	79.0	67.4	57.6	49.4	42.5	36.7	31.7	27.5	23.9	20.9	18.2	16.0	14.0	12.3	10.9	9.6	8.5	7.5	6.7	6.0	5.3	4.7	4.2	3.8	3.4	3.1	2.8	2.5	1.8	1.7	1.7
100	>200	>200	>200	181.4	152.4	128.5	108.8	92.4	78.7	67.3	57.7	49.7	42.9	37.1	32.2	28.0	24.4	21.3	18.7	16.4	14.4	12.7	11.2	9.9	8.8	7.8	7.0	6.2	5.5	5.0	4.4	4.0	3.6	3.2	2.9	2.6	1.8	1.8
101	>200	>200	>200	>200	177.8	149.9	126.9	107.8	91.9	78.5	67.4	57.9	50.0	43.2	37.5	32.6	28.4	24.9	21.8	19.1	16.8	14.8	13.1	11.6	10.3	9.1	8.1	7.2	6.5	5.8	5.2	4.6	4.2	3.8	3.4	3.1	2.8	2.6
102	>200	>200	>200	>200	>200	174.6	147.8	125.5	107.0	91.5	78.4	67.5	58.2	50.4	43.7	38.0	33.1	28.9	25.3	22.2	19.6	17.3	15.2	13.5	12.0	10.6	9.5	8.4	7.5	6.7	6.0	5.4	4.9	4.4	3.9	3.6	3.2	3.0
103	>200	>200	>200	>200	>200	>200	171.7	145.9	124.3	106.3	91.2	78.4	67.7	58.5	50.8	44.2	38.5	33.6	29.5	25.9	22.8	20.1	17.7	15.7	13.9	12.4	11.0	9.8	8.7	7.8	7.0	6.3	5.7	5.1	4.6	4.1	3.7	3.5
104	>200	>200	>200	>200	>200	>200	199.3	169.3	144.3	123.4	105.8	91.0	78.5	67.9	58.9	51.2	44.7	39.0	34.2	30.0	26.4	23.3	20.6	18.2	16.1	14.3	12.8	11.4	10.2	9.1	8.1	7.3	6.6	5.9	5.3	4.8	4.3	4.1
105	>200	>200	>200	>200	>200	>200	>200	196.1	167.1	142.9	122.6	105.4	91.0	78.7	68.2	59.3	51.7	45.2	39.6	34.8	30.6	27.0	23.8	21.1	18.7	16.6	14.8	13.2	11.8	10.5	9.4	8.5	7.6	6.8	6.2	5.6	5.0	4.7
106	>200	>200	>200	>200	>200	>200	>200	>200	193.2	165.2	141.7	121.9	105.2	91.0	78.9	68.6	59.8	52.3	45.8	40.2	35.4	31.2	27.5	24.4	21.6	19.2	17.1	15.2	13.6	12.2	10.9	9.8	8.8	7.9	7.1	6.4	5.8	5.5
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	190.8	163.6	140.8	121.4	105.0	91.1	79.2	69.1	60.4	52.9	46.4	40.8	36.0	31.8	28.1	25.0	22.2	19.7	17.6	15.7	14.0	12.6	11.3	10.1	9.1	8.2	7.4	6.7	6.3
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.6	162.2	140.0	121.1	105.0	91.3	79.6	69.6	60.9	53.5	47.1	41.5	36.6	32.4	28.8	25.6	22.7	20.3	18.1	16.2	14.5	13.0	11.7	10.5	9.5	8.6	7.7	7.3
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	186.7	161.1	139.4	120.9	105.1	91.6	80.1	70.1	61.6	54.2	47.8	42.2	37.3	33.1	29.4	26.2	23.3	20.8	18.6	16.7	15.0	13.5	12.1	10.9	9.8	8.9	8.4
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.1	160.1	138.9	120.8	105.3	92.0	80.6	70.8	62.2	54.9	48.5	42.9	38.0	33.8	30.1	26.8	23.9	21.4	19.2	17.2	15.5	13.9	12.5	11.3	10.2	9.6
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	183.8	159.4	138.6	120.8	105.6	92.5	81.2	71.4	63.0	55.6	49.2	43.7	38.8	34.5	30.8	27.5	24.6	22.0	19.8	17.7	16.0	14.4	13.0	11.7	11.0
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.6	158.8	138.5	121.0	106.0	93.0	81.8	72.1	63.7	56.4	50.0	44.4	39.5	35.3	31.5	28.2	25.2	22.6	20.3	18.3	16.5	14.9	13.4	12.7
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.7	158.4	138.4	121.3	106.4	93.6	82.6	72.9	64.5	57.2	50.8	45.2	40.3	36.0	32.2	28.9	25.9	23.3	20.9	18.9	17.0	15.4	14.5
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.0	158.2	138.6	121.6	107.0	94.3	83.3	73.7	65.4	58.1	51.7	46.1	41.2	36.8	33.0	29.6	26.6	23.9	21.6	19.5	17.6	16.6
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.5	158.1	138.8	122.1	107.6	95.1	84.2	74.6	66.3	59.0	52.6	47.0	42.0	37.6	33.8	30.3	27.3	24.6	22.2	20.1	18.9
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.2	158.2	139.1	122.7	108.3	95.9	85.0	75.5	67.2	59.9	53.5	47.9	42.9	38.5	34.6	31.1	28.0	25.3	22.9	21.5
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.0	158.4	139.6	123.3	109.1	96.8	86.0	76.5	68.2	60.9	54.5	48.8	43.8	39.4	35.4	31.9	28.8	26.0	24.5
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.0	158.7	140.2	124.1	110.0	97.7	87.0	77.5	69.2	61.9	55.5	49.8	44.7	40.3	36.3	32.7	29.6	27.9
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.1	159.1	140.8	124.9	110.9	98.7	88.0	78.6	70.3	63.0	56.5	50.8	45.7	41.2	37.2	33.6	31.6
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.4	159.7	141.6	125.8	112.0	99.8	89.1	79.7	71.4	64.1	57.6	51.8	46.7	42.1	38.1	35.9
121	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.9	160.4	142.5	126.8	113.0	100.9	90.3	80.9	72.6	65.2	58.7	52.9	47.7	43.1	40.6
122	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.4	161.2	143.4	127.9	114.2	102.1	91.5	82.1	73.8	66.4	59.8	54.0	48.8	45.9
123	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.1	162.1	144.5	129.0	115.4	103.4	92.8	83.4	75.0	67.6	61.0	55.1	51.9
124	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.9	163.1	145.6	130.3	116.7	104.7	94.1	84.7	76.3	68.9	62.2	58.6
125	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	183.9	164.2	146.9	131.6	118.1	106.1	95.5	86.0	77.6	70.2	66.1
126	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	184.9	165.4	148.2	133.0	119.5	107.5	96.9	87.4	79.0	74.4
127	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	186.1	166.7	149.6	134.4	121.0	109.0	98.4	88.9	83.7
128	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	187.4	168.1	151.1	136.0	122.5	110.6	99.9	94.1
129	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.8	169.6	152.7	137.6	124.2	112.2	105.6
130	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	190.3	171.2	154.3	139.3	125.8	118.5
131	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.9	172.9	156.1	141.0	132.8
132	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.6	174.7	157.9	148.7
133	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.4	176.6	166.3
134	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.3	185.8

Figure B-50 Tabular Representation of Parking Nomograph for B767-300ER on 17 °F (-8 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

17 F	Gross B-767-300ER Weight (lbs)																																					
Ice Thickness (in)	205000	210000	215000	220000	225000	230000	235000	240000	245000	250000	255000	260000	265000	270000	275000	280000	285000	290000	295000	300000	305000	310000	315000	320000	325000	330000	335000	340000	345000	350000	355000	360000	365000	370000	375000	380000	385000	388000
52	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
53	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
54	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0
55	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
56	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
57	0.4	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
58	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
59	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
60	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
61	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
62	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
63	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1
64	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1
65	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
66	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
67	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
68	1.1	1.0	1.0	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
69	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2
70	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
71	1.4	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
72	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3
73	1.6	1.5	1.4	1.4	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3
74	1.7	1.6	1.5	1.5	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3
75	2.8	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4
76	3.5	2.9	2.4	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4
77	4.3	3.6	3.0	2.5	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4
78	5.4	4.5	3.7	3.1	2.6	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5
79	6.6	5.5	4.6	3.8	3.2	2.7	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5
80	8.2	6.8	5.7	4.7	4.0	3.4	2.8	2.4	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5
81	10.1	8.4	7.0	5.8	4.9	4.1	3.5	3.0	2.5	1.7	1.7	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6
82	12.4	10.2	8.5	7.1	6.0	5.1	4.3	3.6	3.1	2.7	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6
83	15.1	12.5	10.4	8.7	7.3	6.2	5.2	4.4	3.8	3.2	2.8	2.4	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.7
84	18.4	15.2	12.7	10.6	8.9	7.5	6.4	5.4	4.6	3.9	3.4	2.9	2.5	1.7	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7
85	22.3	18.5	15.4	12.9	10.8	9.1	7.7	6.6	5.6	4.8	4.1	3.5	3.0	2.6	1.8	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7
86	26.9	22.3	18.6	15.6	13.1	11.0	9.3	7.9	6.8	5.8	5.0	4.3	3.7	3.2	2.8	2.4	1.7	1.6	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8
87	32.4	26.9	22.4	18.8	15.8	13.3	11.3	9.6	8.1	7.0	6.0	5.1	4.4	3.8	3.3	2.9	2.5	1.8	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.9	0.8
88	39.0	32.4	27.0	22.6	19.0	16.0	13.5	11.5	9.8	8.4	7.2	6.2	5.3	4.6	4.0	3.5	3.0	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9
89	46.8	38.8	32.3	27.0	22.7	19.2	16.2	13.8	11.7	10.0	8.6	7.4	6.4	5.5	4.8	4.2	3.6	3.2	2.8	2.4	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9
90	55.9	46.4	38.6	32.3	27.2	22.9	19.4	16.5	14.0	12.0	10.3	8.9	7.6	6.6	5.7	5.0	4.3	3.8	3.3	2.9	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.3	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0
91	66.7	55.3	46.1	38.6	32.4	27.3	23.1	19.6	16.7	14.3	12.3	10.6	9.1	7.9	6.8	5.9	5.2	4.5	4.0	3.5	3.1	2.7	2.4	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.1
92	79.3	65.8	54.8	45.9	38.5	32.5	27.5	23.4	19.9	17.0	14.6	12.6	10.8	9.4	8.1	7.1	6.2	5.4	4.7	4.1	3.6	3.2	2.8	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1
93	94.1	78.1	65.1	54.4	45.7	38.6	32.7	27.7	23.6	20.2	17.3	14.9	12.9	11.1	9.7	8.4	7.3	6.4	5.6	4.9	4.3	3.8	3.4	3.0	2.6	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.3	1.2	1.2
94	111.5	92.5	77.0	64.5	54.2	45.7	38.7	32.8	28.0	23.9	20.5	17.7	15.2	13.2	11.4	9.9	8.7	7.6	6.6	5.8	5.1	4.5	4.0	3.5	3.1	2.8	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.3
95	131.7	109.2	91.0	76.1	64.0	54.0	45.7	38.8	33.1	28.3	24.2	20.9	18.0	15.6	13.5	11.7	10.2	8.9	7.8	6.9	6.0	5.3	4.7	4.2	3.7	3.3	2.9	2.6	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.4	1.3
96	155.2	128.7	107.3	89.8	75.4	63.6	53.8	45.7	39.0	33.3	28.6	24.6	21.2	18.3	15.9	13.8	12.1	10.5	9.2	8.1	7.1	6.3	5.6	4.9	4.4	3.9	3.4	3.1	2.7	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4
97	182.5	151.4	126.2	105.6	88.7	74.8	63.3	53.8	45.8	39.2	33.6	28.9	24.9	21.6	18.7	16.3	14.2	12.4	10.9	9.5	8.4	7.4	6.5	5.8	5.1	4.6	4.0	3.6	3.2	2.9	2.6	1.8	1.7	1.7	1.6	1.6	1.5	1.5
98	>200	177.7	148.1	123.9	104.1	87.8	74.3	63.1	53.8	46.0	39.4	33.9	29.3	25.3	22.0	19.1	16.6	14.5	12.7	11.2	9.8	8.7	7.7	6.8	6.0	5.3	4.8	4.2	3.8	3.4	3.0	2.7	2.4	1.8	1.7	1.6	1.6	1.6
99	>200	>200	173.4	145.1	121.9	102.8	87.0	73.9	63.0	53.9	46.2	39.7	34.3	29.7	25.7	22.4	19.5	17.0	14.9	13.1	11.5	10.2	9.0	7.9	7.0	6.3	5.6	5.0	4.4	4.0	3.6	3.2	2.9	2.6	1.8	1.7	1.7	1.6
100	>200	>200	>200	169.6	142.5	120.2	101.7	86.4	73.6	63.0	54.0	46.5	40.1	34.7	30.1	26.2	22.8	19.9	17.4	15.3	13.5	11.9	10.5	9.3	8.2	7.3	6.5	5.8	5.2	4.6	4.2	3.7	3.3	3.0	2.7	2.4	1.8	1.7
101	>200	>200	>200	197.9	166.3	140.2	118.7	100.8	85.9	73.5	63.0	54.2	46.8	40.5	35.1	30.5	26.6	23.2	20.4	17.9	15.7	13.9	12.2	10.8	9.6	8.5	7.6	6.8	6.0	5.4	4.8	4.3	3.9	3.5	3.2	2.9	2.6	2.4
102	>200	>200	>200	>200	193.7	163.3	138.2	117.4	100.1	85.6	73.4	63.1	54.5	47.1	40.9	35.5	31.0	27.1	23.7	20.8	18.3	16.1	14.3	12.6	11.2	9.9	8.8	7.9	7.0	6.3	5.6	5.1	4.5	4.1	3.7	3.3	3.0	2.8
103	>200	>200	>200	>200	>200	189.9	160.7	136.5	116.3	99.5	85.3	73.4	63.3	54.8	47.5	41.3	36.0	31.5	27.6	24.2	21.3	18.8	16.6	14.7	13.0	11.6	10.3	9.2	8.2	7.3	6.6	5.9	5.3	4.8	4.3	3.9	3.5	3.3
104	>200	>200	>200	>200	>200	>200	186.5	158.4	135.0	115.4	99.0	85.2	73.5	63.6	55.1	47.9	41.8	36.5	32.0	28.1	24.7	21.8	19.2	17.0	15.1	13.4	11.9	10.6	9.5	8.5	7.6	6.8	6.1	5.5	5.0	4.5	4.1	3.8
105	>200	>200	>200	>200	>200	>200	>200	183.5	156.4	133.7	114.7	98.7	85.1	73.6	63.9	55.5	48.4	42.3	37.1	32.5	28.6	25.2	22.3	19.7	17.5	15.5	13.8	12.3	11.0	9.8	8.8	7.9	7.1	6.4	5.8	5.2	4.7	4.4
106	>200	>200	>200	>200	>200	>200	>200	>200	180.9	154.7	132.6	114.1	98.4	85.2	73.9	64.2	56.0	48.9	42.9	37.6	33.1	29.2	25.8	22.8	20.2	18.0	16.0	14.3	12.7	11.4	10.2	9.2	8.2	7.4	6.7	6.0	5.4	5.1
107	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.6	153.2	131.8	113.7	98.3	85.3	74.2	64.7	56.5	49.5	43.4	38.2	33.7	29.8	26.3	23.4	20.7	18.5	16.5	14.7	13.1	11.8	10.6	9.5	8.5	7.7	6.9	6.3	5.9
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	176.6	151.9	131.0	113.4	98.3	85.5	74.5	65.1	57.1	50.1	44.1	38.8	34.3	30.4	26.9	23.9	21.3	19.0	16.9	15.2	13.6	12.2	10.9	9.9	8.9	8.0	7.2	6.8
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	174.8	150.8	130.5	113.2	98.4	85.8	75.0	65.7	57.6	50.7	44.7	39.5	35.0	31.0	27.5	24.5	21.8	19.5	17.4	15.6	14.0	12.6	11.3	10.2	9.2	8.3	7.8
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	173.3	149.9	130.1	113.1	98.6	86.2	75.5	66.3	58.3	51.4	45.4	40.2	35.6	31.6	28.2	25.1	22.4	20.1	18.0	16.1	14.5	13.0	11.7	10.6	9.6	9.0
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.9	172.1	149.3	129.8	113.2	98.9	86.6	76.0	66.9	59.0	52.1	46.1	40.9	36.3	32.3	28.8	25.7	23.0	20.6	18.5	16.6	15.0	13.5	12.2	11.0	10.3
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.2	171.0	148.7	129.7	113.3	99.2	87.1	76.6	67.6	59.7	52.8	46.8	41.6	37.0	33.0	29.5	26.4	23.6	21.2	19.0	17.1	15.4	13.9	12.6	11.9
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.7	170.2	148.4	129.7	113.6	99.7	87.7	77.3	68.3	60.4	53.6	47.6	42.4	37.8	33.7	30.2	27.0	24.3	21.8	19.6	17.7	15.9	14.4	13.6
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	194.5	169.5	148.2	129.8	113.9	100.2	88.3	78.0	69.1	61.2	54.4	48.4	43.2	38.5	34.5	30.9	27.7	24.9	22.4	20.2	18.2	16.5	15.5
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.5	169.1	148.1	130.0	114.4	100.8	89.1	78.8	69.9	62.1	55.3	49.3	44.0	39.3	35.2	31.6	28.4	25.6	23.0	20.8	18.8	17.7
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.7	168.8	148.2	130.3	114.9	101.5	89.8	79.7	70.8	63.0	56.1	50.1	44.8	40.2	36.0	32.4	29.1	26.3	23.7	21.4	20.2
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.1	168.6	148.3	130.8	115.5	102.2	90.7	80.5	71.7	63.9	57.1	51.0	45.7	41.0	36.9	33.2	29.9	27.0	24.4	23.0
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.7	168.6	148.7	131.3	116.2	103.1	91.6	81.5	72.6	64.9	58.0	52.0	46.6	41.9	37.7	34.0	30.7	27.7	26.1
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.5	168.8	149.1	132.0	117.0	104.0	92.5	82.5	73.6	65.9	59.0	53.0	47.6	42.8	38.6	34.8	31.5	29.6
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.4	169.1	149.6	132.7	117.9	104.9	93.5	83.5	74.7	66.9	60.0	54.0	48.6	43.8	39.5	35.7	33.6
121	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.5	169.5	150.3	133.5	118.8	105.9	94.6	84.6	75.8	68.0	61.1	55.0	49.6	44.7	40.4	38.1
122	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.7	170.0	151.0	134.4	119.8	107.0	95.7	85.8	76.9	69.1	62.2	56.1	50.6	45.7	43.0
123	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.1	170.7	151.9	135.4	120.9	108.2	96.9	86.9	78.1	70.3	63.4	57.2	51.7	48.6
124	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.7	171.5	152.9	136.5	122.1	109.4	98.1	88.2	79.4	71.5	64.5	58.3	54.9
125	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.3	172.4	153.9	137.7	123.3	110.7	99.4	89.5	80.6	72.8	65.8	61.9
126	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	194.1	173.4	155.1	138.9	124.6	112.0	100.8	90.8	82.0	74.1	69.7
127	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.1	174.5	156.3	140.2	126.0	113.4	102.2	92.2	83.3	78.5
128	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	196.1	175.7	157.6	141.6	127.5	114.9	103.7	93.7	88.2
129	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.3	177.0	159.0	143.1	129.0	116.4	105.2	99.0
130	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.5	178.4	160.6	144.7	130.6	118.0	111.1
131	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	199.9	179.9	162.1	146.3	132.2	124.5
132	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.5	163.8	148.0	139.4
133	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	183.2	165.6	155.9
134	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.0	174.2

Figure B-51 Tabular Representation of Parking Nomograph for B767-300ER on 18 °F (-7.5 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

18 F	Gross B-767-300ER Weight (lbs)																																					
Ice Thickness (in)	205000	210000	215000	220000	225000	230000	235000	240000	245000	250000	255000	260000	265000	270000	275000	280000	285000	290000	295000	300000	305000	310000	315000	320000	325000	330000	335000	340000	345000	350000	355000	360000	365000	370000	375000	380000	385000	388000
52	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
53	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
54	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0
55	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
56	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
57	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
58	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
59	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
60	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
61	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
62	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
63	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1
64	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1
65	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
66	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
67	1.0	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
68	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
69	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2
70	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2
71	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
72	1.5	1.4	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3
73	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3
74	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3
75	2.6	1.7	1.6	1.5	1.5	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4
76	3.2	2.7	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4
77	4.0	3.3	2.8	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4
78	5.0	4.1	3.5	2.9	2.4	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5
79	6.2	5.1	4.3	3.6	3.0	2.5	1.7	1.6	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5
80	7.6	6.3	5.3	4.4	3.7	3.1	2.6	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5
81	9.4	7.8	6.5	5.4	4.6	3.8	3.3	2.8	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6
82	11.5	9.6	8.0	6.7	5.6	4.7	4.0	3.4	2.9	2.5	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.6	0.6	0.6
83	14.1	11.7	9.7	8.1	6.8	5.8	4.9	4.1	3.5	3.0	2.6	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.6
84	17.1	14.2	11.8	9.9	8.3	7.0	5.9	5.0	4.3	3.7	3.1	2.7	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7
85	20.8	17.2	14.3	12.0	10.1	8.5	7.2	6.1	5.2	4.5	3.8	3.3	2.8	2.5	1.7	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7
86	25.1	20.8	17.4	14.5	12.2	10.3	8.7	7.4	6.3	5.4	4.6	4.0	3.4	3.0	2.6	1.8	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8
87	30.3	25.1	20.9	17.5	14.7	12.4	10.5	8.9	7.6	6.5	5.6	4.8	4.1	3.6	3.1	2.7	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8
88	36.4	30.2	25.2	21.1	17.7	14.9	12.6	10.7	9.1	7.8	6.7	5.8	5.0	4.3	3.7	3.2	2.8	2.5	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.9
89	43.6	36.2	30.2	25.2	21.2	17.9	15.1	12.9	11.0	9.4	8.0	6.9	6.0	5.2	4.5	3.9	3.4	3.0	2.6	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9
90	52.2	43.3	36.1	30.2	25.4	21.4	18.1	15.4	13.1	11.2	9.6	8.3	7.1	6.2	5.4	4.7	4.1	3.5	3.1	2.7	2.4	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0
91	62.3	51.6	43.0	36.0	30.3	25.5	21.6	18.3	15.6	13.4	11.5	9.9	8.5	7.4	6.4	5.5	4.8	4.2	3.7	3.2	2.9	2.5	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0
92	74.1	61.5	51.2	42.8	36.0	30.4	25.7	21.8	18.6	15.9	13.6	11.7	10.1	8.8	7.6	6.6	5.8	5.0	4.4	3.9	3.4	3.0	2.6	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1
93	87.9	72.9	60.8	50.9	42.7	36.0	30.5	25.9	22.1	18.9	16.2	13.9	12.0	10.4	9.0	7.8	6.8	6.0	5.2	4.6	4.0	3.6	3.1	2.8	2.5	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2
94	104.1	86.4	72.0	60.7	50.6	42.7	36.1	30.7	26.1	22.3	19.2	16.5	14.2	12.3	10.7	9.3	8.1	7.1	6.2	5.4	4.8	4.2	3.7	3.3	2.9	2.6	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.3	1.2
95	123.0	102.0	85.0	71.1	59.8	50.4	42.7	36.2	30.9	26.4	22.6	19.5	16.8	14.5	12.6	11.0	9.6	8.4	7.3	6.4	5.6	5.0	4.4	3.9	3.5	3.1	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3
96	145.0	120.3	100.2	83.9	70.5	59.4	50.3	42.7	36.4	31.1	26.7	23.0	19.8	17.1	14.9	12.9	11.3	9.8	8.6	7.6	6.7	5.9	5.2	4.6	4.1	3.6	3.2	2.9	2.6	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.4
97	170.5	141.5	117.9	98.6	82.9	69.9	59.2	50.2	42.8	36.6	31.4	27.0	23.3	20.2	17.5	15.2	13.3	11.6	10.1	8.9	7.8	6.9	6.1	5.4	4.8	4.3	3.8	3.4	3.0	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5	1.4
98	>200	166.1	138.4	115.8	97.3	82.0	69.4	59.0	50.3	43.0	36.9	31.7	27.4	23.7	20.5	17.8	15.6	13.6	11.9	10.5	9.2	8.1	7.2	6.3	5.6	5.0	4.4	4.0	3.5	3.2	2.8	2.5	1.8	1.7	1.7	1.6	1.5	1.5
99	>200	194.5	162.1	135.6	114.0	96.1	81.3	69.1	58.9	50.3	43.2	37.1	32.0	27.7	24.0	20.9	18.2	15.9	14.0	12.2	10.8	9.5	8.4	7.4	6.6	5.8	5.2	4.6	4.1	3.7	3.3	3.0	2.7	2.4	1.7	1.7	1.6	1.6
100	>200	>200	189.5	158.6	133.2	112.4	95.1	80.8	68.8	58.9	50.5	43.4	37.5	32.4	28.1	24.4	21.3	18.6	16.3	14.3	12.6	11.1	9.8	8.7	7.7	6.8	6.1	5.4	4.8	4.3	3.9	3.5	3.1	2.8	2.5	1.8	1.7	1.7
101	>200	>200	>200	185.1	155.5	131.1	111.0	94.3	80.3	68.7	58.9	50.7	43.7	37.8	32.8	28.5	24.9	21.7	19.0	16.7	14.7	13.0	11.4	10.1	9.0	8.0	7.1	6.3	5.7	5.1	4.5	4.1	3.7	3.3	3.0	2.7	2.4	1.8
102	>200	>200	>200	>200	181.1	152.7	129.3	109.8	93.6	80.0	68.6	59.0	50.9	44.1	38.2	33.2	29.0	25.3	22.2	19.5	17.1	15.1	13.3	11.8	10.5	9.3	8.3	7.4	6.6	5.9	5.3	4.7	4.3	3.8	3.4	3.1	2.8	2.6
103	>200	>200	>200	>200	>200	177.5	150.3	127.7	108.8	93.0	79.8	68.6	59.2	51.2	44.4	38.6	33.7	29.4	25.8	22.6	19.9	17.5	15.5	13.7	12.2	10.8	9.6	8.6	7.7	6.8	6.1	5.5	4.9	4.4	4.0	3.6	3.3	3.1
104	>200	>200	>200	>200	>200	>200	174.4	148.1	126.3	108.0	92.6	79.7	68.7	59.4	51.6	44.8	39.1	34.2	29.9	26.3	23.1	20.4	18.0	15.9	14.1	12.5	11.2	10.0	8.9	7.9	7.1	6.4	5.7	5.2	4.7	4.2	3.8	3.6
105	>200	>200	>200	>200	>200	>200	>200	171.6	146.3	125.1	107.3	92.3	79.6	68.9	59.7	52.0	45.3	39.6	34.7	30.4	26.8	23.6	20.8	18.4	16.4	14.5	12.9	11.5	10.3	9.2	8.2	7.4	6.7	6.0	5.4	4.9	4.4	4.1
106	>200	>200	>200	>200	>200	>200	>200	198.5	169.2	144.7	124.1	106.7	92.1	79.7	69.1	60.1	52.4	45.8	40.1	35.2	31.0	27.3	24.1	21.3	18.9	16.8	15.0	13.3	11.9	10.7	9.5	8.6	7.7	6.9	6.2	5.6	5.1	4.8
107	>200	>200	>200	>200	>200	>200	>200	>200	195.4	167.1	143.3	123.3	106.3	92.0	79.8	69.4	60.5	52.9	46.3	40.6	35.8	31.5	27.8	24.6	21.9	19.4	17.3	15.4	13.8	12.3	11.0	9.9	8.9	8.0	7.2	6.5	5.9	5.5
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.6	165.2	142.1	122.6	106.1	92.0	80.0	69.7	60.9	53.4	46.9	41.2	36.3	32.1	28.4	25.2	22.4	19.9	17.8	15.9	14.2	12.7	11.4	10.2	9.2	8.3	7.5	6.8	6.4
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	190.1	163.6	141.1	122.1	105.9	92.1	80.3	70.2	61.4	53.9	47.5	41.8	37.0	32.7	29.0	25.8	22.9	20.4	18.3	16.3	14.6	13.1	11.8	10.6	9.6	8.6	7.8	7.3
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.0	162.2	140.3	121.7	105.8	92.3	80.6	70.6	62.0	54.5	48.1	42.5	37.6	33.3	29.6	26.4	23.5	21.0	18.8	16.8	15.1	13.6	12.2	11.0	9.9	9.0	8.4
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	186.1	161.0	139.7	121.5	105.9	92.5	81.1	71.2	62.6	55.2	48.7	43.1	38.3	34.0	30.2	27.0	24.1	21.5	19.3	17.3	15.6	14.0	12.6	11.4	10.3	9.7
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	184.5	160.1	139.2	121.4	106.1	92.9	81.5	71.7	63.2	55.9	49.4	43.8	38.9	34.7	30.9	27.6	24.7	22.1	19.8	17.8	16.0	14.5	13.0	11.8	11.1
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	183.2	159.3	138.9	121.4	106.3	93.3	82.1	72.4	63.9	56.6	50.7	44.6	39.7	35.4	31.6	28.2	25.3	22.7	20.4	18.4	16.5	14.9	13.5	12.7
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.1	158.7	138.7	121.5	106.6	93.8	82.7	73.1	64.7	57.3	50.9	45.3	40.4	36.1	32.3	28.9	25.9	23.3	21.0	18.9	17.1	15.4	14.5
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.1	158.3	138.6	121.7	107.1	94.4	83.4	73.8	65.4	58.1	51.7	46.1	41.2	36.8	33.0	29.6	26.6	23.9	21.6	19.5	17.6	16.6
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.4	158.0	138.7	122.0	107.6	95.0	84.1	74.6	66.3	59.0	52.6	46.9	42.0	37.6	33.7	30.3	27.3	24.6	22.2	20.1	18.9
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.9	157.9	138.9	122.4	108.2	95.7	84.9	75.4	67.1	59.8	53.4	47.8	42.8	38.4	34.5	31.1	28.0	25.3	22.8	21.5
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.5	157.9	139.2	123.0	108.8	96.5	85.7	76.3	68.0	60.7	54.3	48.7	43.7	39.2	35.3	31.8	28.7	25.9	24.4
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.3	158.1	139.6	123.6	109.6	97.3	86.6	77.2	69.0	61.7	55.3	49.6	44.6	40.1	36.1	32.6	29.5	27.7
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.2	158.3	140.1	124.3	110.4	98.2	87.6	78.2	70.0	62.7	56.2	50.5	45.5	41.0	37.0	33.4	31.5
121	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.3	158.7	140.8	125.0	111.3	99.2	88.6	79.2	71.0	63.7	57.2	51.5	46.4	41.9	37.8	35.6
122	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.6	159.3	141.5	125.9	112.2	100.2	89.7	80.3	72.1	64.8	58.3	52.5	47.4	42.8	40.3
123	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.0	159.9	142.3	126.8	113.3	101.3	90.8	81.4	73.2	65.9	59.3	53.6	48.4	45.6
124	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.5	160.6	143.2	127.9	114.4	102.5	91.9	82.6	74.3	67.0	60.5	54.6	51.4
125	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.1	161.5	144.2	129.0	115.5	103.7	93.2	83.8	75.5	68.2	61.6	58.0
126	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.9	162.4	145.3	130.1	116.8	104.9	94.4	85.1	76.8	69.4	65.3
127	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.7	163.5	146.4	131.4	118.1	106.2	95.7	86.4	78.1	73.5
128	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	183.7	164.6	147.7	132.7	119.4	107.6	97.1	87.8	82.6
129	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	184.8	165.8	149.0	134.1	120.9	109.1	98.6	92.8
130	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	186.0	167.2	150.4	135.6	122.3	110.6	104.1
131	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	187.4	168.6	151.9	137.1	123.9	116.7
132	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.8	170.1	153.5	138.7	130.6
133	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	190.3	171.7	155.2	146.1
134	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.9	173.4	163.3

Figure B-52 Tabular Representation of Parking Nomograph for B767-300ER on 19 °F (-7 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

Gross B-767-300ER Weight (lbs)

19 F / Ice Thickness (in)	205000	210000	215000	220000	225000	230000	235000	240000	245000	250000	255000	260000	265000	270000	275000	280000	285000	290000	295000
52	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
53	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
54	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
55	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
56	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
57	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1
58	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1
59	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
60	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
61	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
62	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2
63	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3
64	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3
65	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3
66	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3
67	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4
68	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4
69	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4
70	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5
71	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5
72	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6
73	1.5	1.5	1.4	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6
74	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7
75	2.4	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7
76	3.0	2.5	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8
77	3.7	3.1	2.6	1.7	1.6	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8
78	4.6	3.9	3.2	2.7	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9
79	5.8	4.8	4.0	3.3	2.8	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	1.0
80	7.1	5.9	4.9	4.1	3.5	2.9	2.5	1.7	1.6	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0
81	8.8	7.3	6.0	5.1	4.3	3.6	3.0	2.6	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1
82	10.7	8.9	7.4	6.2	5.2	4.4	3.7	3.2	2.7	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2
83	13.1	10.9	9.1	7.6	6.4	5.4	4.5	3.9	3.3	2.8	2.4	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.2
84	15.9	13.2	11.0	9.2	7.7	6.5	5.5	4.7	4.0	3.4	2.9	2.5	1.7	1.7	1.6	1.5	1.5	1.4	1.3
85	19.3	16.1	13.4	11.2	9.4	7.9	6.7	5.7	4.9	4.2	3.6	3.1	2.6	1.8	1.7	1.6	1.5	1.5	1.4
86	23.4	19.4	16.2	13.5	11.4	9.6	8.1	6.9	5.9	5.0	4.3	3.7	3.2	2.8	2.4	1.7	1.6	1.6	1.5
87	28.2	23.4	19.5	16.3	13.7	11.6	9.8	8.3	7.1	6.1	5.2	4.5	3.9	3.3	2.9	2.5	1.7	1.7	1.6
88	33.9	28.2	23.5	19.6	16.5	13.9	11.8	10.0	8.5	7.3	6.2	5.4	4.6	4.0	3.5	3.0	2.6	1.8	1.7
89	40.7	33.8	28.1	23.5	19.8	16.7	14.1	12.0	10.2	8.7	7.5	6.4	5.6	4.8	4.2	3.6	3.2	2.8	2.4
90	48.7	40.4	33.7	28.2	23.7	20.0	16.9	14.3	12.2	10.5	9.0	7.7	6.7	5.8	5.0	4.3	3.8	3.3	2.9
91	58.1	48.2	40.2	33.6	28.2	23.8	20.1	17.1	14.6	12.5	10.7	9.2	7.9	6.9	6.0	5.2	4.5	3.9	3.5
92	69.1	57.3	47.8	40.0	33.6	28.3	24.0	20.4	17.4	14.8	12.7	10.9	9.4	8.2	7.1	6.2	5.4	4.7	4.1
93	82.1	68.1	56.7	47.5	39.9	33.6	28.5	24.2	20.6	17.6	15.1	13.0	11.2	9.7	8.4	7.3	6.4	5.6	4.9
94	97.2	80.6	67.2	56.7	47.2	39.8	33.7	28.6	24.4	20.9	17.9	15.4	13.3	11.5	10.0	8.7	7.6	6.6	5.8
95	114.8	95.3	79.4	66.4	55.8	47.1	39.8	33.8	28.8	24.7	21.1	18.2	15.7	13.6	11.8	10.2	8.9	7.8	6.8
96	135.4	112.3	93.6	78.3	65.8	55.5	47.0	39.9	34.0	29.1	24.9	21.4	18.5	16.0	13.9	12.1	10.5	9.2	8.1
97	159.3	132.1	110.1	92.1	77.4	65.3	55.2	46.9	40.0	34.2	29.3	25.2	21.8	18.8	16.3	14.2	12.4	10.8	9.5
98	187.0	155.1	129.3	108.2	90.9	76.6	64.9	55.1	47.0	40.1	34.4	29.6	25.6	22.1	19.2	16.7	14.5	12.7	11.1
99	>200	181.7	151.4	126.7	106.5	89.8	76.0	64.5	55.0	47.0	40.3	34.7	29.9	25.9	22.5	19.5	17.0	14.9	13.0
100	>200	>200	177.1	148.2	124.5	105.0	88.9	75.5	64.3	55.0	47.2	40.6	35.0	30.3	26.3	22.8	19.9	17.4	15.2
101	>200	>200	>200	172.9	145.3	122.5	103.7	88.1	75.1	64.2	55.1	47.4	40.9	35.3	30.7	26.7	23.2	20.3	17.8
102	>200	>200	>200	>200	169.2	142.7	120.8	102.6	87.4	74.8	64.1	55.2	47.6	41.2	35.7	31.1	27.1	23.7	20.7
103	>200	>200	>200	>200	196.8	165.9	140.5	119.3	101.7	86.9	74.6	64.1	55.3	47.9	41.5	36.1	31.5	27.5	24.1
104	>200	>200	>200	>200	>200	192.6	163.0	138.5	118.0	100.9	86.5	74.5	64.2	55.6	48.2	41.9	36.5	31.9	28.0
105	>200	>200	>200	>200	>200	>200	188.9	160.4	136.7	116.9	100.3	86.3	74.4	64.4	55.8	48.6	42.3	37.0	32.4
106	>200	>200	>200	>200	>200	>200	>200	185.6	158.2	135.3	116.0	99.8	86.1	74.5	64.6	56.2	49.0	42.8	37.5
107	>200	>200	>200	>200	>200	>200	>200	>200	182.7	156.2	134.0	115.2	99.4	86.0	74.6	64.9	56.6	49.4	43.3
108	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.1	154.5	132.9	114.6	99.2	86.0	74.8	65.2	57.0	49.9
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.8	153.0	132.0	114.2	99.0	86.1	75.1	65.6	57.5
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	175.8	151.7	131.2	113.8	99.0	86.3	75.4	66.1
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	174.1	150.6	130.7	113.6	99.1	86.6	75.8
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	199.5	172.6	149.7	130.2	113.5	99.2	86.9
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.6	171.4	149.0	129.9	113.5	99.4
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.9	170.3	148.5	129.8	113.7
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	194.4	169.5	148.1	129.7
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.2	168.8	147.9
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.2	168.3
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.4
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
121	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
122	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
123	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
124	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
125	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
126	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
127	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
128	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
129	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
130	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
131	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
132	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
133	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
134	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

19 F / Ice Thickness (in)	300000	305000	310000	315000	320000	325000	330000	335000	340000	345000	350000	355000	360000	365000	370000	375000	380000	385000	388000
52	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
53	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
54	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0
55	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
56	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
57	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
58	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
59	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
60	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
61	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
62	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
63	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
64	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1
65	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
66	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
67	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
68	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
69	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2
70	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2
71	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
72	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3
73	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3
74	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3
75	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
76	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4
77	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4
78	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4
79	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5
80	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5
81	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5
82	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6
83	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6
84	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7
85	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7
86	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8
87	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8
88	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.9
89	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9
90	2.5	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	1.0
91	3.0	2.7	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0
92	3.6	3.2	2.8	2.5	1.7	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.1	1.1	1.1
93	4.3	3.8	3.3	2.9	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1
94	5.1	4.5	3.9	3.5	3.1	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2
95	6.0	5.3	4.6	4.1	3.6	3.2	2.9	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.3
96	7.1	6.2	5.5	4.8	4.3	3.8	3.4	3.0	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3
97	8.3	7.3	6.4	5.7	5.0	4.5	4.0	3.5	3.2	2.8	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4
98	9.8	8.6	7.6	6.7	5.9	5.2	4.7	4.1	3.7	3.3	3.0	2.6	2.4	1.7	1.7	1.6	1.6	1.5	1.5
99	11.4	10.1	8.9	7.8	6.9	6.1	5.5	4.9	4.3	3.9	3.5	3.1	2.8	2.5	1.8	1.7	1.6	1.6	1.6
100	13.4	11.8	10.4	9.2	8.1	7.2	6.4	5.7	5.1	4.5	4.0	3.6	3.3	2.9	2.6	2.4	1.7	1.7	1.6
101	15.6	13.7	12.1	10.7	9.5	8.4	7.5	6.6	5.9	5.3	4.7	4.2	3.8	3.4	3.1	2.8	2.5	1.8	1.7
102	18.2	16.0	14.1	12.5	11.0	9.8	8.7	7.7	6.9	6.2	5.5	4.9	4.4	4.0	3.6	3.2	2.9	2.6	2.5
103	21.1	18.6	16.4	14.5	12.8	11.4	10.1	9.0	8.0	7.2	6.4	5.7	5.1	4.6	4.2	3.7	3.4	3.1	2.9
104	24.5	21.6	19.0	16.8	14.9	13.2	11.7	10.4	9.3	8.3	7.4	6.7	6.0	5.4	4.8	4.4	3.9	3.5	3.3
105	28.4	25.0	22.1	19.5	17.2	15.3	13.6	12.1	10.8	9.6	8.6	7.7	6.9	6.2	5.6	5.0	4.5	4.1	3.9
106	32.9	28.9	25.5	22.5	19.9	17.7	15.7	14.0	12.5	11.1	10.0	8.9	8.0	7.2	6.5	5.8	5.3	4.8	4.5
107	38.0	33.4	29.5	26.0	23.0	20.4	18.1	16.2	14.4	12.9	11.5	10.3	9.2	8.3	7.5	6.7	6.1	5.5	5.2
108	43.8	38.5	34.0	30.0	26.6	23.6	20.9	18.6	16.6	14.8	13.3	11.9	10.7	9.6	8.6	7.8	7.0	6.3	6.0
109	50.4	44.4	39.1	34.6	30.6	27.1	24.1	21.4	19.1	17.1	15.3	13.7	12.3	11.0	9.9	8.9	8.1	7.3	6.9
110	58.0	51.0	45.0	39.7	35.2	31.2	27.7	24.6	22.0	19.6	17.5	15.7	14.1	12.7	11.4	10.3	9.3	8.4	7.9
111	66.6	58.5	51.6	45.6	40.3	35.8	31.8	28.3	25.2	22.5	20.1	18.0	16.2	14.5	13.1	11.8	10.6	9.6	9.1
112	76.3	67.1	59.2	52.3	46.2	41.0	36.4	32.4	28.9	25.8	23.1	20.7	18.6	16.7	15.0	13.5	12.2	11.0	10.4
113	87.3	76.8	67.7	59.8	52.9	46.9	41.7	37.1	33.1	29.5	26.4	23.7	21.2	19.1	17.2	15.5	14.0	12.6	11.9
114	99.8	87.8	77.4	68.3	60.5	53.6	47.7	42.4	37.8	33.8	30.2	27.1	24.3	21.8	19.6	17.7	16.0	14.4	13.6
115	113.9	100.2	88.3	78.0	69.0	61.2	54.4	48.4	43.1	38.5	34.5	30.9	27.7	24.9	22.4	20.2	18.2	16.5	15.5
116	129.8	114.2	100.7	88.9	78.7	69.8	62.0	55.2	49.2	43.9	39.3	35.2	31.6	28.4	25.5	23.0	20.8	18.8	17.7
117	147.7	130.0	114.6	101.2	89.6	79.4	70.6	62.8	56.0	50.0	44.7	40.1	35.9	32.3	29.1	26.2	23.6	21.4	20.1
118	168.0	147.8	130.3	115.1	101.9	90.3	80.2	71.4	63.7	56.8	50.8	45.5	40.9	36.7	33.0	29.8	26.9	24.3	22.9
119	190.7	167.8	147.9	130.7	115.7	102.6	91.1	81.1	72.3	64.5	57.7	51.7	46.4	41.7	37.5	33.8	30.5	27.6	26.0
120	>200	190.3	167.8	148.2	131.2	116.3	103.3	92.0	82.0	73.2	65.5	58.7	52.6	47.3	42.6	38.4	34.6	31.3	29.4
121	>200	>200	190.0	167.9	148.6	131.8	117.0	104.2	92.9	82.9	74.2	66.4	59.6	53.6	48.2	43.4	39.2	35.4	33.4
122	>200	>200	>200	189.9	168.1	149.1	132.4	117.9	105.1	93.8	83.9	75.2	67.5	60.6	54.5	49.2	44.4	40.1	37.7
123	>200	>200	>200	>200	190.0	168.5	149.7	133.2	118.8	106.0	94.9	85.0	76.2	68.5	61.7	55.6	50.1	45.3	42.7
124	>200	>200	>200	>200	>200	190.2	169.0	150.4	134.1	119.7	107.1	95.9	86.1	77.3	69.6	62.7	56.6	51.1	48.2
125	>200	>200	>200	>200	>200	>200	190.5	169.6	151.2	135.0	120.7	108.2	97.1	87.2	78.5	70.7	63.8	57.7	54.3
126	>200	>200	>200	>200	>200	>200	>200	191.0	170.3	152.1	136.0	121.9	109.3	98.2	88.4	79.7	71.9	65.0	61.2
127	>200	>200	>200	>200	>200	>200	>200	>200	191.6	171.1	153.1	137.1	123.0	110.6	99.5	89.7	80.9	73.1	68.8
128	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.4	172.1	154.1	138.3	124.3	111.8	100.8	90.9	82.2	77.4
129	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.2	173.1	155.3	139.6	125.6	113.2	102.1	92.3	86.9
130	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	194.7	174.7	156.6	140.9	127.0	114.6	103.5	97.5
131	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.3	175.5	157.9	142.3	128.4	116.0	109.3
132	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	196.5	176.8	159.3	143.8	129.9	122.3
133	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.8	178.2	160.9	145.4	136.9
134	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	199.2	179.8	162.4	153.0

Figure B-53 Tabular Representation of Parking Nomograph for B767-300ER on 20 °F (-6.5 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

20 F	Gross B-767-300ER Weight (lbs)																																				
Ice Thickness (in)	205000	210000	215000	220000	225000	230000	235000	240000	245000	250000	255000	260000	265000	270000	275000	280000	285000	290000	295000	300000	305000	310000	315000	320000	325000	330000	335000	340000	345000	350000	355000	360000	365000	370000	375000	380000	385000	388000
52	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
53	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
54	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0
55	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0
56	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
57	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
58	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
59	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
60	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
61	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
62	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
63	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
64	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1
65	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
66	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
67	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
68	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
69	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
70	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2
71	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
72	1.4	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
73	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3
74	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3
75	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3
76	2.8	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4
77	3.5	2.9	2.4	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4
78	4.3	3.6	3.0	2.5	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4
79	5.4	4.4	3.7	3.1	2.6	1.7	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5
80	6.6	5.5	4.6	3.8	3.2	2.7	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5
81	8.1	6.8	5.6	4.7	4.0	3.3	2.8	2.4	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5
82	10.0	8.3	6.9	5.8	4.8	4.1	3.5	2.9	2.5	1.7	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6
83	12.2	10.1	8.4	7.1	5.9	5.0	4.2	3.6	3.1	2.6	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6
84	14.8	12.3	10.3	8.6	7.2	6.1	5.1	4.4	3.7	3.2	2.7	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.7
85	18.0	14.9	12.5	10.4	8.8	7.4	6.2	5.3	4.5	3.9	3.3	2.9	2.5	1.7	1.7	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7
86	21.8	18.1	15.1	12.6	10.6	8.9	7.6	6.4	5.5	4.7	4.0	3.5	3.0	2.6	1.8	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7
87	26.3	21.8	18.2	15.2	12.8	10.8	9.1	7.7	6.6	5.6	4.8	4.2	3.6	3.1	2.7	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8	0.8
88	31.6	26.2	21.9	18.3	15.4	13.0	11.0	9.3	7.9	6.8	5.8	5.0	4.3	3.7	3.2	2.8	2.5	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8
89	38.0	31.5	26.2	22.0	18.4	15.6	13.2	11.2	9.5	8.1	7.0	6.0	5.2	4.5	3.9	3.4	2.9	2.6	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9
90	45.4	37.7	31.4	26.3	22.1	18.6	15.7	13.4	11.4	9.7	8.4	7.2	6.2	5.4	4.7	4.0	3.5	3.1	2.7	2.4	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9
91	54.2	44.9	37.4	31.3	26.3	22.2	18.8	16.0	13.6	11.6	10.0	8.6	7.4	6.4	5.6	4.8	4.2	3.7	3.2	2.8	2.5	1.7	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0
92	64.5	53.5	44.6	37.3	31.3	26.4	22.4	19.0	16.2	13.8	11.9	10.2	8.8	7.6	6.6	5.7	5.0	4.4	3.8	3.4	3.0	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0
93	76.5	63.5	52.9	44.3	37.2	31.4	26.6	22.6	19.2	16.4	14.1	12.1	10.5	9.0	7.8	6.8	5.9	5.2	4.6	4.0	3.5	3.1	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.1	1.1
94	90.7	75.2	62.7	52.4	44.1	37.2	31.4	26.7	22.8	19.5	16.7	14.4	12.4	10.7	9.3	8.1	7.0	6.2	5.4	4.7	4.2	3.7	3.2	2.9	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2
95	107.2	88.9	74.1	62.0	52.1	43.9	37.2	31.6	26.9	23.0	19.7	17.0	14.6	12.7	11.0	9.6	8.3	7.3	6.4	5.6	4.9	4.3	3.8	3.4	3.0	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.4	1.4	1.4	1.3	1.3	1.2
96	126.3	104.8	87.3	73.1	61.4	51.8	43.8	37.2	31.7	27.1	23.3	20.0	17.3	14.9	13.0	11.3	9.8	8.6	7.5	6.6	5.8	5.1	4.5	4.0	3.5	3.2	2.8	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3
97	148.7	123.3	102.8	86.0	72.2	60.9	51.6	43.8	37.3	31.9	27.4	23.5	20.3	17.6	15.2	13.3	11.6	10.1	8.8	7.8	6.8	6.0	5.3	4.7	4.2	3.7	3.3	2.9	2.6	1.8	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4
98	174.5	144.8	120.7	101.0	84.8	71.5	60.5	51.4	43.8	37.5	32.1	27.6	23.9	20.6	17.9	15.6	13.6	11.9	10.4	9.1	8.0	7.1	6.2	5.5	4.9	4.4	3.9	3.5	3.1	2.8	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.5
99	>200	169.7	141.4	118.3	99.4	83.8	70.9	60.3	51.4	43.9	37.7	32.4	27.9	24.7	21.0	18.2	15.9	13.9	12.2	10.7	9.4	8.3	7.3	6.5	5.7	5.1	4.5	4.0	3.6	3.2	2.9	2.6	1.8	1.7	1.7	1.6	1.6	1.5
100	>200	198.4	165.3	138.3	116.2	98.0	83.0	70.5	60.1	51.4	44.0	37.9	32.7	28.3	24.5	21.3	18.6	16.2	14.2	12.5	11.0	9.7	8.6	7.6	6.7	6.0	5.3	4.7	4.2	3.8	3.4	3.0	2.7	2.5	1.8	1.7	1.6	1.6
101	>200	>200	193.0	161.5	135.7	114.4	96.8	82.3	70.1	59.9	51.4	44.2	38.2	33.0	28.6	24.9	21.7	19.0	16.6	14.6	12.8	11.3	10.0	8.8	7.8	7.0	6.2	5.5	4.9	4.4	4.0	3.5	3.2	2.9	2.6	1.8	1.7	1.7
102	>200	>200	>200	188.1	158.0	133.3	112.8	95.8	81.7	69.8	59.9	51.5	44.4	38.4	33.4	29.0	25.3	22.1	19.4	17.0	14.9	13.2	11.6	10.3	9.1	8.1	7.2	6.4	5.7	5.1	4.6	4.1	3.7	3.3	3.0	2.7	2.5	1.8
103	>200	>200	>200	>200	183.8	155.0	131.2	111.4	95.0	81.2	69.6	59.9	51.7	44.7	38.8	33.7	29.4	25.7	22.5	19.8	17.4	15.3	13.5	12.0	10.6	9.4	8.4	7.5	6.7	6.0	5.4	4.8	4.3	3.9	3.5	3.2	2.9	2.7
104	>200	>200	>200	>200	>200	179.9	152.3	129.4	110.2	94.3	80.8	69.5	60.0	51.9	45.0	39.2	34.1	29.8	26.1	22.9	20.2	17.8	15.7	13.9	12.3	11.0	9.7	8.7	7.8	6.9	6.2	5.6	5.0	4.5	4.1	3.7	3.3	3.1
105	>200	>200	>200	>200	>200	>200	176.5	149.9	127.8	109.2	93.7	80.6	69.5	60.2	52.2	45.4	39.6	34.6	30.3	26.6	23.4	20.6	18.2	16.1	14.3	12.7	11.3	10.1	9.0	8.0	7.2	6.5	5.8	5.2	4.7	4.2	3.8	3.6
106	>200	>200	>200	>200	>200	>200	>200	173.4	147.8	126.4	108.4	93.2	80.4	69.6	60.4	52.5	45.8	40.0	35.0	30.7	27.0	23.8	21.1	18.6	16.5	14.7	13.1	11.6	10.4	9.3	8.3	7.5	6.7	6.0	5.4	4.9	4.4	4.2
107	>200	>200	>200	>200	>200	>200	>200	>200	170.7	146.0	125.2	107.7	92.9	80.4	69.7	60.6	52.9	46.2	40.5	35.5	31.2	27.5	24.3	21.5	19.1	17.0	15.1	13.5	12.0	10.7	9.6	8.6	7.8	7.0	6.3	5.7	5.1	4.8
108	>200	>200	>200	>200	>200	>200	>200	>200	196.8	168.3	144.4	124.2	107.1	92.7	80.4	69.9	60.9	53.3	46.6	40.9	36.0	31.8	28.0	24.8	22.0	19.6	17.4	15.5	13.9	12.4	11.1	10.0	8.9	8.1	7.3	6.5	5.9	5.6
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.8	166.2	143.0	123.3	106.7	92.6	80.5	70.2	61.3	53.7	47.1	41.5	36.6	32.3	28.6	25.3	22.5	20.0	17.9	16.0	14.3	12.8	11.5	10.3	9.3	8.4	7.5	6.8	6.4
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.1	164.4	141.8	122.7	106.4	92.5	80.7	70.5	61.7	54.2	47.7	42.0	37.1	32.9	29.1	25.9	23.0	20.5	18.3	16.4	14.7	13.2	11.8	10.7	9.6	8.7	7.8	7.4
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.7	162.8	140.8	122.1	106.2	92.6	80.9	70.9	62.2	54.7	48.2	42.6	37.7	33.4	29.7	26.4	23.6	21.0	18.8	16.9	15.1	13.6	12.2	11.0	10.0	9.0	8.5
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	186.5	161.4	140.0	121.7	106.1	92.7	81.2	71.3	62.7	55.3	48.8	43.2	38.3	34.1	30.3	27.0	24.1	21.6	19.3	17.3	15.6	14.0	12.6	11.4	10.3	9.7
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	184.7	160.2	139.3	121.5	106.1	93.0	81.6	71.8	63.3	55.9	49.5	43.9	39.0	34.7	30.9	27.6	24.7	22.1	19.9	17.8	16.1	14.5	13.1	11.8	11.1
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	183.1	159.3	138.8	121.3	106.3	93.3	82.1	72.3	63.9	56.6	50.2	44.6	39.7	35.3	31.6	28.2	25.3	22.7	20.4	18.3	16.5	14.9	13.5	12.7
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.8	158.5	138.5	121.3	106.5	93.7	82.6	72.9	64.6	57.2	50.9	45.3	40.3	36.0	32.2	28.9	25.9	23.3	20.9	18.9	17.0	15.4	14.5
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.6	157.9	138.3	121.4	106.8	94.1	83.2	73.6	65.3	58.0	51.6	46.0	41.1	36.7	32.9	29.5	26.5	23.9	21.5	19.4	17.5	16.5
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.7	157.4	138.2	121.6	107.2	94.7	83.8	74.3	66.0	58.7	52.4	46.8	41.8	37.5	33.6	30.2	27.2	24.5	22.1	20.0	18.8
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.0	157.1	138.2	121.8	107.6	95.3	84.5	75.0	66.8	59.5	53.2	47.6	42.6	38.2	34.3	30.9	27.9	25.1	22.7	21.4
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.4	157.0	138.4	122.2	108.2	95.9	85.2	75.8	67.6	60.4	54.0	48.4	43.4	39.0	35.1	31.6	28.5	25.8	24.3
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.0	156.9	138.6	122.7	108.8	96.7	86.0	76.7	68.5	61.3	54.9	49.2	44.2	39.8	35.9	32.4	29.3	27.5
121	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.8	157.0	139.0	123.3	109.5	97.4	86.9	77.6	69.4	62.2	55.8	50.1	45.1	40.6	36.7	33.1	31.2
122	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.7	157.3	139.5	123.9	110.3	98.3	87.8	78.5	70.3	63.1	56.7	51.0	46.0	41.5	37.5	35.3
123	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.8	157.6	140.0	124.6	111.1	99.2	88.7	79.5	71.3	64.1	57.7	52.0	46.9	42.4	39.9
124	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.0	158.1	140.7	125.4	112.0	100.2	89.8	80.5	72.4	65.1	58.7	53.0	47.9	45.1
125	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.3	158.7	141.5	126.3	113.0	101.2	90.8	81.6	73.4	66.2	59.7	54.0	50.8
126	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.8	159.4	142.3	127.3	114.0	102.3	91.9	82.7	74.6	67.3	60.8	57.2
127	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.3	160.1	143.2	128.3	115.1	103.5	93.1	83.9	75.7	68.4	64.4
128	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.0	161.0	144.3	129.4	116.3	104.7	94.3	85.1	76.9	72.4
129	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.8	162.0	145.4	130.6	117.5	105.9	95.6	86.4	81.3
130	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.8	163.1	146.6	131.9	118.8	107.3	96.9	91.3
131	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.8	164.3	147.8	133.2	120.2	108.6	102.3
132	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	183.9	165.5	149.2	134.6	121.6	114.5
133	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.2	166.9	150.6	136.1	128.1
134	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	186.5	168.3	152.1	143.2

Figure B-54 Tabular Representation of Parking Nomograph for B767-300ER on 21 °F (-6 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

21 F — Gross B-767-300ER Weight (lbs); rows: Ice Thickness (in)

Ice Thickness (in)	205000	210000	215000	220000	225000	230000	235000	240000	245000	250000	255000	260000	265000	270000	275000	280000	285000	290000	295000
52	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
53	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
54	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
55	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
56	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
57	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1
58	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1
59	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
60	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
61	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
62	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2
63	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2
64	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3
65	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3
66	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3
67	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4
68	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4
69	1.1	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4
70	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5
71	1.3	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5
72	1.4	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5
73	1.5	1.4	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6
74	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6
75	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7
76	2.6	1.7	1.6	1.5	1.5	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7
77	3.2	2.7	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8
78	4.0	3.3	2.8	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8
79	5.0	4.1	3.4	2.9	2.4	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	1.0	0.9
80	6.2	5.1	4.3	3.6	3.0	2.5	1.7	1.6	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0
81	7.6	6.3	5.2	4.4	3.7	3.1	2.6	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0
82	9.3	7.7	6.4	5.4	4.5	3.8	3.2	2.7	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1
83	11.3	9.4	7.8	6.6	5.5	4.6	3.9	3.3	2.8	2.4	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.2	1.2
84	13.8	11.5	9.6	8.0	6.7	5.7	4.8	4.1	3.5	3.0	2.5	1.7	1.7	1.6	1.5	1.4	1.4	1.3	1.3
85	16.8	13.9	11.6	9.7	8.1	6.9	5.8	4.9	4.2	3.6	3.1	2.7	1.8	1.7	1.6	1.5	1.5	1.4	1.4
86	20.3	16.8	14.0	11.7	9.9	8.3	7.0	6.0	5.1	4.4	3.7	3.2	2.8	2.4	1.7	1.6	1.6	1.5	1.4
87	24.5	20.3	16.9	14.2	11.9	10.0	8.5	7.2	6.1	5.3	4.5	3.9	3.3	2.9	2.5	1.7	1.7	1.6	1.5
88	29.5	24.4	20.4	17.0	14.3	12.1	10.2	8.7	7.4	6.3	5.4	4.7	4.0	3.5	3.0	2.6	1.8	1.7	1.6
89	35.4	29.3	24.4	20.4	17.2	14.5	12.3	10.4	8.9	7.6	6.5	5.6	4.8	4.2	3.6	3.2	2.7	2.4	1.7
90	42.3	35.1	29.2	24.5	20.6	17.3	14.7	12.5	10.6	9.1	7.8	6.7	5.8	5.0	4.3	3.8	3.3	2.9	2.5
91	50.5	41.9	34.9	29.2	24.5	20.7	17.5	14.9	12.7	10.8	9.3	8.0	6.9	6.0	5.2	4.5	3.9	3.4	3.0
92	60.1	49.9	41.5	34.8	29.2	24.6	20.8	17.7	15.1	12.9	11.1	9.5	8.2	7.1	6.2	5.4	4.7	4.1	3.6
93	71.4	59.2	49.3	41.3	34.7	29.2	24.8	21.0	17.9	15.3	13.1	11.3	9.7	8.4	7.3	6.4	5.5	4.8	4.2
94	84.5	70.1	58.4	48.9	41.1	34.6	29.3	24.9	21.2	18.1	15.6	13.4	11.6	10.0	8.7	7.5	6.6	5.7	5.0
95	99.9	82.9	69.1	57.8	48.6	40.9	34.7	29.4	25.1	21.5	18.4	15.8	13.7	11.8	10.2	8.9	7.8	6.8	5.9
96	117.8	97.8	81.5	68.2	57.3	48.3	40.9	34.7	29.6	25.3	21.7	18.7	16.1	13.9	12.1	10.5	9.2	8.0	7.0
97	138.7	115.0	95.9	80.2	67.4	56.8	48.1	40.9	34.8	29.8	25.5	22.0	18.9	16.4	14.2	12.4	10.8	9.4	8.2
98	162.8	135.1	112.6	94.2	79.1	66.7	56.5	48.0	40.9	35.0	30.0	25.8	22.3	19.2	16.7	14.5	12.7	11.1	9.7
99	190.8	158.3	131.9	110.4	92.7	78.2	66.2	56.2	47.9	41.0	35.1	30.2	26.1	22.6	19.6	17.0	14.8	13.0	11.4
100	>200	185.2	154.3	129.1	108.5	91.5	77.4	65.8	56.0	47.9	41.1	35.4	30.5	26.4	22.9	19.9	17.3	15.2	13.3
101	>200	>200	180.1	150.7	126.6	106.8	90.4	76.8	65.4	55.9	48.0	41.3	35.6	30.8	26.7	23.2	20.3	17.7	15.5
102	>200	>200	>200	175.6	147.5	124.4	105.3	89.4	76.2	65.2	55.9	48.1	41.5	35.9	31.1	27.1	23.6	20.6	18.1
103	>200	>200	>200	>200	171.6	144.7	122.5	104.0	88.7	75.8	65.0	55.9	48.2	41.7	36.2	31.5	27.4	24.0	21.0
104	>200	>200	>200	>200	199.2	168.0	142.2	120.8	102.9	88.0	75.5	64.9	56.0	48.5	42.0	36.6	31.9	27.8	24.4
105	>200	>200	>200	>200	>200	194.7	164.8	140.0	119.3	102.0	87.5	75.3	64.9	56.2	48.7	42.4	36.9	32.3	28.3
106	>200	>200	>200	>200	>200	>200	190.6	161.9	138.0	118.0	101.2	87.1	75.1	65.0	56.4	49.0	42.7	37.3	32.7
107	>200	>200	>200	>200	>200	>200	>200	187.0	159.4	136.3	116.9	100.6	86.8	75.1	65.1	56.6	49.4	43.1	37.8
108	>200	>200	>200	>200	>200	>200	>200	>200	183.8	157.2	134.8	116.0	100.1	86.6	75.1	65.3	56.9	49.7	43.6
109	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.0	155.2	133.5	115.2	99.7	86.5	75.2	65.5	57.3	50.2
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.5	153.5	132.5	114.6	99.4	86.4	75.4	65.8	57.7
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	176.2	152.1	131.5	114.1	99.2	86.5	75.6	66.2
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	174.3	150.8	130.8	113.7	99.2	86.6	75.9
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	199.5	172.6	149.7	130.2	113.5	99.2	86.9
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.3	171.1	148.8	129.7	113.4	99.3
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.3	169.9	148.1	129.4	113.4
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.7	168.8	147.5	129.2
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.2	168.0	147.1
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.0	167.3
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	190.0
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
121	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
122	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
123	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
124	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
125	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
126	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
127	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
128	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
129	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
130	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
131	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
132	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
133	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
134	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

Ice Thickness (in)	300000	305000	310000	315000	320000	325000	330000	335000	340000	345000	350000	355000	360000	365000	370000	375000	380000	385000	388000
52	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
53	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
54	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
55	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0
56	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
57	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
58	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
59	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
60	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
61	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
62	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
63	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
64	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1
65	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1
66	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
67	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
68	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
69	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
70	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2
71	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2
72	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
73	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3
74	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3
75	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3
76	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4
77	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4
78	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4
79	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5
80	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5
81	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5
82	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6
83	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6
84	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6
85	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7
86	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7
87	1.5	1.4	1.4	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8
88	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8
89	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.9
90	1.8	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9
91	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0
92	3.1	2.8	2.4	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0
93	3.7	3.3	2.9	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1
94	4.4	3.9	3.4	3.0	2.7	2.4	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1
95	5.2	4.6	4.0	3.6	3.2	2.8	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2
96	6.2	5.4	4.8	4.2	3.7	3.3	2.9	2.6	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.3
97	7.2	6.4	5.6	5.0	4.4	3.9	3.5	3.1	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3
98	8.5	7.5	6.6	5.8	5.2	4.6	4.1	3.6	3.2	2.9	2.6	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.4
99	10.0	8.8	7.7	6.8	6.0	5.4	4.8	4.2	3.8	3.4	3.0	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5
100	11.7	10.3	9.0	8.0	7.1	6.3	5.6	5.0	4.4	3.9	3.5	3.2	2.8	2.5	1.8	1.7	1.7	1.6	1.6
101	13.6	12.0	10.6	9.3	8.2	7.3	6.5	5.8	5.2	4.6	4.1	3.7	3.3	3.0	2.7	2.4	1.7	1.7	1.7
102	15.9	13.9	12.3	10.9	9.6	8.5	7.6	6.7	6.0	5.4	4.8	4.3	3.9	3.5	3.1	2.8	2.5	1.8	1.7
103	18.4	16.2	14.3	12.6	11.2	9.9	8.8	7.8	7.0	6.2	5.6	5.0	4.5	4.0	3.6	3.3	2.9	2.7	2.5
104	21.4	18.8	16.6	14.7	13.0	11.5	10.2	9.1	8.1	7.2	6.5	5.8	5.2	4.7	4.2	3.8	3.4	3.1	2.9
105	24.8	21.8	19.2	17.0	15.0	13.3	11.8	10.5	9.4	8.4	7.5	6.7	6.0	5.4	4.9	4.4	4.0	3.6	3.4
106	28.7	25.3	22.3	19.7	17.4	15.4	13.7	12.2	10.9	9.7	8.7	7.8	7.0	6.3	5.6	5.1	4.6	4.1	3.9
107	33.2	29.2	25.7	22.7	20.1	17.8	15.8	14.1	12.6	11.2	10.0	9.0	8.1	7.2	6.5	5.9	5.3	4.8	4.5
108	38.2	33.6	29.7	26.2	23.2	20.6	18.3	16.3	14.5	12.9	11.6	10.4	9.3	8.4	7.5	6.8	6.1	5.5	5.2
109	44.0	38.7	34.1	30.2	26.7	23.7	21.0	18.7	16.7	14.9	13.3	11.9	10.7	9.6	8.7	7.8	7.0	6.4	6.0
110	50.6	44.5	39.3	34.7	30.7	27.2	24.2	21.5	19.2	17.1	15.3	13.7	12.3	11.1	10.0	9.0	8.1	7.3	6.9
111	58.1	51.1	45.1	39.8	35.2	31.2	27.8	24.7	22.0	19.7	17.6	15.8	14.1	12.7	11.4	10.3	9.3	8.4	7.9
112	66.6	58.6	51.7	45.6	40.4	35.8	31.8	28.3	25.2	22.5	20.2	18.1	16.2	14.6	13.1	11.8	10.7	9.6	9.1
113	76.3	67.1	59.1	52.2	46.2	41.0	36.4	32.4	28.9	25.8	23.1	20.7	18.6	16.7	15.0	13.5	12.2	11.0	10.4
114	87.2	76.7	67.6	59.7	52.9	46.9	41.6	37.1	33.0	29.5	26.4	23.6	21.2	19.1	17.1	15.5	13.9	12.6	11.9
115	99.5	87.5	77.2	68.2	60.3	53.5	47.5	42.3	37.7	33.7	30.1	27.0	24.2	21.8	19.6	17.6	15.9	14.4	13.5
116	113.4	99.8	88.0	77.7	68.8	61.0	54.2	48.2	43.0	38.4	34.3	30.8	27.6	24.8	22.3	20.1	18.1	16.4	15.4
117	129.2	113.6	100.2	88.5	78.3	69.4	61.7	54.9	48.9	43.7	39.1	35.0	31.4	28.2	25.4	22.9	20.7	18.7	17.6
118	146.9	129.2	113.9	100.6	89.0	79.0	70.1	62.4	55.7	49.7	44.5	39.8	35.7	32.1	28.9	26.0	23.5	21.2	20.0
119	166.8	146.7	129.3	114.3	101.1	89.7	79.7	70.9	63.2	56.4	50.5	45.2	40.6	36.5	32.8	29.6	26.7	24.1	22.7
120	189.2	166.4	146.7	129.6	114.7	101.7	90.4	80.4	71.7	64.0	57.3	51.3	46.0	41.4	37.2	33.5	30.3	27.3	25.8
121	>200	188.6	166.2	146.8	130.0	115.2	102.4	91.1	81.2	72.5	64.9	58.1	52.1	46.9	42.2	38.0	34.3	31.0	29.2
122	>200	>200	188.1	166.2	147.1	130.4	115.9	103.1	91.9	82.1	73.4	65.8	59.0	53.0	47.7	43.0	38.8	35.1	33.0
123	>200	>200	>200	187.8	166.2	147.4	130.9	116.5	103.9	92.8	83.0	74.3	66.7	59.9	53.9	48.6	43.9	39.6	37.3
124	>200	>200	>200	>200	187.7	166.4	147.8	131.6	117.3	104.8	93.7	83.9	75.3	67.7	60.9	54.9	49.5	44.8	42.1
125	>200	>200	>200	>200	>200	187.7	166.7	148.4	132.3	118.1	105.7	94.7	84.9	76.3	68.7	61.9	55.9	50.5	47.5
126	>200	>200	>200	>200	>200	>200	187.9	167.2	149.0	133.1	119.0	106.7	95.7	86.0	77.4	69.7	62.9	56.9	53.5
127	>200	>200	>200	>200	>200	>200	>200	188.2	167.7	149.8	134.0	120.0	107.7	96.8	87.1	78.5	70.8	64.0	60.3
128	>200	>200	>200	>200	>200	>200	>200	>200	188.6	168.4	150.6	134.9	121.1	108.8	97.9	88.2	79.6	71.9	67.7
129	>200	>200	>200	>200	>200	>200	>200	>200	>200	189.1	169.2	151.6	136.0	122.2	110.0	99.1	89.4	80.8	76.1
130	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	189.8	170.0	152.6	137.1	123.4	111.2	100.3	90.7	85.4
131	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	190.6	171.0	153.7	138.3	124.6	112.5	101.6	95.7
132	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.5	172.1	154.9	139.6	125.9	113.8	107.2
133	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.5	173.2	156.1	140.9	127.3	119.9
134	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.6	174.5	157.5	142.3	134.0

Figure B-55 Tabular Representation of Parking Nomograph for B767-300ER on 22 °F (-5.5 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

22 F

Gross B-767-300ER Weight (lbs)

Ice Thickness (in)	205000	210000	215000	220000	225000	230000	235000	240000	245000	250000	255000	260000	265000	270000	275000	280000	285000	290000	295000	300000	305000	310000	315000	320000	325000	330000	335000	340000	345000	350000	355000	360000	365000	370000	375000	380000	385000	388000
52	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
53	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
54	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
55	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0
56	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
57	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
58	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
59	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
60	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
61	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
62	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
63	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
64	0.7	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1
65	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1
66	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
67	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
68	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
69	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
70	1.1	1.1	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2
71	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2
72	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
73	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3
74	1.5	1.5	1.4	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3
75	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3
76	2.4	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
77	3.0	2.5	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4
78	3.7	3.1	2.6	1.7	1.6	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4
79	4.6	3.8	3.2	2.7	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4
80	5.7	4.7	4.0	3.3	2.8	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5
81	7.0	5.8	4.9	4.1	3.4	2.9	2.4	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5
82	8.6	7.2	6.0	5.0	4.2	3.5	3.0	2.5	1.7	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5
83	10.5	8.8	7.3	6.1	5.1	4.3	3.7	3.1	2.6	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6
84	12.9	10.7	8.9	7.4	6.2	5.3	4.5	3.8	3.2	2.8	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.6	0.6
85	15.6	12.9	10.8	9.0	7.6	6.4	5.4	4.6	3.9	3.3	2.9	2.5	1.7	1.7	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.7
86	18.9	15.7	13.1	10.9	9.2	7.7	6.5	5.6	4.7	4.1	3.5	3.0	2.6	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7
87	22.8	18.9	15.8	13.2	11.1	9.3	7.9	6.7	5.7	4.9	4.2	3.6	3.1	2.7	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7
88	27.4	22.8	19.0	15.9	13.3	11.2	9.5	8.1	6.9	5.9	5.0	4.3	3.7	3.2	2.8	2.4	1.7	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8
89	32.9	27.3	22.8	19.0	16.0	13.5	11.4	9.7	8.3	7.1	6.1	5.2	4.5	3.9	3.4	2.9	2.6	1.8	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8
90	39.4	32.7	27.2	22.8	19.1	16.1	13.7	11.6	9.9	8.5	7.3	6.2	5.4	4.7	4.0	3.5	3.1	2.7	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9
91	47.0	39.0	32.5	27.2	22.8	19.3	16.3	13.8	11.8	10.1	8.7	7.4	6.4	5.6	4.8	4.2	3.7	3.2	2.8	2.5	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9
92	56.0	46.4	38.7	32.4	27.2	22.9	19.4	16.5	14.1	12.0	10.3	8.9	7.6	6.6	5.7	5.0	4.3	3.8	3.3	2.9	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.3	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0
93	66.5	55.2	46.0	38.5	32.3	27.2	23.1	19.6	16.7	14.3	12.2	10.5	9.1	7.9	6.8	5.9	5.2	4.5	4.0	3.5	3.1	2.7	2.4	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.1
94	78.8	65.3	54.5	45.6	38.3	32.3	27.3	23.2	19.8	16.9	14.5	12.5	10.8	9.3	8.1	7.0	6.1	5.3	4.7	4.1	3.6	3.2	2.8	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1
95	93.1	77.3	64.4	53.9	45.2	38.2	32.3	27.4	23.4	20.0	17.1	14.7	12.7	11.0	9.5	8.3	7.2	6.3	5.5	4.9	4.3	3.8	3.3	2.9	2.6	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2
96	109.8	91.1	75.9	63.5	53.4	45.0	38.1	32.4	27.6	23.6	20.2	17.4	15.0	13.0	11.3	9.8	8.5	7.5	6.5	5.7	5.0	4.4	3.9	3.5	3.1	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2
97	129.3	107.2	89.4	74.8	62.8	53.0	44.8	38.1	32.5	27.8	23.8	20.5	17.7	15.3	13.3	11.5	10.0	8.8	7.7	6.7	5.9	5.2	4.6	4.1	3.6	3.2	2.9	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3
98	151.8	125.9	104.9	87.8	73.8	62.2	52.7	44.7	38.1	32.6	28.0	24.0	20.7	17.9	15.6	13.5	11.8	10.3	9.0	7.9	7.0	6.1	5.4	4.8	4.3	3.8	3.4	3.0	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4
99	177.9	147.6	123.0	102.9	86.5	72.9	61.7	52.4	44.7	38.2	32.8	28.2	24.3	21.0	18.2	15.9	13.8	12.1	10.6	9.3	8.2	7.2	6.4	5.6	5.0	4.4	3.9	3.5	3.1	2.8	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.5
100	>200	172.7	143.9	120.4	101.1	85.3	72.2	61.3	52.3	44.7	38.3	33.0	28.4	24.6	21.3	18.6	16.2	14.1	12.4	10.9	9.6	8.4	7.4	6.6	5.8	5.2	4.6	4.1	3.7	3.3	2.9	2.6	2.4	1.7	1.7	1.6	1.6	1.5
101	>200	>200	168.0	140.6	118.1	99.6	84.3	71.6	61.0	52.2	44.7	38.5	33.2	28.7	24.9	21.7	18.9	16.5	14.5	12.7	11.2	9.8	8.7	7.7	6.8	6.1	5.4	4.8	4.3	3.8	3.4	3.1	2.8	2.5	1.8	1.7	1.7	1.6
102	>200	>200	195.7	163.8	137.6	116.0	98.2	83.4	71.1	60.8	52.1	44.9	38.7	33.5	29.0	25.3	22.0	19.2	16.8	14.8	13.0	11.5	10.1	9.0	7.9	7.1	6.3	5.6	5.0	4.5	4.0	3.6	3.2	2.9	2.6	1.8	1.7	1.7
103	>200	>200	>200	190.5	160.0	135.0	114.2	97.0	82.7	70.7	60.7	52.2	45.0	38.9	33.8	29.4	25.6	22.4	19.6	17.2	15.1	13.3	11.8	10.4	9.2	8.2	7.3	6.5	5.8	5.2	4.7	4.2	3.8	3.4	3.0	2.8	2.5	1.8
104	>200	>200	>200	>200	185.8	156.7	132.7	112.7	96.0	82.1	70.4	60.6	52.3	45.2	39.2	34.1	29.7	26.0	22.8	20.0	17.6	15.5	13.7	12.1	10.7	9.5	8.5	7.6	6.8	6.0	5.4	4.9	4.4	3.9	3.5	3.2	2.9	2.7
105	>200	>200	>200	>200	>200	181.6	153.8	130.6	111.3	95.2	81.6	70.2	60.6	52.4	45.5	39.5	34.5	30.1	26.4	23.2	20.4	18.0	15.9	14.0	12.4	11.1	9.8	8.8	7.8	7.0	6.3	5.6	5.1	4.6	4.1	3.7	3.3	3.1
106	>200	>200	>200	>200	>200	>200	177.9	151.1	128.8	110.1	94.4	81.2	70.1	60.6	52.6	45.7	39.9	34.8	30.5	26.8	23.6	20.8	18.4	16.2	14.4	12.8	11.4	10.2	9.1	8.1	7.3	6.5	5.9	5.3	4.7	4.3	3.9	3.6
107	>200	>200	>200	>200	>200	>200	>200	174.6	148.8	127.2	109.1	93.9	81.0	70.1	60.8	52.8	46.1	40.3	35.3	30.9	27.2	24.0	21.2	18.8	16.6	14.8	13.2	11.7	10.5	9.4	8.4	7.5	6.8	6.1	5.5	4.9	4.5	4.2
108	>200	>200	>200	>200	>200	>200	>200	>200	171.6	146.7	125.8	108.3	93.4	80.8	70.1	60.9	53.1	46.4	40.7	35.7	31.4	27.7	24.5	21.6	19.2	17.0	15.2	13.5	12.1	10.8	9.7	8.7	7.8	7.0	6.3	5.7	5.2	4.9
109	>200	>200	>200	>200	>200	>200	>200	>200	197.6	169.0	144.9	124.7	107.5	93.0	80.7	70.2	61.2	53.5	46.8	41.1	36.2	31.9	28.2	24.9	22.1	19.6	17.5	15.6	13.9	12.4	11.1	10.0	9.0	8.1	7.3	6.6	5.9	5.6
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	194.3	166.6	143.3	123.7	107.0	92.8	80.7	70.3	61.5	53.8	47.3	41.6	36.7	32.4	28.7	25.4	22.6	20.1	17.9	16.0	14.3	12.8	11.5	10.3	9.3	8.4	7.6	6.8	6.4
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.3	164.6	142.0	122.8	106.5	92.6	80.8	70.6	61.8	54.3	47.7	42.1	37.2	32.9	29.2	25.9	23.1	20.6	18.4	16.4	14.7	13.2	11.9	10.7	9.6	8.7	7.8	7.4
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.6	162.7	140.8	122.1	106.2	92.6	80.9	70.9	62.2	54.7	48.2	42.6	37.7	33.4	29.7	26.4	23.6	21.0	18.8	16.9	15.1	13.6	12.2	11.0	9.9	9.0	8.5
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	186.3	161.2	139.8	121.6	106.0	92.6	81.1	71.7	62.6	55.2	48.8	43.7	38.3	34.0	30.3	27.0	24.1	21.6	19.3	17.3	15.6	14.0	12.6	11.4	10.3	9.7
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	184.3	159.8	139.0	121.2	105.9	92.7	81.4	71.6	63.1	55.8	49.4	43.8	38.9	34.6	30.8	27.5	24.6	22.1	19.8	17.8	16.0	14.4	13.0	11.8	11.1
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.5	158.7	138.3	120.9	105.9	92.9	81.8	72.1	63.7	56.4	50.0	44.4	39.5	35.2	31.4	28.1	25.2	22.6	20.3	18.3	16.5	14.9	13.4	12.6
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.9	157.7	137.8	120.7	106.0	93.2	82.2	72.6	64.2	57.0	50.6	45.0	40.2	35.9	32.1	28.7	25.8	23.2	20.8	18.8	17.0	15.3	14.4
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.6	156.9	137.4	120.7	106.1	93.6	82.7	73.2	64.9	57.6	51.3	45.7	40.8	36.5	32.7	29.4	26.4	23.7	21.4	19.3	17.4	16.4
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.4	156.3	137.2	120.7	106.4	94.0	83.7	73.8	65.5	58.3	52.0	46.4	41.5	37.2	33.4	30.0	27.0	24.3	21.9	19.8	18.7
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.5	155.8	137.1	120.8	106.8	94.5	83.8	74.4	66.2	59.1	52.7	47.2	42.3	37.9	34.1	30.7	27.6	24.9	22.5	21.2
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	176.8	155.5	137.1	121.1	107.2	95.0	84.4	75.1	67.0	59.8	53.5	47.9	43.0	38.6	34.8	31.3	28.3	25.6	24.1
121	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	176.2	155.3	137.2	121.4	107.7	95.7	85.1	75.9	67.8	60.6	54.3	48.7	43.8	39.4	35.5	32.0	29.0	27.3
122	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	199.4	175.8	155.3	137.4	121.9	108.3	96.3	85.9	76.7	68.6	61.5	55.1	49.6	44.6	40.2	36.3	32.8	30.9
123	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.7	175.5	155.3	137.8	122.4	108.9	97.1	86.7	77.6	69.5	62.3	56.0	50.4	45.4	41.0	37.0	34.9
124	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.2	175.4	155.5	138.2	123.0	109.6	97.9	87.6	78.4	70.4	63.2	56.9	51.3	46.3	41.8	39.4
125	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.8	175.4	155.9	138.7	123.7	110.4	98.8	88.5	79.4	71.3	64.2	57.9	52.2	47.2	44.4
126	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.7	175.6	156.3	139.3	124.4	111.3	99.7	89.4	80.4	72.3	65.2	58.8	53.1	50.0
127	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.6	175.9	156.8	140.0	125.2	112.2	100.7	90.5	81.4	73.4	66.2	59.8	56.3
128	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.7	176.3	157.4	140.8	126.1	113.2	101.7	91.5	82.5	74.4	67.3	63.3
129	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.0	176.8	158.2	141.7	127.1	114.2	102.8	92.6	83.6	75.5	71.1
130	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.4	177.5	159.0	142.6	128.2	115.3	103.9	93.8	84.8	79.8
131	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.9	178.2	159.9	143.7	129.3	116.5	105.1	95.0	89.5
132	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	199.6	179.1	160.9	144.8	130.5	117.8	106.4	100.2
133	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.0	162.0	146.0	131.7	119.1	112.1
134	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.1	163.2	147.3	133.1	125.3

Figure B-56 Tabular Representation of Parking Nomograph for B767-300ER on 23 °F (-5 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

23 F	Gross B-767-300ER Weight (lbs)																																					
Ice Thickness (in)	205000	210000	215000	220000	225000	230000	235000	240000	245000	250000	255000	260000	265000	270000	275000	280000	285000	290000	295000	300000	305000	310000	315000	320000	325000	330000	335000	340000	345000	350000	355000	360000	365000	370000	375000	380000	385000	388000
52	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
53	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
54	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
55	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0
56	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
57	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
58	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
59	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
60	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
61	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
62	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
63	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
64	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
65	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1
66	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
67	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
68	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
69	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
70	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
71	1.2	1.1	1.1	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2
72	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
73	1.4	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
74	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3
75	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3
76	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3
77	2.8	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4
78	3.5	2.9	2.4	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4
79	4.3	3.6	3.0	2.5	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4
80	5.3	4.4	3.7	3.1	2.6	1.7	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5
81	6.5	5.4	4.5	3.8	3.2	2.7	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5
82	8.0	6.7	5.5	4.6	3.9	3.3	2.8	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5
83	9.8	8.1	6.8	5.7	4.8	4.0	3.4	2.9	2.5	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6
84	11.9	9.9	8.3	6.9	5.8	4.9	4.1	3.5	3.0	2.6	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6
85	14.5	12.0	10.0	8.4	7.0	5.9	5.0	4.3	3.6	3.1	2.7	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6
86	17.6	14.6	12.1	10.2	8.5	7.2	6.1	5.2	4.4	3.8	3.2	2.8	2.4	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7
87	21.2	17.6	14.7	12.3	10.3	8.7	7.4	6.2	5.3	4.5	3.9	3.4	2.9	2.5	1.7	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7
88	25.5	21.2	17.6	14.8	12.4	10.5	8.8	7.5	6.4	5.5	4.7	4.0	3.5	3.0	2.6	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8
89	30.6	25.4	21.2	17.7	14.9	12.5	10.6	9.0	7.7	6.6	5.6	4.8	4.2	3.6	3.1	2.7	2.4	1.7	1.6	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8
90	36.7	30.4	25.3	21.2	17.8	15.0	12.7	10.8	9.2	7.9	6.7	5.8	5.0	4.3	3.8	3.3	2.8	2.5	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9
91	43.8	36.3	30.2	25.3	21.3	17.9	15.2	12.9	11.0	9.4	8.1	6.9	6.0	5.2	4.5	3.9	3.4	3.0	2.6	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9
92	52.1	43.2	36.0	30.1	25.3	21.4	18.1	15.3	13.1	11.2	9.6	8.3	7.1	6.2	5.3	4.6	4.0	3.5	3.1	2.7	2.4	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0
93	61.9	51.3	42.8	35.8	30.1	25.4	21.5	18.2	15.5	13.3	11.4	9.8	8.5	7.3	6.3	5.5	4.8	4.2	3.7	3.2	2.8	2.5	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0
94	73.4	60.9	50.7	42.4	35.6	30.1	25.4	21.6	18.4	15.7	13.5	11.6	10.0	8.7	7.5	6.5	5.7	5.0	4.4	3.8	3.4	3.0	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1
95	86.7	71.9	59.9	50.2	42.1	35.5	30.1	25.5	21.8	18.6	16.0	13.7	11.8	10.2	8.9	7.7	6.7	5.9	5.2	4.5	4.0	3.5	3.1	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.2
96	102.3	84.9	70.7	59.2	49.7	41.9	35.5	30.1	25.7	22.0	18.8	16.2	14.0	12.1	10.5	9.1	8.0	6.9	6.1	5.3	4.7	4.1	3.7	3.2	2.9	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2
97	120.4	99.9	83.2	69.7	58.5	49.3	41.8	35.5	30.2	25.9	22.2	19.1	16.5	14.2	12.3	10.7	9.4	8.2	7.2	6.3	5.5	4.9	4.3	3.8	3.4	3.0	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3
98	141.5	117.3	97.8	81.8	68.7	58.0	49.1	41.7	35.5	30.4	26.0	22.4	19.3	16.7	14.5	12.6	11.0	9.6	8.4	7.4	6.5	5.7	5.1	4.5	4.0	3.5	3.1	2.8	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.4
99	165.8	137.6	114.6	95.9	80.6	67.9	57.5	48.9	41.6	35.6	30.5	26.3	22.7	19.6	17.0	14.8	12.9	11.3	9.9	8.7	7.6	6.7	5.9	5.2	4.7	4.1	3.7	3.3	2.9	2.6	1.8	1.7	1.7	1.6	1.6	1.5	1.5	1.4
100	194.0	160.9	134.1	112.2	94.3	79.5	67.3	57.2	48.7	41.6	35.7	30.7	26.5	22.9	19.9	17.3	15.1	13.2	11.5	10.1	8.9	7.9	6.9	6.1	5.4	4.8	4.3	3.8	3.4	3.1	2.7	2.5	1.8	1.7	1.6	1.6	1.5	1.5
101	>200	187.9	156.6	131.0	110.1	92.8	78.6	66.7	56.9	48.6	41.7	35.9	31.0	26.8	23.2	20.2	17.6	15.4	13.5	11.8	10.4	9.2	8.1	7.2	6.4	5.6	5.0	4.5	4.0	3.6	3.2	2.9	2.6	1.8	1.7	1.7	1.6	1.6
102	>200	>200	182.5	152.7	128.3	108.2	91.6	77.8	66.3	56.7	48.6	41.8	36.1	31.2	27.1	23.5	20.5	17.9	15.7	13.8	12.1	10.7	9.4	8.4	7.4	6.6	5.9	5.2	4.7	4.2	3.7	3.4	3.0	2.7	2.4	1.8	1.7	1.7
103	>200	>200	>200	177.6	149.2	125.8	106.5	90.5	77.1	65.9	56.5	48.6	42.0	36.3	31.5	27.4	23.9	20.9	18.3	16.0	14.1	12.4	11.0	9.7	8.6	7.7	6.8	6.1	5.4	4.9	4.3	3.9	3.5	3.2	2.8	2.6	1.8	1.7
104	>200	>200	>200	>200	173.3	146.1	123.7	105.1	89.5	76.6	65.7	56.5	48.7	42.2	36.6	31.8	27.7	24.2	21.2	18.6	16.4	14.4	12.8	11.3	10.0	8.9	7.9	7.1	6.3	5.6	5.0	4.5	4.1	3.7	3.3	3.0	2.7	2.5
105	>200	>200	>200	>200	>200	169.4	143.4	121.8	103.8	88.7	76.1	65.5	56.5	48.9	42.4	36.9	32.1	28.1	24.6	21.6	19.0	16.7	14.8	13.1	11.6	10.3	9.2	8.2	7.3	6.5	5.9	5.3	4.7	4.2	3.8	3.5	3.1	2.9
106	>200	>200	>200	>200	>200	196.0	165.9	140.9	120.1	102.7	88.1	75.8	65.4	56.6	49.1	42.7	37.2	32.5	28.5	25.0	22.0	19.4	17.1	15.1	13.4	11.9	10.6	9.5	8.5	7.6	6.8	6.1	5.5	4.9	4.4	4.0	3.6	3.4
107	>200	>200	>200	>200	>200	>200	191.7	162.8	138.8	118.7	101.8	87.5	75.5	65.3	56.7	49.3	43.0	37.5	32.9	28.9	25.4	22.4	19.8	17.5	15.5	13.8	12.3	10.9	9.8	8.7	7.8	7.0	6.3	5.7	5.1	4.6	4.2	3.9
108	>200	>200	>200	>200	>200	>200	>200	187.8	160.1	136.9	117.4	101.0	87.1	75.4	65.4	56.8	49.6	43.3	37.9	33.3	29.3	25.8	22.8	20.2	17.9	15.9	14.2	12.6	11.3	10.1	9.0	8.1	7.3	6.5	5.9	5.3	4.8	4.5
109	>200	>200	>200	>200	>200	>200	>200	>200	184.3	157.6	135.2	116.3	100.3	86.8	75.3	65.5	57.1	49.9	43.7	38.3	33.7	29.7	26.3	23.2	20.6	18.3	16.3	14.5	13.0	11.6	10.4	9.3	8.4	7.5	6.8	6.1	5.5	5.2
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.3	155.5	133.7	115.4	99.8	86.6	75.3	65.6	57.4	50.2	44.1	38.8	34.2	30.2	26.7	23.7	21.1	18.7	16.7	14.9	13.3	12.0	10.7	9.6	8.7	7.8	7.1	6.4	6.0
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.5	153.5	132.5	114.6	99.4	86.4	75.4	65.9	57.7	50.6	44.5	39.3	34.7	30.7	27.2	24.2	21.5	19.2	17.1	15.3	13.7	12.3	11.1	10.0	9.0	8.1	7.3	6.9
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	176.0	151.9	131.4	114.0	99.1	86.4	75.5	66.1	58.1	51.1	45.0	39.8	35.2	31.2	27.7	24.7	22.0	19.6	17.6	15.7	14.1	12.7	11.4	10.3	9.3	8.4	7.9
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	173.9	150.4	130.5	113.5	98.9	86.4	75.7	66.5	58.5	51.5	45.5	40.3	35.7	31.7	28.2	25.2	22.5	20.1	18.0	16.2	14.5	13.1	11.8	10.6	9.6	9.0
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.8	172.0	149.2	129.7	113.1	98.8	86.6	76.0	66.8	58.9	52.1	46.1	40.9	36.3	32.3	28.8	25.7	23.0	20.6	18.5	16.6	14.9	13.5	12.2	11.0	10.3
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	196.3	170.3	148.1	129.1	112.8	98.8	86.8	76.3	67.3	59.4	52.6	46.6	41.4	36.9	32.9	29.4	26.3	23.5	21.1	19.0	17.1	15.4	13.9	12.5	11.8
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	194.2	168.9	147.2	128.6	112.7	98.9	87.0	76.7	67.8	60.0	53.2	47.2	42.0	37.5	33.5	29.9	26.8	24.1	21.6	19.5	17.5	15.8	14.3	13.5
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.3	167.6	146.5	128.3	112.6	99.1	87.4	77.2	68.3	60.6	53.8	47.9	42.7	38.1	34.1	30.5	27.4	24.6	22.2	20.0	18.0	16.3	15.3
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	190.6	166.6	145.9	128.1	112.7	99.3	87.8	77.7	68.9	61.2	54.5	48.5	43.3	38.8	34.7	31.2	28.0	25.2	22.7	20.5	18.5	17.4
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	189.2	165.7	145.5	128.0	112.8	99.7	88.2	78.2	69.5	61.8	55.1	49.2	44.0	39.5	35.4	31.8	28.6	25.8	23.3	21.0	19.8
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.0	165.1	145.2	128.0	113.1	100.1	88.7	78.8	70.2	62.6	55.9	50.0	44.8	40.2	36.1	32.5	29.3	26.4	23.9	22.5
121	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	187.0	164.5	145.0	128.1	113.4	100.6	89.3	79.5	70.9	63.3	56.6	50.7	45.5	40.9	36.8	33.2	29.9	27.0	25.5
122	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	186.2	164.2	145.0	128.3	113.8	101.1	90.0	80.2	71.6	64.1	57.4	51.5	46.3	41.6	37.5	33.9	30.6	28.8
123	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.6	163.9	145.1	128.7	114.3	101.7	90.7	81.0	72.4	64.9	58.2	52.3	47.1	42.4	38.3	34.6	32.6
124	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.1	163.8	145.3	129.1	114.9	102.4	91.4	81.8	73.3	65.7	59.1	53.2	47.9	43.2	39.1	36.8
125	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	184.8	163.9	145.6	129.6	115.5	103.1	92.3	82.7	74.2	66.6	60.0	54.0	48.8	44.1	41.5
126	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	184.6	164.0	146.0	130.1	116.2	104.0	93.1	83.6	75.1	67.6	60.9	54.9	49.6	46.8
127	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	184.6	164.3	146.5	130.8	117.0	104.8	94.0	84.5	76.0	68.5	61.8	55.9	52.6
128	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	184.7	164.7	147.1	131.6	117.9	105.7	95.0	85.5	77.1	69.5	62.8	59.2
129	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.0	165.2	147.8	132.4	118.8	106.7	96.0	86.6	78.1	70.6	66.5
130	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.4	165.8	148.5	133.3	119.8	107.8	97.1	87.6	79.2	74.6
131	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.9	166.5	149.4	134.3	120.8	108.9	98.3	88.8	83.6
132	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	186.5	167.3	150.4	135.3	121.9	110.0	99.4	93.6
133	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	187.2	168.2	151.4	136.4	123.1	111.3	104.8
134	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.1	169.2	152.5	137.6	124.4	117.1

Figure B-57 Tabular Representation of Parking Nomograph for B767-300ER on 24 °F (-4.5 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

24 F	Gross B-767-300ER Weight (lbs)																																					
Ice Thickness (in)	205000	210000	215000	220000	225000	230000	235000	240000	245000	250000	255000	260000	265000	270000	275000	280000	285000	290000	295000	300000	305000	310000	315000	320000	325000	330000	335000	340000	345000	350000	355000	360000	365000	370000	375000	380000	385000	388000
52	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
53	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
54	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
55	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0
56	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
57	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
58	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
59	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
60	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
61	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
62	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
63	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
64	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
65	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1
66	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1
67	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
68	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
69	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
70	1.1	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
71	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2
72	1.3	1.2	1.1	1.1	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
73	1.4	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
74	1.5	1.4	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3
75	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3
76	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3
77	2.6	1.7	1.6	1.5	1.5	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4
78	3.2	2.7	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4
79	4.0	3.3	2.8	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4
80	5.0	4.1	3.4	2.9	2.4	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5
81	6.1	5.1	4.2	3.6	3.0	2.5	1.7	1.6	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5
82	7.5	6.3	5.2	4.4	3.7	3.1	2.6	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5
83	9.2	7.7	6.4	5.3	4.5	3.8	3.2	2.7	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6
84	11.3	9.3	7.8	6.5	5.5	4.6	3.9	3.3	2.8	2.4	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6
85	13.7	11.4	9.5	7.9	6.6	5.6	4.7	4.0	3.4	2.9	2.5	1.7	1.7	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6
86	16.6	13.8	11.5	9.6	8.1	6.8	5.8	4.9	4.2	3.6	3.1	2.6	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7
87	20.0	16.6	13.8	11.6	9.7	8.2	6.9	5.9	5.0	4.3	3.7	3.2	2.7	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7
88	24.1	20.0	16.7	14.0	11.7	9.9	8.4	7.1	6.1	5.2	4.4	3.8	3.3	2.9	2.5	1.7	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8
89	29.0	24.0	20.0	16.8	14.1	11.9	10.1	8.5	7.3	6.2	5.3	4.6	4.0	3.4	3.0	2.6	1.8	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8
90	34.7	28.8	24.0	20.1	16.9	14.2	12.0	10.2	8.7	7.5	6.4	5.5	4.7	4.1	3.6	3.1	2.7	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.9
91	41.5	34.4	28.7	24.0	20.2	17.0	14.4	12.2	10.4	8.9	7.6	6.6	5.7	4.9	4.3	3.7	3.2	2.8	2.5	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9
92	49.4	41.0	34.2	28.6	24.0	20.3	17.1	14.6	12.4	10.6	9.1	7.8	6.8	5.8	5.1	4.4	3.8	3.4	2.9	2.6	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	1.0
93	58.8	48.8	40.6	34.0	28.6	24.1	20.4	17.3	14.8	12.6	10.8	9.3	8.0	6.9	6.0	5.2	4.6	4.0	3.5	3.1	2.7	2.4	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0
94	69.7	57.8	48.2	40.3	33.9	28.6	24.2	20.5	17.5	15.0	12.8	11.0	9.5	8.2	7.1	6.2	5.4	4.7	4.1	3.6	3.2	2.8	2.5	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.1	1.1	1.1
95	82.4	68.4	57.0	47.7	40.1	33.8	28.6	24.3	20.7	17.7	15.2	13.1	11.3	9.7	8.5	7.3	6.4	5.6	4.9	4.3	3.8	3.3	2.9	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1
96	97.3	80.7	67.3	56.3	47.3	39.9	33.8	28.7	24.4	20.9	17.9	15.4	13.3	11.5	10.0	8.7	7.6	6.6	5.8	5.1	4.5	3.9	3.5	3.1	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2
97	114.6	95.1	79.2	66.3	55.7	47.0	39.8	33.8	28.8	24.6	21.1	18.2	15.7	13.5	11.8	10.2	8.9	7.8	6.8	6.0	5.3	4.6	4.1	3.6	3.2	2.9	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.3
98	134.7	111.8	93.1	77.9	65.5	55.2	46.7	39.7	33.8	28.9	24.8	21.3	18.4	15.9	13.8	12.0	10.5	9.1	8.0	7.0	6.2	5.5	4.8	4.3	3.8	3.4	3.0	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3
99	158.0	131.1	109.2	91.4	76.8	64.7	54.8	46.6	39.7	33.9	29.1	25.0	21.6	18.7	16.2	14.1	12.3	10.7	9.4	8.3	7.3	6.4	5.7	5.0	4.4	3.9	3.5	3.1	2.8	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4
100	184.9	153.4	127.8	107.0	89.9	75.8	64.2	54.5	46.4	39.7	34.1	29.3	25.3	21.9	19.0	16.5	14.4	12.6	11.0	9.7	8.5	7.5	6.6	5.9	5.2	4.6	4.1	3.7	3.3	2.9	2.6	1.8	1.7	1.7	1.6	1.6	1.5	1.5
101	>200	179.2	149.4	125.0	105.0	88.5	74.9	63.7	54.3	46.4	39.8	34.2	29.5	25.5	22.2	19.3	16.8	14.7	12.9	11.3	9.9	8.7	7.7	6.8	6.1	5.4	4.8	4.3	3.8	3.4	3.1	2.7	2.5	1.8	1.7	1.6	1.6	1.6
102	>200	>200	174.1	145.7	122.4	103.2	87.4	74.2	63.3	54.1	46.4	39.9	34.4	29.8	25.8	22.5	19.6	17.1	15.0	13.2	11.6	10.2	9.0	8.0	7.1	6.3	5.6	5.0	4.5	4.0	3.6	3.2	2.9	2.6	1.8	1.7	1.7	1.6
103	>200	>200	>200	169.6	142.5	120.2	101.7	86.4	73.6	63.0	54.0	46.4	40.1	34.7	30.1	26.1	22.8	19.9	17.4	15.3	13.5	11.9	10.5	9.3	8.2	7.3	6.5	5.8	5.2	4.6	4.2	3.7	3.3	3.0	2.7	2.4	1.8	1.7
104	>200	>200	>200	197.0	165.5	139.6	118.2	100.4	85.5	73.1	62.7	54.0	46.6	40.3	34.9	30.4	26.5	23.1	20.3	17.8	15.7	13.8	12.2	10.8	9.6	8.5	7.6	6.7	6.0	5.4	4.8	4.3	3.9	3.5	3.2	2.8	2.6	2.4
105	>200	>200	>200	>200	192.0	161.9	137.0	116.4	99.2	84.8	72.7	62.6	54.0	46.7	40.5	35.2	30.7	26.8	23.5	20.6	18.2	16.0	14.1	12.5	11.1	9.9	8.8	7.8	7.0	6.2	5.6	5.0	4.5	4.1	3.7	3.3	3.0	2.8
106	>200	>200	>200	>200	>200	187.4	158.7	134.8	114.9	98.2	84.2	72.5	62.5	54.1	46.9	40.8	35.6	31.1	27.2	23.9	21.0	18.5	16.4	14.5	12.8	11.4	10.2	9.1	8.1	7.2	6.5	5.8	5.2	4.7	4.2	3.8	3.5	3.3
107	>200	>200	>200	>200	>200	>200	183.4	155.8	132.8	113.5	97.4	83.7	72.2	62.5	54.2	47.1	41.1	35.9	31.5	27.6	24.3	21.4	18.9	16.7	14.8	13.2	11.7	10.5	9.3	8.4	7.5	6.7	6.0	5.4	4.9	4.4	4.0	3.8
108	>200	>200	>200	>200	>200	>200	>200	179.7	153.2	131.0	112.3	96.6	83.4	72.1	62.6	54.4	47.4	41.4	36.3	31.9	28.0	24.7	21.8	19.3	17.1	15.2	13.5	12.1	10.8	9.6	8.6	7.8	7.0	6.3	5.6	5.1	4.6	4.3
109	>200	>200	>200	>200	>200	>200	>200	>200	176.5	150.9	129.4	111.3	96.1	83.1	72.1	62.7	54.6	47.8	41.8	36.7	32.3	28.5	25.1	22.3	19.7	17.5	15.6	13.9	12.4	11.1	10.0	8.9	8.0	7.2	6.5	5.9	5.3	5.0
110	>200	>200	>200	>200	>200	>200	>200	>200	>200	173.6	148.9	128.1	110.5	95.6	82.9	72.1	62.9	54.9	48.1	42.2	37.2	32.8	28.9	25.6	22.7	20.2	18.0	16.0	14.3	12.8	11.4	10.3	9.2	8.3	7.5	6.8	6.1	5.7
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	199.4	171.0	147.1	126.9	109.8	95.2	82.8	72.2	63.1	55.3	48.5	42.7	37.6	33.2	29.4	26.1	23.2	20.6	18.4	16.4	14.7	13.2	11.8	10.6	9.5	8.6	7.8	7.0	6.6
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	196.1	168.7	145.6	125.9	109.2	95.0	82.8	72.4	63.4	55.6	48.9	43.2	38.1	33.7	29.9	26.6	23.6	21.1	18.8	16.8	15.1	13.5	12.2	10.9	9.9	8.9	8.0	7.6
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.2	166.7	144.7	125.1	108.8	94.8	82.9	72.6	63.7	56.1	49.4	43.7	38.6	34.3	30.4	27.1	24.1	21.6	19.3	17.3	15.5	13.9	12.5	11.3	10.2	9.2	8.7
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	190.7	165.0	143.1	124.4	108.5	94.8	83.0	72.9	64.1	56.5	49.9	44.2	39.2	34.8	31.0	27.6	24.7	22.1	19.8	17.7	15.9	14.3	12.9	11.7	10.5	9.9
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.4	163.4	142.1	123.9	108.3	94.8	83.2	73.2	64.6	57.0	50.5	44.8	39.8	35.4	31.5	28.2	25.2	22.6	20.2	18.2	16.4	14.8	13.3	12.0	11.3
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	186.4	162.1	141.3	123.5	108.2	94.9	83.5	73.6	65.0	57.6	51.0	45.3	40.4	36.0	32.1	28.7	25.7	23.1	20.8	18.7	16.8	15.2	13.7	12.9
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	184.6	161.0	140.7	123.2	108.1	95.1	83.9	74.1	65.6	58.1	51.7	46.0	41.0	36.6	32.7	29.3	26.3	23.6	21.3	19.2	17.3	15.6	14.7
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	183.1	160.0	140.2	123.0	108.2	95.4	84.3	74.6	66.1	58.8	52.3	46.6	41.6	37.2	33.4	29.9	26.9	24.2	21.8	19.7	17.8	16.7
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.8	159.2	139.8	123.0	108.4	95.8	84.8	75.2	66.8	59.4	53.0	47.3	42.3	37.9	34.0	30.6	27.5	24.8	22.4	20.2	19.0
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.7	158.6	139.5	123.0	108.7	96.2	85.3	75.8	67.4	60.1	53.7	48.0	43.0	38.6	34.7	31.2	28.1	25.4	22.9	21.6
121	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.8	158.2	139.4	123.2	109.0	96.7	85.9	76.4	68.1	60.8	54.4	48.8	43.7	39.3	35.4	31.9	28.8	26.0	24.5
122	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.1	157.9	139.4	123.4	109.4	97.2	86.5	77.1	68.9	61.6	55.2	49.5	44.5	40.0	36.1	32.6	29.4	27.7
123	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.5	157.7	139.6	123.8	109.9	97.8	87.2	77.9	69.7	62.4	56.0	50.3	45.3	40.8	36.8	33.3	31.3
124	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.1	157.6	139.8	124.2	110.5	98.5	88.0	78.7	70.5	63.3	56.8	51.1	46.1	41.6	37.6	35.4
125	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.8	157.7	140.1	124.7	111.2	99.3	88.8	79.5	71.4	64.1	57.7	52.0	46.9	42.4	39.9
126	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.7	157.9	140.5	125.3	111.9	100.1	89.6	80.4	72.3	65.0	58.6	52.9	47.8	45.0
127	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.8	158.2	141.0	126.0	112.7	100.9	90.6	81.4	73.2	66.0	59.5	53.8	50.7
128	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	199.9	177.9	158.6	141.7	126.7	113.5	101.8	91.5	82.4	74.2	67.0	60.5	57.0
129	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	199.9	178.2	159.1	142.3	127.5	114.4	102.8	92.5	83.4	75.2	68.0	64.0
130	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.6	159.8	143.1	128.4	115.4	103.8	93.6	84.5	76.3	71.9
131	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.1	160.5	144.0	129.4	116.4	104.9	94.7	85.6	80.6
132	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.8	161.3	145.0	130.4	117.5	106.1	95.9	90.3
133	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.5	162.2	146.0	131.6	118.7	107.3	101.0
134	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.4	163.2	147.1	132.7	119.9	112.9

Figure B-58 Tabular Representation of Parking Nomograph for B767-300ER on 25 °F (-4 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

25 F	Gross B-767-300ER Weight (lbs)																																					
Ice Thickness (in)	205000	210000	215000	220000	225000	230000	235000	240000	245000	250000	255000	260000	265000	270000	275000	280000	285000	290000	295000	300000	305000	310000	315000	320000	325000	330000	335000	340000	345000	350000	355000	360000	365000	370000	375000	380000	385000	388000
52	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
53	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
54	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
55	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
56	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0
57	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
58	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
59	0.4	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
60	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
61	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
62	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
63	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
64	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
65	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1
66	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1
67	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
68	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
69	1.0	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
70	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
71	1.1	1.1	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2
72	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2
73	1.3	1.3	1.2	1.1	1.1	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
74	1.4	1.4	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3
75	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3
76	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3
77	2.4	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4
78	3.0	2.5	1.7	1.6	1.5	1.5	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4
79	3.8	3.1	2.6	1.7	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4
80	4.7	3.9	3.2	2.7	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4
81	5.8	4.8	4.0	3.3	2.8	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5
82	7.1	5.9	4.9	4.1	3.4	2.9	2.5	1.7	1.6	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5
83	8.7	7.2	6.0	5.0	4.2	3.6	3.0	2.6	1.7	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5
84	10.6	8.8	7.3	6.1	5.2	4.3	3.7	3.1	2.7	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6
85	12.9	10.7	8.9	7.5	6.3	5.3	4.5	3.8	3.2	2.8	2.4	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6
86	15.7	13.0	10.8	9.1	7.6	6.4	5.4	4.6	3.9	3.4	2.9	2.5	1.7	1.7	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.7
87	18.9	15.7	13.1	10.9	9.2	7.8	6.6	5.6	4.8	4.1	3.5	3.0	2.6	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7
88	22.8	18.9	15.8	13.2	11.1	9.4	7.9	6.7	5.7	4.9	4.2	3.6	3.1	2.7	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7
89	27.4	22.8	19.0	15.9	13.3	11.2	9.5	8.1	6.9	5.9	5.0	4.3	3.7	3.2	2.8	2.4	1.7	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8
90	32.9	27.3	22.7	19.0	16.0	13.5	11.4	9.7	8.3	7.1	6.1	5.2	4.5	3.9	3.4	2.9	2.6	1.8	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8
91	39.3	32.6	27.2	22.7	19.1	16.1	13.6	11.6	9.9	8.4	7.2	6.2	5.4	4.6	4.0	3.5	3.1	2.7	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9
92	46.9	38.9	32.4	27.1	22.8	19.2	16.3	13.8	11.8	10.1	8.6	7.4	6.4	5.5	4.8	4.2	3.6	3.2	2.8	2.4	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9
93	55.8	46.3	38.6	32.3	27.1	22.9	19.3	16.4	14.0	12.0	10.3	8.8	7.6	6.6	5.7	5.0	4.3	3.8	3.3	2.9	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.3	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0
94	66.2	54.9	45.8	38.3	32.2	27.1	23.0	19.5	16.6	14.2	12.2	10.5	9.0	7.8	6.8	5.9	5.1	4.5	3.9	3.5	3.0	2.7	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.1
95	78.4	65.0	54.2	45.3	38.1	32.1	27.2	23.1	19.7	16.8	14.4	12.4	10.7	9.3	8.0	7.0	6.1	5.3	4.7	4.1	3.6	3.2	2.8	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1
96	92.5	76.8	64.0	53.5	45.0	37.9	32.1	27.3	23.2	19.9	17.0	14.7	12.6	10.9	9.5	8.3	7.2	6.3	5.5	4.8	4.3	3.7	3.3	2.9	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2
97	109.1	90.5	75.4	63.1	53.0	44.7	37.8	32.1	27.4	23.4	20.1	17.3	14.9	12.9	11.2	9.7	8.5	7.4	6.5	5.7	5.0	4.4	3.9	3.5	3.1	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2
98	128.3	106.4	88.7	74.2	62.3	52.6	44.5	37.8	32.2	27.5	23.6	20.3	17.5	15.2	13.1	11.4	10.0	8.7	7.6	6.7	5.9	5.2	4.6	4.1	3.6	3.2	2.8	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3
99	150.5	124.9	104.0	87.1	73.1	61.7	52.2	44.3	37.8	32.3	27.7	23.8	20.6	17.8	15.4	13.4	11.7	10.2	9.0	7.9	6.9	6.1	5.4	4.8	4.2	3.8	3.3	3.0	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4
100	176.3	146.2	121.9	102.0	85.7	72.2	61.1	51.9	44.3	37.8	32.5	27.9	24.1	20.8	18.1	15.7	13.7	12.0	10.5	9.2	8.1	7.1	6.3	5.6	4.9	4.4	3.9	3.5	3.1	2.8	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.5
101	>200	170.9	142.4	119.2	100.1	84.4	71.5	60.7	51.7	44.2	37.9	32.6	28.2	24.4	21.1	18.4	16.0	14.0	12.3	10.8	9.5	8.3	7.4	6.5	5.8	5.1	4.6	4.1	3.6	3.3	2.9	2.6	1.8	1.7	1.7	1.6	1.6	1.5
102	>200	199.4	166.2	139.0	116.8	98.5	83.4	70.8	60.4	51.6	44.3	38.1	32.8	28.4	24.6	21.4	18.7	16.3	14.3	12.6	11.0	9.7	8.6	7.6	6.7	6.0	5.3	4.8	4.2	3.8	3.4	3.1	2.7	2.5	1.8	1.7	1.6	1.6
103	>200	>200	193.5	161.9	136.0	114.7	97.1	82.5	70.3	60.1	51.5	44.3	38.3	33.1	28.7	25.0	21.8	19.0	16.7	14.6	12.9	11.3	10.0	8.9	7.9	7.0	6.2	5.5	4.9	4.4	4.0	3.6	3.2	2.9	2.6	1.8	1.7	1.7
104	>200	>200	>200	188.2	158.1	133.3	112.8	95.9	81.7	69.9	59.9	51.5	44.5	38.5	33.4	29.0	25.3	22.1	19.4	17.0	14.9	13.2	11.6	10.3	9.1	8.1	7.2	6.4	5.7	5.1	4.6	4.1	3.7	3.3	3.0	2.7	2.5	1.8
105	>200	>200	>200	>200	183.4	154.7	130.9	111.2	94.8	81.0	69.5	59.8	51.6	44.6	38.7	33.7	29.3	25.6	22.5	19.7	17.3	15.3	13.5	12.0	10.6	9.4	8.4	7.5	6.7	6.0	5.3	4.8	4.3	3.9	3.5	3.2	2.8	2.7
106	>200	>200	>200	>200	>200	179.2	151.7	128.8	109.8	93.9	80.5	69.3	59.8	51.7	44.8	39.0	34.0	29.7	26.0	22.8	20.1	17.7	15.6	13.8	12.3	10.9	9.7	8.7	7.7	6.9	6.2	5.6	5.0	4.5	4.0	3.7	3.3	3.1
107	>200	>200	>200	>200	>200	>200	175.4	149.0	127.0	108.6	93.1	80.1	69.1	59.8	51.8	45.1	39.3	34.3	30.1	26.4	23.2	20.5	18.1	16.0	14.2	12.6	11.2	10.0	8.9	8.0	7.2	6.4	5.8	5.2	4.7	4.2	3.8	3.6
108	>200	>200	>200	>200	>200	>200	>200	172.0	146.6	125.3	107.5	92.5	79.8	69.0	59.9	52.1	45.4	39.7	34.7	30.5	26.8	23.6	20.9	18.5	16.4	14.6	13.0	11.6	10.3	9.2	8.3	7.4	6.7	6.0	5.4	4.9	4.4	4.1
109	>200	>200	>200	>200	>200	>200	>200	198.2	168.9	144.4	123.9	106.6	91.9	79.5	69.0	60.0	52.3	45.7	40.0	35.1	30.9	27.3	24.1	21.3	18.9	16.8	14.9	13.3	11.9	10.6	9.5	8.5	7.7	6.9	6.2	5.6	5.1	4.8
110	>200	>200	>200	>200	>200	>200	>200	>200	194.4	166.2	142.6	122.6	105.8	91.5	79.4	69.0	60.2	52.6	46.1	40.4	35.6	31.4	27.7	24.5	21.7	19.3	17.2	15.3	13.7	12.2	11.0	9.8	8.8	8.0	7.2	6.5	5.8	5.5
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.0	163.8	140.9	121.6	105.2	91.2	79.3	69.2	60.4	52.9	46.5	40.9	36.0	31.8	28.2	25.0	22.2	19.8	17.6	15.7	14.1	12.6	11.3	10.2	9.1	8.2	7.4	6.7	6.3
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.0	161.7	139.5	120.7	104.7	91.0	79.4	69.3	60.7	53.3	46.9	41.3	36.5	32.3	28.7	25.5	22.7	20.2	18.0	16.1	14.5	13.0	11.7	10.5	9.5	8.5	7.7	7.3
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.2	159.8	138.3	119.9	104.3	90.9	79.5	69.6	61.1	53.7	47.4	41.8	37.0	32.8	29.2	26.0	23.1	20.7	18.5	16.6	14.9	13.4	12.0	10.8	9.8	8.8	8.3
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.8	158.2	137.2	119.3	104.0	90.9	79.6	69.9	61.5	54.2	47.9	42.4	37.6	33.4	29.7	26.5	23.6	21.2	18.9	17.0	15.3	13.7	12.4	11.2	10.1	9.5
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.7	156.8	136.3	118.8	103.9	91.0	79.9	70.2	61.9	54.7	48.4	42.9	38.1	33.9	30.3	27.0	24.2	21.6	19.4	17.5	15.7	14.2	12.8	11.5	10.9
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	178.9	155.5	135.6	118.5	103.8	91.1	80.1	70.7	62.4	55.2	49.0	43.5	38.7	34.5	30.8	27.6	24.7	22.2	19.9	17.9	16.1	14.6	13.2	12.4
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.2	154.5	135.0	118.3	103.8	91.3	80.5	71.1	62.9	55.8	49.6	44.1	39.3	35.1	31.4	28.1	25.3	22.7	20.4	18.4	16.6	15.0	14.1
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	175.8	153.6	134.6	118.1	103.9	91.6	80.9	71.6	63.5	56.4	50.2	44.8	40.0	35.8	32.0	28.7	25.8	23.2	20.9	18.9	17.1	16.1
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	199.8	174.6	153.0	134.3	118.1	104.1	92.0	81.4	72.2	64.1	57.1	50.9	45.4	40.6	36.4	32.7	29.4	26.4	23.8	21.5	19.4	18.3
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.2	173.6	152.4	134.1	118.2	104.4	92.4	81.9	72.8	64.8	57.8	51.6	46.1	41.3	37.1	33.3	30.0	27.0	24.4	22.0	20.7
121	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	196.8	172.8	152.0	134.0	118.4	104.8	92.9	82.5	73.5	65.5	58.5	52.3	46.9	42.0	37.8	34.0	30.6	27.6	25.0	23.5
122	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.7	172.1	151.8	134.1	118.6	105.2	93.5	83.2	74.2	66.2	59.2	53.1	47.6	42.8	38.5	34.7	31.3	28.3	26.6
123	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	194.7	171.7	151.6	134.2	119.0	105.7	94.1	83.9	74.9	67.0	60.0	53.9	48.4	43.5	39.2	35.4	32.0	30.1
124	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.9	171.3	151.6	134.5	119.4	106.3	94.8	84.6	75.7	67.8	60.8	54.7	49.2	44.3	40.0	36.2	34.0
125	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.3	171.1	151.7	134.8	120.0	107.0	95.5	85.4	76.5	68.7	61.7	55.5	50.0	45.2	40.8	38.4
126	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.9	171.1	152.0	135.2	120.6	107.7	96.3	86.3	77.4	69.6	62.6	56.4	50.9	46.0	43.3
127	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.6	171.1	152.3	135.8	121.2	108.5	97.2	87.2	78.3	70.5	63.5	57.3	51.8	48.8
128	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.5	171.3	152.7	136.4	122.0	109.3	98.1	88.1	79.3	71.5	64.5	58.3	54.9
129	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.5	171.7	153.3	137.1	122.8	110.2	99.0	89.1	80.3	72.5	65.5	61.7
130	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	192.7	172.1	153.9	137.9	123.7	111.2	100.0	90.7	81.4	73.5	69.2
131	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.0	172.6	154.7	138.8	124.7	112.2	101.1	91.2	82.5	77.6
132	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.4	173.3	155.5	139.7	125.7	113.3	102.2	92.4	87.0
133	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	194.0	174.0	156.4	140.7	126.8	114.4	103.4	97.4
134	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	194.6	174.9	157.4	141.8	128.0	115.7	108.9

Figure B-59 Tabular Representation of Parking Nomograph for B767-300ER on 26 °F (-3.5 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

26 F	Gross B-767-300ER Weight (lbs)																																					
Ice Thickness (in)	205000	210000	215000	220000	225000	230000	235000	240000	245000	250000	255000	260000	265000	270000	275000	280000	285000	290000	295000	300000	305000	310000	315000	320000	325000	330000	335000	340000	345000	350000	355000	360000	365000	370000	375000	380000	385000	388000
52	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
53	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
54	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
55	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
56	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0
57	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
58	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
59	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
60	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
61	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
62	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
63	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
64	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
65	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
66	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1
67	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
68	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
69	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
70	1.0	1.0	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
71	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
72	1.2	1.1	1.1	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2
73	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
74	1.4	1.3	1.2	1.2	1.1	1.1	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3
75	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3
76	1.6	1.5	1.5	1.4	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3
77	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
78	2.8	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4
79	3.5	2.9	2.4	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4
80	4.4	3.6	3.0	2.5	1.7	1.6	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4
81	5.4	4.5	3.7	3.1	2.6	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5
82	6.7	5.5	4.6	3.9	3.2	2.7	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5
83	8.2	6.8	5.6	4.7	4.0	3.3	2.8	2.4	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5
84	10.0	8.3	6.9	5.8	4.9	4.1	3.5	2.9	2.5	1.7	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6
85	12.2	10.1	8.4	7.0	5.9	5.0	4.2	3.6	3.1	2.6	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6
86	14.8	12.3	10.2	8.5	7.2	6.1	5.1	4.4	3.7	3.2	2.7	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6
87	17.9	14.8	12.4	10.3	8.7	7.3	6.2	5.3	4.5	3.8	3.3	2.8	2.4	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7
88	21.6	17.9	14.9	12.5	10.5	8.8	7.5	6.4	5.4	4.6	4.0	3.4	2.9	2.5	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7
89	26.0	21.5	17.9	15.0	12.6	10.6	9.0	7.6	6.5	5.6	4.8	4.1	3.5	3.1	2.7	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8	0.8
90	31.1	25.8	21.5	18.0	15.1	12.8	10.8	9.2	7.8	6.7	5.7	4.9	4.3	3.7	3.2	2.8	2.4	1.7	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8
91	37.3	30.9	25.8	21.5	18.1	15.3	12.9	11.0	9.4	8.0	6.9	5.9	5.1	4.4	3.8	3.3	2.9	2.5	1.8	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9
92	44.5	36.9	30.7	25.7	21.6	18.2	15.4	13.1	11.2	9.5	8.2	7.0	6.1	5.3	4.6	4.0	3.5	3.0	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.3	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9
93	52.9	43.9	36.6	30.6	25.7	21.7	18.4	15.6	13.3	11.4	9.7	8.4	7.2	6.3	5.4	4.7	4.1	3.6	3.1	2.8	2.4	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0
94	62.8	52.1	43.4	36.3	30.5	25.7	21.8	18.5	15.8	13.5	11.6	10.0	8.6	7.4	6.4	5.6	4.9	4.3	3.7	3.3	2.9	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0
95	74.4	61.8	51.5	43.1	36.2	30.5	25.8	21.9	18.7	16.0	13.7	11.8	10.2	8.8	7.6	6.6	5.8	5.1	4.4	3.9	3.4	3.0	2.7	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1
96	88.0	73.0	60.8	50.9	42.7	36.1	30.5	25.9	22.1	18.9	16.2	13.9	12.0	10.4	9.0	7.8	6.8	6.0	5.2	4.6	4.0	3.6	3.1	2.8	2.5	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2
97	103.7	86.1	71.7	60.0	50.4	42.5	36.0	30.6	26.0	22.3	19.1	16.4	14.2	12.3	10.6	9.2	8.1	7.0	6.2	5.4	4.8	4.2	3.7	3.3	2.9	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.3	1.2
98	122.1	101.3	84.4	70.6	59.3	50.0	42.3	36.0	30.7	26.2	22.5	19.3	16.7	14.4	12.5	10.9	9.5	8.3	7.3	6.4	5.6	4.9	4.4	3.9	3.4	3.0	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3
99	143.3	118.9	99.1	82.9	69.7	58.7	49.7	42.2	36.0	30.8	26.4	22.7	19.6	16.9	14.7	12.8	11.1	9.7	8.5	7.5	6.6	5.8	5.1	4.5	4.0	3.6	3.2	2.8	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.4
100	168.0	139.3	116.1	97.2	81.6	68.8	58.3	49.5	42.2	36.1	30.9	26.6	23.0	19.9	17.2	15.0	13.1	11.4	10.0	8.8	7.7	6.8	6.0	5.3	4.7	4.2	3.7	3.3	3.0	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5	1.4
101	196.4	163.0	135.8	113.6	95.5	80.5	68.1	57.9	49.3	42.2	36.2	31.1	26.8	23.2	20.1	17.5	15.3	13.3	11.7	10.3	9.0	8.0	7.0	6.2	5.5	4.9	4.4	3.9	3.5	3.1	2.8	2.5	1.8	1.7	1.6	1.6	1.5	1.5
102	>200	190.2	158.5	132.6	111.4	94.0	79.5	67.6	57.6	49.2	42.2	36.3	31.3	27.1	23.5	20.4	17.8	15.6	13.6	12.0	10.5	9.3	8.2	7.3	6.4	5.7	5.1	4.5	4.1	3.6	3.2	2.9	2.6	1.8	1.7	1.7	1.6	1.6
103	>200	>200	184.6	154.5	129.8	109.5	92.7	78.7	67.1	57.4	49.2	42.3	36.5	31.6	27.4	23.8	20.8	18.1	15.9	14.0	12.3	10.8	9.6	8.5	7.5	6.7	5.9	5.3	4.7	4.2	3.8	3.4	3.0	2.7	2.5	1.8	1.7	1.7
104	>200	>200	>200	179.7	150.9	127.3	107.7	91.5	78.0	66.7	57.2	49.2	42.5	36.7	31.9	27.7	24.1	21.1	18.5	16.2	14.3	12.6	11.1	9.8	8.7	7.7	6.9	6.1	5.5	4.9	4.4	3.9	3.5	3.2	2.9	2.6	1.8	1.8
105	>200	>200	>200	>200	175.2	147.8	125.1	106.2	90.5	77.4	66.4	57.1	49.3	42.6	37.0	32.2	28.0	24.5	21.5	18.8	16.6	14.6	12.9	11.4	10.1	9.0	8.0	7.1	6.4	5.7	5.1	4.6	4.1	3.7	3.3	3.0	2.7	2.6
106	>200	>200	>200	>200	>200	171.2	144.9	123.1	104.9	89.7	76.9	66.2	57.1	49.4	42.8	37.3	32.5	28.4	24.9	21.8	19.2	16.9	14.9	13.2	11.7	10.4	9.3	8.3	7.4	6.6	5.9	5.3	4.8	4.3	3.9	3.5	3.2	3.0
107	>200	>200	>200	>200	>200	198.1	167.7	142.4	121.4	103.8	89.0	76.6	66.1	57.1	49.6	43.1	37.6	32.8	28.8	25.2	22.2	19.6	17.3	15.3	13.6	12.1	10.7	9.6	8.5	7.6	6.8	6.1	5.5	5.0	4.5	4.0	3.6	3.4
108	>200	>200	>200	>200	>200	>200	193.6	164.5	140.2	119.9	102.8	88.4	76.3	66.0	57.3	49.8	43.4	37.9	33.2	29.2	25.7	22.6	20.0	17.7	15.7	13.9	12.4	11.0	9.9	8.8	7.9	7.1	6.4	5.7	5.2	4.7	4.2	4.0
109	>200	>200	>200	>200	>200	>200	>200	189.7	161.6	138.2	118.5	102.0	88.0	76.1	66.0	57.4	50.0	43.7	38.3	33.6	29.6	26.1	23.0	20.4	18.1	16.1	14.3	12.7	11.4	10.2	9.1	8.2	7.3	6.6	6.0	5.4	4.9	4.6
110	>200	>200	>200	>200	>200	>200	>200	>200	186.1	159.1	136.5	117.4	101.3	87.6	76.0	66.1	57.6	50.4	44.1	38.7	34.1	30.0	26.5	23.5	20.8	18.5	16.5	14.7	13.1	11.7	10.5	9.4	8.5	7.6	6.9	6.2	5.6	5.3
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.9	156.9	135.0	116.4	100.7	87.4	76.0	66.2	57.9	50.7	44.5	39.1	34.5	30.5	27.0	23.9	21.3	18.9	16.9	15.1	13.5	12.1	10.8	9.7	8.8	7.9	7.1	6.4	6.1
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.1	154.9	133.6	115.6	100.3	87.2	76.0	66.4	58.2	51.1	44.9	39.6	35.0	31.0	27.5	24.4	21.7	19.4	17.3	15.5	13.8	12.4	11.2	10.0	9.1	8.2	7.4	7.0
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	177.5	153.2	132.5	114.9	100.0	87.1	76.1	66.7	58.5	51.5	45.4	40.1	35.5	31.5	28.0	24.9	22.2	19.8	17.7	15.9	14.2	12.8	11.5	10.4	9.4	8.5	8.0
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	175.3	151.7	131.5	114.4	99.7	87.1	76.3	67.0	58.9	52.0	45.9	40.6	36.0	32.0	28.5	25.4	22.7	20.3	18.2	16.3	14.6	13.2	11.9	10.7	9.7	9.1
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	173.3	150.3	130.7	114.0	99.6	87.2	76.6	67.4	59.4	52.5	46.4	41.2	36.6	32.6	29.0	25.9	23.2	20.8	18.6	16.7	15.1	13.6	12.2	11.1	10.4
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.8	171.6	149.2	130.1	113.7	99.6	87.4	76.9	67.8	59.9	53.0	47.0	41.7	37.2	33.1	29.6	26.5	23.7	21.3	19.1	17.2	15.5	14.0	12.6	11.9
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.6	170.1	148.3	129.6	113.5	99.6	87.6	77.3	68.3	60.4	53.6	47.6	42.3	37.8	33.7	30.2	27.0	24.2	21.8	19.6	17.7	15.9	14.4	13.6
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.6	168.8	147.5	129.2	113.4	99.8	88.0	77.7	68.8	61.0	54.2	48.2	43.0	38.4	34.3	30.8	27.6	24.8	22.3	20.1	18.1	16.4	15.4
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	191.9	167.7	146.9	128.9	113.4	100.0	88.3	78.2	69.3	61.6	54.8	48.9	43.6	39.0	35.0	31.4	28.2	25.4	22.9	20.6	18.6	17.5
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	190.4	166.8	146.4	128.8	113.5	100.3	88.8	78.7	69.9	62.2	55.5	49.5	44.3	39.7	35.6	32.0	28.8	26.0	23.4	21.2	19.9
121	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	189.2	166.0	146.1	128.8	113.8	100.7	89.3	79.3	70.6	62.9	56.2	50.3	45.0	40.4	36.3	32.7	29.4	26.6	24.0	22.6
122	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.1	165.5	145.9	128.9	114.0	101.1	89.8	80.0	71.3	63.7	56.9	51.0	45.8	41.1	37.0	33.3	30.1	27.2	25.6
123	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	187.2	165.0	145.8	129.0	114.4	101.6	90.5	80.6	72.0	64.4	57.7	51.8	46.5	41.9	37.7	34.0	30.8	29.0
124	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	186.5	164.8	145.8	129.3	114.9	102.2	91.1	81.4	72.8	65.2	58.5	52.6	47.3	42.6	38.5	34.8	32.7
125	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	186.0	164.6	146.0	129.7	115.4	102.9	91.9	82.2	73.6	66.1	59.4	53.4	48.1	43.4	39.3	37.0
126	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.6	164.6	146.2	130.1	116.0	103.6	92.7	83.0	74.5	66.9	60.2	54.3	49.0	44.3	41.7
127	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.4	164.7	146.6	130.7	116.7	104.4	93.5	83.9	75.4	67.8	61.1	55.2	49.9	46.9
128	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.3	164.9	147.1	131.3	117.5	105.2	94.4	84.8	76.3	68.8	62.1	56.1	52.8
129	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.4	165.3	147.6	132.0	118.3	106.1	95.4	85.8	77.3	69.8	63.1	59.4
130	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.6	165.8	148.3	132.8	119.7	107.1	96.4	86.8	78.4	70.8	66.7
131	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.9	166.3	149.0	133.7	120.1	108.1	97.4	87.9	79.4	74.8
132	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	186.4	167.0	149.8	134.6	121.2	109.2	98.5	89.0	83.8
133	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	187.0	167.7	150.7	135.6	122.2	110.3	99.7	93.9
134	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	187.6	168.6	151.7	136.7	123.4	111.5	105.0

Figure B-60 Tabular Representation of Parking Nomograph for B767-300ER on 27 °F (-2.5 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

Gross B-767-300ER Weight (lbs)

Ice Thickness (in)

27 F	205000	210000	215000	220000	225000	230000	235000	240000	245000	250000	255000	260000	265000	270000	275000	280000	285000	290000	295000	300000	305000	310000	315000	320000	325000	330000	335000	340000	345000	350000	355000	360000	365000	370000	375000	380000	385000	388000
52	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
53	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
54	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
55	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
56	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0
57	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
58	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
59	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
60	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
61	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
62	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
63	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
64	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
65	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
66	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1
67	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
68	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
69	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
70	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
71	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
72	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2
73	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
74	1.4	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
75	1.5	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3
76	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3
77	1.7	1.6	1.5	1.5	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3
78	2.7	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4
79	3.3	2.8	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4
80	4.1	3.4	2.9	2.4	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4
81	5.1	4.3	3.5	3.0	2.5	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5
82	6.3	5.2	4.4	3.7	3.1	2.6	1.7	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5
83	7.8	6.4	5.4	4.5	3.8	3.2	2.7	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5
84	9.5	7.9	6.6	5.5	4.6	3.9	3.3	2.8	2.4	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6
85	11.6	9.6	8.0	6.7	5.6	4.7	4.0	3.4	2.9	2.5	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6
86	14.0	11.6	9.7	8.1	6.8	5.8	4.9	4.1	3.5	3.0	2.6	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.6
87	17.0	14.1	11.8	9.8	8.3	7.0	5.9	5.0	4.3	3.6	3.1	2.7	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7
88	20.5	17.0	14.2	11.9	10.0	8.4	7.1	6.0	5.2	4.4	3.8	3.3	2.8	2.4	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7
89	24.7	20.5	17.1	14.3	12.0	10.1	8.6	7.3	6.2	5.3	4.6	3.9	3.4	2.9	2.5	1.8	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8
90	29.7	24.6	20.5	17.2	14.4	12.2	10.3	8.7	7.5	6.4	5.5	4.7	4.1	3.5	3.0	2.6	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8
91	35.5	29.5	24.6	20.6	17.3	14.6	12.3	10.5	8.9	7.6	6.5	5.6	4.9	4.2	3.6	3.2	2.8	2.4	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.9
92	42.4	35.2	29.3	24.5	20.6	17.4	14.7	12.5	10.7	9.1	7.8	6.7	5.8	5.0	4.3	3.8	3.3	2.9	2.5	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9
93	50.5	41.9	34.9	29.2	24.6	20.7	17.5	14.9	12.7	10.8	9.3	8.0	6.9	6.0	5.2	4.5	3.9	3.4	3.0	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0
94	60.1	49.8	41.5	34.7	29.2	24.6	20.8	17.7	15.1	12.9	11.1	9.5	8.2	7.1	6.2	5.4	4.7	4.1	3.6	3.1	2.8	2.4	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0
95	71.2	59.1	49.2	41.2	34.6	29.2	24.7	21.0	17.9	15.3	13.1	11.3	9.7	8.4	7.3	6.3	5.5	4.8	4.2	3.7	3.3	2.9	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1
96	84.2	69.8	58.2	48.7	40.9	34.5	29.2	24.8	21.1	18.1	15.5	13.3	11.5	9.9	8.6	7.5	6.5	5.7	5.0	4.4	3.9	3.4	3.0	2.7	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1
97	99.3	82.4	68.7	57.4	48.3	40.7	34.4	29.3	24.9	21.3	18.3	15.7	13.6	11.7	10.2	8.9	7.7	6.7	5.9	5.2	4.6	4.0	3.6	3.1	2.8	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2
98	116.9	97.0	80.8	67.6	56.8	47.9	40.6	34.4	29.4	25.1	21.5	18.5	16.0	13.8	12.0	10.4	9.1	7.9	7.0	6.1	5.4	4.7	4.2	3.7	3.3	2.9	2.6	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.3
99	137.4	114.0	95.0	79.5	66.7	56.3	47.6	40.5	34.5	29.5	25.3	21.8	18.8	16.2	14.1	12.2	10.7	9.3	8.2	7.2	6.3	5.6	4.9	4.3	3.9	3.4	3.0	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3
100	161.0	133.6	111.3	93.2	78.3	66.0	55.9	47.4	40.4	34.6	29.7	25.5	22.0	19.0	16.5	14.4	12.5	10.9	9.6	8.4	7.4	6.5	5.8	5.1	4.5	4.0	3.6	3.2	2.8	2.5	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.4
101	188.4	156.3	130.3	109.0	91.6	77.2	65.4	55.5	47.3	40.5	34.7	29.8	25.7	22.3	19.3	16.8	14.6	12.8	11.2	9.8	8.7	7.6	6.7	6.0	5.3	4.7	4.2	3.7	3.3	3.0	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.5
102	>200	182.5	152.1	127.3	106.9	90.2	76.3	64.8	55.3	47.2	40.5	34.9	30.1	26.0	22.6	19.6	17.1	14.9	13.1	11.5	10.1	8.9	7.9	7.0	6.2	5.5	4.9	4.4	3.9	3.5	3.1	2.8	2.5	1.8	1.7	1.7	1.6	1.6
103	>200	>200	177.3	148.3	124.6	105.1	89.0	75.6	64.4	55.1	47.2	40.6	35.0	30.3	26.3	22.9	19.9	17.4	15.3	13.4	11.8	10.4	9.2	8.1	7.2	6.4	5.7	5.1	4.5	4.1	3.6	3.3	2.9	2.6	2.4	1.7	1.7	1.6
104	>200	>200	>200	172.6	145.0	122.3	103.5	87.9	74.9	64.1	54.9	47.3	40.8	35.3	30.6	26.6	23.2	20.3	17.8	15.6	13.7	12.1	10.7	9.4	8.4	7.4	6.6	5.9	5.3	4.7	4.2	3.8	3.4	3.1	2.8	2.5	1.8	1.7
105	>200	>200	>200	>200	168.4	142.0	120.2	102.1	87.0	74.4	63.8	54.9	47.3	41.0	35.5	30.9	26.9	23.5	20.6	18.1	15.9	14.0	12.4	11.0	9.7	8.6	7.7	6.9	6.1	5.5	4.9	4.4	4.0	3.6	3.2	2.9	2.6	2.5
106	>200	>200	>200	>200	195.2	164.6	139.3	118.3	100.9	86.2	74.0	63.6	54.9	47.5	41.2	35.8	31.2	27.3	23.9	21.0	18.5	16.3	14.4	12.7	11.3	10.0	8.9	7.9	7.1	6.3	5.7	5.1	4.6	4.1	3.7	3.4	3.0	2.9
107	>200	>200	>200	>200	>200	190.5	161.2	137.0	116.7	99.8	85.6	73.6	63.5	55.0	47.7	41.5	36.1	31.6	27.7	24.3	21.4	18.8	16.6	14.7	13.1	11.6	10.3	9.2	8.2	7.3	6.6	5.9	5.3	4.8	4.3	3.9	3.5	3.3
108	>200	>200	>200	>200	>200	>200	186.3	158.7	134.9	115.3	98.9	85.1	73.4	63.5	55.1	47.9	41.8	36.5	32.0	28.1	24.7	21.8	19.2	17.0	15.1	13.4	11.9	10.6	9.5	8.5	7.6	6.8	6.1	5.5	5.0	4.5	4.1	3.8
109	>200	>200	>200	>200	>200	>200	>200	182.5	155.6	133.0	114.1	98.1	84.7	73.2	63.5	55.2	48.2	42.1	36.9	32.4	28.5	25.1	22.2	19.6	17.4	15.5	13.8	12.3	10.9	9.8	8.8	7.9	7.1	6.4	5.7	5.2	4.7	4.4
110	>200	>200	>200	>200	>200	>200	>200	>200	179.2	153.2	131.4	113.0	97.5	84.4	73.2	63.6	55.5	48.5	42.5	37.3	32.8	28.9	25.5	22.6	20.0	17.8	15.8	14.1	12.6	11.3	10.1	9.1	8.1	7.3	6.6	6.0	5.4	5.1
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	176.2	151.1	130.0	112.1	97.0	84.1	73.2	63.8	55.7	48.8	42.9	37.7	33.2	29.4	26.0	23.0	20.5	18.2	16.2	14.5	13.0	11.6	10.4	9.4	8.4	7.6	6.9	6.2	5.8
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	173.5	149.2	128.7	111.4	96.6	84.0	73.2	64.0	56.1	49.2	43.3	38.2	33.7	29.8	26.5	23.5	20.9	18.6	16.6	14.9	13.3	12.0	10.8	9.7	8.7	7.9	7.1	6.7
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	198.9	171.1	147.6	127.7	110.8	96.3	84.0	73.4	64.3	56.4	49.6	43.8	38.6	34.2	30.3	26.9	24.0	21.4	19.1	17.1	15.3	13.7	12.3	11.1	10.0	9.0	8.2	7.7
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	195.9	169.0	146.2	126.8	110.3	96.1	84.0	73.6	64.6	56.8	50.1	44.2	39.2	34.7	30.8	27.5	24.5	21.9	19.5	17.5	15.7	14.1	12.7	11.4	10.3	9.3	8.8
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.2	167.1	145.0	126.1	109.9	96.0	84.1	73.8	65.0	57.3	50.6	44.8	39.7	35.3	31.4	28.0	25.0	22.3	20.0	18.0	16.1	14.5	13.1	11.8	10.7	10.0
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	190.8	165.5	143.9	125.5	109.7	96.0	84.3	74.2	65.4	57.8	51.1	45.3	40.3	35.8	31.9	28.5	25.5	22.9	20.5	18.4	16.6	14.9	13.5	12.2	11.5
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	188.7	164.1	143.1	125.0	109.5	96.1	84.6	74.5	65.9	58.3	51.7	45.9	40.9	36.4	32.5	29.1	26.1	23.4	21.0	18.9	17.0	15.4	13.9	13.1
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	186.9	162.9	142.4	124.7	109.5	96.3	84.9	75.0	66.4	58.8	52.3	46.5	41.5	37.0	33.1	29.7	26.6	23.9	21.5	19.4	17.5	15.8	14.9
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.3	161.9	141.8	124.5	109.5	96.5	85.3	75.5	66.9	59.5	52.9	47.2	42.1	37.7	33.8	30.3	27.2	24.5	22.1	19.9	18.0	16.9
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	183.9	161.1	141.4	124.4	109.6	96.9	85.7	76.0	67.5	60.1	53.6	47.8	42.8	38.3	34.4	30.9	27.8	25.1	22.6	20.4	19.2
121	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	182.7	160.4	141.1	124.4	109.9	97.2	86.2	76.6	68.2	60.8	54.3	48.5	43.5	39.0	35.1	31.6	28.4	25.7	23.2	21.8
122	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.7	159.9	140.9	124.5	110.2	97.7	86.8	77.2	68.9	61.5	55.0	49.3	44.2	39.7	35.7	32.2	29.1	26.3	24.7
123	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.9	159.5	140.9	124.7	110.6	98.2	87.4	77.9	69.6	62.2	55.8	50.0	45.0	40.5	36.5	32.9	29.7	28.0
124	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.3	159.3	141.0	125.0	111.0	98.8	88.1	78.7	70.4	63.0	56.6	50.8	45.7	41.2	37.2	33.6	31.6
125	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.8	159.2	141.1	125.4	111.6	99.5	88.8	79.5	71.2	63.9	57.4	51.6	46.5	42.0	37.9	35.7
126	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.5	159.2	141.4	125.9	112.2	100.2	89.6	80.3	72.0	64.7	58.2	52.5	47.4	42.8	40.3
127	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.3	159.3	141.8	126.4	112.9	101.0	90.5	81.2	72.9	65.6	59.1	53.4	48.2	45.4
128	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.3	159.6	142.3	127.0	113.6	101.8	91.3	82.1	73.9	66.6	60.1	54.3	51.1
129	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.4	160.0	142.8	127.8	114.5	102.7	92.3	83.0	74.8	67.5	61.0	57.5
130	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.7	160.4	143.5	128.6	115.3	103.6	93.3	84.1	75.8	68.5	64.5
131	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.0	161.0	144.7	129.4	116.3	104.7	94.3	85.1	76.9	72.4
132	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.5	161.7	145.1	130.4	117.3	105.7	95.4	86.2	81.2
133	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.1	162.5	146.0	131.4	118.4	106.8	96.5	90.9
134	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.8	163.3	147.0	132.4	119.5	108.0	101.7

Figure B-61 Tabular Representation of Parking Nomograph for B767-300ER on 28 °F (-2 °C) Sea Ice

(Values in Table are Parking Time in Hours at a Single Location)

Gross B-767-300ER Weight (lbs)

28 F / Ice Thickness (in)	205000	210000	215000	220000	225000	230000	235000	240000	245000	250000	255000	260000	265000	270000	275000	280000	285000	290000
52	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
53	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
54	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
55	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
56	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
57	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
58	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
59	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1
60	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1
61	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
62	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
63	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
64	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2
65	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3
66	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3
67	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3
68	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3
69	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4
70	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4
71	1.1	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4
72	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5
73	1.3	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5
74	1.4	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6
75	1.5	1.4	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6
76	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7
77	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7
78	2.6	1.7	1.6	1.5	1.5	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.8
79	3.2	2.6	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8
80	4.0	3.3	2.7	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9
81	4.9	4.1	3.4	2.8	2.4	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9
82	6.1	5.0	4.2	3.5	2.9	2.5	1.7	1.6	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0
83	7.4	6.2	5.1	4.3	3.6	3.0	2.6	1.7	1.7	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1
84	9.1	7.6	6.3	5.3	4.4	3.7	3.2	2.7	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2
85	11.1	9.2	7.7	6.4	5.4	4.5	3.9	3.3	2.8	2.4	1.7	1.6	1.6	1.5	1.4	1.3	1.3	1.2
86	13.5	11.2	9.3	7.8	6.6	5.5	4.7	4.0	3.4	2.9	2.5	1.7	1.7	1.6	1.5	1.4	1.4	1.3
87	16.4	13.6	11.3	9.5	7.9	6.7	5.7	4.8	4.1	3.5	3.0	2.6	1.8	1.7	1.6	1.5	1.5	1.4
88	19.8	16.4	13.7	11.4	9.6	8.1	6.9	5.8	5.0	4.2	3.6	3.1	2.7	1.8	1.7	1.6	1.6	1.5
89	23.8	19.8	16.5	13.8	11.6	9.8	8.3	7.0	6.0	5.1	4.4	3.8	3.3	2.8	2.4	1.7	1.7	1.6
90	28.6	23.7	19.8	16.5	13.9	11.7	9.9	8.4	7.2	6.1	5.3	4.5	3.9	3.4	2.9	2.5	1.8	1.7
91	34.3	28.4	23.7	19.8	16.6	14.0	11.9	10.1	8.6	7.4	6.3	5.4	4.7	4.0	3.5	3.1	2.7	1.8
92	40.9	34.0	28.3	23.7	19.9	16.8	14.2	12.1	10.3	8.8	7.5	6.5	5.6	4.8	4.2	3.6	3.2	2.8
93	48.8	40.5	33.7	28.2	23.7	20.0	16.9	14.4	12.2	10.5	9.0	7.7	6.7	5.8	5.0	4.3	3.8	3.3
94	58.0	48.1	40.1	33.5	28.2	23.8	20.1	17.1	14.6	12.4	10.7	9.2	7.9	6.9	5.9	5.2	4.5	3.9
95	68.8	57.0	47.5	39.8	33.4	28.2	23.9	20.3	17.3	14.8	12.7	10.9	9.4	8.1	7.0	6.1	5.3	4.7
96	81.4	67.5	56.2	47.1	39.5	33.3	28.2	24.0	20.4	17.5	15.0	12.9	11.1	9.6	8.3	7.3	6.3	5.5
97	96.0	79.7	66.4	55.5	46.7	39.4	33.3	28.3	24.1	20.6	17.7	15.2	13.1	11.3	9.8	8.6	7.5	6.5
98	113.1	93.8	78.2	65.4	55.0	46.3	39.2	33.3	28.4	24.3	20.8	17.9	15.5	13.4	11.6	10.1	8.8	7.7
99	132.9	110.3	91.9	76.9	64.6	54.5	46.1	39.2	33.4	28.5	24.5	21.1	18.2	15.7	13.6	11.9	10.3	9.0
100	155.9	129.3	107.8	90.2	75.8	63.9	54.1	45.9	39.1	33.5	28.7	24.7	21.3	18.4	16.0	13.9	12.1	10.6
101	182.5	151.4	126.1	105.5	88.7	74.8	63.3	53.8	45.8	39.2	33.6	28.9	24.9	21.6	18.7	16.3	14.2	12.4
102	>200	176.8	147.3	123.3	103.6	87.3	73.9	62.8	53.5	45.8	39.2	33.8	29.1	25.2	21.9	19.0	16.6	14.5
103	>200	>200	171.8	143.7	120.8	101.8	86.2	73.2	62.4	53.4	45.8	39.4	34.0	29.4	25.5	22.2	19.3	16.9
104	>200	>200	199.9	167.3	140.5	118.5	100.3	85.2	72.6	62.1	53.3	45.8	39.5	34.2	29.7	25.8	22.5	19.6
105	>200	>200	>200	194.3	163.3	137.7	116.5	99.0	84.4	72.1	61.9	53.2	45.9	39.7	34.5	30.0	26.1	22.8
106	>200	>200	>200	>200	189.3	159.7	135.1	114.8	97.8	83.6	71.7	61.7	53.2	46.1	40.0	34.7	30.3	26.5
107	>200	>200	>200	>200	>200	184.8	156.4	132.9	113.3	96.8	83.1	71.4	61.6	53.3	46.2	40.2	35.1	30.6
108	>200	>200	>200	>200	>200	>200	180.8	153.6	130.9	111.9	96.0	82.6	71.2	61.6	53.5	46.5	40.5	35.4
109	>200	>200	>200	>200	>200	>200	>200	177.2	151.0	129.1	110.7	95.3	82.2	71.1	61.7	53.6	46.8	40.9
110	>200	>200	>200	>200	>200	>200	>200	>200	174.0	148.8	127.6	109.8	94.7	81.9	71.1	61.8	53.9	47.1
111	>200	>200	>200	>200	>200	>200	>200	>200	>200	171.1	146.7	126.2	108.9	94.2	81.7	71.1	62.0	54.1
112	>200	>200	>200	>200	>200	>200	>200	>200	>200	196.5	168.5	145.0	125.1	108.2	93.9	81.6	71.2	62.2
113	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	193.3	166.3	143.4	124.1	107.6	93.6	81.6	71.3
114	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	190.4	164.3	142.1	123.3	107.2	93.4	81.7
115	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	187.8	162.5	141.0	122.6	106.9	93.4
116	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	185.6	161.0	140.0	122.0	106.6
117	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	183.6	159.6	139.2	121.6
118	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	181.8	158.5	138.5
119	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	180.3	157.5
120	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	179.0
121	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
122	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
123	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
124	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
125	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
126	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
127	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
128	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
129	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
130	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
131	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
132	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
133	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200
134	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200

28 F / Ice Thickness (in)	295000	300000	305000	310000	315000	320000	325000	330000	335000	340000	345000	350000	355000	360000	365000	370000	375000	380000	385000	388000
52	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
53	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
54	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
55	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
56	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0
57	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0
58	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
59	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
60	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
61	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
62	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
63	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
64	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
65	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
66	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1
67	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1
68	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
69	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
70	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
71	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
72	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2
73	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2
74	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
75	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3
76	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3
77	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3
78	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4
79	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4
80	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4
81	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5
82	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5
83	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5
84	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6
85	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6
86	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6
87	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7
88	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7
89	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8
90	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8
91	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.9
92	2.4	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9
93	2.9	2.5	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	1.0
94	3.4	3.0	2.7	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0
95	4.1	3.6	3.2	2.8	2.5	1.7	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.1	1.1	1.1
96	4.8	4.2	3.7	3.3	2.9	2.6	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1
97	5.7	5.0	4.4	3.9	3.4	3.0	2.7	2.4	1.7	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.3	1.2	1.2
98	6.7	5.9	5.2	4.6	4.0	3.6	3.2	2.8	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.3
99	7.9	6.9	6.1	5.4	4.8	4.2	3.7	3.3	2.9	2.6	1.8	1.7	1.7	1.6	1.6	1.5	1.4	1.4	1.4	1.3
100	9.3	8.1	7.2	6.3	5.6	4.9	4.4	3.9	3.5	3.1	2.8	2.5	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4
101	10.9	9.5	8.4	7.4	6.5	5.8	5.1	4.5	4.0	3.6	3.2	2.9	2.6	1.8	1.7	1.7	1.6	1.6	1.5	1.5
102	12.7	11.1	9.8	8.6	7.6	6.7	6.0	5.3	4.7	4.2	3.8	3.4	3.0	2.7	2.4	1.7	1.7	1.6	1.6	1.6
103	14.8	13.0	11.4	10.1	8.9	7.9	7.0	6.2	5.5	4.9	4.4	3.9	3.5	3.2	2.8	2.6	1.8	1.7	1.7	1.6
104	17.2	15.1	13.3	11.7	10.3	9.2	8.1	7.2	6.4	5.7	5.1	4.6	4.1	3.7	3.3	3.0	2.7	2.4	1.7	1.7
105	20.0	17.5	15.4	13.6	12.0	10.6	9.4	8.4	7.5	6.6	5.9	5.3	4.8	4.3	3.8	3.5	3.1	2.8	2.5	2.4
106	23.2	20.3	17.9	15.8	13.9	12.3	10.9	9.7	8.6	7.7	6.9	6.2	5.5	4.9	4.4	4.0	3.6	3.3	2.9	2.8
107	26.8	23.6	20.7	18.3	16.1	14.3	12.7	11.2	10.0	8.9	8.0	7.1	6.4	5.7	5.1	4.6	4.2	3.8	3.4	3.2
108	31.0	27.2	24.0	21.1	18.6	16.5	14.6	13.0	11.6	10.3	9.2	8.2	7.4	6.6	5.9	5.4	4.8	4.4	3.9	3.7
109	35.8	31.4	27.6	24.4	21.5	19.0	16.9	15.0	13.4	11.9	10.6	9.5	8.5	7.6	6.9	6.2	5.6	5.0	4.5	4.3
110	41.2	36.2	31.8	28.1	24.8	21.9	19.5	17.3	15.4	13.7	12.2	11.0	9.8	8.8	7.9	7.1	6.4	5.8	5.2	4.9
111	47.4	41.6	36.6	32.3	28.5	25.2	22.4	19.9	17.7	15.8	14.1	12.6	11.3	10.1	9.1	8.2	7.4	6.7	6.0	5.7
112	54.5	47.8	42.1	37.1	32.8	29.0	25.7	22.8	20.3	18.1	16.2	14.5	13.0	11.6	10.4	9.4	8.5	7.6	6.9	6.5
113	62.5	54.8	48.2	42.5	37.6	33.2	29.5	26.2	23.3	20.8	18.6	16.6	14.9	13.3	12.0	10.8	9.7	8.8	7.9	7.5
114	71.5	62.8	55.2	48.7	43.0	38.1	33.8	30.0	26.7	23.8	21.2	19.0	17.0	15.3	13.7	12.3	11.1	10.0	9.1	8.5
115	81.8	71.8	63.2	55.7	49.2	43.5	38.6	34.3	30.5	27.2	24.3	21.7	19.5	17.5	15.7	14.1	12.7	11.5	10.4	9.8
116	93.4	82.0	72.1	63.6	56.2	49.7	44.1	39.2	34.9	31.1	27.7	24.8	22.2	19.9	17.9	16.1	14.5	13.1	11.9	11.2
117	106.5	93.5	82.3	72.5	64.1	56.7	50.3	44.7	39.7	35.4	31.6	28.3	25.4	22.7	20.4	18.4	16.6	15.0	13.5	12.7
118	121.3	106.5	93.7	82.6	73.0	64.6	57.3	50.9	45.3	40.4	36.0	32.2	28.9	25.9	23.3	20.9	18.9	17.0	15.4	14.5
119	138.0	121.1	106.6	93.9	83.0	73.4	65.1	57.9	51.5	45.9	41.0	36.7	32.8	29.5	26.5	23.8	21.5	19.4	17.5	16.5
120	156.8	137.6	121.1	106.7	94.3	83.4	74.0	65.7	58.5	52.1	46.6	41.7	37.3	33.5	30.1	27.1	24.4	22.0	19.9	18.7
121	177.9	156.1	137.4	121.1	107.0	94.7	83.9	74.6	66.4	59.2	52.8	47.3	42.3	38.0	34.1	30.7	27.7	25.0	22.6	21.3
122	>200	176.9	155.7	137.2	121.2	107.3	95.1	84.5	75.2	67.1	59.9	53.6	48.0	43.0	38.7	34.8	31.4	28.3	25.6	24.1
123	>200	>200	176.2	155.3	137.2	121.4	107.7	95.7	85.1	75.9	67.8	60.6	54.3	48.7	43.8	39.4	35.5	32.0	29.0	27.3
124	>200	>200	199.2	175.6	155.1	137.3	121.8	108.2	96.3	85.8	76.6	68.5	61.4	55.1	49.5	44.6	40.1	36.2	32.7	30.8
125	>200	>200	>200	198.3	175.2	155.1	137.5	122.2	108.7	96.9	86.5	77.4	69.3	62.2	55.9	50.3	45.3	40.9	37.0	34.8
126	>200	>200	>200	>200	197.6	174.9	155.1	137.8	122.6	109.3	97.6	87.3	78.2	70.2	63.1	56.8	51.1	46.2	41.7	39.3
127	>200	>200	>200	>200	>200	197.1	174.8	155.3	138.2	123.2	110.0	98.4	88.2	79.1	71.1	64.0	57.6	52.0	47.0	44.3
128	>200	>200	>200	>200	>200	>200	196.8	174.8	155.6	138.7	123.8	110.8	99.2	89.0	80.0	72.0	64.9	58.6	52.9	49.8
129	>200	>200	>200	>200	>200	>200	>200	196.6	174.9	155.9	139.3	124.6	111.6	100.1	90.0	81.0	73.0	65.8	59.5	56.0
130	>200	>200	>200	>200	>200	>200	>200	>200	196.5	175.2	156.4	139.9	125.4	112.5	101.1	90.9	82.0	74.0	66.8	62.9
131	>200	>200	>200	>200	>200	>200	>200	>200	>200	196.6	175.6	157.0	140.7	126.2	113.4	102.1	92.0	83.0	75.0	70.6
132	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	196.8	176.0	157.7	141.5	127.2	114.4	103.1	93.1	84.1	79.2
133	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.2	176.6	158.5	142.4	128.2	115.5	104.2	94.2	88.7
134	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	>200	197.6	177.3	159.4	143.4	129.2	116.6	105.4	99.2

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B-10 TEST PLAN FOR SEA ICE RUNWAY WHEELED AIRCRAFT OPERATIONS CERTIFICATION

B-10.1 Introduction.

This test plan documents and explains the required steps, methods, and tools required to certify the sea ice runway for wheeled aircraft operations. The primary attributes that govern certification are dimensions and grades, markings, pavement strength (short and long term), and ice temperature profiles.

B-10.2 Certification Process.

B-10.2.1 Dimensions and Grades.

B-10.2.1.1

Measure features in the airfield area (as depicted in Figures 2-1, 2-3, and 2-5). Use available and expedient survey methods and tools (e.g., taping, measuring wheel, transit, laser) to verify that the dimensions and grades of the following airfield components are as required in Tables 2-1 through 2-4.

- Runway
- Shoulders
- Overrun area (each end, if present)
- Taxiway
- Apron (refuel, load/unload, turnaround)
- End clear areas
- Lateral clear areas

B-10.2.1.2

Verify dimensions and grades of each feature at the approximate locations shown in Figures 2-1, 2-3, and 2-5. Note that some areas and zones will blend seamlessly (without indication) into other areas, such as where the runway width transitions to the shoulders. In these situations, simply measure and verify that the combined dimensions of the features are per specification.

B-10.2.1.3

On Figures 2-1, 2-3, and 5, place a check mark (✓) by each dimension and grade that has been measured and approved and place an X by any dimension that fails the inspection, noting where the failure is located. Measurements that fail the inspection must be documented and brought to the attention of the airfield manager.

B-10.2.2 Markings, Lighting, and NAVAIDS.

UFC 3-535-01 governs the placement of markings and NAVAIDS.

B-10.2.2.1

Check that markings, lighting, and NAVAIDS are in the correct positions and properly annotated as described in paragraphs 2-3, 2-4, and 2-5. **Note:** Direct on-snow marking is prohibited.

B-10.2.2.2

Verify that the bottom of the marker (flag) is at least 0.3 meter (1 foot) above the snow surface. Marker dimensions (which vary depending on required markings) must conform to Figure 2-6, Detail 3.

B-10.2.2.3

Check that flags are attached to frangible (break-away or bend-away) poles. Suitable poles can be made of common bamboo or lightweight plastic, but must not be metal or large, solid wood (e.g., 100-millimeter by 100-millimeter [4-inch by 4-inch] posts).

B-10.2.2.4

Each flag will be stretched out between two poles and attached to the poles by means that are wind-proof and sturdy (but removable), such as with clamps and cords.

B-10.2.2.5

On Figure 2-5, place a check mark (✓) by each flag that is properly placed and marked, and place an X by any missing, misplaced, or improperly marked flags. Flagging problems must be documented and brought to the attention of the airfield manager.

B-10.2.3 Sea Ice Temperature.

Note: Required with or without the presence of snow cap on sea ice surface.

B-10.2.3.1

The importance of temperature measurements for structural certification cannot be overstressed. Sea ice temperature is ideally measured with a continuously recording imbedded sensor string located at a number of representative locations. If such sensors are not available, manual temperature readings must be taken during the warmest (air temperature) three-hour period during the day. Collect ice temperatures (measured at a depth of 150 millimeters [6 inches]) at a minimum of four locations on the runway proper and at two locations in the apron/parking area. Temperature data will be collected at a minimum of the following frequencies:

- Period 1: Once every two weeks
- Period 2: Once every week
- Period 3: Three times per week; and 24 hours before each C-17 aircraft flight.
- Period 4: Once every day

B-10.2.3.2 Sea Ice Evaluation Temperature.

The sea ice temperature used for evaluating the structural capacity (referred to as the “evaluation temperature”) shall be determined by calculating the simple average of the measured temperatures at the (minimum) six locations sampled. For example, if the measured temperatures are 10, 12, 13, 11, 14 and 10 °F, the evaluation temperature is equal to (10+12+13+11+14+10) ÷ 6 = 11.7 °F. The evaluation temperature is then used, with sea ice thickness to determine safe landing and parking parameters.

B-10.2.4 Sea Ice Thickness.

B-10.2.4.1

The sea ice thickness used for evaluating the structural capacity (referred to as the “evaluation thickness”) will be determined using a statistical approach applied to the set of measured thickness data points. The evaluation thickness shall be equal to or less than 85% of all the measured thicknesses. This corresponds to an evaluation thickness of one standard deviation below the mean. If 10 or less thickness measurements are made then the lowest of the measured values shall be used as the evaluation thickness. An example calculation to establish the statistical sea ice thickness used for evaluation purposes is detailed in Appendix B-7.

B-10.2.4.2

Actual ice thickness must be measured at no less than 16 random locations spread throughout the runway surface, with no less than half being located within a 15-meter (50-foot) -wide swath down the center of the runway. Ideally, since a statistical approach is used, more measurements will lead to greater confidence levels. Thickness measurements must begin at least 10 days before the intended onset of flight operations. Measurements will continue throughout the entire duration of flight operations. Measurement frequency will be the same as for temperature measurements (see paragraph B-10.2.3.1).

B-10.2.5 Measurement Density.

Increased measurement density over that given in paragraph B-10.2.3.1 (for temperature or thickness) is only required during operating periods when the average thickness of the sea ice is nearing the point where it may limit gross aircraft weights and parking times for the aircraft type to be operated. For large aircraft, this will likely be the case any time first-year sea ice is encountered. See Appendix B-7 for a description of the process for statistically establishing sea ice thickness.

B-10.2.6 Approval and Documentation Storage.

The certification team leader and the airfield manager will sign the final results from the data analysis. These signed documents and the electronic and hardcopy data and analysis results will be provided to and maintained by the airfield manager and will also be provided to the certification team leader for forwarding to HQ AMC/A7OI.

B-11 TEST PLAN FOR PEGASUS RUNWAY WHEELED AIRCRAFT OPERATIONS CERTIFICATION

B-11.1 Introduction.

This test plan documents and explains the required steps, methods, and tools required to certify the Pegasus runway for wheeled aircraft operations. The primary attributes that govern certification are dimensions and grades, markings, pavement strength (hardness), and snow and ice temperature profiles. Use this test plan, the accompanying charts (Figures B-62 and B-63), and the Ice Runway Strength Survey Tool program to achieve a satisfactory runway evaluation and analysis.

B-11.2 Certification Process.

B-11.2.1 Dimensions and Grades.

B-11.2.1.1

Measure features in the runway area (as depicted in Figures 2-1, 2-2, and 2-3). Use available and expedient survey methods and tools (e.g., taping, measuring wheel, transit, laser) to verify that the dimensions and grades of the following characteristics are as required in Tables 2-1 through 2-4.

- Runway
- Shoulders
- Overrun area (each end, if present)
- Taxiway
- Apron (refuel, load/unload, turnaround)
- End clear areas
- Lateral clearance areas

B-11.2.1.2

Dimensions and grades of each feature will be verified at the approximate locations shown in Figures 2-1 through 2-4. Note that some areas and zones will blend seamlessly (without indication) into other areas, such as where the runway width transitions to the shoulders. In these situations, simply measure and verify that the combined dimensions of the features are per specification.

B-11.2.1.3

On Figures 2-1 through 2-4, place a checkmark (✓) by each dimension and grade that has been measured and approved, and place an X by any dimension that fails the inspection, noting where the failure is located. Measurements that fail the inspection must be documented and brought to the attention of the airfield manager.

B-11.2.2 Markings, Lighting, and NAVAIDS.

Markings and NAVAIDS placement is governed by UFC 3-535-01.

B-11.2.2.1

Check that markings, lighting, and NAVAIDS are in the correct positions and properly annotated as described in paragraphs 2-3, 2-4, and 2-5. **Note: Direct on-snow marking is prohibited.**

B-11.2.2.2

Verify that the bottom of the marker (flag) is at least 0.3 meter (1 foot) above the snow surface. Marker dimensions (which vary depending on required markings) must conform to Figure 2-6, Detail 3.

B-11.2.2.3

Check that flagging is attached to frangible (break-away or bend-away) poles. Suitable poles can be made of common bamboo or lightweight plastic but must not be metal or large, solid wood (e.g., 102-millimeter by 102-millimeter [4-inch by 4-inch] posts).

B-11.2.2.4

Each flag will be stretched out between two poles and attached to the poles by means that are wind-proof and sturdy (but removable), such as clamps and cords.

B-11.2.2.5

On Figure 2-5, place a checkmark (✓) by each flag that is properly placed and marked and place an X by any missing, misplaced, or improperly marked flags. Flagging problems must be documented and brought to the attention of the airfield manager.

B-11.2.3 Pavement Hardness (Strength).

B-11.2.3.1

Measure snow pavement hardness with a DCP or RSP at the locations shown in Figure B-62 (on the circles). Penetrometer measurements can be taken at any time of day, at any air temperature, and in any weather conditions, following the procedures presented in Appendix B-1. A field data sheet (Figure B-63) is provided for logging measurements made with a DCP. The various Pegasus runway surfaces are comprised of a compacted snow pavement built upon a very thick, solid ice base. All runway surface features meant to carry an aircraft wheel load will be required to achieve the same strength rating.

B-11.2.3.2

The layout of data entry in the field data sheet (Figure B-63) is designed to allow the certification team to walk the runway in an efficient path while taking DCP or RSP hardness and temperature measurements. This field data will later be entered at McMurdo Station into a computer database for analysis and results.

B-11.2.4 Compacted Snow Temperature.

B-11.2.4.1

Surface and subsurface temperatures will be measured with a portable thermometer on the day of review at the locations shown in Figure B-62 (marked with an X). Enter these data into the field data sheet (Figure B-63). Snow temperature measurements can be taken at any time of day, at any air temperature, and in any weather conditions, but ideally will coincide with strength measurements.

B-11.2.4.2

For the portable thermometer test, a stainless-steel temperature probe is pushed into the snow on the surface and at depths of 50 millimeters, 100 millimeters (4 inches), and 150 millimeters (6 inches) (or the base of the white ice pavement), and is held against the snow for 30 seconds to gain an accurate reading. If the snow is too hard to insert the probe, a small trench will be cut out of the snow pavement to allow the probe to be inserted horizontally. The temperature probe shall be calibrated yearly.

B-11.2.4.3

If glacial ice temperatures (from either the buried probes or portable thermometer measurements) are above or have been above –4 °C (25 °F), proof rolling tests are required to inspect for potential melt damage in the warm areas. Proof rolling is described in paragraph B-4.1.1 and further described in CRREL Monograph 98-1.

B-11.2.5 Data Reduction and Analysis.

With the field data sheet in hand, re-enter the penetrometer data (blows, and penetration per blow set) and the portable thermometer temperature data into the Ice Runway Strength Survey Tool program (contact the National Science Foundation POC in paragraph 1-3 for access to this Microsoft® Excel-based program). The program will process the data and graph the DCP index value for each runway location tested, and the results will also be automatically compared to the strength go/no-go criteria given in Table B-1. Finally, the temperature data will be automatically compared to the upper limit of –4 °C (25 °F), with a final result provided.

B-11.2.6 Approval and Documentation Storage.

The certification team leader and the airfield manager will sign the final results from the data analysis. These signed approvals and the electronic and hardcopy data and analysis results will be provided to and maintained by the airfield manager and will also be provided to the certification team leader for forwarding to HQ AMC.

Figure B-62 Locations for Surface Properties Measurements

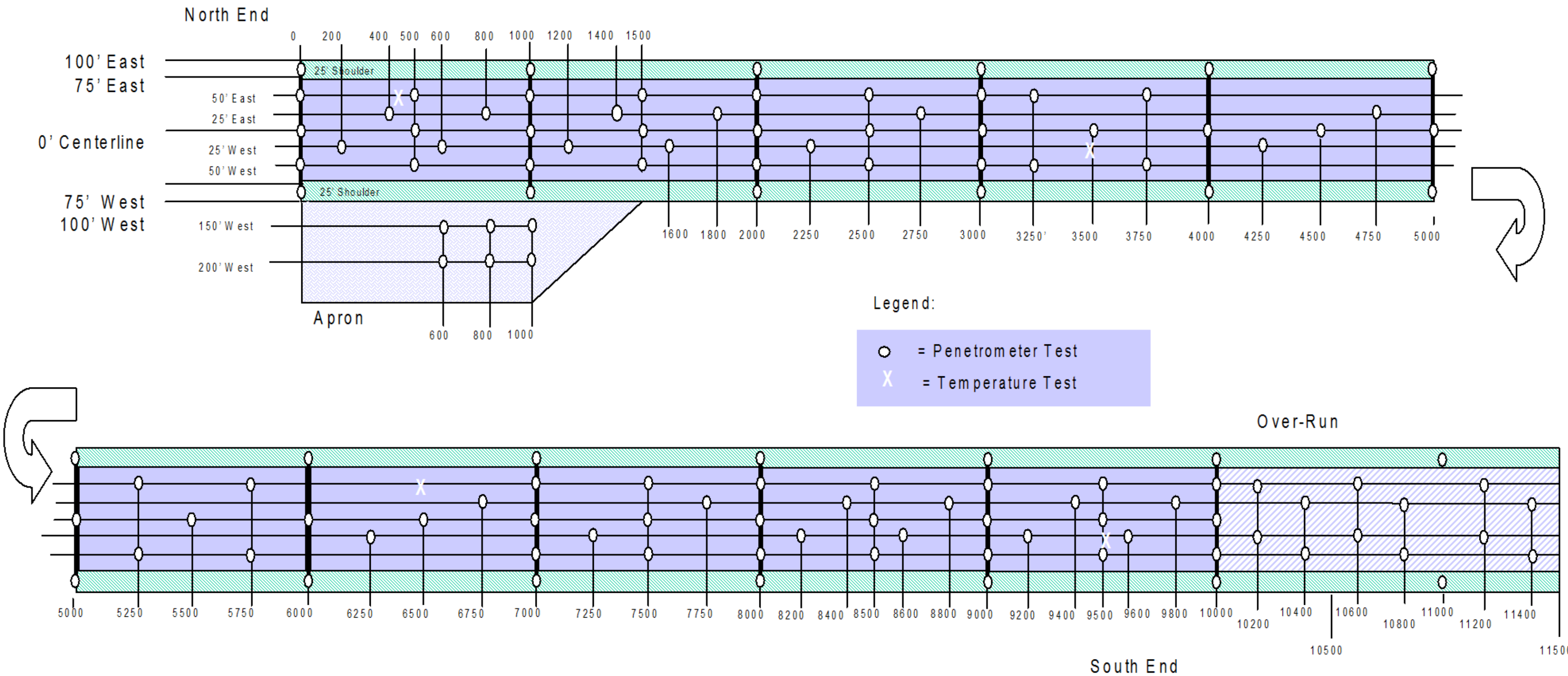


Figure B-63 Sample Field Data Sheet (Configured for DCP Measurements)

Pegasus Runway Hardness and Temperature - Field Data Sheet

DCP - Dynamic Cone Penetrometer

1. Read Separate Instructions On Proper Use and Care Of The DCP Device
2. Obtain Penetration and Temperature Data at Locations Shown Below (Also See Fig. XX).
3. Re-enter all Field Data (Blows, Accumulated Depths, Temperature) into the Runway Hardness and Temperature Analysis Program (Excel).
4. Print out Field Data Sheet and Analysis Program Results and retain at on-site location.

The Data Entry Block
(See Example Data in chart below)

Number of Blows → | 6 | 25 | ← Accumulated Penetration Depth (mm) Per Blow Set
(Blow Set) (goal is a minimum of 25 mm for each blow set)

DCP Penetrometer Field Data

DCP Data Collected By: ______________ Date: ______________ DCP Drop Weight: 17.6 lb (8.6 kg)

Accumulating Depth (mm) ⟶ (Note: The depth achieved with each Blow Set should be at least 25 mm)

Data Collection Locations		Blow Set 1		Blow Set 2		Blow Set 3		Blow Set 4		Blow Set 5		Blow Set 6		Blow Set 7		Blow Set 8		
Distance Down Runway, Feet (Starting at North End)	Lateral Location, Feet (From Runway Centerline)	Number of Blows	Accum. Depth	Number of Blows	Accum. Depth	Number of Blows	Accum. Depth	Number of Blows	Accum. Depth	Number of Blows	Accum. Depth	Number of Blows	Accum. Depth	Number of Blows	Accum. Depth	Number of Blows	Accum. Depth	Comments or Observations
	Example Data ⟶	7	25	8	50	8	75	7	100	5	125	5	150	6	175	6	200	Gas spill 2' away - soft, needs patch
(-) 1000 North OverRun	0																	
(-) 500 North OverRun	0																	
0	(+) 50																	
0	0																	
0	(-) 50																	
200	(-) 25																	
400	(+) 25																	
500	(+) 50	Temperature Test. Surface:________°C, 5cm:________°C, 10cm:________°C, 15cm:________°C																
500	(+) 50																	
500	0																	
500	(-) 50																	
600	(-) 25																	
800	(+) 25																	
1000	(+) 50																	
1000	0																	
1000	(-) 50																	
1200	(-) 25																	
1400	(+) 25																	

B-12 TYPICAL AIRFIELD LAYOUT FOR PEGASUS GLACIAL ICE RUNWAY, ROSS ICE SHELF, ANTARCTICA

Figure B-64 Pegasus Runway Site Plan

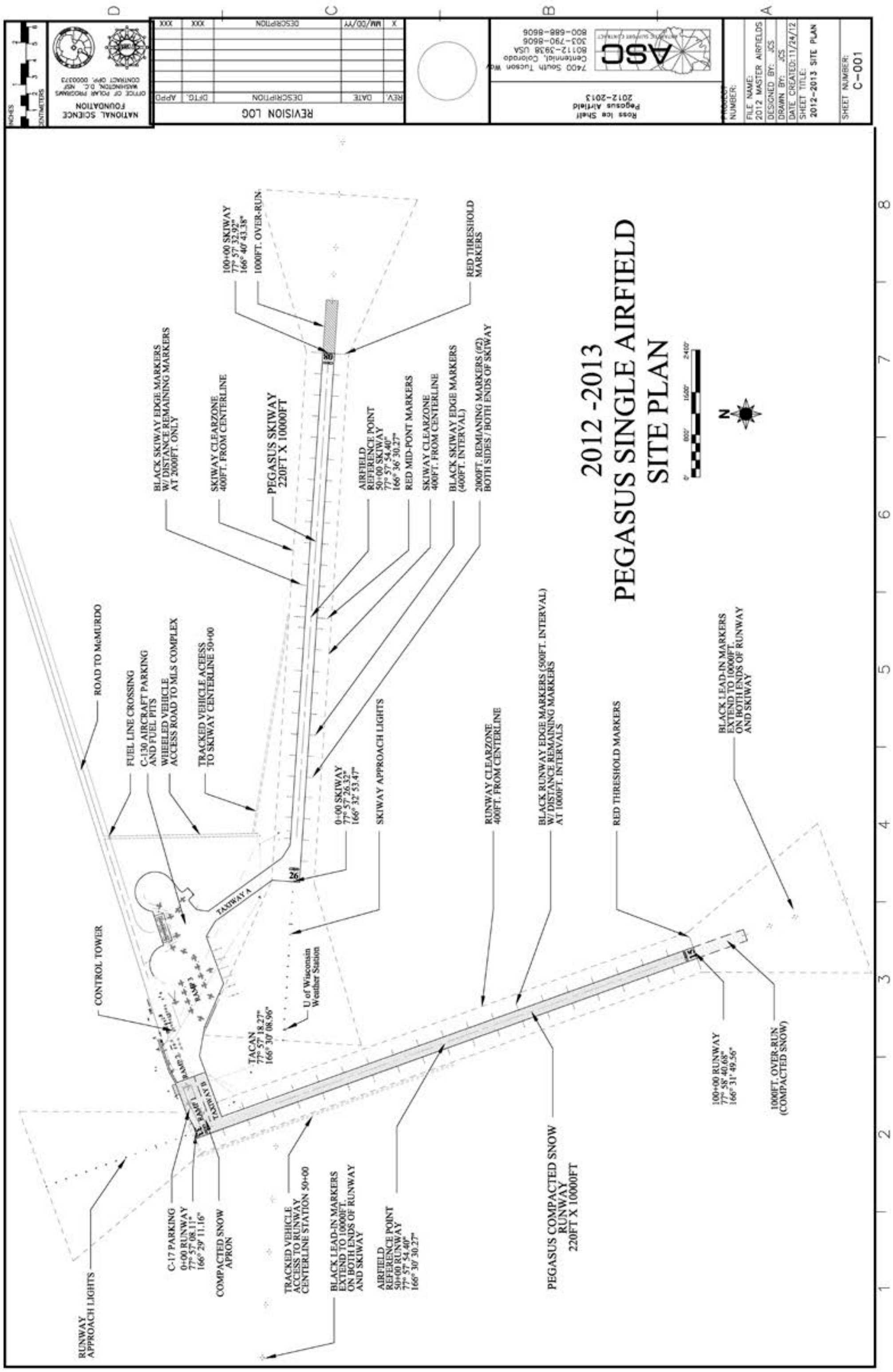


Figure B-65 Pegasus Airfield Apron Layout

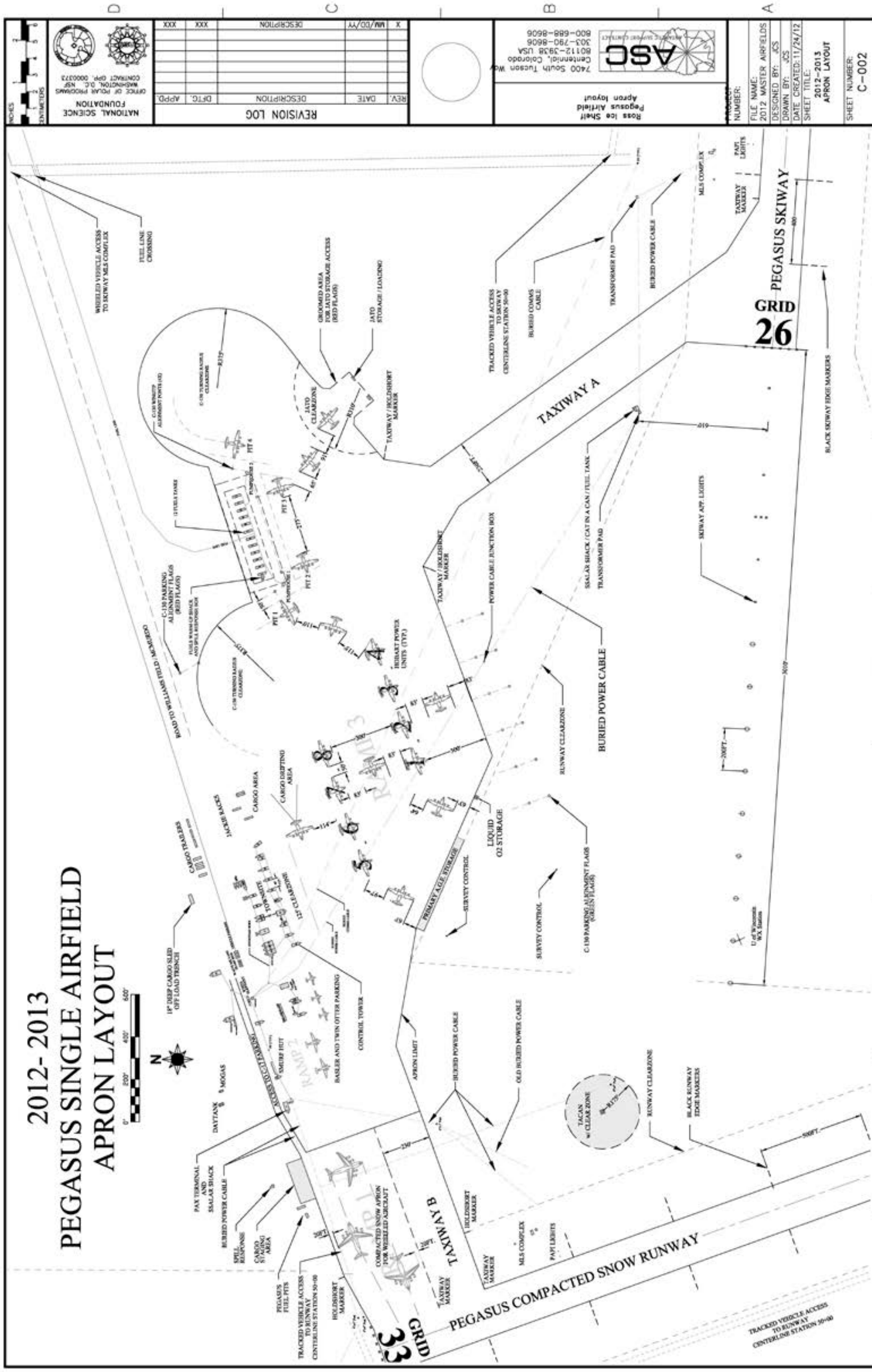
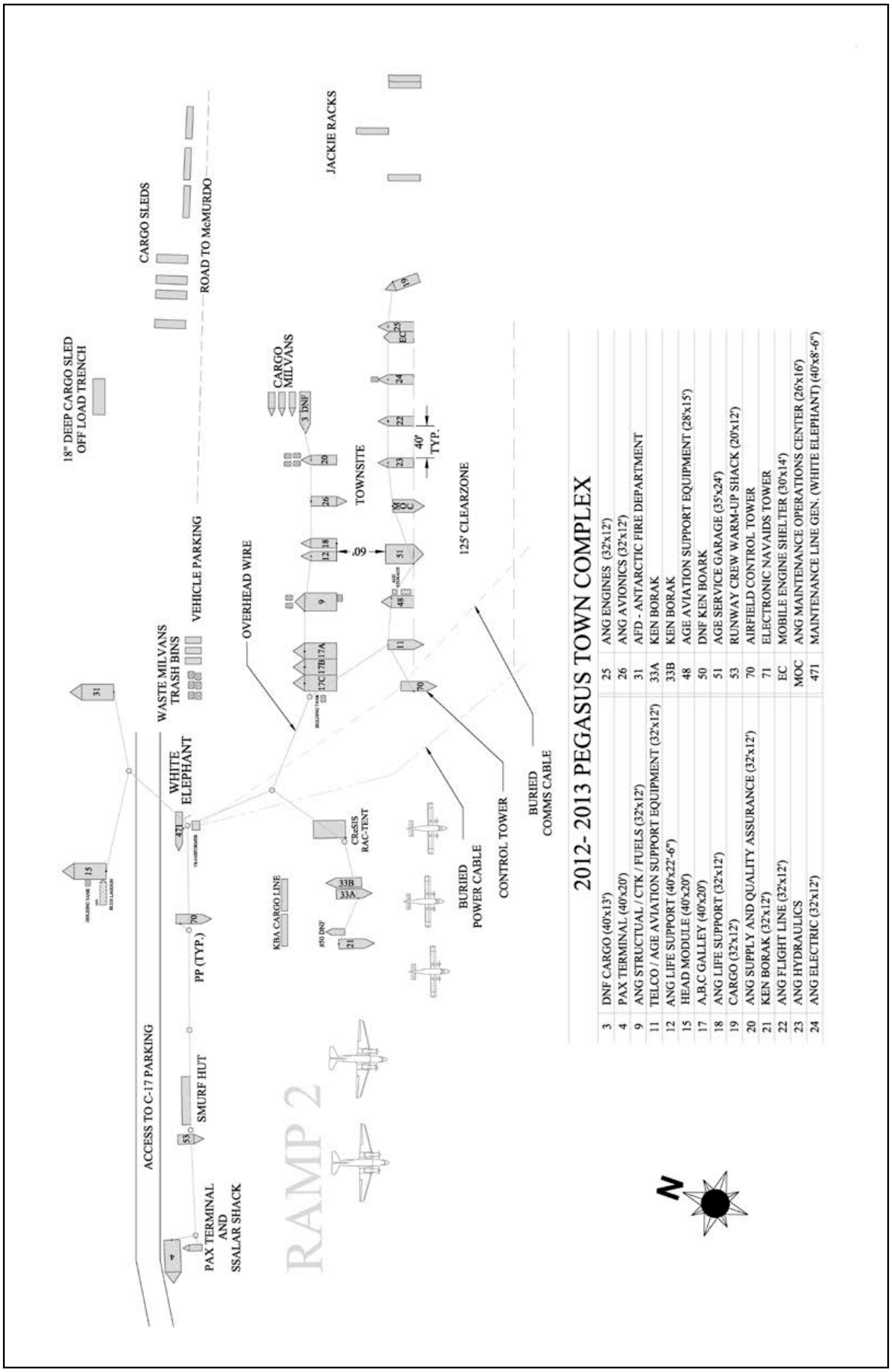


Figure B-66 Pegasus Town Complex



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B-13 TYPICAL AIRFIELD LAYOUT FOR SEA ICE AIRFIELD, MCMURDO SOUND, ANTARCTICA

Figure B-67 McMurdo Sound Runway Site Plan

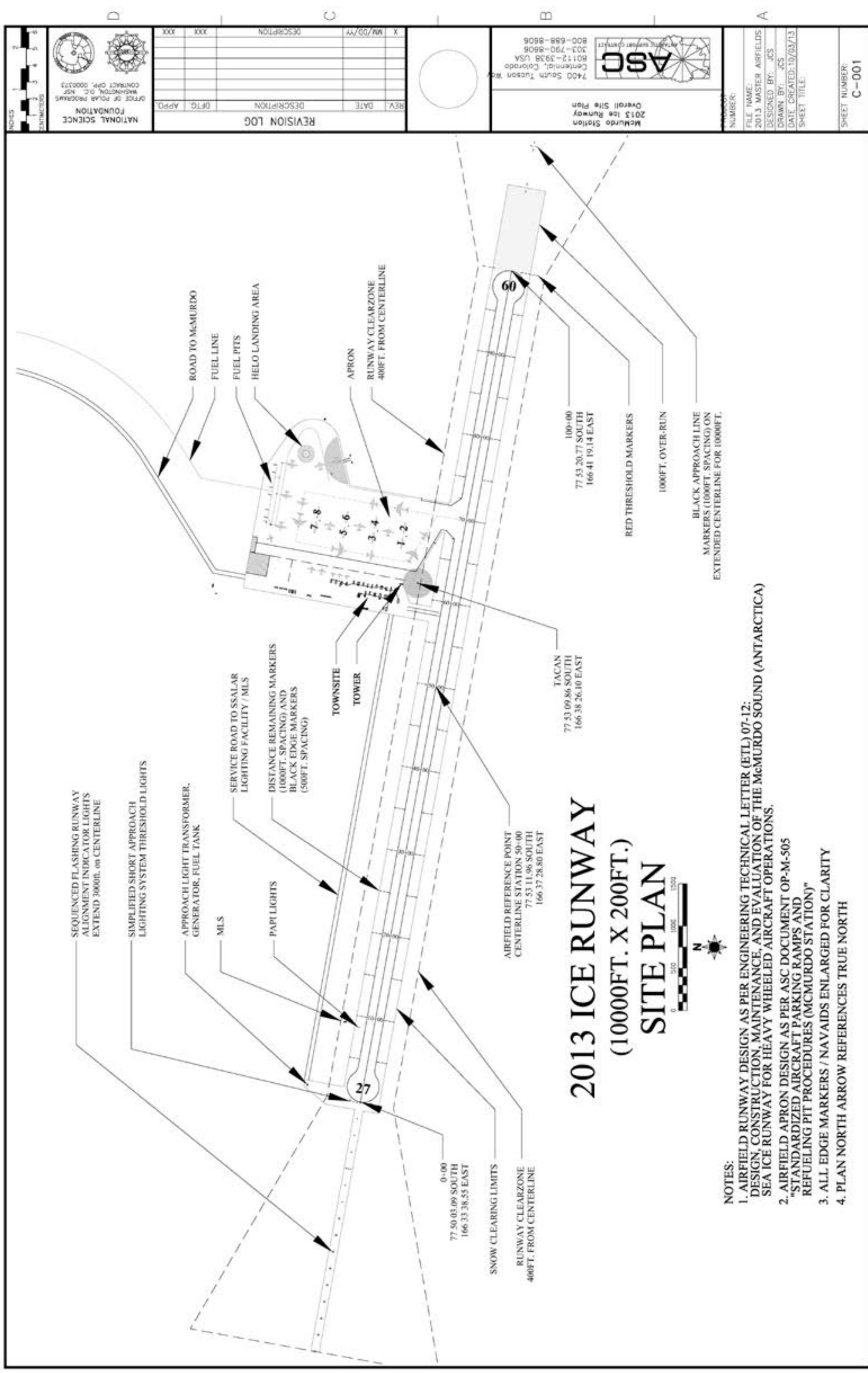


Figure B-68 McMurdo Sound Apron Layout

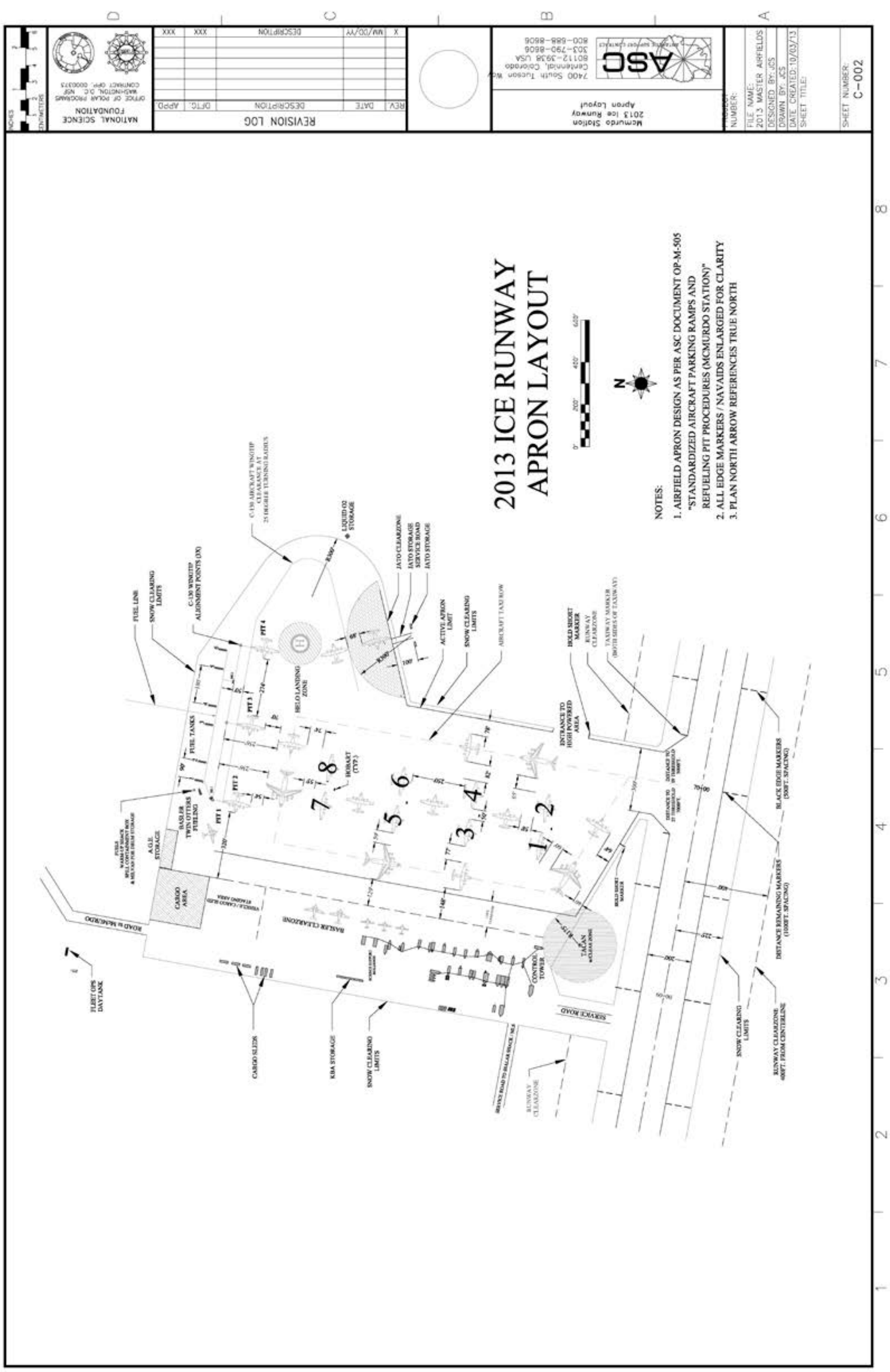


Figure B-69 McMurdo Sound Town Complex

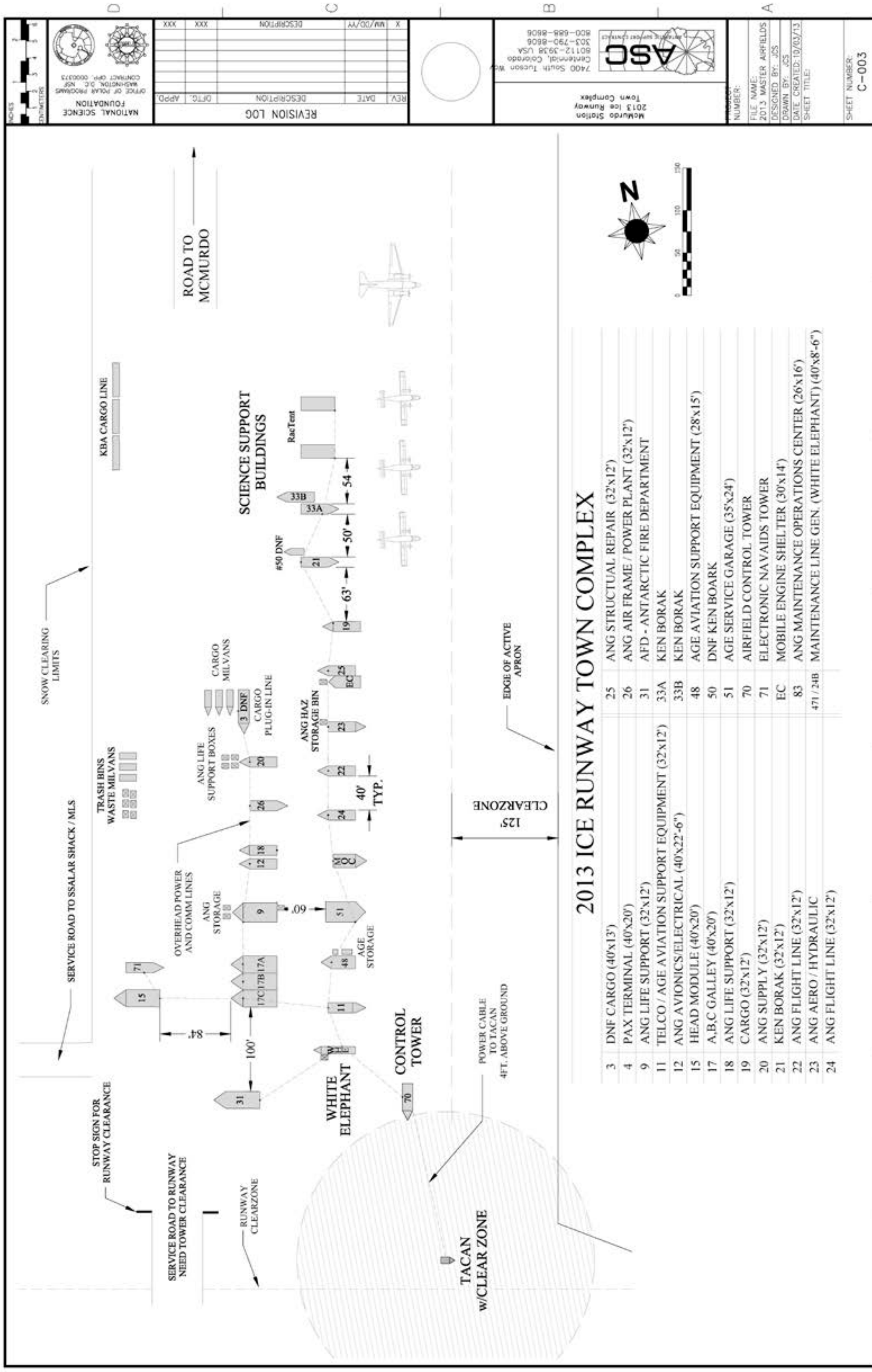
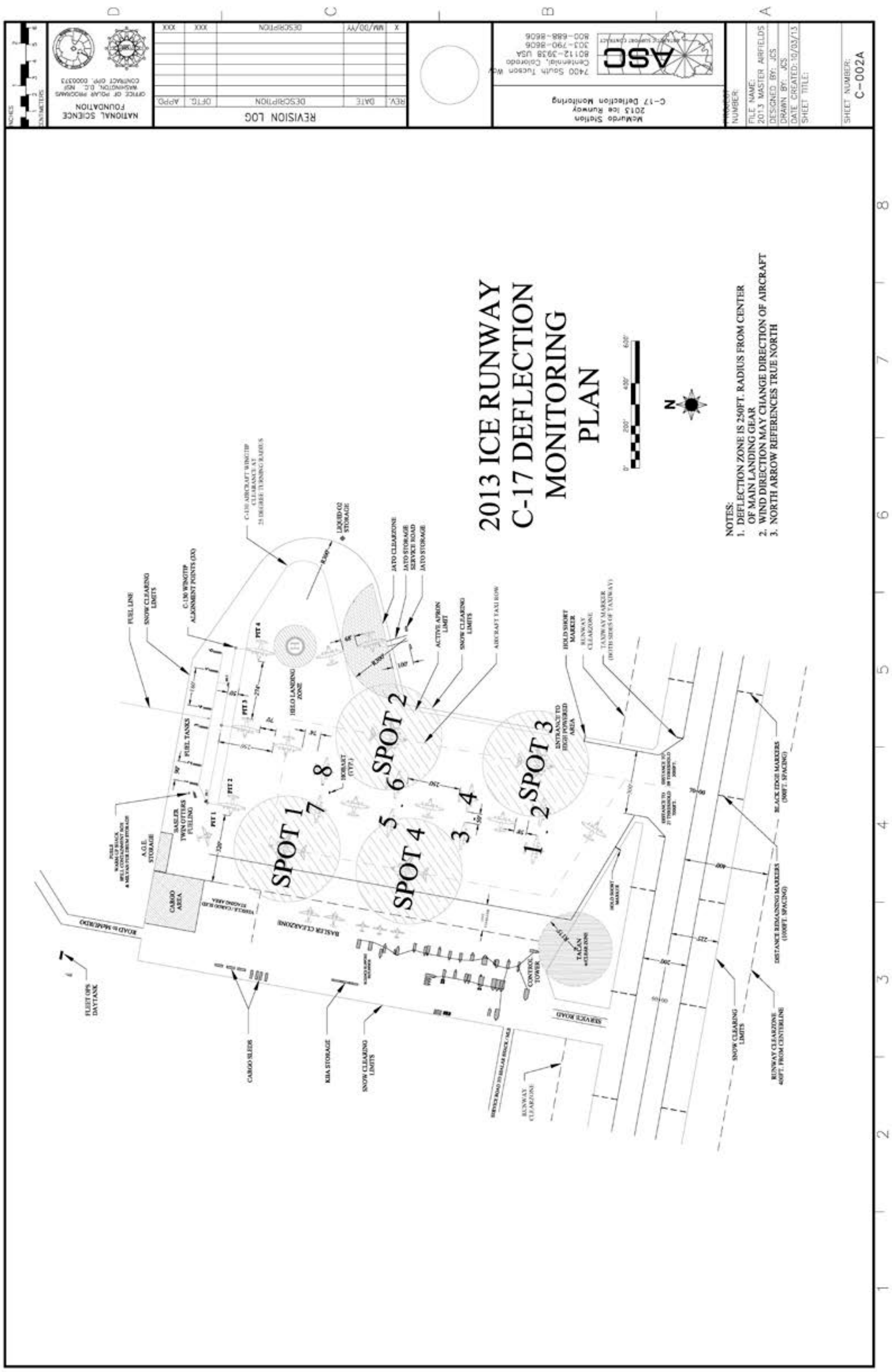


Figure B-70 McMurdo Sound C-17 Deflection Monitoring Plan



B-14 CONVERSION FACTORS

TO CONVERT	TO	DIVIDE BY
LENGTH		
millimeters (mm)	inches (in)	25.4
centimeters (cm)	inches (in)	2.54
meters (m)	inches (in)	0.0254
meters (m)	feet (ft)	0.3048
meters (m)	yards (yd)	0.9144
kilometers (km)	miles (mi)	1.60948
AREA		
square millimeters (mm^2)	square inches (in^2)	645.16
square centimeters (cm^2)	square inches (in^2)	6.4516
square meters (m^2)	square inches (in^2)	0.00064516
square meters (m^2)	square feet (ft^2)	0.09290
square meters (m^2)	square yards (yd^2)	0.83613
square kilometers (km^2)	square miles (mi^2)	2.59043
square kilometers (km^2)	acres	0.00404
VOLUME		
cubic millimeters (mm^3)	cubic inches (in^3)	16,387
cubic centimeters (cm^3)	cubic inches (in^3)	16,487,000
cubic meters (m^3)	cubic feet (ft^3)	0.028317
cubic meters (m^3)	cubic yards (yd^3)	0.764559
MASS		
kilograms (kg)	pounds (lb)	0.45359
FORCE		
Newtons (N)	pounds (lbf)	4.44822
STRESS		
kiloPascals (kPa)	psi	6.89476
TEMPERATURE		
Degrees Centigrade (°C)	Degrees Fahrenheit (°F)	Multiply by 1.8, then add 32

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APPENDIX C GLOSSARY

C-1 ACRONYMS

13 AEG/CC	13th Air Expeditionary Group Commander
18 AF/CC	18th Air Force Commander
A3	Operations Directorate
AFD	airfield database
AFI	Air Force Instruction
AMCI	Air Mobility Command Instruction
ASTM	American Society for Testing and Materials
AWOS	airport weather observation station
CBR	California bearing ratio
CRREL	U.S. Army Cold Regions Research and Engineering Laboratory
DCP	dynamic cone penetrometer
DOD	Department of Defense
ETL	Engineering Technical Letter
FC	Facilities Criteria
FAA	Federal Aviation Administration
ft	foot
GDSS	Global Decision Support System
HQ AMC	Headquarters, Air Mobility Command
HQ AMC/A3	Headquarters, Air Mobility Command, Operations Directorate
HQ AMC/A3V	Headquarters, Air Mobility Command, Operations Directorate, Aircrew Standardization Evaluation Division
HQ AMC/A3AS	Headquarters, Air Mobility Command, Operations Directorate, Airfield Operations Division, Airfield Suitability Branch
HQ AMC/A7	Headquarters, Air Mobility Command, Installations and Mission Support Directorate

HQ AMC/A7OI	Headquarters, Air Mobility Command, Installations and Mission Support Directorate, Operations Division
HQ AMC/A7OI	Headquarters, Air Mobility Command, Installations and Mission Support Directorate, Operations Division, Infrastructure Support Branch
HQ PACAF/A3	Headquarters, Pacific Air Forces, Operations Directorate
HQ PACAF/A7	Headquarters, Pacific Air Forces, Installations and Mission Support Directorate
IFR	instrument flight rules
ILS	instrument landing system
in	inch
kPa	kilopascals
m	meter
MAJCOM	major command
MALSR	medium-intensity approach lights
MATCT	mobile air traffic control tower
MLS	microwave landing system
mm	millimeters
MOG	maximum on ground
NAVAIDS	navigational aid system
OPCON	operational control
PAPI	precision approach path indicator
PCASE	Pavement Computer Assisted Structural Engineering
PLZ	prepared landing zone
psi	pounds per square inch
RAIL	runway alignment indicator light
REIL	runway end identifier light
RSP	Russian snow penetrometer

SFL	sequenced flashing strobe lights
SSALR	simplified short approach lighting with RAILS
TACAN	tactical air navigation
TCH	threshold crossing height
TERPS	terminal instrument procedures
UFC	Unified Facilities Criteria
USAF	United States Air Force
USAP	United States Antarctic Program
VFR	visual flight rules

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C-2 DEFINITION OF TERMS

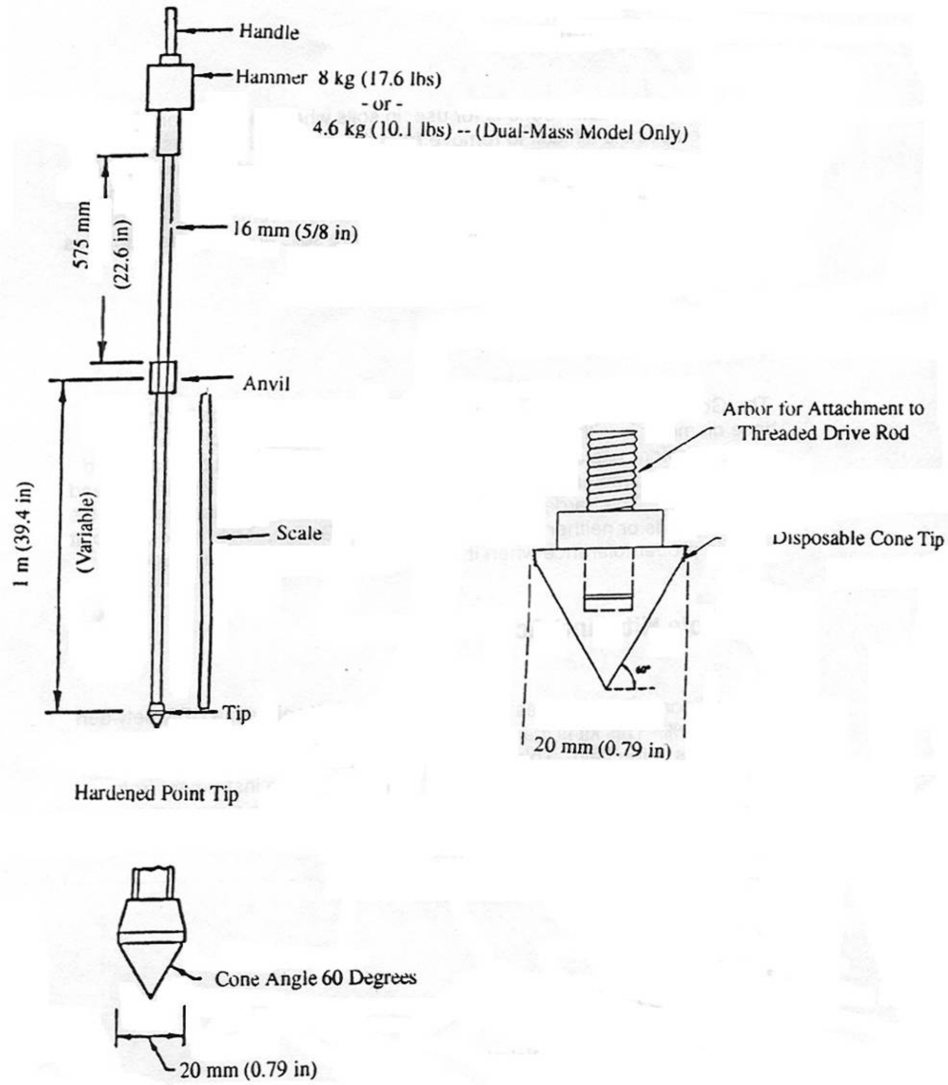
California Bearing Ratio (CBR): An index test of soil strength determined using a 1935.5-square-millimeter (3-square-inch) piston forced into the soil. The load required to achieve a 2.5- or 5-millimeter (0.1- or 0.2-inch) penetration (whichever provides lowest CBR value) is compared to a standard load for similar penetrations into a well-graded, crushed aggregate. The test is widely used for military structural airfield assessment; test procedures are in ASTM D1883.

Dynamic Cone Penetrometer (DCP): The DCP is a portable soil field test device to allow rapid measurement of soil strength (see Figure C-1). An 8-kilogram (17.6-pound) or 4.6-kilogram (10.1-pound) sliding hammer is used to drive a 60^{o}, 20-millimeter (0.8-inch) -diameter cone into the soil. The DCP strength index, in units of millimeters per blow, is calculated as:

$$\text{DCP Index} = (P/N)\ F$$

where P is the accumulated cone penetration after each set of N hammer blows, and F is a configuration factor (F = 1.0 for 8-kilogram hammer DCP; F = 1.742 for 4.6-kilogram hammer DCP). The DCP strength index has been correlated to more time-consuming tests like CBR and is widely used in the military for expedient soil strength assessments for roads and airfields. A complete description of the DCP and its use are contained in U.S. Army Waterways Experiment Station Instructional Report GL-92-3 and ASTM D6951. See Attachment 1 for penetrometer user information.

Figure C-1 Dynamic Cone Penetrometer (DCP)



Exposed Sea Ice Surface: Whether graded or not, an exposed sea ice surface has little or no snow present to act as a cover. Such a surface will present poor braking resistance at temperatures above -8 °C (18 °F).

Fresh, Loose Snow Surface: Natural unprocessed snow resting on a runway surface. Such a cover of snow enhances braking resistance at all temperatures and assists in protecting against the damaging effects of solar heating at temperatures above -8 °C (18 °F). However, too much snow will produce additional drag on tires, making takeoffs difficult. Loose snow in excess of 25 millimeters (1 inch) in depth shall be removed from the runway.

Glacial Ice Runway Surface: A durable weather- and abrasion-resistant surface generated from level grading of natural glacial ice (alpine-, continental-, or shelf-type) that is derived from naturally consolidated snow. For a more detailed description see CRREL Monograph 98-1.

Graded Sea Ice Surface: To remove natural undulations in a sea ice surface, including adhered patches of snow, a serrated grader blade is used, often with a laser-guided leveling system, to prepare the runway surface. This surface has a high degree of small-scale (12 to 100 millimeters [0.5 to 4 inches]) roughness which is felt as “chatter” in a fast-moving aircraft.

Processed Snow Surface: Also called “white ice,” this is a durable weather- and abrasion-resistant surface made from processing (e.g., compacting or tilling) natural snow that overlies the graded glacial ice or sea ice surface. The processed snow surface is smooth and has good braking and solar insulation-blocking characteristics.

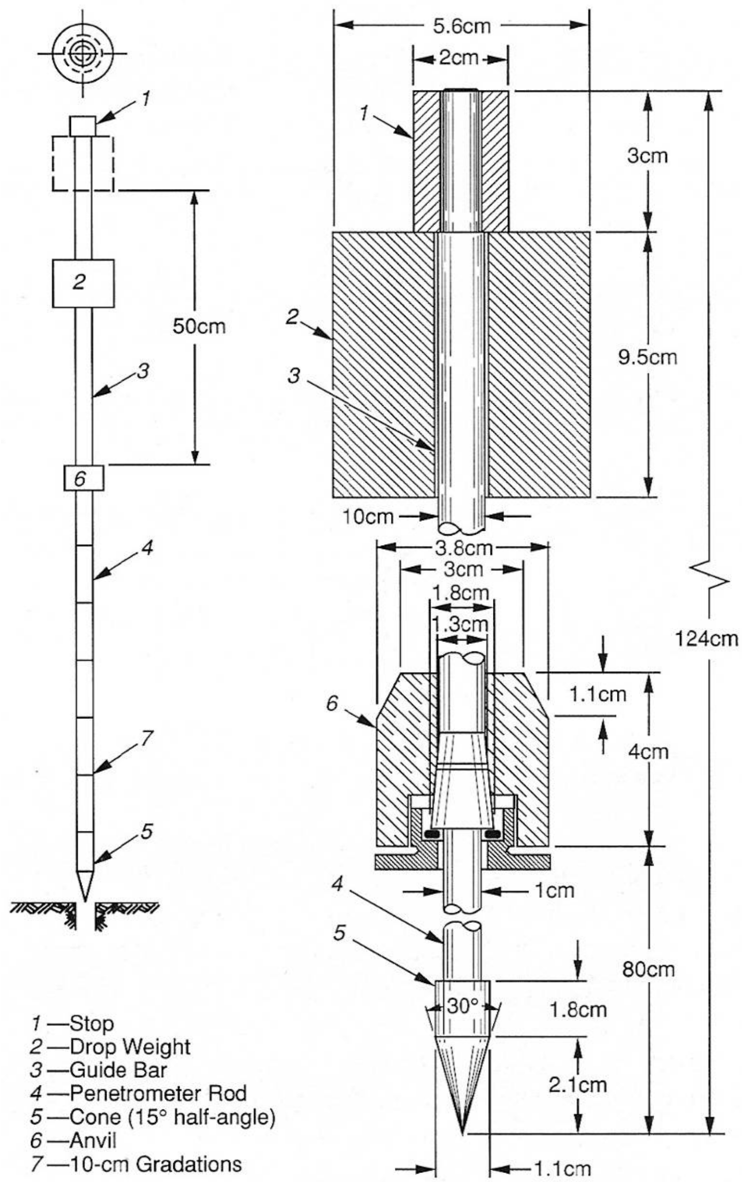
Prepared Landing Zone (PLZ): For the purposes of this FC, a PLZ refers to a landing zone constructed to support routine and moderately frequent (average one to two flights per day) wheeled cargo aircraft traffic, with no adverse effect on airframes, but that is not paved with traditional construction materials (i.e., asphalt or concrete). The amount of engineering effort required to develop a PLZ depends on the planned operation and the existing surface and weather conditions. Options for surface preparation are governed by the material present at the site and may include plowing, grading, planing, roller compaction, tilling, and vibratory compaction.

Russian Snow Penetrometer (RSP): The RSP is a portable test device to allow rapid measurement of snow strength (see Figure C-2). A 1.75-kilogram (3.85-pound) sliding hammer is dropped from a height of 500 millimeters (19.7 inches) to drive into the snow a 30^o cone with a maximum diameter of 11 millimeters (0.4 inch). During a test, penetration distance and the number of blows to produce it are recorded. The RSP index, in units of kilograms, is calculated as:

$$\text{RSP Index} = (W\ h\ n\ L^{-1}) + W + Q$$

where W is the mass of the drop hammer (kilograms), h is the height of the hammer drop (millimeters), n is the number of hammer blows to generate L (millimeters) penetration, and Q is the total mass of the penetrometer (kilograms) less its hammer. Details of penetrometer testing in processed snow can be found in CRREL Technical Report 153. See Appendix B-1 for penetrometer user information.

Figure C-2 Russian Snow Penetrometer (RSP)



Sastrugi: A long wavelike ridge of snow, formed by wind and found on the polar plains.

Sea Ice Runway Surface: The original exposed or level-graded surface of a floating slab of naturally frozen seawater.

Seasonal Operations: Seasonal operations denote aircraft activities being confined to certain periods of the year when flight and runway conditions are most favorable and when airlift is required. At McMurdo Station, the Pegasus runway is mostly operated when air temperatures are above -50 °C (-58 °F) and when sunlight is present. However, flights do sometimes occur in the shoulder seasons or during winter with alternative runway markers. The sea ice runway is only operated when (a) air temperatures are above -50 °C (-58 °F); (b) sunlight is present; and (c) when ice thickness and strength combine to allow safe landing and parking.

UFC 3-260-16
3 February 2019

UNIFIED FACILITIES CRITERIA (UFC)

O&M MANUAL:
STANDARD PRACTICE FOR AIRFIELD PAVEMENT CONDITION SURVEYS

UNIFIED FACILITIES CRITERIA (UFC)

O&M MANUAL: STANDARD PRACTICE FOR AIRFIELD PAVEMENT CONDITION SURVEYS

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER CENTER (Preparing Activity)

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

Change No.	**Date**	**Location**

This UFC supersedes UFC 3-260-16FA, *Airfield Pavement Condition Survey Procedures Pavements*, dated 16 January 2004, UFC 3-270-05, *Paver Concrete Surfaced Airfields Pavement Condition Index (PCI)*, dated 15 March 2001, and UFC 3-270-06, *Paver Asphalt Surfaced Airfields Pavement Condition Index (PCI)*, dated 15 March 2001.

FOREWORD

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

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and the Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Military Departments, the Defense Agencies, and DOD Field Activities should contact the preparing Service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DOD working group. Recommended changes with supporting rationale should be sent to the respective Service proponent office by the following electronic form: Criteria Change Request. The form is also accessible from the Internet site listed below.

- UFC are effective upon issuance and are distributed only in electronic media from the following source: Whole Building Design Guide web site http://dod.wbdg.org/.

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

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UNIFIED FACILITIES CRITERIA (UFC)
REVISION SUMMARY SHEET

Document: UFC 3-260-16, *O&M Manual: Standard Practice for Airfield Pavement Condition Surveys*

Superseding: This UFC supersedes UFC 3-260-16FA, *Airfield Pavement Condition Survey Procedures Pavements*, dated 16 January 2004, UFC 3-270-05, *Paver Concrete Surfaced Airfields Pavement Condition Index (PCI)*, dated 15 March 2001, and UFC 3-270-06, *Paver Asphalt Surfaced Airfields Pavement Condition Index (PCI)*, dated 15 March 2001.

Description: This UFC provides procedures for performing a pavement condition survey at all airfields with DOD missions. This UFC is intended for use by all personnel responsible for such surveys.

Reasons for Document: This revision addresses unification issues and the latest airfield pavement condition survey methodologies.

Impact: This document does not impact design cost, initial cost, energy savings, or life cycle costs.

Unification Issues: None

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FIGURES

TABLES

EQUATIONS

CHAPTER 1 INTRODUCTION

1-1 PURPOSE AND SCOPE.

1-1.1 This Unified Facilities Criteria (UFC) provides the procedure for performing a pavement condition survey at all airfields with present or potential DOD missions. This UFC is intended for use by all personnel responsible for such surveys.

1-1.2 The objectives of a pavement condition survey are to determine the present condition of the pavement in terms of apparent structural integrity and operational surface condition, to provide a common index for comparing the condition and performance of pavements at all air stations along with a rational basis for justification of pavement repair projects, and to provide feedback on pavement performance for validating and improving current pavement design, evaluation, and maintenance procedures.

1-1.3 The airfield pavement condition survey is a visual inspection of both rigid and flexible pavement for signs of pavement distress. The pavement condition index (PCI) is a numerical rating that indicates the type and severity of the inspected distress. The airfield condition survey and the resulting PCI are the primary means of obtaining and recording important airfield pavement performance data. This UFC describes the condition survey of both flexible pavements (all pavements with conventional bituminous concrete surfaces) and rigid pavements (jointed portland cement concrete [PCC] pavements) and the procedure for determining the PCI of the inspected pavement.

1-1.4 The pavement network is divided into branches that are in turn divided into sections. Each section is divided into sample units. The type and severity of pavement distress is assessed by visual inspection of the pavement sample units. The quantity of the distress is measured as described in Appendix A (flexible pavement) and Appendix B (rigid pavement). The distress data are used to calculate the PCI for each sample unit. The PCI of the pavement section is determined based on the PCI of the inspected sample units within the section. The distresses can be numbered using several conventions. Within this UFC, two numbering conventions are presented. One uses the convention adopted within the PAVER software, which starts the numbering of flexible distresses at 41 and continues through 57. For rigid pavement, the distresses start with 61 and continue through 76. This is done to ensure the distresses for the flexible and rigid airfield distresses have unique numerical identifiers and to allow for separate distresses for flexible and rigid roadways to have unique numerical identifiers from 1 to 39. The second convention provided in Appendix A and Appendix B is consistent with ASTM D5340 and is contained in braces: {#}. This numbering convention produces multiple distresses for the same numerical identifier and should be used with caution.

For additional information on performing pavement condition surveys for NATO countries, refer to STANAG 7181.

1-2 APPLICABILITY.

This UFC applies to all Service elements and contractors performing airfield pavement condition surveys.

1-3 GLOSSARY.

Appendix F contains a list of acronyms, abbreviations, and definitions.

1-4 REFERENCES.

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

CHAPTER 2 INSPECTION PROCEDURE

2-1 PAVEMENT SECTIONING.

The first step in the condition survey is the designation of pavement sections. Each branch, such as a runway or taxiway, is divided into sections that are definable in terms of the same design, the same construction history, the same traffic area, and generally the same overall condition. Generally, sections are determined from pavement design and construction records and can be further subdivided as deemed necessary based on a preliminary survey. It is important that all pavement in a given section be such that it is considered uniform. For example, the center portion of some runways in the traffic lanes are separate sections from the portion outside the traffic lanes.

2-2 SAMPLE UNITS.

2-2.1 Definition.

A sample unit is a defined portion of a pavement section designated only for the purpose of pavement inspection.

2-2.2 Sample Unit Sizes.

2-2.2.1 Asphalt-Surfaced Airfields.

For asphalt-surfaced airfields, each sample unit area is defined as 5,000 ± 2,000 square feet (465 ± 186 square meters). Note that sample unit sizes close to the recommended mean are preferred for accuracy.

2-2.2.2 Concrete-Surfaced Airfields.

For concrete airfields with joints spaced less than or equal to 25 feet (7.6 meters), the recommended sample unit size is 20 ± 8 slabs. For slabs with joints spaced greater than 25 feet (7.6 meters), imaginary joints less than or equal to 25 feet (7.6 meters) apart and in perfect condition are assumed. For example, if slabs have joints spaced 60 feet (18.3 meters) apart, imaginary joints are assumed at 20 feet (6.1 meters). Thus, each slab is counted as three slabs for the purpose of pavement inspection. This is needed because the deduct values were developed for jointed concrete slabs less than or equal to 25 feet (7.6 meters).

2-2.3 Examples.

Figures 2-1 and 2-2, respectively, illustrate the division of a jointed rigid pavement and flexible pavement section into sample units. Each sample unit is numbered where it is identifiable for future inspections, maintenance needs, or statistical sample purposes. Inspect each of the selected sample units and determine its PCI. The PCI of a pavement section is determined by the size-weighted average of the PCI of each sample unit inspected within the section.

Figure 2-1 Example Division of a Jointed Rigid Pavement Section into Sample Units of 20 Slabs

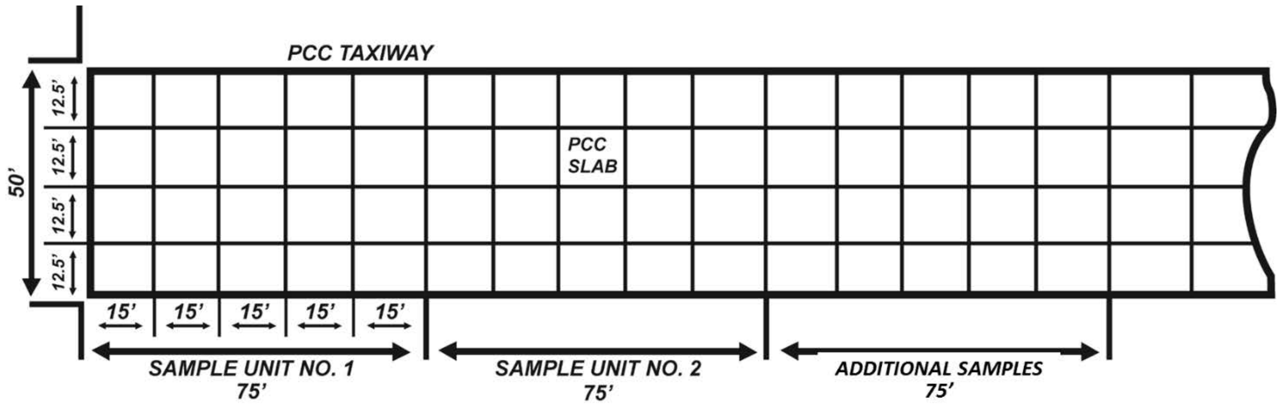
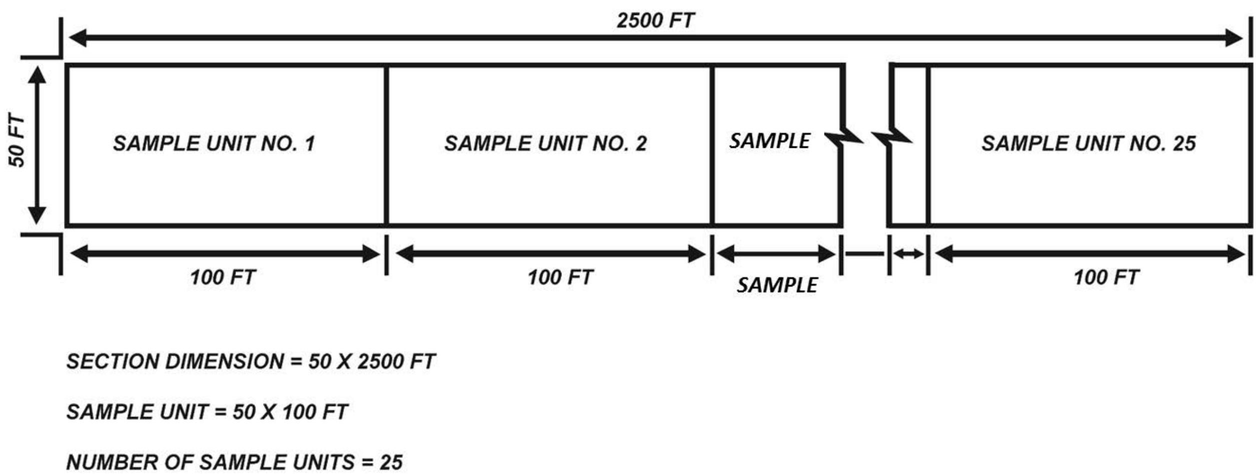


Figure 2-2 Example Division of a Flexible Pavement Section into Sample Units



2-3 NETWORK-LEVEL INSPECTION.

2-3.1 Determining the Number of Sample Units to be Inspected.

A network-level survey is conducted by surveying a few sample units per section. Table 2-1 provides an example of criteria used by some agencies for determining the number of sample units to survey at the network level. The number of units to be inspected (n) is increased by 1 for every increase of five units in section (N) until N equals 15. When N equals 16 to 40, the value of n is set at 4. When the value of N is greater than 40, n is set at 10 percent of N and rounded up to the next whole sample unit. For example, if $N = 52$ then $n = 6$ (rounded up from 5.2).

Table 2-1 Example of Network-Level Sampling Criteria Used by Some Agencies

No. of Sample Units in Section (*N*)	No. of Units to be Inspected (*n*)
1 to 5	1
6 to 10	2
11 to 15	3
16 to 40	4
Over 40	10 percent of *N* (round up to next whole sample unit)

2-3.2 Selecting Sample Units to Inspect.

When selecting sample units to inspect as recommended in Table 2-1, ensure the sample units are representative (not random) of the overall condition of the section. The main objective for budget estimating and network condition assessment is to obtain a meaningful rating with the least cost.

2-4 PROJECT-LEVEL INSPECTION.

2-4.1 Determining the Number of Sample Units to be Inspected.

Management at the project level requires accurate data for the preparation of work plans and contracts; therefore, more sample units are inspected than are usually sampled for network-level management. The first step in sampling is to determine the minimum number of sample units (*n*) to survey to obtain an adequate estimate of the section's PCI. This number is determined for a project-level evaluation by using the curves shown in Figure 2-3. Using this number, a reasonable estimate of the true mean PCI of the section is obtained. There is a 95 percent probability that the estimate is within ±5 points of the true mean PCI (the PCI obtained if all the sample units were inspected).

The curves in Figure 2-3 were constructed using Equation 2-1:

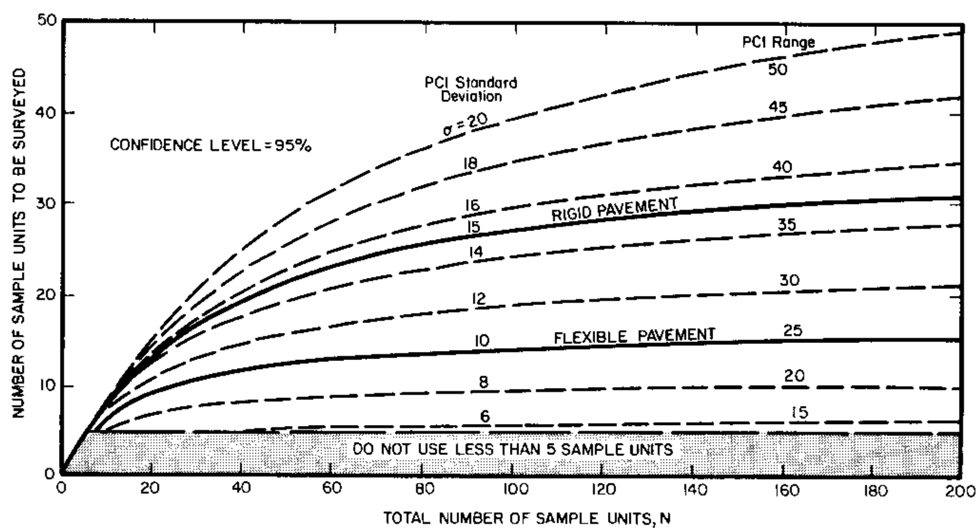
Equation 2-1 Minimum Sample Units

$$n = \frac{N(s^2)}{\frac{e^2}{4}(N-1) + s^2}$$

where:
n = minimum number of sample units
N = total number of sample units in the pavement section
e = allowable error in the estimate of the section PCI (The value e was set equal to 5 when constructing the curves of Figure 2-3.)
s = standard deviation of the PCI between sample units in the section

The curves in Figure 2-3 are based on the PCI standard deviation among sample units or PCI range (i.e., lowest sample unit PCI subtracted from the highest sample unit PCI). For the initial inspection, the PCI standard deviation for a pavement section is assumed to be 10 for asphalt concrete (AC) -surfaced pavements (or a PCI range of 25) and 15 for PCC-surfaced pavements (or a PCI range of 35). These values are based on field data obtained from many surveys; however, if local experience is different, use the average standard deviation reflecting local conditions for the initial inspection. For subsequent inspections, use the actual PCI standard deviation or range (determined from the previous inspection) to determine the minimum number of sample units to be surveyed. When the total number of samples within a section is less than five, survey all of the sample units.

Figure 2-3 Selection of the Minimum Number of Sample Units[1]



1 Shahin et al., 1976-1977

2-4.2 Selecting Sample Units to Inspect.

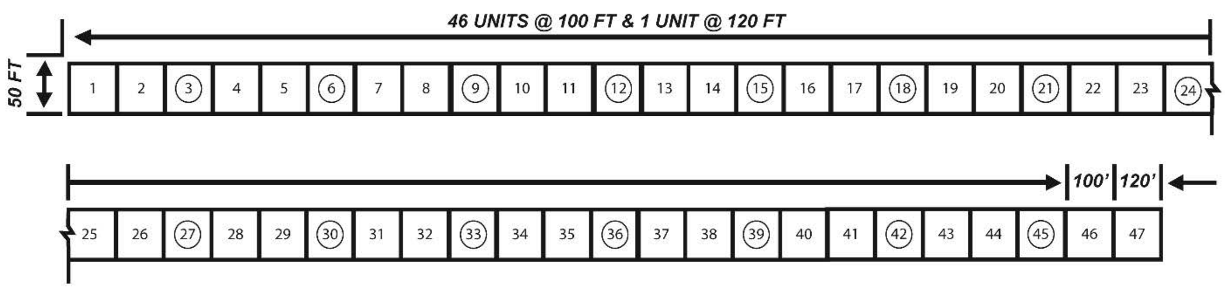
Space the sample units to be inspected equally throughout the section, with the first unit chosen at random. This technique, known as “systematic random,” is illustrated in Figure 2-4 and described by the following three steps:

1. The sample interval (*i*) is determined by $i = N \div n$, where N equals the total number of available sample units and n equals the minimum number of sample units to be surveyed. The sampling interval (*i*) is rounded to the smaller whole number (for example, 3.6 is rounded to 3.0).

2. Random starts are selected between sample unit 1 and the sampling interval (*i*). For example, if $i = 3$, the random start would be a number from 1 to 3.

3. The sample units to be surveyed are identified as S, $S+i$, $S+2i$, and so forth. If the selected start is 3 and the sampling interval is 3 then the sample units to be surveyed are 3, 6, 9, 12, and so forth.

Figure 2-4 Example of Systematic Random Sampling



TOTAL NUMBER OF SAMPLE UNITS IN SECTION (N)	*= 47*
MINIMUM NUMBER OF UNITS TO BE SURVEYED (n)	*= 13*
INTERVAL (i) = N / n = 47 / 13 = 3.6	*= 3*
RANDOM START (S)	*= 3*

2-5 SELECTION OF ADDITIONAL SAMPLE UNITS.

One of the major drawbacks to both systematic random sampling at the project level and representative sampling at the network level is that sample units in exceptionally bad condition may not necessarily be included in the survey. At the same time, sample units that have a one-time-occurrence type of distress (for example, utility cut patching) may be included inappropriately as a random sample.

To overcome these drawbacks, identify any unusual sample units and inspect them as additional units rather than as random or representative units. When additional sample units are included in the survey, the calculation of the section PCI is altered to prevent extrapolation of the unusual conditions across the entire section. This procedure is described in more detail in Chapter 3.

2-6 PAVEMENT DISTRESS RECORDING.

2-6.1 Example PCI Survey Sheets: Airfield Pavements.

Figures 2-5 and 2-6 are sample PCI survey sheets. Blank forms are in Appendix E.

Figure 2-5 Asphalt-Surfaced Airfield Pavements Example PCI Survey Sheet

AC Airfield Pavement Condition Survey Data Sheet (Automated)		
PID Delta_R1230_B01	INSPECTOR NAME S. Smith	
FROM RW 12 End	BRANCH USE Runway	DATE INSPECTED 06/20/2018
TO TW A	SECTION WIDTH 100 FT	SECTION LENGTH 2000 FT

AC Surfaced Distress Codes			
41. Alligator Cracking {1}	46. Jet Blast {6}	51. Polished Aggregate {11}	56. Swell {16}
42. Bleeding {2}	47. JT. Reflection (PCC) {7}	52. Raveling {12}	57. Weathering {17}
43. Block Cracking {3}	48. Long. & Trans. Cracking {8}	53. Rutting {13}	
44. Corrugation {4}	49. Oil Spillage {9}	54. Shoving From PCC {14}	
45. Depression {5}	50. Patching {10}	55. Slippage Cracking {15}	

SAMPLE NUMBER		SAMPLE AREA	
DISTRESS CODE	L	M	H
48	47 FT	16 FT	
41	53 FT		
45	75 FT		
53		28 SF	

SKETCH/COMMENTS

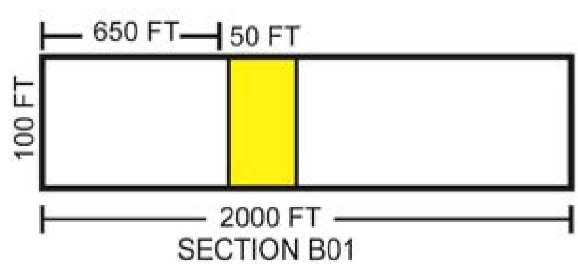


Figure 2-6 Concrete-Surfaced Airfield Pavements Example PCI Survey Sheet

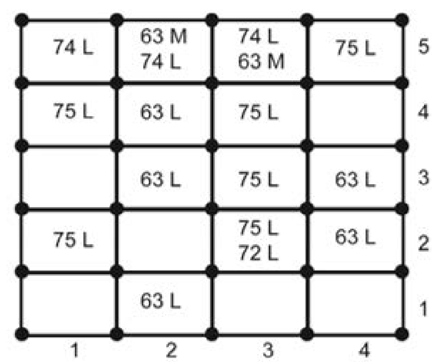
PCC AIRFIELD PAVEMENT CONDITION SURVEY DATA SHEET (Automated)			
PID Delta_R1230_B03		INSPECTOR NAME S. Smith	
FROM TW F		BRANCH USE Runway	DATE INSPECTED 06/20/2018
TO RW 30 END		SECTION WIDTH 100 FT	SECTION LENGTH 2000 FT
SLAB WIDTH 25 FT	SLAB LENGTH 25 FT	NUMBER OF SLABS 320	

PCC Surfaced Distress Codes			
61. Blowup {1}	65. Joint Seal Damage {5}	69. Pumping {9}	73. Shrinkage Cracks {13}
62. Corner Break {2}	66. Patching, Small < 1.5 m (< 5 ft) {6}	70. Scaling {10}	74. Spalling, Joints {14}
63. Cracks {3}	67. Patching, Large/ Utility Cut {7}	71. Settlement/Faulting {11}	75. Spalling, Corner {15}
64. Durability Cracking {4}	68. Popouts {8}	72. Shattered Slab {12}	76. ASR {16}

SAMPLE NUMBER 005 | **SLABS IN SAMPLE 20**

DISTRESS CODE	L	M	H
63	5	2	
74	3		
72	1		
75	6		

SKETCH/COMMENTS



CHAPTER 3 PCI CALCULATION PROCEDURE

3-1 INTRODUCTION.

The PCI is calculated for each inspected sample unit. The PCI cannot be computed for the entire pavement section without computing the PCI for the sample units first. The PCI calculation is based on the deduct values, which are weighting factors from 0 to 100 that indicate the impact each distress has on pavement condition. A deduct value of 0 indicates that a distress has no effect on either pavement structural integrity or surface operational condition, whereas a value of 100 indicates an extremely serious distress.

3-2 CALCULATION OF A SAMPLE UNIT PCI FOR ASPHALT-SURFACED PAVEMENTS.

The PCI calculation procedure is illustrated for the sample unit example shown in Figure 3-1. The calculation steps are summarized in Figure 3-2 and paragraphs 3-2.1 through 3-2.4.

Figure 3-1 Asphalt-Surfaced Airfield PCI Survey Data Sheet Example

AC Airfield Pavement Condition Survey Data Sheet (Automated)		
PID Delta_R1230_B01	INSPECTOR NAME S. Smith	
FROM RW 12 End	BRANCH USE Runway	DATE INSPECTED 06/20/2018
TO TW A	SECTION WIDTH 100 FT	SECTION LENGTH 2000 FT

AC Surfaced Distress Codes			
41. Alligator Cracking {1}	46. Jet Blast {6}	51. Polished Aggregate {11}	56. Swell {16}
42. Bleeding {2}	47. JT. Reflection (PCC) {7}	52. Raveling {12}	57. Weathering {17}
43. Block Cracking {3}	48. Long. & Trans. Cracking {8}	53. Rutting {13}	
44. Corrugation {4}	49. Oil Spillage {9}	54. Shoving From PCC {14}	
45. Depression {5}	50. Patching {10}	55. Slippage Cracking {15}	

SAMPLE NUMBER	008	SAMPLE AREA	5000 SF
DISTRESS CODE	**L**	**M**	**H**
48	47 FT	16 FT	
41	53 FT		
45	75 FT		
53		28 SF	

SKETCH/COMMENTS

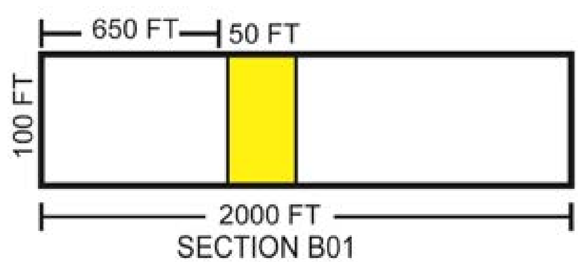
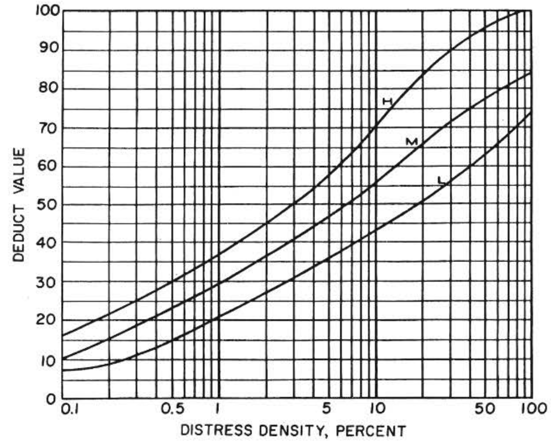
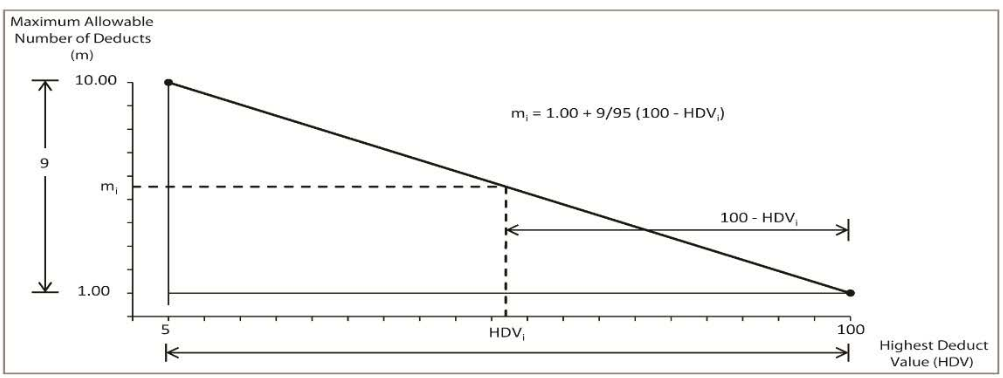


Figure 3-2 PCI Calculation Steps for Sample Unit

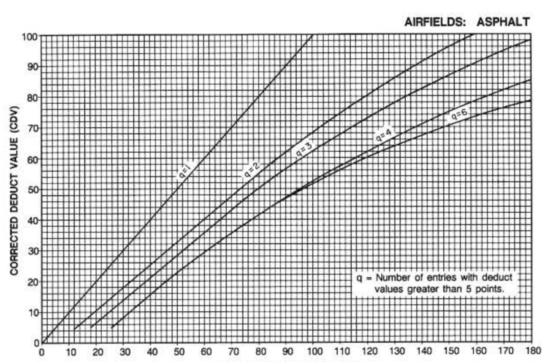
STEP 1: DETERMINE DEDUCT VALUES



STEP 2: DETERMINE MAXIMUM ALLOWABLE NUMBER OF DEDUCTS (m)



STEP 3: DETERMINE MAXIMUM CORRECTED DEDUCT VALUE



STEP 4: CALCULATE PCI

PCI = 100 - MAXIMUM CDV

3-2.1 Step 1: Determine Deduct Values.

Table 3-1 shows the results of the calculation of the deduct values for the distresses shown in Figure 3-1.

1a. Add the totals for each distress type at each severity level and record them as shown in Table 3-1. Distress quantities are measured in square feet (square meters), linear feet (meters), or number of occurrences, depending on the distress type.

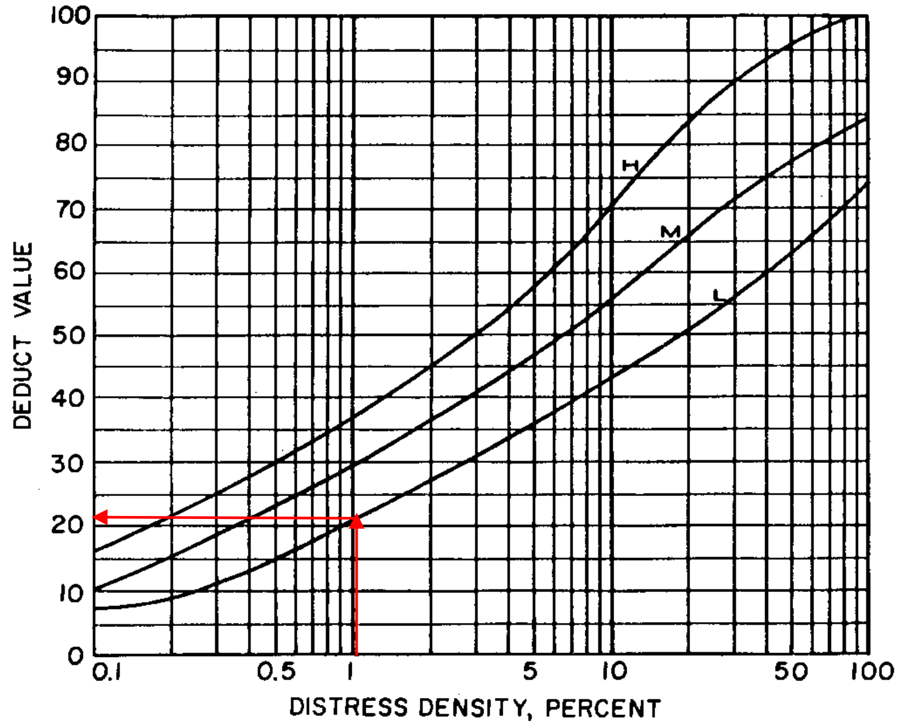
1b. Divide the quantity of each distress type at each severity level by the total area of the sample unit then multiply by 100 to obtain the percentage of density per sample unit for each distress type and severity.

1c. Determine the deduct value for each distress type and severity level combination from the distress deduct value curves. Figure 3-3 shows an example of a deduct curve for distress type 41, alligator cracking, for asphalt-surfaced airfield pavements. Deduct curves for all asphalt airfield distresses are provided in Appendix C.

Table 3-1 Calculation of Deduct Values for Distresses Shown in Figure 3-1

Paver Distress	ASTM Distress	Description	Severity	Qty (ft/ft^2)	Qty (m/m^2)	Density	Deduct
(41)	{1}	Alligator cracking	L	53 ft^2	4.9 m^2	1.06	21.0
(45)	{5}	Depression	L	75 ft^2	7.0 m^2	1.5	9.2
(48)	{8}	Longitudinal and transverse cracking	L	47 ft	14.3 m	0.94	4.8
(48)	{8}	Longitudinal and transverse cracking	M	16 ft	4.9 m	0.32	6.7
(53)	{13}	Rutting	M	25 ft^2	2.3 m^2	0.5	20.2
ft^2 (m^2) = square feet (square meters) ft (m) = feet (meters)							

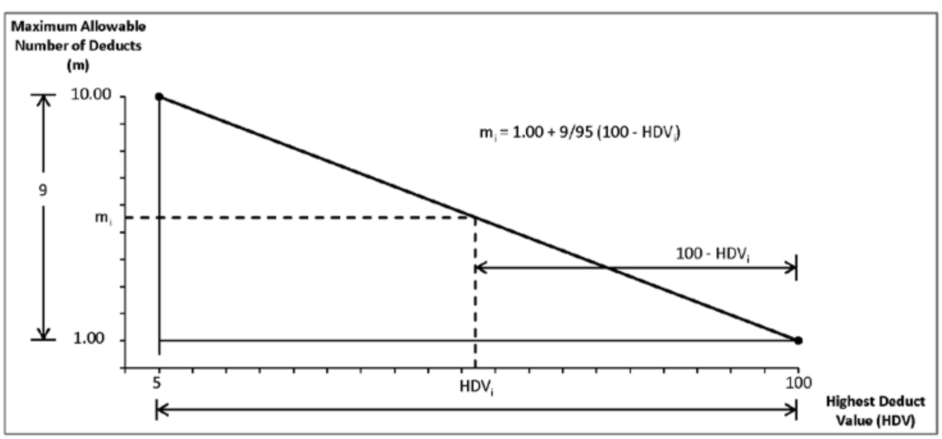
Figure 3-3 AC Pavement Deduct Curve for Alligator Cracking Distress



3-2.2 Step 2: Determine the Maximum Allowable Number of Deducts (*m*).

The maximum allowable number of deducts is calculated as shown in Figure 3-4 or using Equation 3-1.

Figure 3-4 Determination of Maximum Allowable Deducts (*m*) for Airfield Pavements



Equation 3-1 Allowable Number of Deducts for Airfields

$$m_i = 1 + \left(\frac{9}{95}\right)(100 - HDV_i)$$

where:
m_i = *allowable number of deducts, including fractions, for sample unit i*
HDV_i = *highest individual deduct value for sample unit i*

For example, in Table 3-1 (calculated from Figure 3-1) the allowable number of deducts is calculated as:

$$m_i = 1 + \left(\frac{9}{95}\right)(100 - 21.02) = 8.48$$

The number of individual deduct values is reduced to *m*, including the fractional part. If fewer than *m* deduct values are available then all the deduct values are used. For the example in Figure 3-1, all the deduct values are used since they are less than *m*.

3-2.3 Step 3: Determine the Maximum Corrected Deduct Value (CDV).

The maximum CDV is determined iteratively as described in these five steps:

3a. List the individual deduct values in descending order as shown in Figure 3-5, row 1. For example, the values in Table 3-1, which were calculated from the example shown in Figure 3-1, are sorted as follows: 21, 20.2, 9.2, 6.7, and 4.8.

3b. Determine the total deduct value by adding all individual deduct values. In the current example, the total deduct value is 61.9.

3c. Determine the CDV from *q* (number of deduct values over 5) and the total deduct value by looking up the appropriate correction curve. Figure 3-6 shows the correction curve for asphalt-surfaced airfield pavements. The CDV for row 1 is calculated as 31.

3d. Reduce to 5.0 the smallest individual deduct value that is greater than 5.0, as shown in row number 2 in Figure 3-5. Repeat steps 3b and 3c until *q* is equal to 1.

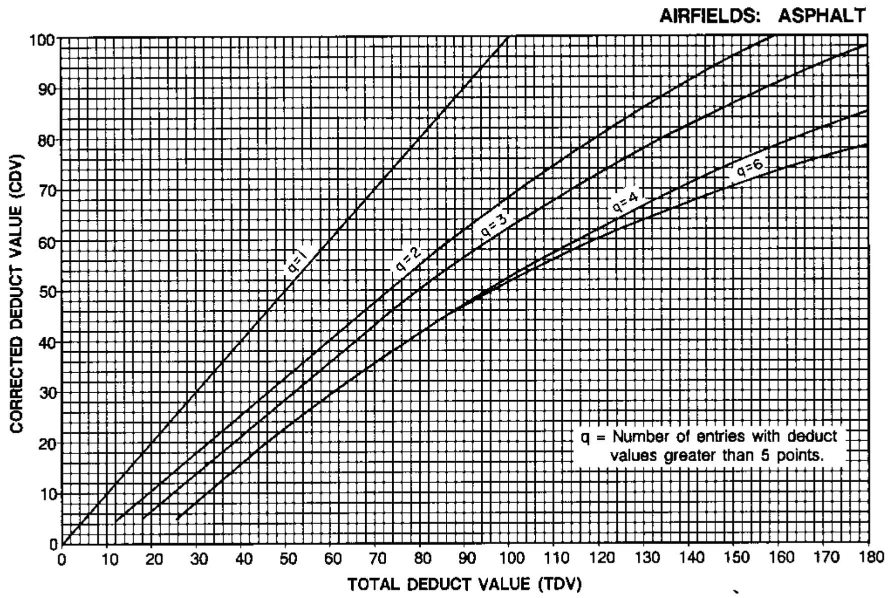
3e. The maximum CDV is the largest of the CDVs determined.

Figure 3-5 PCI Calculation Sheet for Example Sample Unit Shown in Figure 3-1

AC m = 8.48 > 5

PCI CALCULATION FORM													
BRANCH Runway				**SECTION** B01				**SAMPLE UNIT** 008					
CALCULATED BY S. Smith				**DATE** 06/20/2018									
Adjustment of the Number of Deduct Values (1 Minimum, 10 Maximum):													
ITERATION NUMBER	**DEDUCT VALUES** (Arrange Values from Highest Value to Lowest Value) * Do not list more values than the Adjustment Number of Deduct Values (round to the next higher integer if a fraction/decimal) ** The last (lowest) value listed may be a fraction of one of the DEDUCT VALUES in the Condition Survey Data Sheet										**DEDUCT TOTAL**	**Number of Deduct Values Greater than (but not equal to) 5.0** **q**	**Corrected Deduct Value** **CDV**
1	21.0	20.2	9.2	6.7	4.8						61.9	4	31
2	21.0	20.2	9.2	5.0	4.8						60.2	3	36
3	21.0	20.2	5.0	5.0	4.8						56.0	2	37
4	21.0	5.0	5.0	5.0	4.8						40.8	1	41
5													
6													
7													
8													
9													
10													
MAXIMUM CDV = 41													
Corrected Pavement Condition Index (PCI) = 100 - MAXIMUM CDV = 59													

Figure 3-6 Correction Curves for AC-Surfaced Airfield Pavements



3-2.4 Step 4: Calculate PCI by Subtracting the Maximum CDV from 100.

For the example, the PCI equals 100 - 41 = 59.

3-3 CALCULATION OF A SAMPLE UNIT PCI FOR CONCRETE-SURFACED PAVEMENTS.

3-3.1 Step 1: Determine Deduct Values.

Table 3-2 shows the results of the calculation of the deduct values for the distresses shown in Figure 3-7.

1a. For each unique combination of distress type and severity level, add the number of slabs in which they occur. For example, Figure 3-7 lists three slabs with low-severity joint spalling.

1b. Divide the number of slabs from step 1a by the total number of slabs in the sample unit then multiply by 100 to obtain the percentage of density per sample unit for each distress type and severity combination.

1c. Determine the deduct values for each distress type and severity level combination using the appropriate deduct curve in Appendix D for concrete airfields.

Figure 3-7 Concrete-Surfaced Airfield PCI Survey Data Sheet Example

PCC AIRFIELD PAVEMENT CONDITION SURVEY DATA SHEET (Automated)			
PID Delta_R1230_B03		INSPECTOR NAME S. Smith	
FROM TW F		BRANCH USE Runway	DATE INSPECTED 06/20/2018
TO RW 30 END		SECTION WIDTH 100 FT	SECTION LENGTH 2000 FT
SLAB WIDTH 25 FT	SLAB LENGTH 25 FT	NUMBER OF SLABS 320	

PCC Surfaced Distress Codes			
61. Blowup {1}	65. Joint Seal Damage {5}	69. Pumping {9}	73. Shrinkage Cracks {13}
62. Corner Break {2}	66. Patching, Small < 1.5 m (< 5 ft) {6}	70. Scaling {10}	74. Spalling, Joints {14}
63. Cracks {3}	67. Patching, Large/ Utility Cut {7}	71. Settlement/Faulting {11}	75. Spalling, Corner {15}
64. Durability Cracking {4}	68. Popouts {8}	72. Shattered Slab {12}	76. ASR {16}

SAMPLE NUMBER 005 | **SLABS IN SAMPLE 20**

DISTRESS CODE	L	M	H
63	5	2	
74	3		
72	1		
75	6		

SKETCH/COMMENTS

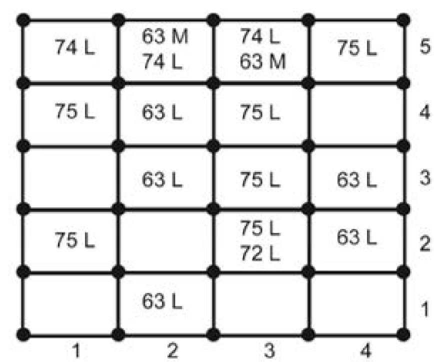


Table 3-2 Calculation of Deduct Values for Distresses Shown in Figure 3-7

Paver Distress	ASTM Distress	Description	Severity	Quantity	Units	Density	Deduct
(63)	{4}	Linear cracking	M	2	Slabs	10	18.7
(63)	{4}	Linear cracking	L	5	Slabs	25	15.4
(72)	{13}	Shattered slab	L	1	Slabs	5	11.0
(74)	{15}	Joint spall	L	3	Slabs	15	4.8
(75)	{16}	Corner spall	L	6	Slabs	30	9.6

3-3.2 Step 2: Determine the Maximum Allowable Number of Deducts (*m*).

This step is the same as the comparable step for asphalt-surfaced pavements described in paragraph 3-2.2. For the example in Figure 3-7, based on a highest deduct value (HDV) of 18.66, m is calculated using Equation 3-1:

$$m_i = 1 + \left(\frac{9}{95}\right)(100 - 18.66) = 8.71$$

The maximum allowable number of deducts, m, was calculated to be 8.71. There are only five deduct values (18.66, 15.43, 11.02, 4.78, and 9.62) so taking a percentage of one of the deduct values is not necessary; however, if in the sample unit m was calculated to be 3.4, it would be necessary to take the three highest deduct values and 40 percent of the fourth-highest deduct value.

3-3.3 Step 3: Determine the Maximum CDV.

Determine the maximum CDV by following the procedures in paragraph 3-2.3 but using the appropriate correction curve in Appendix D for concrete airfields.

3-3.4 Step 4: Calculate the PCI by Subtracting the Maximum CDV from 100.

Figure 3-8 summarizes the PCI calculation for the example of PCC pavement data shown in Figure 3-7.

Figure 3-8 PCI Calculation Sheet for the Example Sample Unit Shown in Figure 3-7

PCC *m* = 8.8 > 5

<table>
<tr><th colspan="14">PCI CALCULATION FORM</th></tr>
<tr><td colspan="3">BRANCH Runway</td><td colspan="6">SECTION B03</td><td colspan="5">SAMPLE UNIT 005</td></tr>
<tr><td colspan="3">CALCULATED BY S. Smith</td><td colspan="6">DATE 06/20/2018</td><td colspan="5"></td></tr>
<tr><td colspan="14">Adjustment of the Number of Deduct Values (1 Minimum, 10 Maximum):</td></tr>
<tr><th rowspan="3">ITERATION NUMBER</th><td colspan="10">DEDUCT VALUES (Arrange Values from Highest Value to Lowest Value)</td><th rowspan="3">DEDUCT TOTAL</th><th rowspan="3">Number of Deduct Values Greater than (but not equal to) 5.0
q</th><th rowspan="3">Corrected Deduct Value

CDV</th></tr>
<tr><td colspan="10">* Do not list more values than the Adjustment Number of Deduct Values (round to the next higher integer if a fraction/decimal)</td></tr>
<tr><td colspan="10">** The last (lowest) value listed may be a fraction of one
of the DEDUCT VALUES in the Condition Survey Data Sheet</td></tr>
<tr><td>1</td><td>18.7</td><td>15.4</td><td>11.0</td><td>9.6</td><td>4.8</td><td></td><td></td><td></td><td></td><td></td><td>59.5</td><td>4</td><td>38</td></tr>
<tr><td>2</td><td>18.7</td><td>15.4</td><td>11.0</td><td>5.0</td><td>4.8</td><td></td><td></td><td></td><td></td><td></td><td>54.9</td><td>3</td><td>38</td></tr>
<tr><td>3</td><td>18.7</td><td>15.4</td><td>5.0</td><td>5.0</td><td>4.8</td><td></td><td></td><td></td><td></td><td></td><td>48.9</td><td>2</td><td>42</td></tr>
<tr><td>4</td><td>18.7</td><td>5.0</td><td>5.0</td><td>5.0</td><td>4.8</td><td></td><td></td><td></td><td></td><td></td><td>38.5</td><td>1</td><td>38</td></tr>
<tr><td>5</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>6</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td>8</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>9</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>10</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="13">MAXIMUM CDV = 42</td><td></td></tr>
<tr><td colspan="13">Corrected Pavement Condition Index (PCI) = 100 - MAXIMUM CDV = 58</td><td></td></tr>
</table>

3-4 CALCULATION OF THE PCI FOR A PAVEMENT SECTION.

If all surveyed sample units are selected either by using the systematic random technique or on the basis of being representative of the section and are equal in size, the PCI of the section is determined by averaging the PCIs of the inspected sample units. If the inspected sample units are not equal in size, use area-weighted averaging as shown in Equation 3-2.

Equation 3-2 Area Weighted Averaging for Unequally Sized Sample Units

$$PCI_s = PCI_r = \frac{\sum_{i=1}^{R}(PCI_{ri}\ A_{ri})}{\sum_{i=1}^{R} A_{ri}}$$

where:
PCI_s = PCI of pavement section
PCI_r = area-weighted average PCI of random (or representative) sample units
PCI_{ri} = PCI of random sample unit number i
A_{ri} = area of the random sample unit i
R = total number of inspected random sample units

If additional sample units are inspected in addition to the random or representative units, the section PCI is computed using Equations 3-3 and 3-4:

Equation 3-3 Area Weighted Average PCI for Additional Sample Units

$$\boldsymbol{PCI_a} = \frac{\sum_{i=1}^{A}(\boldsymbol{PCI_{ai}} \times \boldsymbol{A_{ai}})}{\sum_{i=1}^{R}(\boldsymbol{A_{ai}})}$$

Equation 3-4 Section PCI for Additional Sample Units

$$PCI_s = \frac{PCI_r\left(A_s - \sum_{i=1}^{A} A_{ai}\right) + PCI_a \times \sum_{i=1}^{A} A_{ai}}{A_s}$$

where:
PCI_a = area weighted average PCI of additional sample units
PCI_{ai} = PCI of additional sample unit number i
A_{ai} = area of additional sample unit I
A_s = total section area

For example, if in a section of 60,000 square feet (5,574 square meters), five random sample units were inspected and determined to have PCIs of 56 (5,000 square feet [465 square meters]), 72 (5,000 square feet [465 square meters]), 65 (5,000 square feet [465 square meters]), 69 (4,000 square feet [372 square meters]), and 61 (4,000 square feet [372 square meters]), and two additional sample units with PCIs of 42 (3,500 square feet [325 square meters]) and 39 (3,500 square feet [325 square meters]) were included, the PCI of the section would be:

$$PCI_r = \frac{(56 \times 5{,}000) + (72 \times 5{,}000) + (65 \times 5{,}000) + (69 \times 4{,}000) + (61 \times 4{,}000)}{5{,}000 + 5{,}000 + 5{,}000 + 4{,}000 + 4{,}000}$$
$$PCI_r = 64.57$$

$$PCI_a = \frac{(42 \times 3{,}500) + (39 \times 3{,}500)}{3{,}500 + 3{,}500}$$
$$PCI_a = 40.5$$

$$PCI_s = \frac{64.57(60{,}000 - 7{,}000) + 40.5 \times 6{,}500}{60{,}000}$$
$$PCI_s = 61$$

3-5 EXTRAPOLATING DISTRESS QUANTITIES FOR A PAVEMENT SECTION.

3-5.1 When a pavement has been inspected by sampling, it is necessary to extrapolate the quantities and densities of distress over the entire pavement section to determine total quantities for the section. If all sample units surveyed were selected at random, the extrapolated quantity of a given distress at a given severity level is determined as shown in the following example for an asphalt-surfaced airfield with medium-severity alligator cracking:

Surface type: AC

Section area: 49,000 square feet (4,552 square meters)

Total number of sample units in section: 10

3-5.2 Five sample units were surveyed at random and the amount of medium-severity alligator cracking was determined as shown in Table 3-3:

Table 3-3 Medium-Severity Alligator Cracking in Five Surveyed Sample Units

Sample Unit ID Number	Sample Unit Area ft^2 (m^2)	Medium-Severity Alligator Cracking ft^2 (m^2)
02	5,000 (465)	200 (18.6)
04	5,000 (465)	400 (37.2)
06	5,000 (465)	300 (27.9)
08	5,000 (465)	100 (9.3)
10	4,000 (372)	200 (18.6)
Total Random	**24,000 (2230)**	**1,200 (111.5)**

3-5.3 The average density for medium-severity alligator cracking then is 1,200 divided by 24,000, or 0.05. The extrapolated quantity is determined by multiplying density by section area (0.05 × 49,000 = 2,450 square feet [227.6 square meters]). If additional sample units were included in the survey, the extrapolation process is slightly different. In the above example, assume that sample unit number 01 was surveyed as an additional unit and that the amount of medium-severity alligator cracking was measured as shown in Table 3-4:

Table 3-4 Medium-Severity Alligator Cracking in an Additional Sample Unit

Additional Sample Unit ID Number	Sample Unit Area ft^2 (m^2)	Medium-Severity Alligator Cracking ft^2 (m^2)
01	5,000 (465)	2,000 (186)
Total Additional	**5,000** (465)	**2,000 (186)**

3-5.4 Since 5,000 square feet (465 square meters) were surveyed as additional in this example, the section's randomly represented area is 49,000 - 5,000 square feet (4,552 – 465 square meters) or 44,000 square feet (4087 square meters). The extrapolated distress quantity is obtained by multiplying the distress density by the section's randomly represented area then adding the amount of additional distress. In this example, the extrapolated distress quantity equals (0.05 × 44,000 square feet (4,087 square meters) + 2,000 square feet (186 square meters) or 4,200 square feet (390 square meters).

APPENDIX A DISTRESS DEFINITIONS - ASPHALT-SURFACED AIRFIELDS.

A-1 INTRODUCTION.

This appendix contains distress definitions and measurement methods for asphalt-surfaced airfields. This information is used to determine the PCI.

Note: Each distress definition is followed by a number in parentheses, indicating the PAVER distress code, and a number in braces, indicating the ASTM D5340 distress code, i.e.,
"Distress (#) {#}." See Table 3-5.

Table A-1 Frequently Occurring Problems in Asphalt Pavement Distress Identification

Situation	Action	Remarks
Alligator cracking and rutting in same area	Record each separately at respective severity level	
Bleeding counted in area	Polished aggregate is not counted in same area	
Polished aggregate in very small amount	Do not count	Polished aggregate is only counted when there is a significant amount
Any distress (including cracking) in a patched area	Do not record	Effect of distress is considered in patch severity level
Block cracking is recorded	For asphalt pavements, not including AC over PCC, if block cracking is recorded, do not record longitudinal and transverse cracking in the same area	
Asphalt overlay over concrete	Block cracking and joint reflection cracking are recorded separately	AC over PCC could have, for example, 100 percent block cracking and 100 feet of joint reflection cracking
Weathering (surface wear) and raveling in the same sample area	Weathering (surface wear) is not recorded if medium- or high-severity raveling is recorded	Raveling is always recorded

A-2 ALLIGATOR (FATIGUE) CRACKING (41) {1}.

A-2.1 Description.

Alligator (or fatigue) cracking is a series of interconnecting cracks caused by fatigue failure of the asphalt surface under repeated traffic loading. The cracking initiates at the bottom of the asphalt surface (or stabilized base) where tensile stress and strain is highest under a wheel load. The cracks propagate to the surface initially as a series of parallel cracks. After repeated traffic loading, the cracks connect and form multi-sided, sharp-angled pieces that develop a pattern resembling chicken wire or the skin of an alligator. The pieces are less than 2 feet (0.6 meter) on the longest side. Alligator cracking occurs only in areas subjected to repeated traffic loadings, such as wheel paths; therefore, it would not occur over an entire area unless the entire area was subjected to traffic loading. (Pattern-type cracking that occurs over an entire area that is not subject to loading is rated as block cracking, which is not a load-associated distress.) Alligator cracking is considered a major structural distress.

A-2.2 Severity Levels.

L Fine, longitudinal hairline cracks running parallel to each other with no or only a few interconnecting cracks. The cracks are not spalled.

M Further development of light alligator cracking into a pattern or network of cracks that may be lightly spalled. Medium-severity alligator cracking is defined by a well-defined pattern of interconnecting cracks, where all pieces are securely held in place (i.e., good aggregate interlock between pieces).

H Network or pattern cracking progresses so that pieces are well-defined and spalled at the edges; some of the pieces rock under traffic and may cause foreign object damage (FOD) potential.

A-2.3 How to Measure.

Alligator cracking is measured in square feet (square meters) of surface area. The major difficulty in measuring this type of distress is that often two or three levels of severity exist within one distressed area. If these portions can be easily distinguished from each other, measure and record separately; however, if the different levels of severity cannot be easily divided, rate the entire area at the highest severity level present. If alligator cracking and rutting occur in the same area, each is recorded separately at its respective severity level.

Figure A-1 Low-Severity Alligator Cracking

Figure A-2 Medium-Severity Alligator Cracking

Figure A-3 High-Severity Alligator Cracking

A-3 BLEEDING (42) {2}.

A-3.1 Description.

Bleeding is a film of bituminous material on the pavement surface that creates a shiny, glass-like, reflecting surface that usually becomes quite sticky. Bleeding is caused by excessive amounts of asphalt cement or tars in the mix and/or low air-void content. Bleeding occurs when asphalt fills the voids of the mix during hot weather and then expands onto the surface of the pavement. Since the bleeding process is not reversible during cold weather, asphalt or tar will accumulate on the surface.

A-3.2 Severity Levels.

No degrees of severity are defined. Note bleeding when it is extensive enough to cause a reduction in skid resistance.

A-3.3 How to Measure.

Bleeding is measured in square feet (square meters) of surface area. If bleeding is counted, polished aggregate is not counted in the same area.

Figure A-4 Bleeding

Figure A-5 Bleeding

A-4 BLOCK CRACKING (43) {3}.

A-4.1 Description.

Block cracks are interconnected cracks that divide the pavement into roughly rectangular pieces. The blocks may range in size from approximately 1 by 1 foot to 10 by 10 feet (0.3 by 0.3 meter to 3 by 3 meters). Block cracking is caused mainly by shrinkage of the AC and daily temperature cycling (which results in daily stress/strain cycling); it is not load-associated. The occurrence of block cracking usually indicates that the asphalt has significantly hardened. Block cracking typically occurs over a large proportion of pavement area but sometimes will occur in non-traffic areas. This type of distress differs from alligator cracking in that alligator cracks form smaller, multi-sided pieces with sharp angles. Also, unlike block cracks, alligator cracks are caused by repeated traffic loadings and therefore are located only in traffic areas (i.e., wheel paths).

A-4.2 Severity Levels.

L Blocks are defined by cracks that are non-spalled (sides of the crack are vertical) or only lightly spalled, causing no FOD potential. Non-filled cracks have 0.25 inch (6 millimeters) or less mean width and filled cracks have filler in satisfactory condition.

M Blocks are defined by either (1) filled or non-filled cracks that are moderately spalled (some FOD potential); (2) non-filled cracks that are not spalled or have only minor spalling (some FOD potential) but have a mean width greater than approximately 0.25 inch (6 millimeters); or (3) filled cracks that are not spalled or have only minor spalling (some FOD potential) but have filler in unsatisfactory condition.

H Blocks are well defined by cracks that are severely spalled, causing a definite FOD potential.

A-4.3 How to Measure.

Block cracking is measured in square feet (square meters) of surface area. It usually occurs at one severity level in a given pavement section; however, measure and record separately any areas of the pavement section having distinctly different levels of severity. For asphalt pavements, not including AC over PCC, if block cracking is recorded, do not record longitudinal and transverse (L&T) cracking in the same area. For asphalt overlay over concrete, separately record block cracking, joint reflection cracking, and L&T cracking reflected from old concrete.

Figure A-6 Low-Severity Block Cracking

Figure A-7 Low-Severity Block Cracking

Figure A-8 Medium-Severity Block Cracking

Figure A-9 Medium-Severity Block Cracking

Figure A-10 High-Severity Block Cracking

Figure A-11 High-Severity Block Cracking

A-5 CORRUGATION (44) {4}.

A-5.1 Description.

Corrugation is a series of closely spaced ridges and valleys (ripples) occurring at fairly regular intervals, usually less than 5 feet (1.5 meters) along the pavement. The ridges are perpendicular to the traffic direction. Traffic action combined with an unstable pavement surface or base usually causes this type of distress.

A-5.2 Severity Levels.

L Corrugations are minor and do not significantly affect ride quality (see measurement criteria below).

M Corrugations are noticeable and significantly affect ride quality (see measurement criteria below).

H Corrugations are easily noticed and severely affect ride quality (see measurement criteria below).

A-5.3 How to Measure.

Corrugation is measured in square feet (square meters) of surface area. The mean elevation difference between the ridges and valleys of the corrugations indicates the level of severity. To determine the mean elevation difference, place a 10-foot (3-meter) straightedge perpendicular to the corrugations so the depth of the valleys is measured in inches (millimeters). The mean depth is calculated from five such measurements. See Table A-2 and Figure A-12.

Table A-2 Corrugation Measurement Criteria

Measurement Criteria Severity	Runaways and High-Speed Taxiways	Taxiways and Aprons
L	< 0.25 inch (< 6 mm)	< 0.5 inch (< 13 mm)
M	0.25 to 0.5 inch (6 to 13 mm)	0.5 to 1 inch (13 to 25 mm)
H	> 0.5 inch (> 13 mm)	> 1 inch (> 25 mm)

Figure A-12 Corrugation

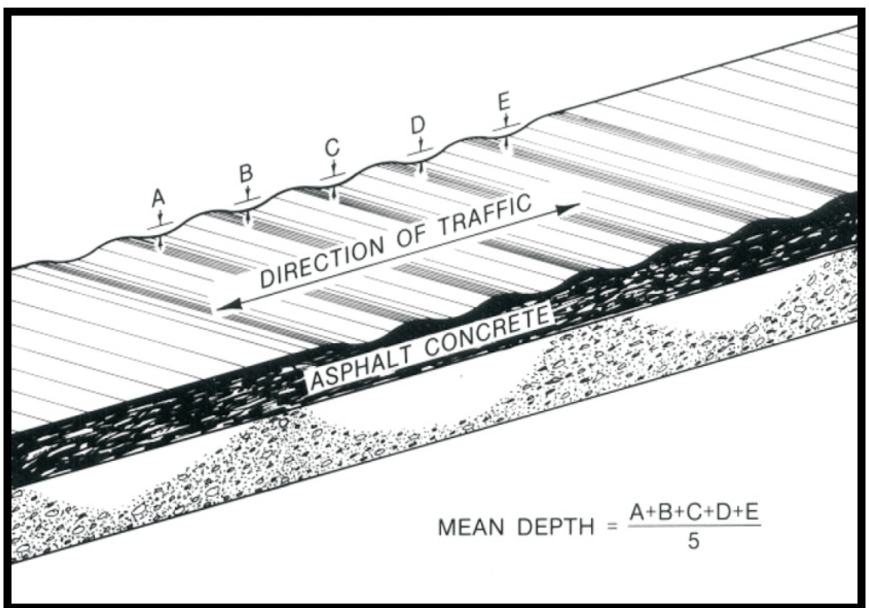
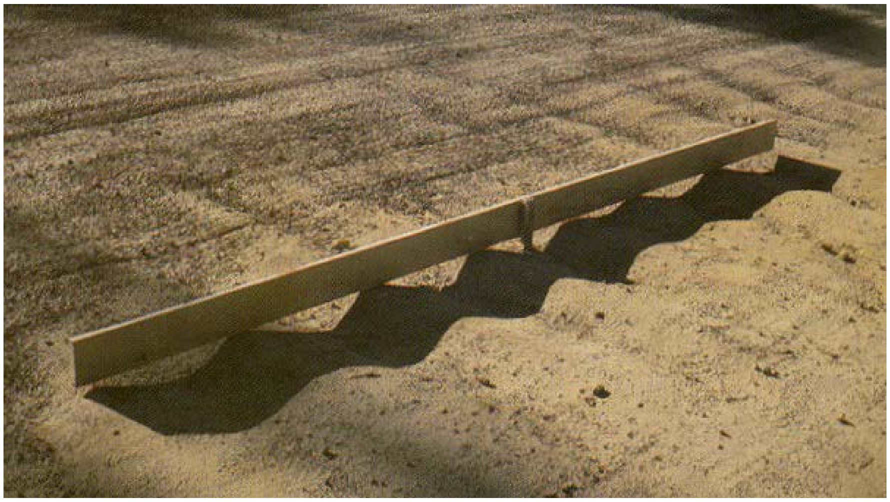


Figure A-13 Low-Severity Corrugation

Figure A-14 Medium-Severity Corrugation

Figure A-15 High-Severity Corrugation



A-6 DEPRESSION (45) {5}.

A-6.1 Description.

Depressions are localized pavement surface areas having elevations slightly lower than those of the surrounding pavement. In many instances, light depressions are not noticeable until after a rain, when ponding water creates “birdbath” areas, but the depressions can also be located without rain because of stains created by ponding water. Depressions can be caused by settlement of the foundation soil or can be built up during construction. Depressions cause roughness and, when filled with water of sufficient depth, can cause hydroplaning of aircraft.

A-6.2 Severity Levels.

L Depression can be observed or located by stained areas, only slightly affects pavement riding quality, and may cause hydroplaning potential on runways (see measurement criteria below).

M Depression can be observed, moderately affects pavement riding quality, and causes hydroplaning potential on runways (see measurement criteria below).

H Depression can be readily observed, severely affects pavement riding quality, and causes definite hydroplaning potential (see measurement criteria below).

A-6.3 How to Measure.

Depressions are measured in square feet (square meters) of surface area. The maximum depth of the depression determines the level of severity. This depth can be measured by placing a 10-foot (3-meter) straightedge across the depressed area and measuring the maximum depth in inches (millimeters). Depressions larger than 10 feet (3 meters) across must be measured by either visual estimation or direct measurement when filled with water.

Table A-3 Maximum Depth of Depression

Severity	Runaways & High-Speed Taxiways	Taxiways & Aprons
L	0.125 to 0.5 in (3 to 13 mm)	0.5 to 1 inch (13 to 25 mm)
M	0.5 to 1 inch (13 to 25 mm)	1 to 2 inches (25 to 51 mm)
H	> 1 inch (> 25 mm)	> 2 inches (> 51 mm)

Figure A-16 Low-Severity Depression

Figure A-17 Medium-Severity Depression

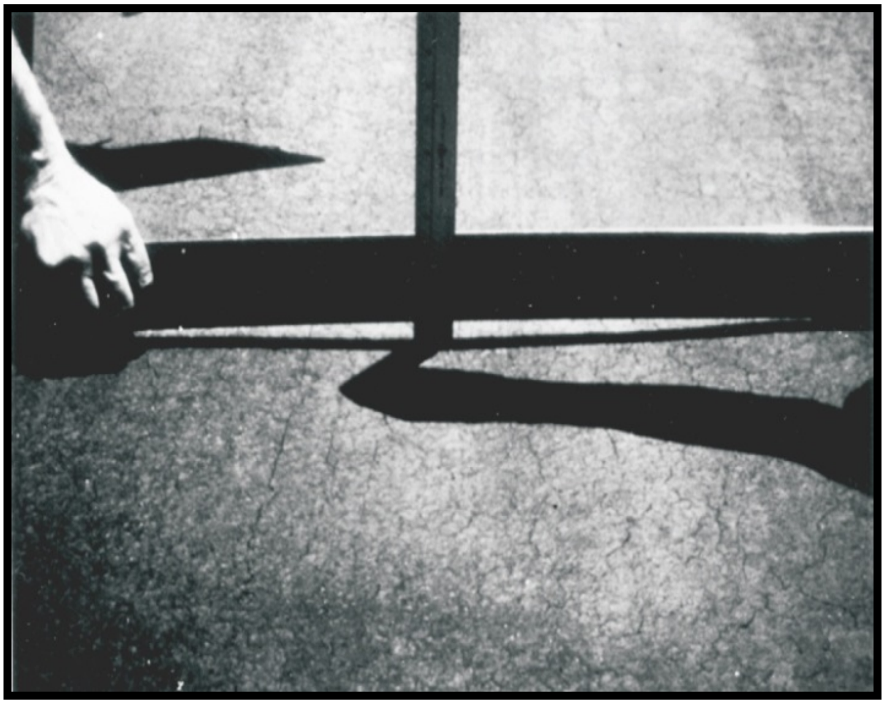


Figure A-18 High-Severity Depression

Figure A-19 High-Severity Depression

A-7 JET BLAST EROSION (46) {6}.

A-7.1 Description.

Jet blast erosion causes darkened areas on the pavement surface when bituminous binder has been burned or carbonized; localized burned areas may vary in depth up to approximately 0.5 inch (13 millimeters).

A-7.2 Severity Levels.

No degrees of severity are defined. It is sufficient to indicate that jet blast erosion exists.

A-7.3 How to Measure.

Jet blast erosion is measured in square feet (square meters) of surface area.

Figure A-20 Jet Blast Erosion

A-8 JOINT REFLECTION CRACKING FROM PCC (47) {7}.

A-8.1 Description.

This distress occurs only on pavements having an asphalt or tar surface over a PCC slab. This category does not include reflection cracking from any other type of base (i.e., cement stabilized, lime stabilized); such cracks are listed as L&T cracks. Joint reflection cracking is caused mainly by movement of the PCC slab beneath the AC surface because of thermal and moisture changes; it is not load-related. However, traffic loading may cause a breakdown of the AC near the crack, resulting in spalling and FOD potential. If the pavement is fragmented along a crack, the crack is said to be spalled. Knowledge of the slab dimensions beneath the AC surface will help identify these cracks.

A-8.2 Severity Levels.

L Cracks have only light spalling (little or no FOD potential) or no spalling and can be filled or non-filled. If non-filled, the cracks have a mean width of 0.25 inch (6 millimeters) or less. Filled cracks are of any width but their filler material is in satisfactory condition.

M One of these conditions exists: (1) cracks are moderately spalled (some FOD potential) and can be either filled or non-filled of any width; (2) filled cracks are not spalled or are only lightly spalled but the filler is in unsatisfactory condition; (3) non-filled cracks are not spalled or are only lightly spalled but the mean crack width is greater than 0.25 inch (6 millimeters); or (4) light random cracking exists near the crack or at the corner of intersecting cracks.

H Cracks are severely spalled (definite FOD potential) and can be either filled or non-filled of any width.

A-8.3 How to Measure.

Joint reflection cracking is measured in linear feet (linear meters). Identify and record the length and severity level of each crack. If the crack does not have the same severity level along its entire length, separately record each portion. For example, a crack that is 50 feet (15 meters) long may have 10 feet (3 meters) of high-severity cracking, 20 feet (6 meters) of medium-severity cracking, and 20 feet (6 meters) of low-severity cracking; these are recorded separately. If the different levels of severity in a portion of a crack cannot be easily divided, rate that portion at the highest severity present.

Figure A-21 Low-Severity Joint Reflection Cracking

Figure A-22 Medium-Severity Joint Reflection Cracking

Figure A-23 High-Severity Joint Reflection Cracking

A-9 LONGITUDINAL AND TRANSVERSE (L&T) CRACKING (48) {8} (NON-PCC JOINT REFLECTIVE).

A-9.1 Description.

Longitudinal cracks are parallel to the pavement's centerline or laydown direction. They may be caused by (1) a poorly constructed paving lane joint, (2) shrinkage of the AC surface due to low temperatures or hardening of the asphalt, or (3) a reflective crack caused by cracks beneath the surface course, including cracks in PCC slabs (but not at PCC joints). Transverse cracks extend across the pavement at approximately right angles to the pavement centerline or direction of laydown. They may be caused by items 2 or 3 above. These types of cracks are not usually load-associated. If the pavement is fragmented along a crack, the crack is said to be spalled.

A-9.2 Severity Levels.

L Cracks have either minor spalling (little or no FOD potential) or no spalling. The cracks can be filled or non-filled. Non-filled cracks have a mean width of 0.25 inch (6 millimeters) or less; filled cracks are of any width but their filler material is in satisfactory condition.

M One of these conditions exists: (1) cracks are moderately spalled (some FOD potential) and can be either filled or non-filled of any width; (2) filled cracks are not spalled or are only lightly spalled but the filler is in unsatisfactory condition; (3) non-filled cracks are not spalled or are only lightly spalled but the mean crack width is greater than 0.25 inch (6 millimeters); or (4) light random cracking exists near the crack or at the corners of intersecting cracks.

H Cracks are severely spalled, causing definite FOD potential. They can be either filled or non-filled of any width.

A-9.3 How to Measure.

L&T cracks are measured in linear feet (linear meters). Identify and record the length and severity of each crack. If the crack does not have the same severity level along its entire length, separately record each portion of the crack with a different severity level. For example, see the explanation of how to measure joint reflection cracking in paragraph A-8.3. If block cracking is recorded, L&T cracking are not recorded in the same area.

Figure A-24 Low-Severity L&T Cracking

Figure A-25 Medium-Severity L&T Cracking

Figure A-26 High-Severity L&T Cracking

A-9.4 Longitudinal and Transverse Cracking (Non-PCC Joint Reflective) in Porous Friction Courses (PFC): Severity Levels.

Note: These severity levels are in addition to the existing definitions.

L Cracks have either minor spalling (little or no FOD potential) or no spalling. The cracks can be filled or non-filled. Non-filled cracks have a mean width of 0.25 inch (6 millimeters) or less; filled cracks are of any width but their filler material is in satisfactory condition. Furthermore, the average raveled area (area with dislodged or missing coarse aggregate larger than 0.19 inch [4.75 millimeters]) around the crack is less than 0.25 inch (6 millimeters) wide.

M The average raveled area (area with dislodged or missing coarse aggregate larger than 0.19 inch [4.75 millimeters]) around the crack is 0.25 to 1 inch (6 to 25 millimeters) wide or one of these conditions exists: (1) cracks are moderately spalled (some FOD potential) and can be either filled or non-filled of any width; (2) filled cracks are not spalled or are only lightly spalled, but the filler is in unsatisfactory condition; (3) non-filled cracks are not spalled or are only lightly spalled but the mean crack width is greater than 0.25 inch (6 millimeters); or (4) light random cracking exists near the crack or at the corners of intersecting cracks.

H The average raveled area (area with dislodged or missing coarse aggregate larger than 0.19 inch [4.75 millimeters]) around the crack is greater than 1 inch (25 millimeters) wide or cracks are severely spalled, causing definite FOD potential. They can be either filled or non-filled of any width.

A-9.5 How to Measure.

L&T cracks are measured in linear feet (linear meters). Identify and record the length and severity of each crack. If the crack does not have the same severity level along its entire length, separately record each portion of the crack with a different severity level. For an example, see the explanation of how to measure joint reflection cracking in paragraph A-8.3. If block cracking is recorded, L&T cracking are not recorded in the same area.

Figure A-27 Low-Severity PFC L&T Cracking

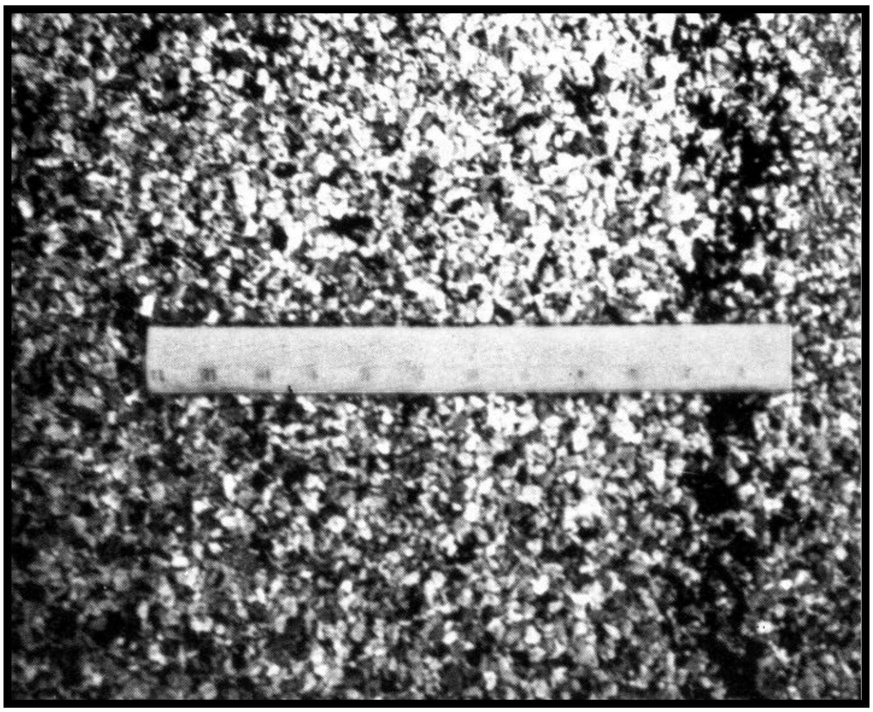


Figure A-28 Medium-Severity PFC L&T Cracking

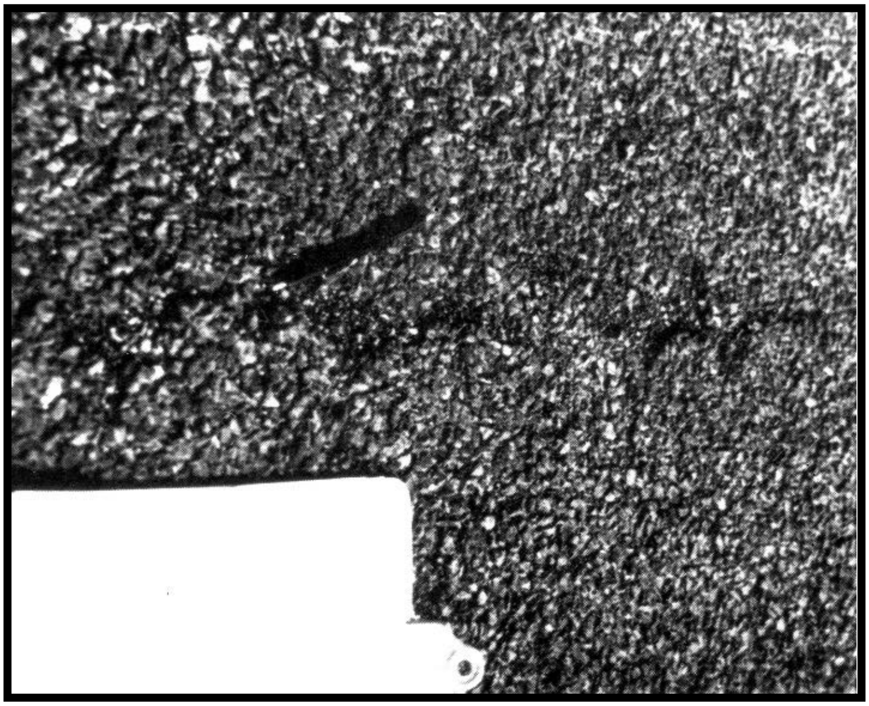


Figure A-29 Medium-Severity PFC L&T Cracking

Figure A-30 High-Severity PFC L&T Cracking

A-10 OIL SPILLAGE (49) {9}.

A-10.1 Description.

Oil spillage is the deterioration or softening of the pavement surface caused by the spilling of oil, fuel, or other solvents.

A-10.2 Severity Levels.

No degrees of severity are defined. It is sufficient to indicate that oil spillage exists.

A-10.3 How to Measure.

Oil spillage is measured in square feet (square meters) of surface area. A stain is not a distress unless material has been lost or the binder has been softened. If hardness is approximately the same as on surrounding pavement and if no material has been lost, do not record as a distress.

Figure A-31 Oil Spill

A-11 PATCHING AND UTILITY CUT PATCH (50) {10}.

A-11.1 Description.

A patch is considered a defect, regardless of how well it is performing.

A-11.2 Severity Levels.

L Patch is in good condition and performing satisfactorily; little or no FOD potential.

M Patch is somewhat deteriorated and affects riding quality to some extent; some FOD potential.

H Patch is badly deteriorated and affects riding quality significantly or has high FOD potential. Patch needs replacement.

The use of dense-graded AC patches on PCC surfaces causes a water-damming effect at the patch that contributes to differential skid resistance of the surface. Rate low-severity, dense-graded patches as medium-severity patches because of the differential friction problem. Medium- and high-severity patches are rated the same as above.

A-11.3 How to Measure.

Patching is measured in square feet (square meters) of surface area; however, if a single patch has areas of differing severity levels, measure and record these areas separately. For example, a 25-square-foot (2.5-square-meter) patch may have 10 square feet (1 square meter) of medium severity and 15 square feet (1.5 square meters) of low severity. Record these areas separately. Any distress found in a patched area is not recorded; however, its effects on the patch will be considered when determining the patch’s severity level.

A very large patch (area > 2,500 square feet [230 square meters]) or feathered-edge pavement may qualify as an additional sample unit or a separate section.

Figure A-32 Low-Severity Patching

Figure A-33 Medium-Severity Patching

Figure A-34 High-Severity Patching

A-12 POLISHED AGGREGATE (51) {11}.

A-12.1 Description.

Aggregate polishing is caused by repeated traffic applications. Polished aggregate is present when close examination of a pavement reveals that the portion of aggregate extending above the asphalt is either very small or there are no rough or angular aggregate particles to provide good skid resistance. Existence of this type of distress is also indicated when the number on a skid resistance rating test is low or has dropped significantly from previous ratings.

A-12.2 Severity Levels.

No degrees of severity are defined; however, when the degree of polishing is significant, polishing is included in the condition survey and rated as a defect.

A-12.3 How to Measure.

Polished aggregate is measured in square feet (square meters) of surface area. If bleeding is counted, polished aggregate is not counted in the same area.

Figure A-35 Polished Aggregate

A-13 RAVELING (52) {12}.

A-13.1 Description.

Raveling is the dislodging or loss of coarse aggregate particles (stone or rocks larger than 0.19 inch [4.75 millimeters]) from the pavement surface. This is characterized by aggregates larger than 0.19 inch (4.75 millimeters) missing or no longer bound to the surface.

A-13.2 Dense Mix Severity Levels.

As used herein, “coarse aggregate” refers to predominant coarse aggregate sizes of the asphalt mix. The term “aggregate clusters” refers to when more than one adjoining coarse aggregate piece is missing. If in doubt about a severity level, examine three representative areas of 1 square yard (1 square meter) each and count the number of missing coarse aggregate particles.

L One of these conditions exists: (1) in a 1-square-yard (1-square-meter) representative area, the number of coarse aggregate particles missing is between five and twenty; or (2) missing aggregate clusters are less than 2 percent of the examined 1-square-yard (1-square-meter) area. In low-severity raveling, there is little or no FOD potential.

M One of these conditions exists: (1) in a 1-square-yard (1-square-meter) representative area, the number of coarse aggregate particles missing is between 21 and 40; or (2) missing aggregate clusters are between 2 and 10 percent of the examined 1-square-yard (1-square-meter) area. In medium-severity raveling, there is some FOD potential.

H One of these conditions exists: (1) in a 1-square-yard (1-square-meter) representative area, the number of coarse aggregate particles missing is over 40; or (2) missing aggregate clusters are more than 10 percent of the examined 1-square-yard (1-square-meter) area. In high-severity raveling, there is significant FOD potential.

A-13.3 How to Measure.

Raveling is measured in square feet (square meters) of surface area. Mechanical damage caused by hook drags, tire rims, or snowplows is counted as areas of high-severity raveling.

Figure A-36 Low-Severity Raveling (Dense Mix)

Figure A-37 Medium-Severity Raveling (Dense Mix)

Figure A-38 High-Severity Raveling (Dense Mix)

A-13.4 Slurry Seal/Coal Tar Over Dense Mix Severity Levels.

L (1) The scaled area is less than 1 percent. (2) In the case of coal tar where pattern cracking has developed, the surface cracks are less than 0.25 inch (6 millimeters) wide.

M (1) The scaled area is between 1 and 10 percent. (2) In the case of coal tar where pattern cracking has developed, the cracks are 0.25 inch (6 millimeters) wide or greater.

H (1) The scaled area is over 10 percent. (2) In the case of coal tar, the surface is peeling off.

A-13.5 How to Measure.

Raveling is measured in square feet (square meters) of surface area. Mechanical damage caused by hook drags, tire rims, or snowplows is counted as areas of high-severity raveling.

Figure A-39 Low-Severity Raveling (Slurry Seal/Coal Tar Over Dense Mix)

Figure A-40 Medium-Severity Raveling (Slurry Seal/Coal Tar Over Dense Mix)

Figure A-41 High-Severity Raveling (Slurry Seal/Coal Tar Over Dense Mix)

A-13.6 Porous Friction Course (PFC) Severity Levels.

L In a 1-square-foot (0.1-square-meter) representative sample, the number of aggregate pieces missing is between five and twenty and/or the number of missing aggregate clusters does not exceed one.

M In a 1-square-foot (0.1-square-meter) representative sample, the number of aggregate pieces missing is between 21 and 40 and/or the number of missing aggregate clusters is greater than one but does not exceed 25 percent of the area.

H In a 1-square-foot (0.1-square-meter) representative sample, the number of aggregate pieces missing is over 40 and/or the number of missing aggregate clusters is greater than 25 percent of the area.

A-13.7 How to Measure.

Raveling is measured in square feet (square meters) of surface area. Mechanical damage caused by hook drags, tire rims, or snowplows is counted as areas of high-severity raveling.

Figure A-42 Low-Severity Raveling (PFC)

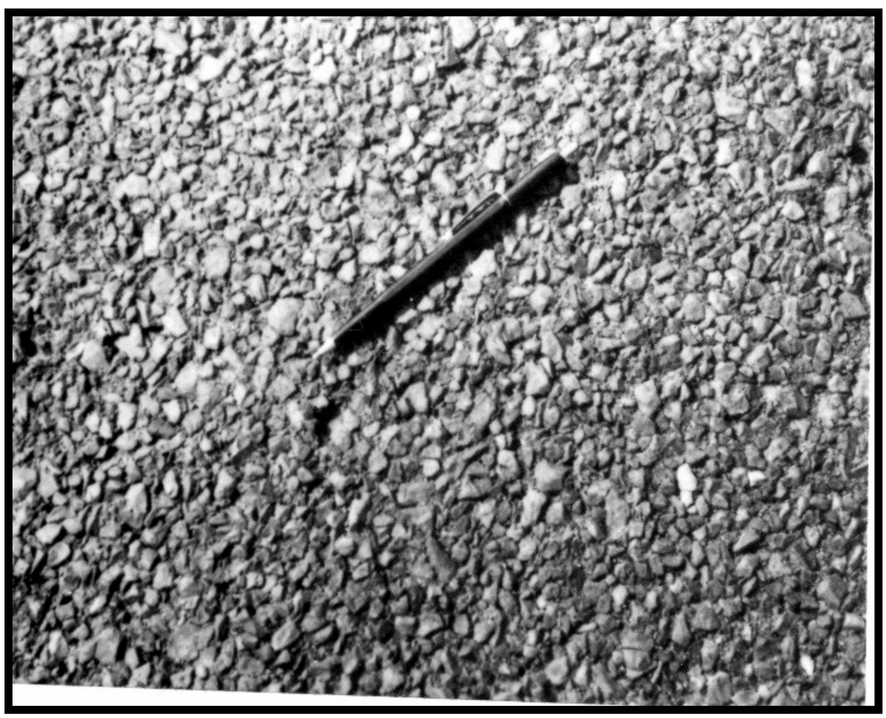


Figure A-43 Medium-Severity Raveling (PFC)

Figure A-44 Medium-Severity Raveling (PFC)

Figure A-45 High-Severity Raveling (PFC)

A-14 RUTTING (53) {13}.

A-14.1 Description.

A rut is a surface depression in the wheel path. Pavement uplift may occur along the sides of the rut; however, in many instances, ruts are noticeable only after a rainfall, when the wheel paths are filled with water. Rutting stems from a permanent deformation in any of the pavement layers or subgrade. It is usually caused by consolidation or lateral movement of the materials due to traffic loads. Significant rutting can lead to major structural failure of the pavement.

A-14.2 How to Measure.

Rutting is measured in square feet (square meters) of surface area and the severity is determined by the mean depth of the rut. The mean rut depth is calculated in inches (millimeters) by laying a straightedge across the rut, measuring the depth, then using measurements taken along the length of the rut to compute the mean.

Table A-4. Mean Rut Depth Criteria

Severity	All Pavement Sections
L	0.25 to 0.5 inch (6 to 13 mm)
M	0.5 to 1 inch (13 to 25 mm)
H	> 1 inch (> 25 mm)

Figure A-46 Rutting

A-15 SHOVING OF ASPHALT PAVEMENT BY PCC SLABS (54) {14}.

A-15.1 Description.

PCC pavements occasionally increase in length at ends where they adjoin flexible pavements (commonly referred to as “pavement growth”). This “growth” shoves the asphalt- or tar-surfaced pavements, causing them to swell and crack. The PCC slab growth is caused by a gradual opening of the joints as they are filled with incompressible materials that prevent them from reclosing.

A-15.2 Severity Levels.

As a guide, Table A-5 is used to determine the severity levels of shoving. At present, no significant research has been conducted to quantify levels of severity of shoving.

Table A-5. Shoving Criteria

Severity	Height Differential
L	< 0.75 inch (< 19 mm)
M	0.75 to 1.5 inch (19 mm to 38 mm)
H	> 1.5 inch (> 38 mm)

L A slight amount of shoving has occurred, with little effect on ride quality and no breakup of the asphalt pavement.

M A significant amount of shoving has occurred, causing moderate roughness or breakup of the asphalt pavement.

H A large amount of shoving has occurred, causing severe roughness or breakup of the asphalt pavement.

A-15.3 How to Measure.

Shoving is measured by determining the area in square feet (square meters) of the swell caused by shoving.

Figure A-47 Low-Severity Shoving

Figure A-48 Medium-Severity Shoving

Figure A-49 High-Severity Shoving

A-16 SLIPPAGE CRACKING (55) {15}.

A-16.1 Description.

Slippage cracks are crescent- or half-moon-shaped cracks having two ends pointed in the direction of traffic. They are produced when braking or turning wheels cause the pavement surface to slide and deform. This usually occurs when there is a low-strength surface mix or poor bond between the surface and next layer of pavement structure.

A-16.2 Severity Levels.

No degrees of severity are defined. It is sufficient to indicate that a slippage crack exists.

A-16.3 How to Measure.

Slippage cracking is measured in square feet (square meters) of surface area.

Figure A-50 Slippage Cracking

A-17 SWELL (56) {16}.

A-17.1 Description.

A swell is characterized by an upward bulge in the pavement's surface. A swell may occur sharply over a small area or as a longer, gradual wave. Either type of swell can be accompanied by surface cracking. A swell is usually caused by frost action in the subgrade or by swelling soil but a small swell can also occur on the surface of an asphalt overlay (over PCC) as a result of a blowup in the PCC slab.

A-17.2 Severity Levels.

L Swell is barely visible and has a minor effect on the pavement's ride quality as determined at the normal aircraft speed for the pavement section under consideration. (Low-severity swells are not always observable but their existence can be confirmed by driving a vehicle over the section at the normal aircraft speed. An upward acceleration will occur if the swell is present.)

M Swell can be observed without difficulty and has a significant effect on the pavement's ride quality as determined at the normal aircraft speed for the pavement section under consideration.

H Swell can be readily observed and severely affects the pavement's ride quality at the normal aircraft speed for the pavement section under consideration.

A-17.3 How to Measure.

The surface area of the swell is measured in square feet (square meters). Consider the type of pavement section (i.e., runway, taxiway, or apron) when determining the severity rating. For example, a swell of sufficient magnitude to cause considerable roughness on a runway at high speeds would be rated as more severe than the same swell located on the apron or taxiway where the normal aircraft operating speeds are much lower. The guidance in Table A-6 is provided for runways:

Table A-6. Swell Criteria

Severity	Height Differential
L	< 0.75 inch (< 19 mm)
M	0.75 to 1.5 inch (19 to 38 mm)
H	> 1.5 inch (> 38 mm)

Figure A-51 Low-Severity Swell

Figure A-52 Medium-Severity Swell

Figure A-53 High-Severity Swell

A-18 WEATHERING (SURFACE WEAR) – DENSE MIX ASPHALT (57) {17}.

A-18.1 Description.

Weathering is the wearing away of the asphalt binder and fine aggregate matrix from the pavement surface.

A-18.2 Severity Levels.

L Asphalt surface is beginning to show signs of aging that may be accelerated by climatic conditions. Loss of the fine aggregate matrix is noticeable and may be accompanied by fading of the asphalt color. Edges of the coarse aggregates are beginning to be exposed (less than 0.04 inch [1 millimeter]). Pavement may be relatively new (as new as six months old).

M Loss of fine aggregate matrix is noticeable and edges of coarse aggregate have been exposed up to one-fourth of the width (of the longest side) of the coarse aggregate due to the loss of fine aggregate matrix.

H Edges of coarse aggregate have been exposed greater than one-fourth of the width (of the longest side) of the coarse aggregate. There is considerable loss of fine aggregate matrix, leading to potential or some loss of coarse aggregate.

A-18.3 How to Measure.

Weathering (surface wear) is measured in square feet (square meters). Weathering (surface wear) is not recorded if medium- or high-severity raveling is recorded.

Figure A-54 Low-Severity Weathering

Figure A-55 Medium-Severity Weathering

Figure A-56 High-Severity Weathering

APPENDIX B DISTRESS DEFINITIONS -CONCRETE-SURFACED AIRFIELDS

B-1 INTRODUCTION.

This appendix contains distress definitions and measuring methods for concrete-surfaced airfields. This information is used to determine the pavement condition index (PCI).

Note: Each distress definition is followed by a number in parentheses, indicating the PAVER distress code, and a number in braces, indicating the ASTM D5340 distress code, i.e.,
"Distress (#) {#}." See Table 3-6.

Table B-1 Frequently Occurring Problems in Pavement Distress Identification

Situation	Action	Remarks
Low-severity scaling (i.e., crazing)	Count only if possible future scaling will occur within 2 to 3 years	
Joint seal damage	This is not counted on a slab-by-slab basis	A severity level based on the overall condition of the joint seal in the sample unit is assigned
Joint spall small enough to be filled during a joint seal repair	Do not record	
Medium- or high-severity intersecting crack (shattered slab)	Do not count any other distress	
Corner or joint spalling caused by "D" cracking	Record only "D" cracking	If spalls are caused by factors other than "D" cracking, record each factor separately
Crack repaired by a narrow patch (e.g., 4 to 10 in. [100 to 250 mm] wide)	Record only crack and not patch at appropriate severity level	
Original distress of patch more severe than patch itself	Record original distress type	If, for example, patch material is present on scaled area of slab, only the scaling is counted

Situation	Action	Remarks
Hairline cracks that are only a few feet (meters) long and do not extend across the entire slab	Rate as shrinkage cracks.	

B-2 BLOWUP (61) {1}.

B-2.1 Description.

Blowups occur in hot weather, usually at a transverse crack or joint that is not wide enough to permit expansion by the concrete slabs. The insufficient width is usually caused by infiltration of incompressible materials into the joint space. When expansion cannot relieve enough pressure, a localized upward movement of the slab edges (buckling) or shattering will occur in the vicinity of the joint. Blowups can also occur at utility cuts and drainage inlets. This type of distress is almost always repaired immediately because of the severe damage potential to aircraft. Blowups are included for reference when closed sections are being evaluated for reopening.

B-2.2 Severity Levels.

L Buckling or shattering has not rendered the pavement inoperative and only a slight amount of roughness exists.

M Buckling or shattering has not rendered the pavement inoperative but a significant amount of roughness exists.

H Buckling or shattering has rendered the pavement inoperative.

Note: For pavements to be considered operational, all foreign material from blowups must have been removed.

B-2.3 How to Count.

A blowup usually occurs at a transverse crack or joint. At a crack, a blowup is counted as being in one slab, but at a joint, two slabs are affected and the distress is recorded as occurring in two slabs.

Figure B-1 Low-Severity Blowup

Figure B-2 Low-Severity Blowup

Figure B-3 Medium-Severity Blowup

Figure B-4 High-Severity Blowup

B-3 CORNER BREAK (62) {2}.

B-3.1 Description.

A corner break is a crack that intersects the joints at a distance less than or equal to one-half the slab length on both sides, measured from the corner of the slab. For example, a slab that is 25 by 25 feet (7.5 by 7.5 meters) and has a crack intersecting the joint 5 feet (1.5 meters) from the corner on one side and 17 feet (5 meters) on the other side is not considered a corner break—it is a diagonal crack. However, a crack that intersects 7 feet (2 meters) on one side and 10 feet (3 meters) on the other is considered a corner break. A corner break differs from a corner spall in that the crack extends vertically through the entire slab thickness while a corner spall intersects the joint at an angle. Load repetition combined with loss of support and curling stresses causes corner breaks.

B-3.2 Severity Levels.

L Crack has either no spalling or minor spalling (no FOD potential). If non-filled, it has a mean width less than approximately 0.125 inch (3 millimeters); a filled crack can be of any width, but the filler material must be in satisfactory condition. The area between the corner break and the joints is not cracked.

M One of these conditions exists: (1) a filled or non-filled crack is moderately spalled (some FOD potential); (2) a non-filled crack has a mean width between 0.125 inch (3 millimeters) and 1 inch (25 millimeters); (3) a filled crack is not spalled or only lightly spalled but the filler is in unsatisfactory condition; or (4) the area between the corner break and the joints is lightly cracked. “Lightly cracked” means one low-severity crack dividing the corner into two pieces.

H One of these conditions exists: (1) a filled or non-filled crack is severely spalled, causing definite FOD potential; (2) a non-filled crack has a mean width greater than approximately 1 inch (25 millimeters), creating tire damage potential; or (3) the area between the corner break and the joints is severely cracked.

B-3.3 How to Count.

A distressed slab is recorded as one slab if it (1) contains a single corner break, (2) contains more than one break of a particular severity, or (3) contains two or more breaks of different severities. For two or more breaks, record the highest level of severity. For example, count as one slab with a medium-severity corner break a slab containing both low- and medium-severity corner breaks. Measure crack widths between vertical walls, not in spalled areas of the crack. If the corner break is faulted 0.125 inch (3 millimeters) or more, increase severity to the next higher level. If the corner is faulted more than 0.5 inch (13 millimeters), rate the corner break at high severity. If faulting in the corner is incidental to faulting in the slab, rate faulting separately. The angle of crack into the slab is usually not evident at low severity. Unless the crack angle can be determined, to differentiate between a corner break and corner spall, use these criteria: If the crack intersects both joints more than 2 feet (600 millimeters) from the corner, it is a corner break. If less than 2 feet (600 millimeters), unless you can verify the crack is vertical, it is a spall.

Figure B-5 Low-Severity Corner Break

Figure B-6 Medium-Severity Corner Break

Figure B-7 High-Severity Corner Break

B-4 LINEAR CRACKS (LONGITUDINAL, TRANSVERSE, AND DIAGONAL) (63) {3}.

B-4.1 Description.

These cracks, which divide the slab into two or three pieces, are usually caused by a combination of load repetition, curling stresses, and shrinkage stresses. (For slabs divided into four or more pieces, see shattered slab/intersecting cracks, paragraph B-13.) Low-severity cracks are usually warping- or friction-related and are not considered major structural distresses. Medium- or high-severity cracks are usually working cracks and are considered major structural distresses.

Hairline cracks that are only a few feet (meters) long and do not extend across the entire slab are rated as shrinkage cracks.

B-4.2 Non-reinforced PCC Severity Levels.

L Crack has no spalling or minor spalling (no FOD potential). If non-filled, it is less than 0.125 inch (3 millimeters) wide. A filled crack can be of any width but its filler material must be in satisfactory condition or the slab is divided into three pieces by low-severity cracks.

M One of these conditions exists: (1) a filled or non-filled crack is moderately spalled (some FOD potential); (2) a non-filled crack has a mean width between 0.125 inch (3 millimeters) and 1 inch (25 millimeters); (3) a filled crack has no spalling or minor spalling but the filler is in unsatisfactory condition; or (4) the slab is divided into three pieces by two or more cracks, one of which is at least medium severity.

H One of the following conditions exists: (1) a filled or non-filled crack is severely spalled (definite FOD potential); (2) a non-filled crack has a mean width approximately greater than 1 inch (25 millimeters), creating tire damage potential; or (3) the slab is divided into three pieces by two or more cracks, one of which is at least high severity.

B-4.3 How to Count.

Once the severity has been identified, the distress is recorded as one slab. If a crack is repaired by a narrow patch (e.g., 4 to 10 inches wide [100 to 250 millimeters]), record only the crack and not the patch at the appropriate severity level.

Cracks used to define and rate corner breaks, “D” cracks, patches, shrinkage cracks, and spalls are not recorded as longitudinal/transverse/diagonal cracks.

Figure B-8 Low-Severity Linear Cracks

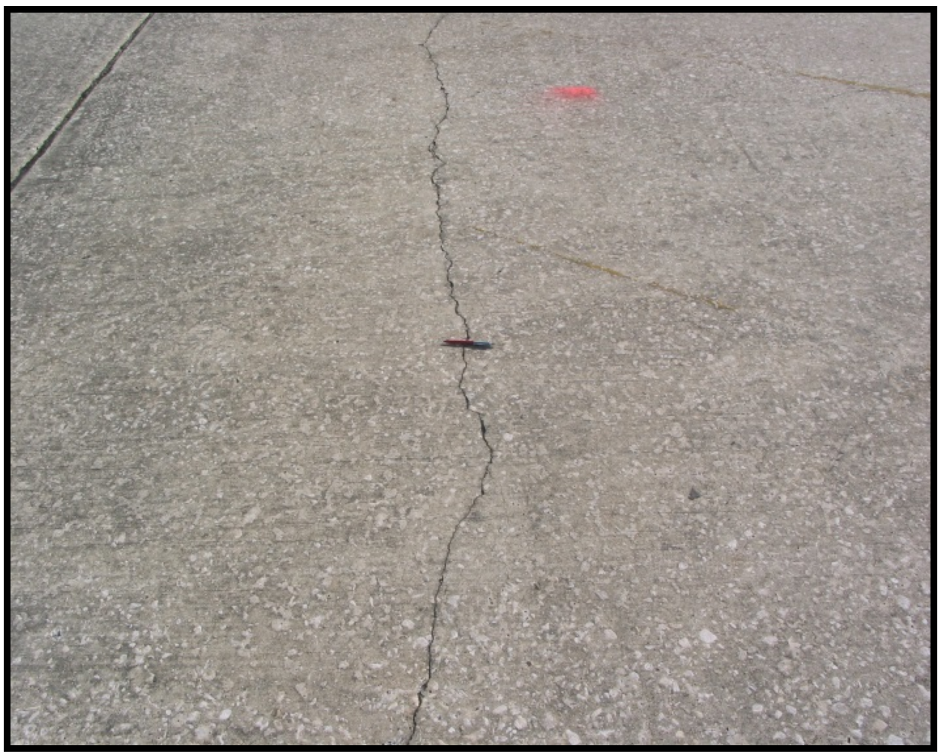


Figure B-9 Medium-Severity Linear Cracks

Figure B-10 High-Severity Linear Cracks

B-4.4 Reinforced Concrete Severity Levels.

L (1) Non-filled crack, 0.125 inch (3 millimeters) to 0.5 inch (13 millimeters) wide, with no faulting or spalling; (2) filled or non-filled cracks of any width < 0.5 inch (13 millimeters), with low-severity spalling; or (3) filled cracks of any width (filler satisfactory) with no faulting or spalling. **Note:** A crack less than 0.125 inch (3 millimeters) wide with no spalling or faulting is counted as shrinkage cracking.

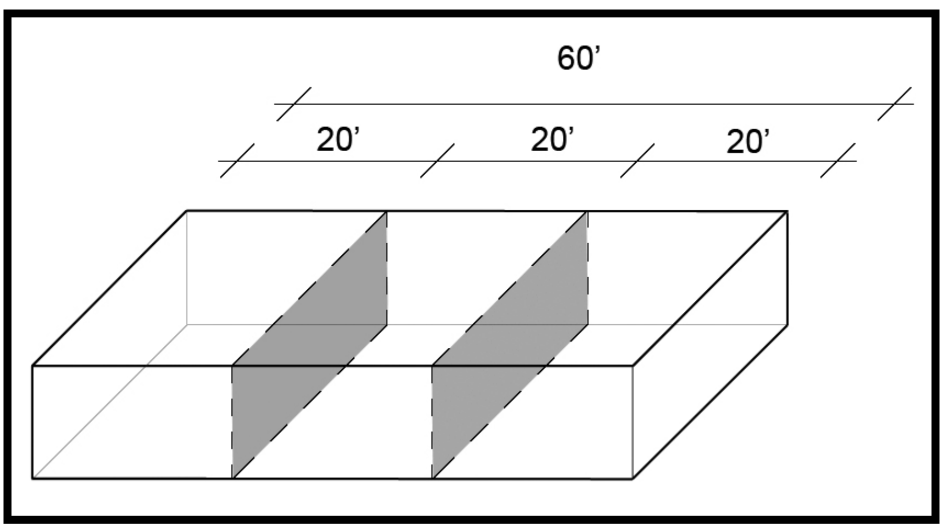
M (1) Non-filled cracks, 0.5 inch (13 millimeters) to 1 inch (25 millimeters) wide, with no faulting or spalling; (2) filled cracks of any width with faulting < 0.375 inch (10 millimeters) or medium-severity spalling; or (3) non-filled cracks of width < 1 inch (25 millimeters) with faulting < 0.375 inch (10 millimeters) or medium-severity spalling.

H (1) Non-filled cracks of width > 1 inch (25 millimeters); (2) non-filled cracks of any width with faulting > 0.375 inch (10 millimeters) or medium-severity spalling; or (3) filled cracks of any width with faulting > 0.375 inch (10 millimeters) or high-severity spalling.

B-4.5 How to Count.

Once the severity has been identified, the distress is recorded as one slab. If a crack is repaired by a narrow patch (e.g., 4 to 10 inches wide [100 to 250 millimeters]), only the crack and not the patch are recorded at the appropriate severity level. Slabs longer than 30 feet (9 meters) are divided into approximately equal length “slabs” having imaginary joints assumed to be in perfect condition.

Figure B-11 Cracks (Reinforced PCC)



B-5 DURABILITY (“D”) CRACKING (64) {4}.

B-5.1 Description.

Durability cracking is caused by the inability of the concrete to withstand environmental factors such as freeze-thaw cycles. It usually appears as a pattern of cracks running parallel to a joint or linear crack. A dark coloring is usually seen around the fine durability cracks. This type of cracking may eventually lead to disintegration of the concrete within 1 to 2 feet (0.3 to 0.6 meter) of the joint or crack.

B-5.2 Severity Levels.

L "D" cracking is defined by hairline cracks occurring in a limited area of the slab, such as one or two corners along one joint. Little or no disintegration has occurred. No FOD potential.

M (1) "D" cracking has developed over a considerable amount of slab area with little or no disintegration or FOD potential; or (2) "D" cracking has occurred in a limited area of the slab, such as in one or two corners or along one joint but pieces are missing and disintegration has occurred. Some FOD potential.

H "D" cracking has developed over a considerable amount of slab area with disintegration or FOD potential.

B-5.3 How to Count.

When the distress is located and rated at one severity, it is counted as one slab. If more than one severity level is found, the slab is counted as having the higher severity distress. If "D" cracking is counted, do not record scaling on the same slab.

Figure B-12 Low-Severity "D" Cracking

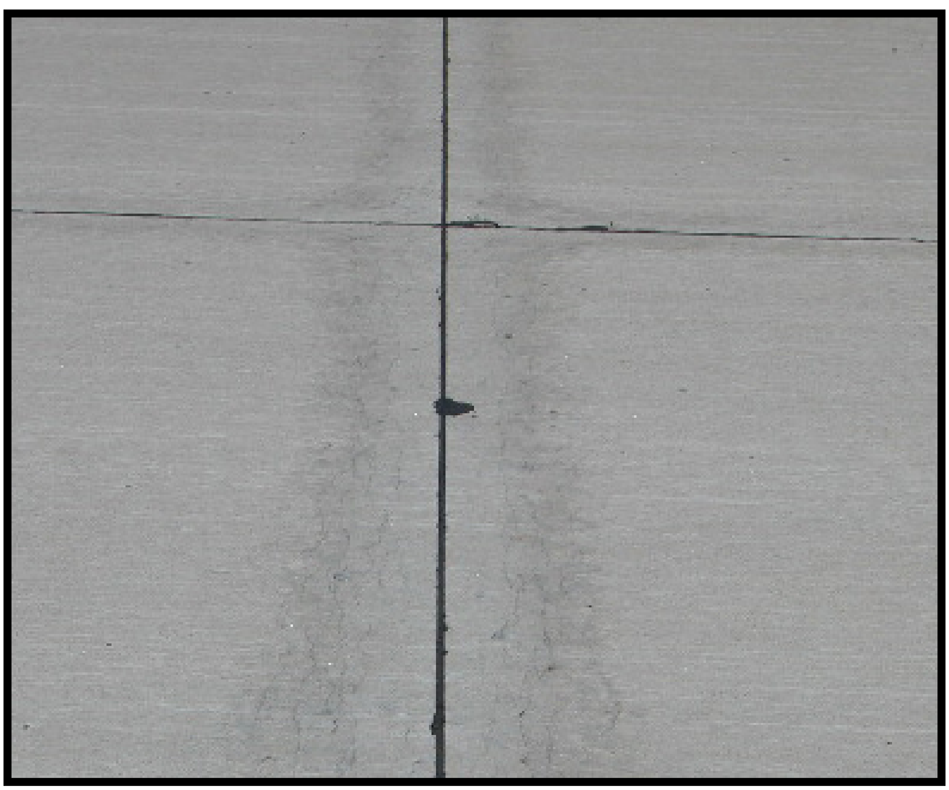


Figure B-13 Medium-Severity "D" Cracking

Figure B-14 High-Severity "D" Cracking

B-6 JOINT SEAL DAMAGE (65) {5}.

B-6.1 Description.

Joint seal damage is any condition that enables soil or rocks to accumulate in the joints or allows significant infiltration of water. Accumulation of incompressible materials prevents the slabs from expanding and may result in buckling, shattering, or spalling. Pliable joint filler bonded to the edges of the slabs protects the joints from accumulating materials and prevents water from seeping down and softening the foundation supporting the slab. Typical types of joint seal damage are (a) stripping of joint sealant, (b) extrusion of joint sealant, (c) weed growth, (d) hardening of the filler (oxidation), (e) loss of bond to the slab edges, and (f) lack or absence of sealant in the joint.

B-6.2 Severity Levels.

L Joint sealer is in generally good condition throughout the sample. Sealant is performing well, with only a minor amount of any of the above types of damage present. Joint seal damage is at low severity if a few of the joints have sealer that has debonded from, but is still in contact with, the joint edge. This condition exists if a knife blade can be inserted between the sealer and joint face without resistance.

M Joint sealer is in generally fair condition over the entire surveyed section, with one or more of the above types of damage occurring to a moderate degree. Sealant needs replacement within two years. Joint seal damage is at medium severity if a few of the joints have any of these conditions: (1) joint sealer is in place but water access is possible through visible openings no more than 0.125 inch (3 millimeters) wide. If a knife blade cannot be inserted easily between sealer and joint face, this condition does not exist; (2) pumping debris is evident at the joint; (3) joint sealer is oxidized and “lifeless” but pliable (like a rope) and generally fills the joint opening; or (4) vegetation in the joint is obvious but does not obscure the joint opening.

H Joint sealer is in generally poor condition over the entire surveyed section, with one or more of the above types of damage occurring to a severe degree. Sealant needs immediate replacement. Joint seal damage is at high severity if 10 percent or more of the joint sealer exceeds the limiting criteria listed above or if 10 percent or more of the sealer is missing.

B-6.3 How to Count.

Joint seal damage is not counted on a slab-by-slab basis but is rated based on the overall condition of the sealant in the sample unit. Joint sealer is in satisfactory condition if it prevents entry of water into the joint, has some elasticity, and if no vegetation is growing between the sealer and joint face. Premolded sealer is rated using the same criteria as above except as follows: (1) premolded sealer is elastic and is firmly pressed against the joint walls and (2) premolded sealer is below the joint edge. If the sealer extends above the surface, it can be caught by moving equipment such as snow plows or brooms and pulled out of the joint. Premolded sealer is recorded at low severity if any part is visible above the joint edge. It is at medium severity if 10 percent or more of the length is above the joint edge or if any part is more than 0.5 inch (13 millimeters) above the joint edge. It is at high severity if 20 percent or more is above the joint edge, if any part is more than 1 inch (25 millimeters) above the joint edge, or if 10 percent or more is missing. Rate joint sealer by joint segment. Sample unit rating is the same as the most severe rating held by at least 20 percent of the segments rated. In rating oxidation, do not rate on appearance, rate on resilience. Some joint sealer will have a very dull surface and may even show surface cracks in the oxidized layer. If the sealer is performing satisfactorily and has good characteristics beneath the surface, it is satisfactory.

Figure B-15 Low-Severity Joint Seal Damage

Figure B-16 Medium-Severity Joint Seal Damage

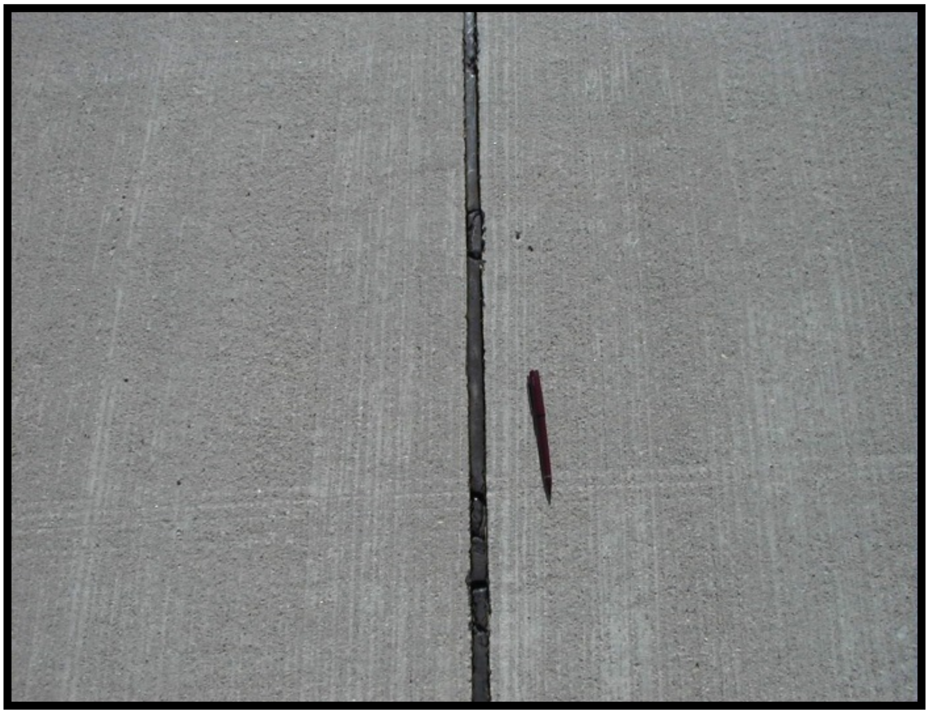


Figure B-17 High-Severity Joint Seal Damage

B-7 PATCHING, SMALL (LESS THAN 5.5 FT^2 [0.5 M^2]) (66) {6}.

B-7.1 Description.

A patch is an area where the original pavement has been removed and replaced by a filler material. For condition evaluation, patching is divided into two types: small (less than 5.5 square feet [0.5 square meter]) and large (over 5.5 square feet [0.5 square meter]). Large patches are described in the next section.

B-7.2 Severity Levels.

L Patch is functioning well, with little or no deterioration.

M Patch has deteriorated and/or moderate spalling can be seen around the edges. Patch material can be dislodged with considerable effort (minor FOD potential).

H Patch has deteriorated, either by spalling around the patch or cracking within the patch, to a state that warrants replacement.

B-7.3 How to Measure.

If one or more small patches having the same severity level are located in a slab, it is counted as one slab containing that distress. If more than one severity level occurs, it is counted as one slab, with the higher severity level being recorded. If a crack is repaired by a narrow patch (e.g., 4 to 10 inches [100 to 250 millimeters] wide), only the crack and not the patch is recorded at the appropriate severity level. If the original distress of a patch is more severe than the patch itself, the original distress type is recorded.

Figure B-18 Low-Severity Small Patch

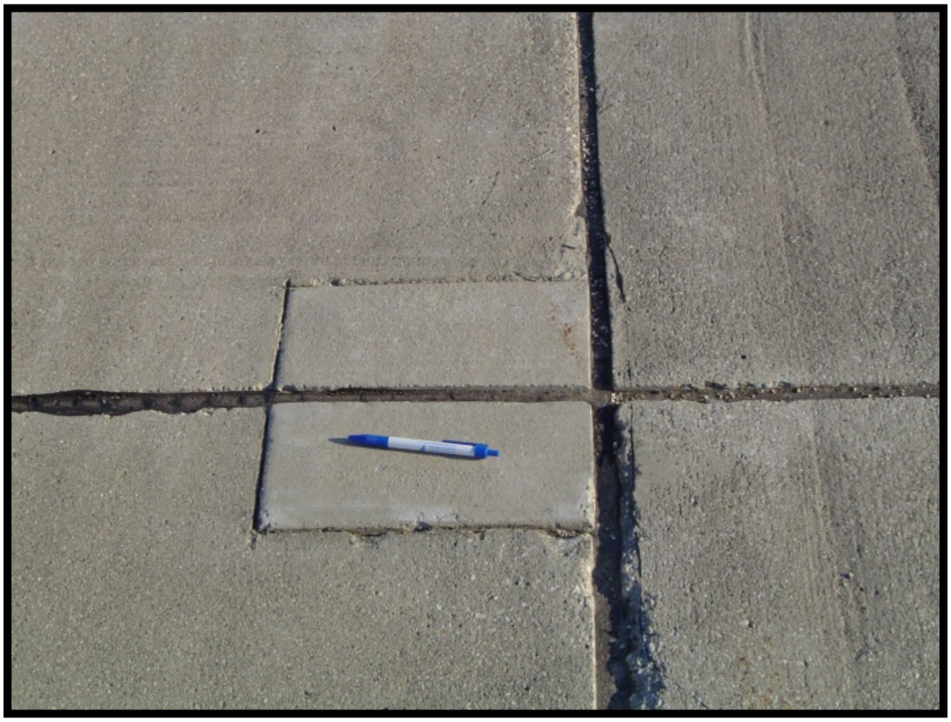


Figure B-19 Medium-Severity Small Patch

Figure B-20 High-Severity Small Patch

B-8 PATCHING, LARGE (OVER 5.5 FT^2 [0.5 M^2]) AND UTILITY CUT (67) {7}.

B-8.1 Description.

Patching is the same as defined in paragraph B-7. A utility cut is a patch that has replaced the original pavement because of placement of underground utilities. The severity levels of a utility cut are the same as those for regular patching.

B-8.2 Severity Levels.

L Patch is functioning well, with very little or no deterioration.

M Patch has deteriorated and/or moderate spalling is visible around the edges. Patch material can be dislodged with considerable effort, causing some FOD potential.

H Patch has deteriorated to a state that causes considerable roughness and/or high FOD potential. The extent of the deterioration warrants replacement of the patch.

B-8.3 How to Count.

The criteria are the same as for small patches (paragraph B-7).

Figure B-21 Low-Severity Large Patch

Figure B-22 Medium-Severity Large Patch

Figure B-23 High Severity Large Patch

B-9 POPOUTS (68) {8}.

B-9.1 Description.

A popout is a small piece of pavement that breaks loose from the surface due to freeze-thaw action in combination with expansive aggregates. Popouts usually range from approximately 1 inch (25 millimeters) to 4 inches (100 millimeters) in diameter and from 0.5 inch (13 millimeters) to 2 inches (50 millimeters) deep.

B-9.2 Severity Levels.

No degrees of severity are defined for popouts; however, when popouts are extensive, they are counted as a distress; i.e., average popout density exceeds approximately three popouts per square yard (square meter) over the entire slab area.

B-9.3 How to Count.

Always measure the density of the distress. If there is any doubt about the average being greater than three popouts per square yard (square meter), at least three random 1-square-yard (1-square-meter) areas are checked. When the average is greater than this density, the slab is counted.

Figure B-24 Popouts

B-10 PUMPING (69) {9}.

B-10.1 Description.

Pumping is the ejection of material by water through joints or cracks caused by deflection of the slab under passing loads. As the water is ejected, it carries particles of gravel, sand, clay, or silt and results in a progressive loss of pavement support. Surface staining and base or subgrade material on the pavement close to joints or cracks are evidence of pumping. Pumping near joints indicates poor joint sealer and loss of support, which will lead to cracking under repeated loads. Identify the joint seal as defective before pumping can be said to exist. Pumping can occur at cracks as well as joints.

B-10.2 Severity Levels.

No degrees of severity are defined. It is sufficient to indicate that pumping exists.

B-10.3 How to Count.

Slabs are counted as follows: one pumping joint between two slabs is counted as two slabs; however, if the remaining joints around the slab are also pumping, one slab is added per additional pumping joint.

Figure B-25 Pumping

Figure B-26 Pumping

B-11 SCALING (70) {10}.

B-11.1 Description.

B-11.1.1 Scaling is surface deterioration caused by construction defects, material defects, and environmental factors. Generally, scaling is exhibited by delamination or disintegration of the slab surface to the depth of the defect.

B-11.1.2 Construction defects include over-finishing, addition of water to the pavement surface during finishing, lack of curing, and attempted surface repairs of fresh concrete with mortar. Generally, this occurs over a portion of a slab.

B-11.1.3 Material defects include inadequate air entrainment for the climate. Generally, this occurs over several slabs that were affected by the concrete batches.

B-11.1.4 Environmental factors include freezing of concrete before adequate strength is gained and thermal cycles from certain aircraft. Generally, this occurs over a large area for freezing and in isolated areas for thermal effects.

B-11.1.5 Typically, the FOD from scaling is removed by sweeping but the concrete will continue to scale until the affected depth is removed or expended.

B-11.2 Severity Levels.

L Minimal loss of surface paste that poses no FOD hazard. No FOD potential.

M The loss of surface paste that poses some FOD potential, including isolated fragments of loose mortar, exposure of the sides of coarse aggregate (less than one-fourth of the width of the coarse aggregate), or evidence of coarse aggregate coming loose from the surface.

H The high severity is associated with low-durability concrete that will continue to pose a high FOD hazard. Typically, the layer of surface mortar is observable at the perimeter of the scaled area and is likely to continue to scale due to environmental or other factors. Indication of high-severity FOD is that routine sweeping is not sufficient to avoid FOD issues.

B-11.3 How to Count.

If two or more levels of severity exist on a slab, the slab is counted as one slab having the maximum level of severity. If "D" cracking or alkali-silica reaction (ASR) is counted, scaling is not counted.

Figure B-27 Low-Severity Scaling

Figure B-28 Medium-Severity Scaling

Figure B-29 High-Severity Scaling

B-12 SETTLEMENT OR FAULTING (71) {11}.

B-12.1 Description.

Settlement or faulting is a difference of elevation at a joint or crack caused by upheaval or consolidation.

B-12.2 Severity Levels.

Severity levels are defined by the difference in elevation across the fault and the associated decrease in ride quality and safety as severity increases.

Table B-2. Difference in Elevation

Severity	Runways/ Taxiways	Aprons
L	< 0.25 inch (< 6 mm)	0.125–0.5 inch (3–13 mm)
M	0.25–0.5 inch (6–13 mm)	0.5–1 inch (13–25 mm)
H	> 0.5 inch (> 13 mm)	> 1 inch (> 25 mm)

B-12.3 How to Count.

In counting settlement, a fault between two slabs is counted as one slab. A straightedge or level is used to aid in measuring the difference in elevation between the two slabs.

Construction-induced elevation differential is not rated in PCI procedures. Where construction differential exists, it can often be identified by the way the high side of the joint was rolled down by finishers (usually within 6 inches [150 millimeters] of the joint) to meet the low-slab elevation.

Figure B-30 Low-Severity Settlement or Faulting

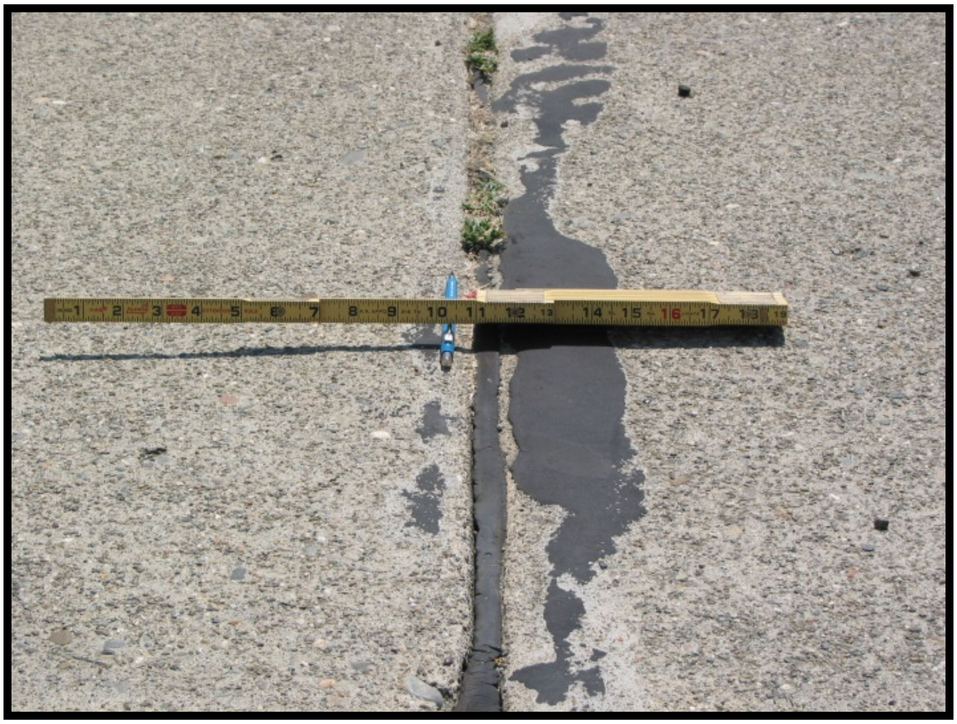
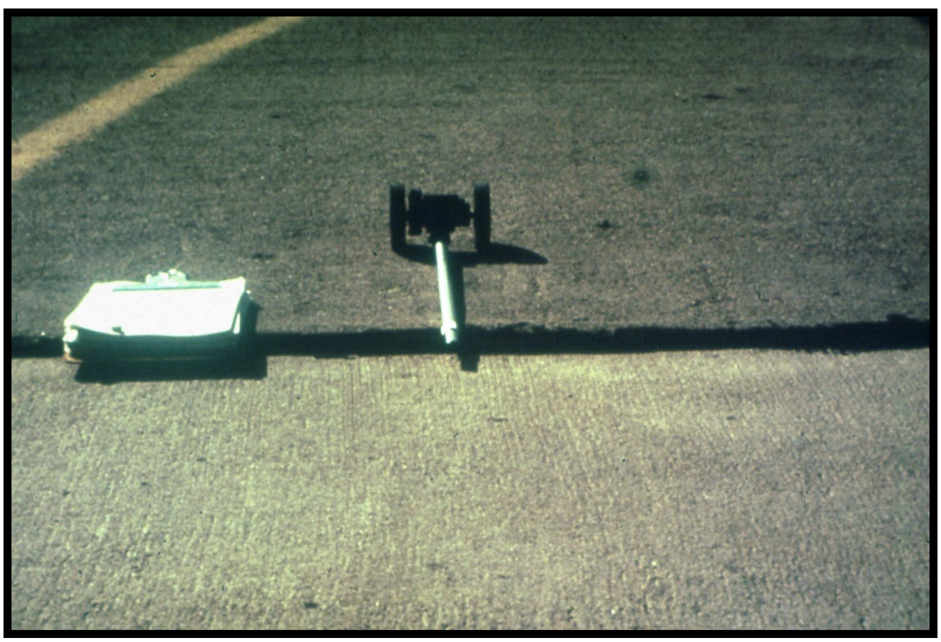


Figure B-31 Low-Severity Settlement or Faulting

Figure B-32 High-Severity Settlement or Faulting



B-13 SHATTERED SLAB/INTERSECTING CRACKS (72) {12}.

B-13.1 Description.

Intersecting cracks are cracks that break the slab into four or more pieces because of overloading and/or inadequate support. The high-severity level of this distress type, as defined below, is referred to as a shattered slab. If all pieces or cracks are contained within a corner break, the distress is categorized as a severe corner break.

B-13.2 Severity Levels.

L Slab is broken into four or five pieces predominantly defined by low-severity cracks.

M (1) Slab is broken into four or five pieces, with over 15 percent of the cracks of medium severity (no high-severity cracks); or (2) slab is broken into six or more pieces, with over 85 percent of the cracks of low severity.

H At this level of severity, the slab is called shattered: (1) slab is broken into four or five pieces, with some or all of the cracks of high severity; (2) slab is broken into six or more pieces, with over 15 percent of the cracks of medium or high severity.

B-13.3 How to Count.

No other distress such as scaling, spalling, or durability cracking is recorded if the distress is medium- or high-severity level since the severity of this distress substantially affects the slab's rating. Shrinkage cracks are not counted in determining whether or not the slab is broken into four or more pieces.

Figure B-33 Low-Severity Shattered Slab/Intersecting Cracks

Figure B-34 Medium-Severity Shattered Slab/Intersecting Cracks

Figure B-35 High-Severity Shattered Slab/Intersecting Cracks

B-14 SHRINKAGE CRACKS (73) {13}.

B-14.1 Description.

Shrinkage cracks are hairline cracks that are usually only a few feet (meters) long and do not extend across the entire slab. They are formed during the setting and curing of the concrete and usually do not extend through the depth of the slab.

B-14.2 Severity Levels.

No degrees of severity are defined. It is sufficient to indicate that shrinkage cracks exist.

B-14.3 How to Count.

If one or more shrinkage cracks exist on one particular slab, the slab is counted as one slab with shrinkage cracks.

Figure B-36 Shrinkage Cracks

B-15 JOINT SPALLING (TRANSVERSE AND LONGITUDINAL JOINTS) (74) {14}.

B-15.1 Description.

Joint spalling is the breakdown of the slab edges within 2 feet (600 millimeters) of the side of the joint. A joint spall usually does not extend vertically through the slab but intersects the joint at an angle. Spalling results from excessive stresses at the joint or crack caused by infiltration of incompressible materials or traffic loads. Weak concrete at the joint (caused by overworking) combined with traffic loads also causes spalling.

Frayed condition as used in the test method in the following table indicates that material is no longer in place along a joint or crack. Spalling indicates material may or may not be missing along a joint or crack.

B-15.2 Severity Levels.

Table B-3 Severity Levels of Spalling

	Spall Length	Description
L	< 2 feet (600 mm)	Spall is broken into pieces or fragmented; little FOD or tire damage potential exists.
L	> 2 feet (600 mm)	(a) Spall is broken into no more than three pieces defined by low- or medium-severity cracks; little or no FOD potential exists; or (b) joint is lightly frayed; little or no FOD potential exists.
M	< 2 feet (600 mm)	Spall is broken into pieces or fragmented, with some of the pieces loose or absent, causing considerable FOD or tire damage potential.
M	> 2 feet (600 mm)	(a) Spall is broken into more than three pieces defined by light or medium cracks; (b) spall is broken into no more than three pieces, with one or more of the cracks being severe, with some FOD potential existing; or (c) joint is moderately frayed, with some FOD potential.
H	> 2 feet (600 mm)	(1) Spall is broken into more than three pieces defined by one or more high-severity cracks with high FOD potential; or (2) joint is severely frayed, with high FOD potential.

B-15.3 How to Count.

If the joint spall is located along the edge of one slab, it is counted as one slab with joint spalling. If spalling is located on more than one edge of the same slab, the edge having the highest severity is counted and recorded as one slab. Joint spalling can also occur along the edges of two adjacent slabs. If this is the case, each slab is counted as having joint spalling. If a joint spall is small enough to be filled during a joint seal repair, it is not recorded.

Figure B-37 Low-Severity Joint Spall

Figure B-38 Medium-Severity Joint Spall

Figure B-39 High-Severity Joint Spall

Figure B-40 High-Severity Joint Spall

B-16 SPALLING (CORNER) (75) {15}.

B-16.1 Description.

Corner spalling is the raveling or breakdown of the slab within approximately 2 feet (600 millimeters) of the corner. A corner spall differs from a corner break in that the spall angles downward to intersect the joint, while a break extends vertically through the slab.

B-16.2 Severity Levels.

L One of these conditions exists: (1) spall is broken into one or two pieces defined by low-severity cracks (little or no FOD potential); or (2) spall is defined by one medium-severity crack (little or no FOD potential).

M One of these conditions exists: (1) spall is broken into two or more pieces defined by one or more medium-severity cracks and a few small fragments may be absent or loose; (2) spall is defined by one severe, fragmented crack that may be accompanied by a few hairline cracks; or (3) spall has deteriorated to the extent that loose material is causing some FOD potential.

H One of these conditions exists: (1) spall is broken into two or more pieces defined by one or more high-severity fragmented cracks, with loose or absent fragments; (2) pieces of the spall have been displaced to the extent that a tire damage hazard exists; or (3) spall has deteriorated to the extent that loose material is causing high FOD potential.

B-16.3 How to Count.

If one or more corner spalls having the same severity level are located in a slab, the slab is counted as one slab with corner spalling. If more than one severity level occurs, it is counted as one slab having the higher severity level.

A corner spall smaller than 3 inches (76 millimeters) wide, measured from the edge of the slab and filled with sealant, is not recorded.

Figure B-41 Low-Severity Corner Spall

Figure B-42 Medium-Severity Corner Spall

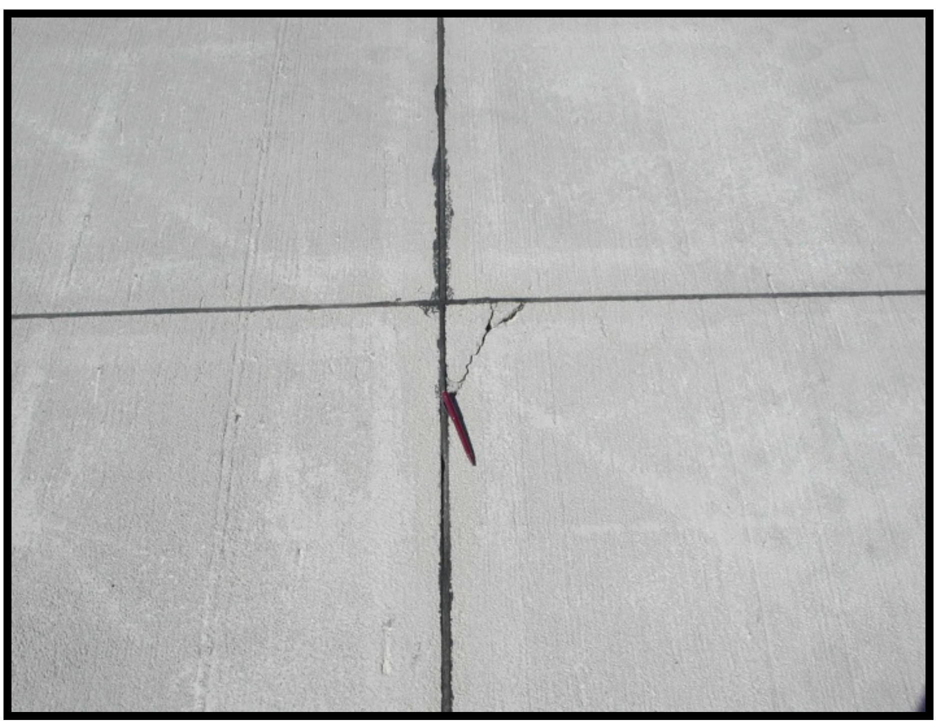
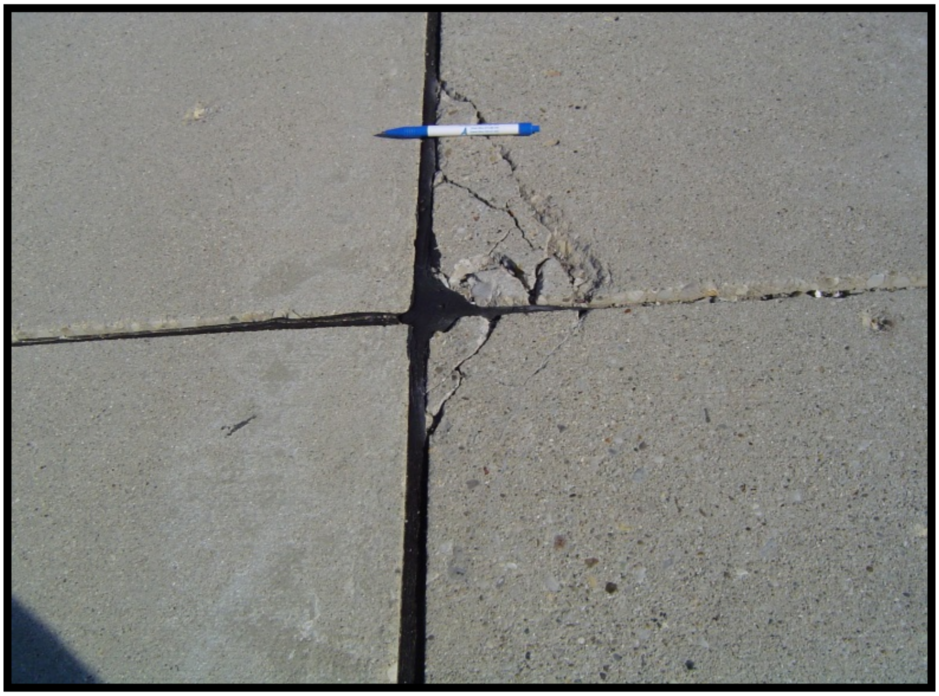


Figure B-43 High-Severity Corner Spall



B-17 ALKALI-SILICA REACTION (ASR) (76) {16}.

B-17.1 Description.

ASR is caused by a chemical reaction between alkalis and certain reactive silica minerals, which form a gel. The gel absorbs water, causing expansion that may damage the concrete and adjacent structures. Alkalis are most often introduced by the portland cement within the pavement. ASR cracking may be accelerated by chemical pavement deicers. Visual indicators that ASR is present include:

- Cracking of the concrete pavement (often in a map pattern)
- White, brown, gray, or other colored gel or staining possibly present at the crack surface
- Aggregate popouts
- Increase in concrete volume (expansion) that may result in distortion of adjacent or integral structures or physical elements. Examples of expansion include shoving of asphalt pavements, light can tilting, slab faulting, joint misalignment, and extrusion of joint seals or expansion joint fillers.

Because ASR is material-dependent, it is generally present throughout the pavement section. Coring and concrete petrographic analysis is the only definitive method to confirm ASR. Keep these factors in mind when identifying the presence of ASR through visual inspection:

- Generally, ASR distresses are not observed in the first few years after construction. In contrast, plastic shrinkage cracking can occur the day of construction and is apparent within the first year.
- ASR is differentiated from D-cracking by the presence of cracking perpendicular to the joint face. D-cracking predominantly develops as a series of parallel cracks to joint faces and linear cracking within the slab.
- ASR is differentiated from map cracking/scaling by the presence of visual signs of expansion.

B-17.2 Severity Levels.

L Minimal to no FOD potential from cracks, joints, or ASR-related popouts; cracks at the surface are tight (predominantly 0.04 inch [1 millimeter] or less). Little to no evidence of movement in pavement or surrounding structures or elements.

M Some FOD potential; increased sweeping or other FOD removal methods may be required; there may be evidence of slab movement and/or some damage to adjacent structures or elements. Medium ASR distress is differentiated from low by having one or more of the following: increased FOD potential, increased cracking of the slab, some fragments along cracks or at crack intersections, possible surface popouts of concrete, pattern of wider cracks (predominantly 0.04 inch [1 millimeter] or wider) that may be subdivided by tighter cracks.

H One or both of these conditions exists: (1) loose or missing concrete fragments that pose high FOD potential; (2) slab surface integrity and function significantly degraded and pavement requires immediate repair; may also require repairs to adjacent structures or elements.

B-17.3 How to Count.

No other distresses are recorded if high-severity ASR is recorded.

Figure B-44 Low-Severity ASR

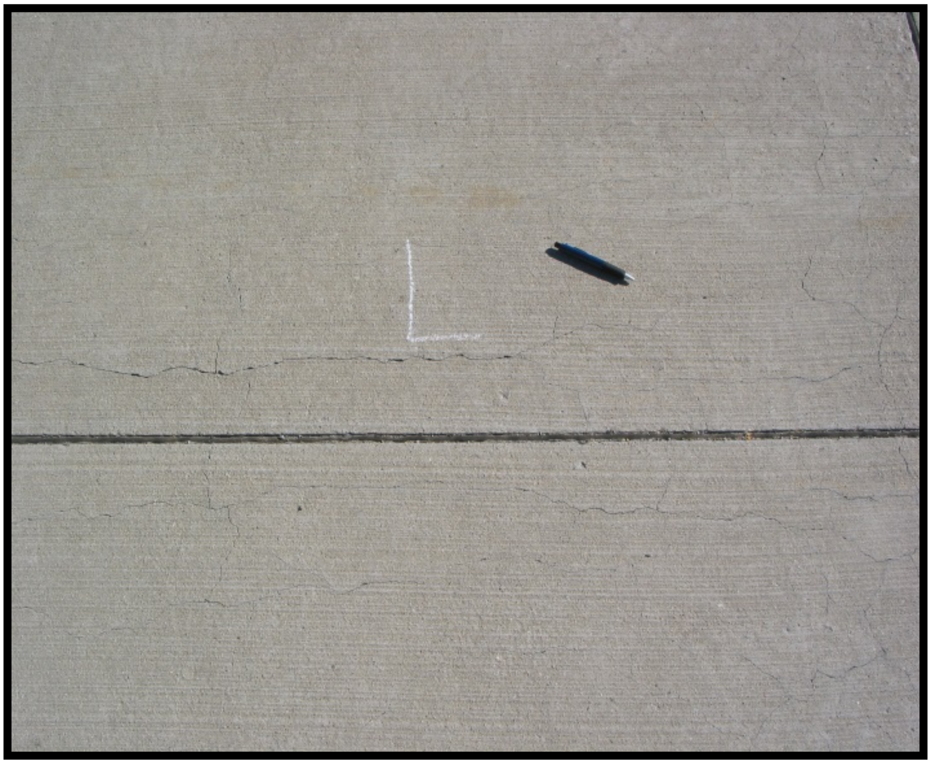


Figure B-45 Medium-Severity ASR

Figure B-46 High-Severity ASR

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APPENDIX C DEDUCT CURVES FOR ASPHALT (BITUMINOUS) AIRFIELD PAVEMENTS

Figure C-1 Deduct Curves for Alligator Cracking (41) {1}

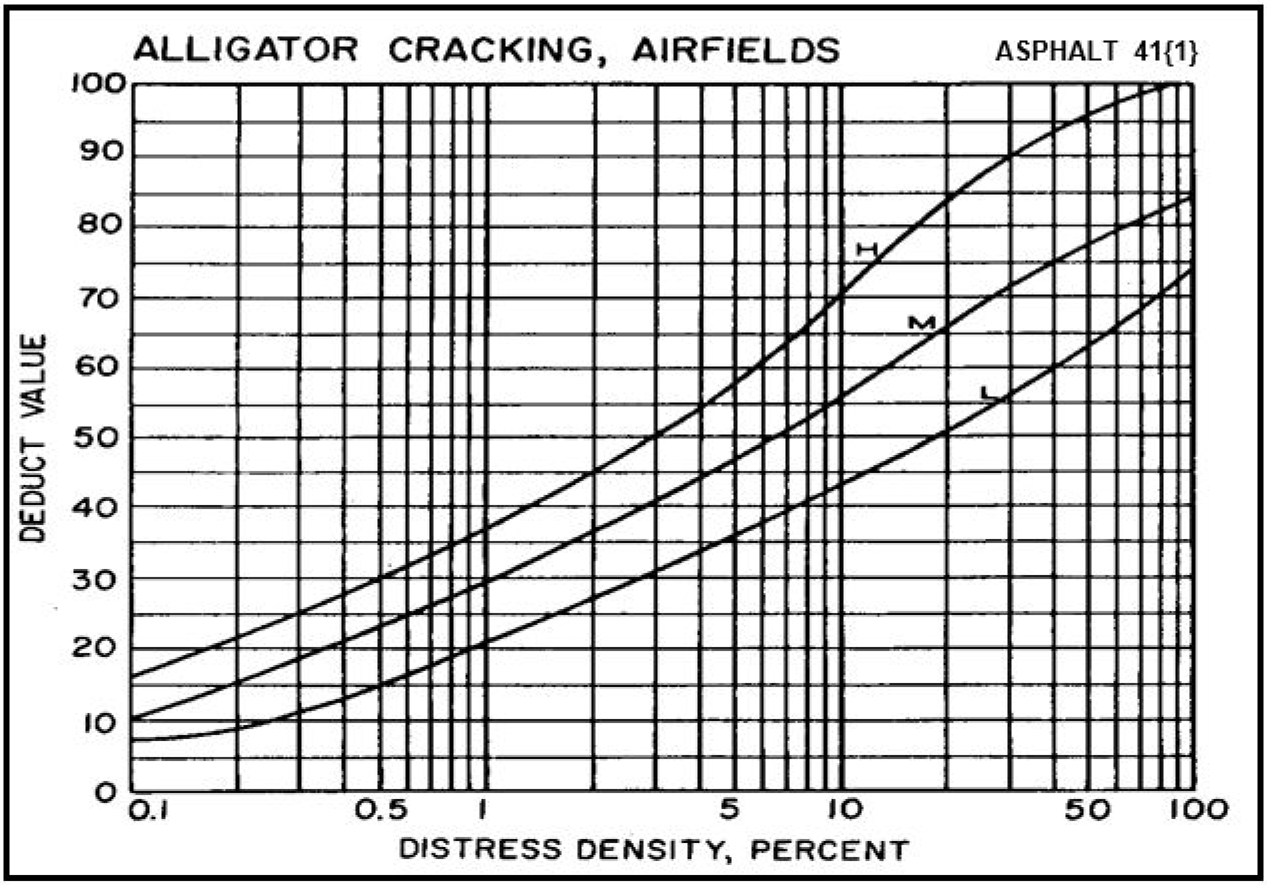


Figure C-2 Deduct Curve for Bleeding (42) {2}

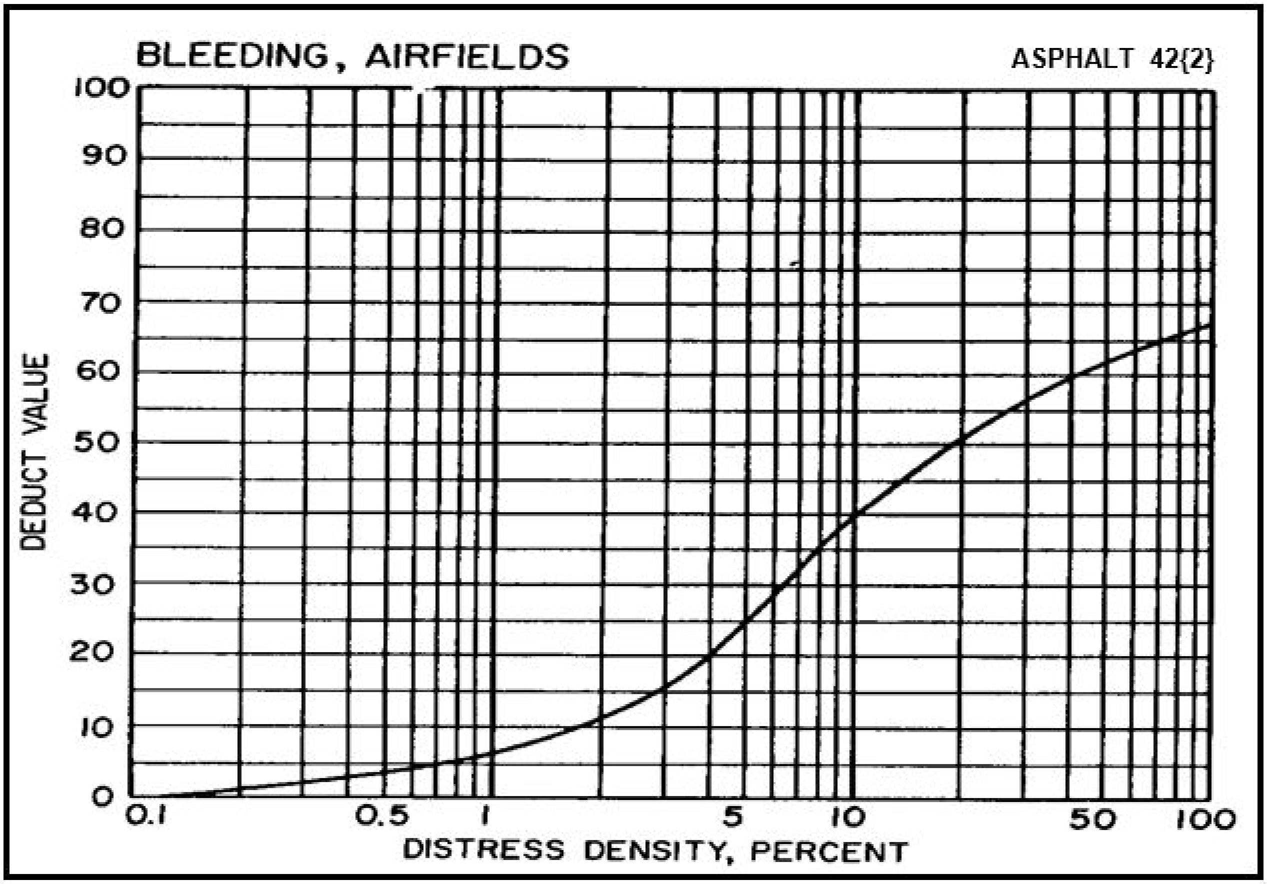


Figure C-3 Deduct Curves for Block Cracking (43) {3}

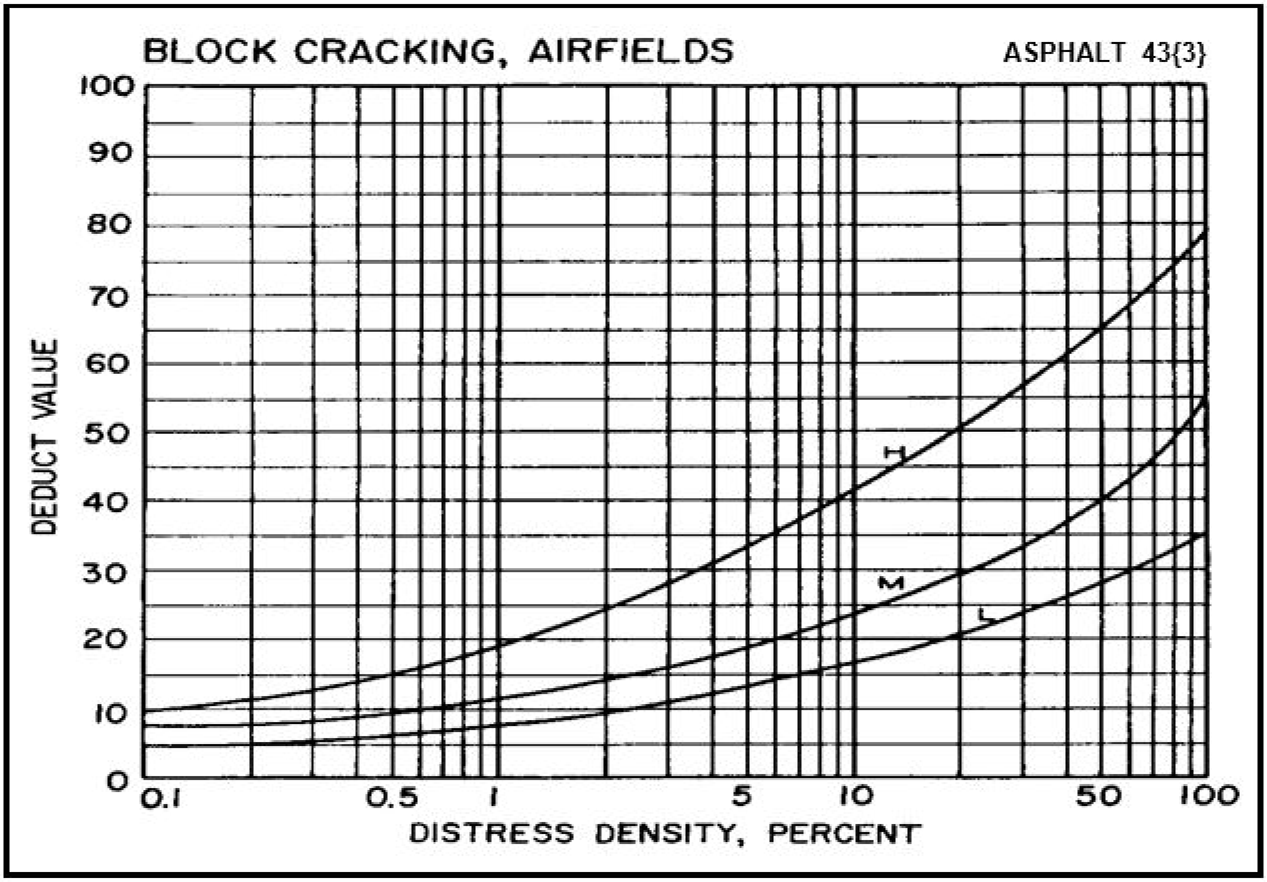


Figure C-4 Deduct Curves for Corrugation (44) {4}

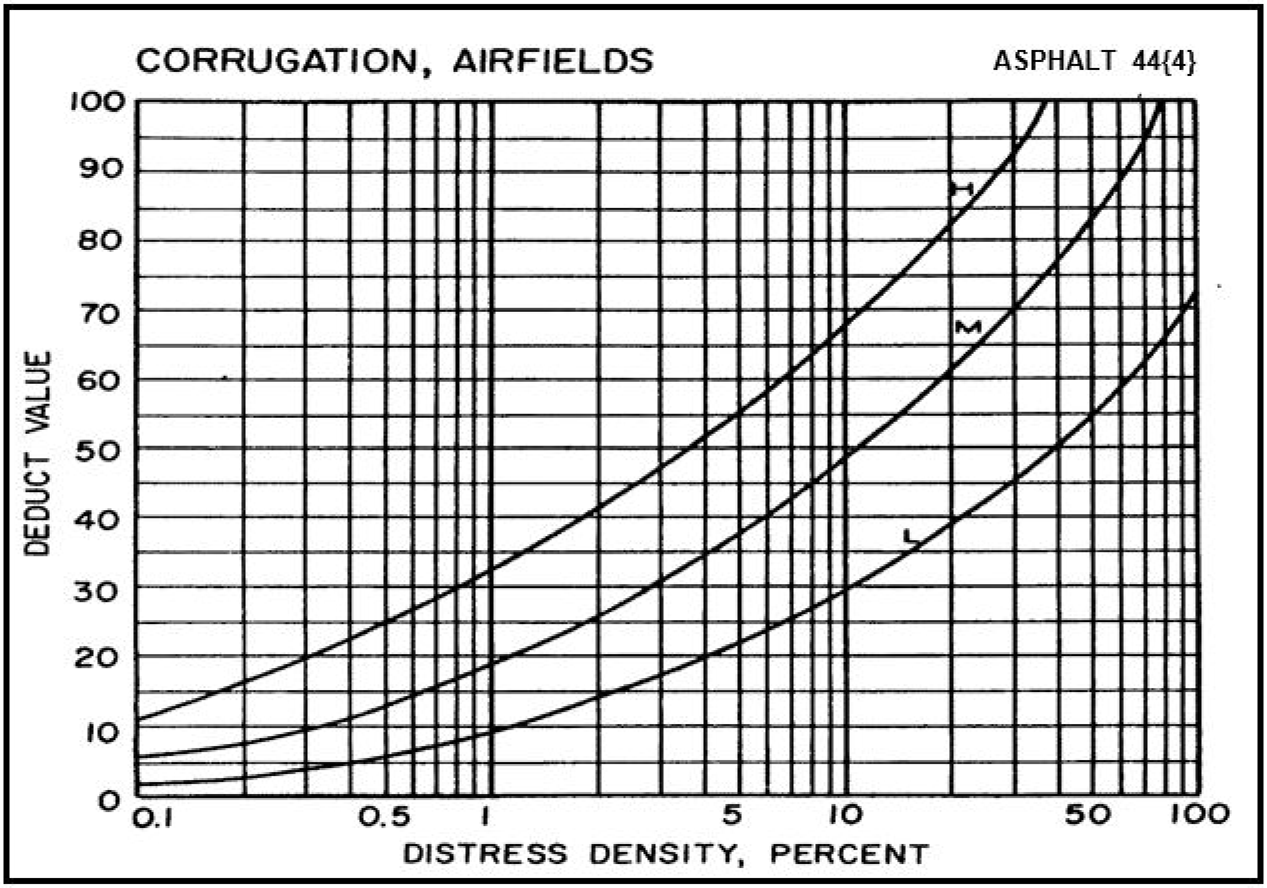


Figure C-5 Deduct Curves for Depression (45) {5}

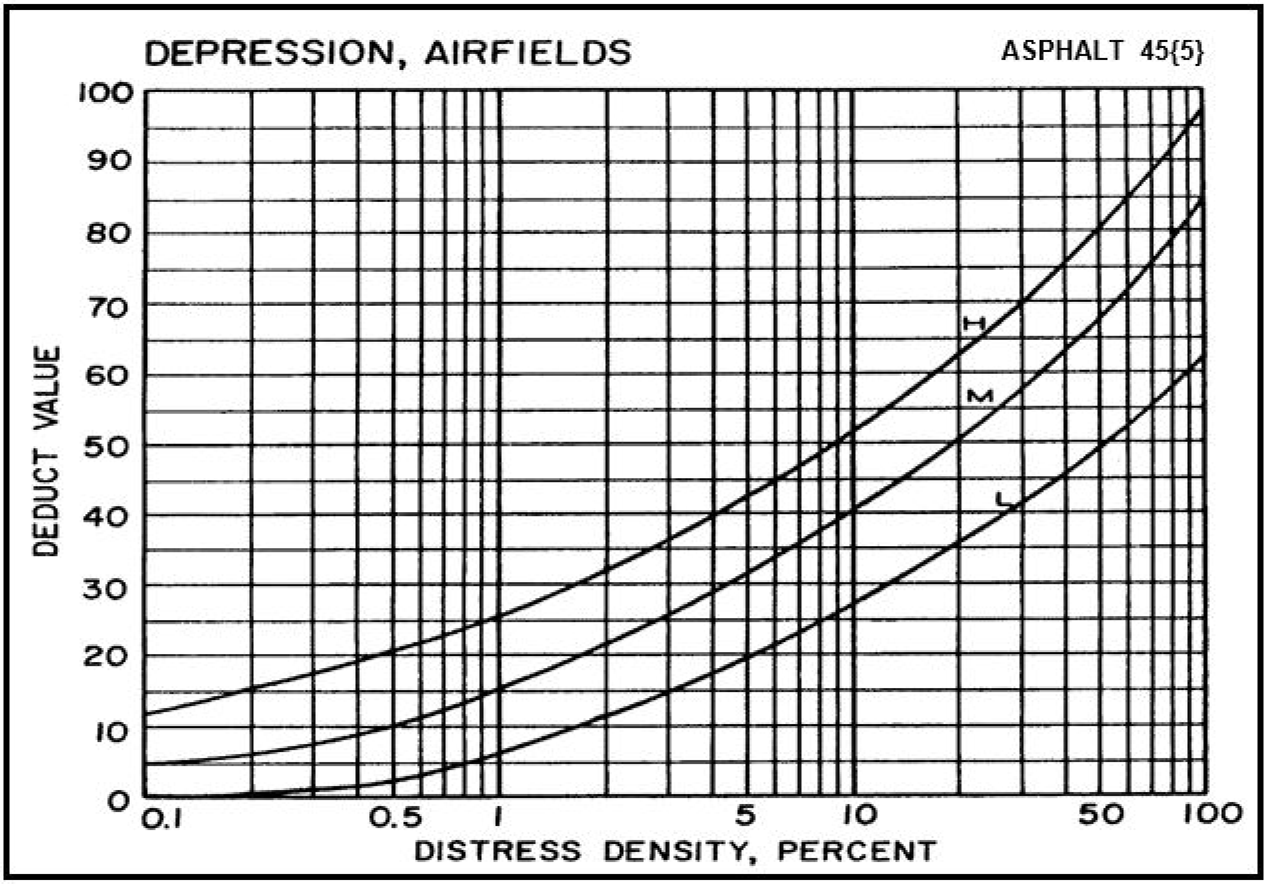


Figure C-6 Deduct Curve for Jet Blast Erosion (46) {6}

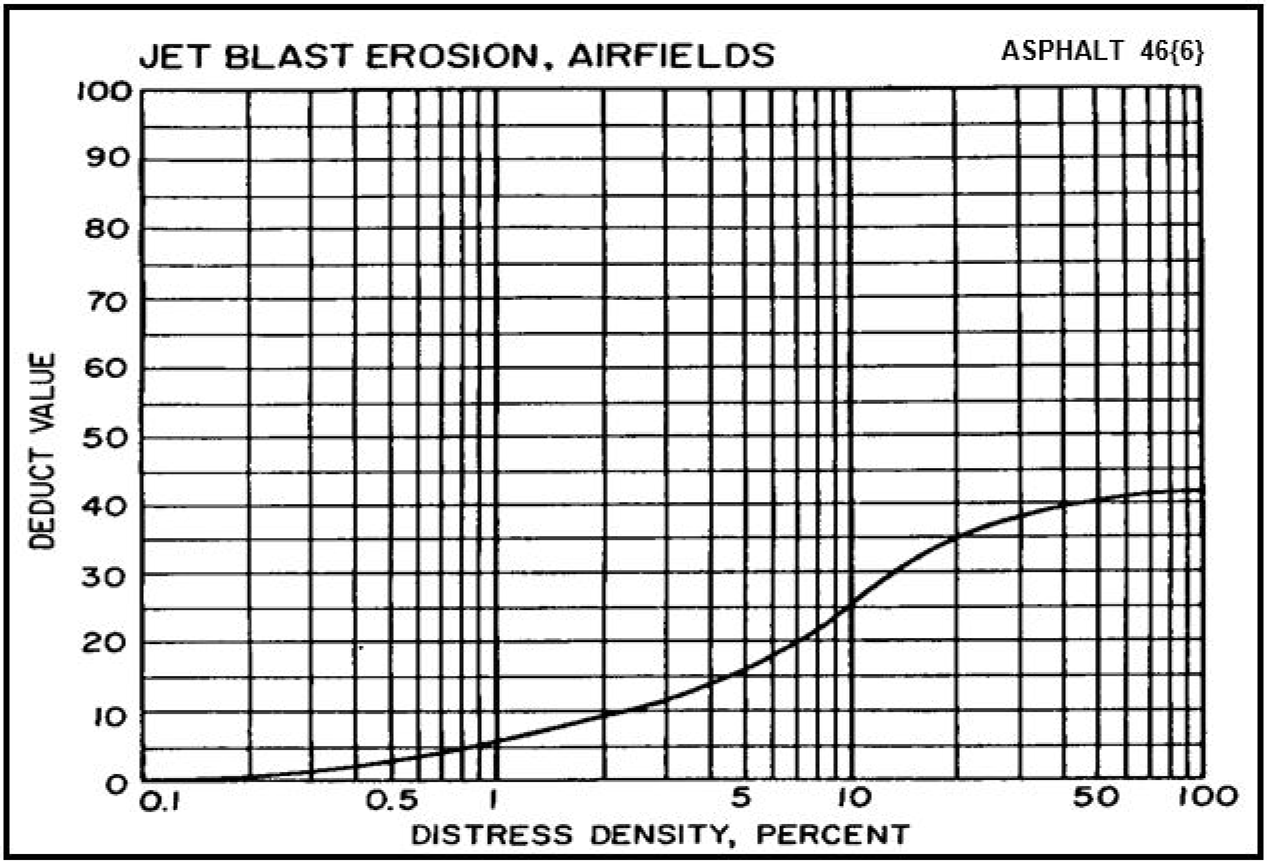


Figure C-7 Deduct Curves for Joint Reflection Cracking (47- English Units) {7}

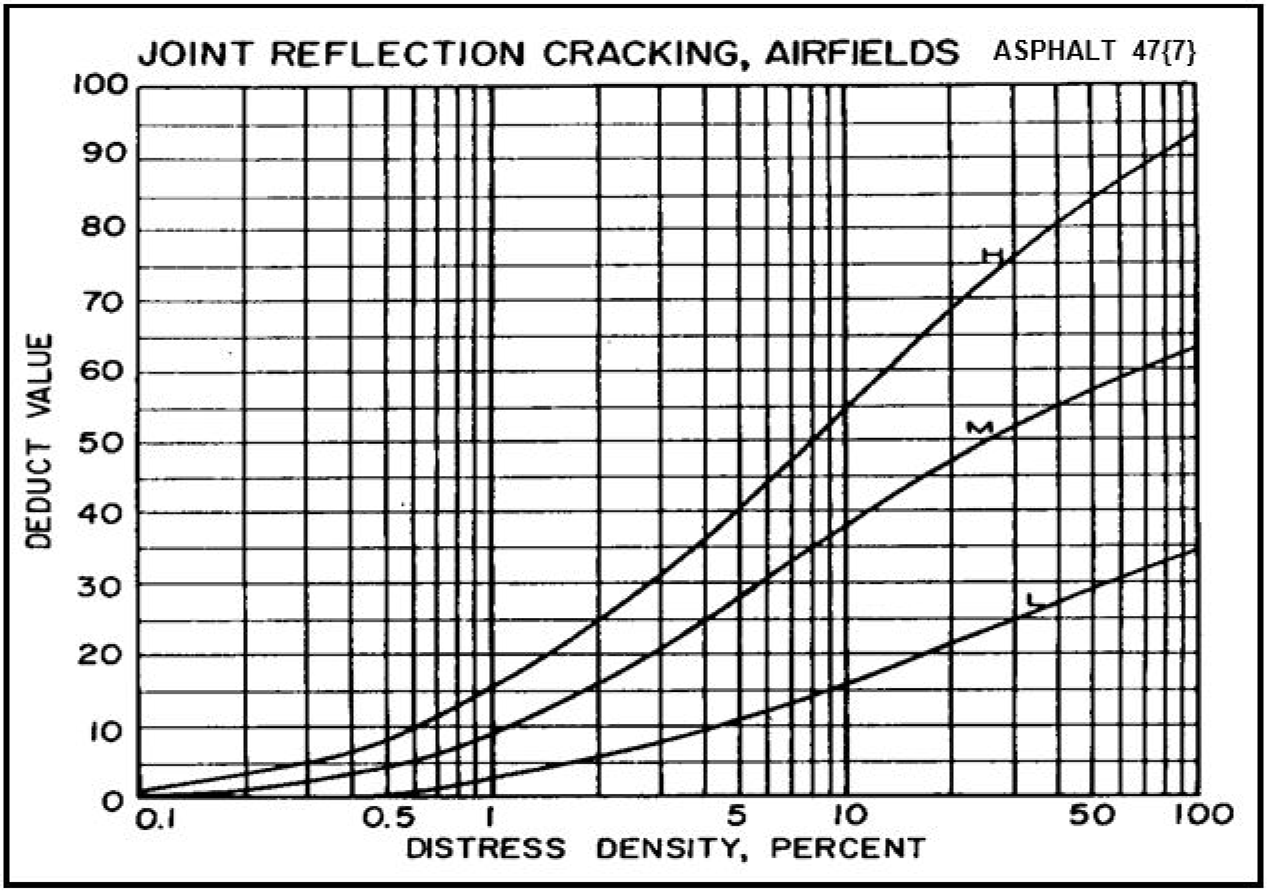


Figure C-8 Deduct Curves for Joint Reflection Cracking (47- Metric Units) {7}

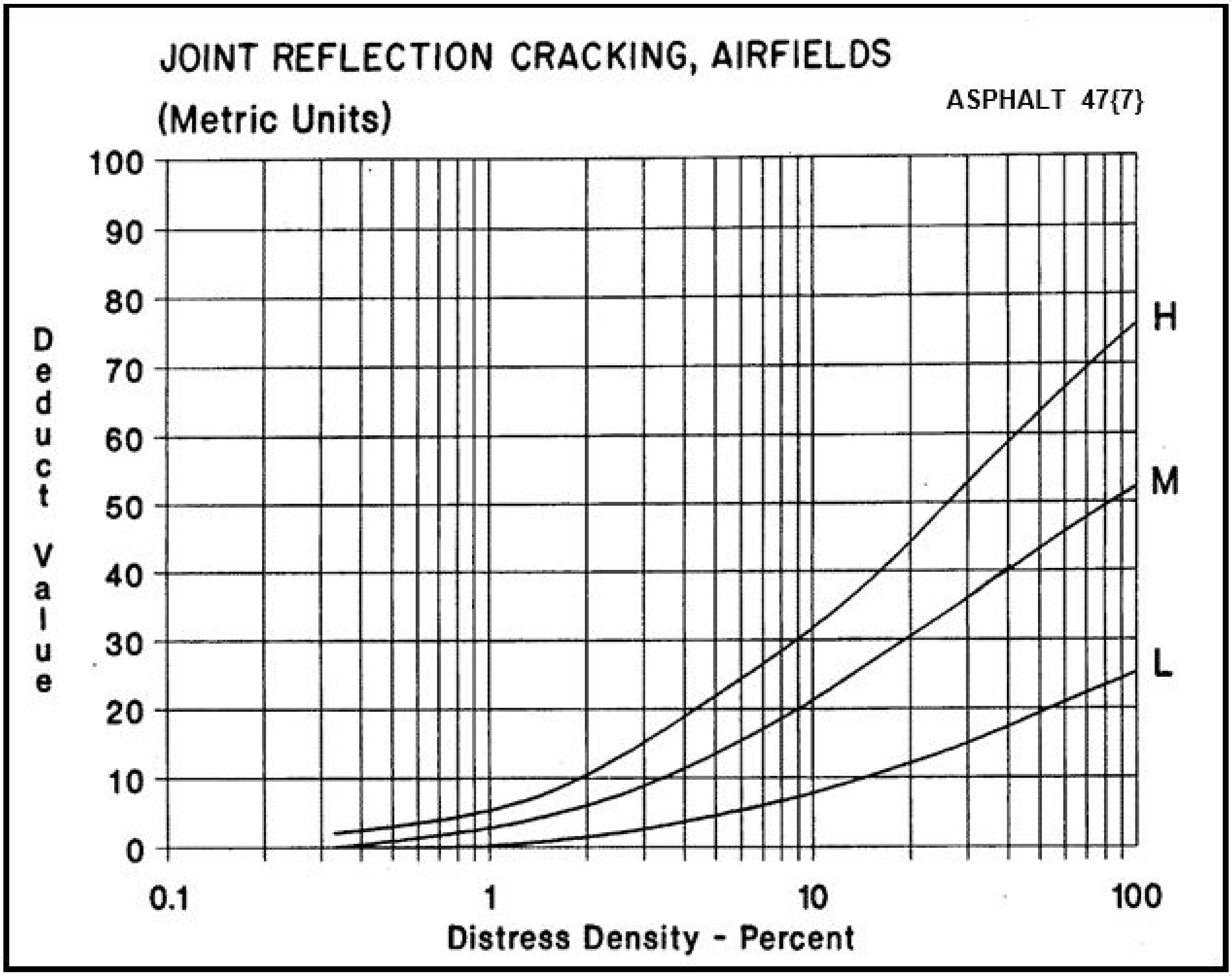


Figure C-9 Deduct Curves for Longitudinal/Transverse (48- English Units) {8}

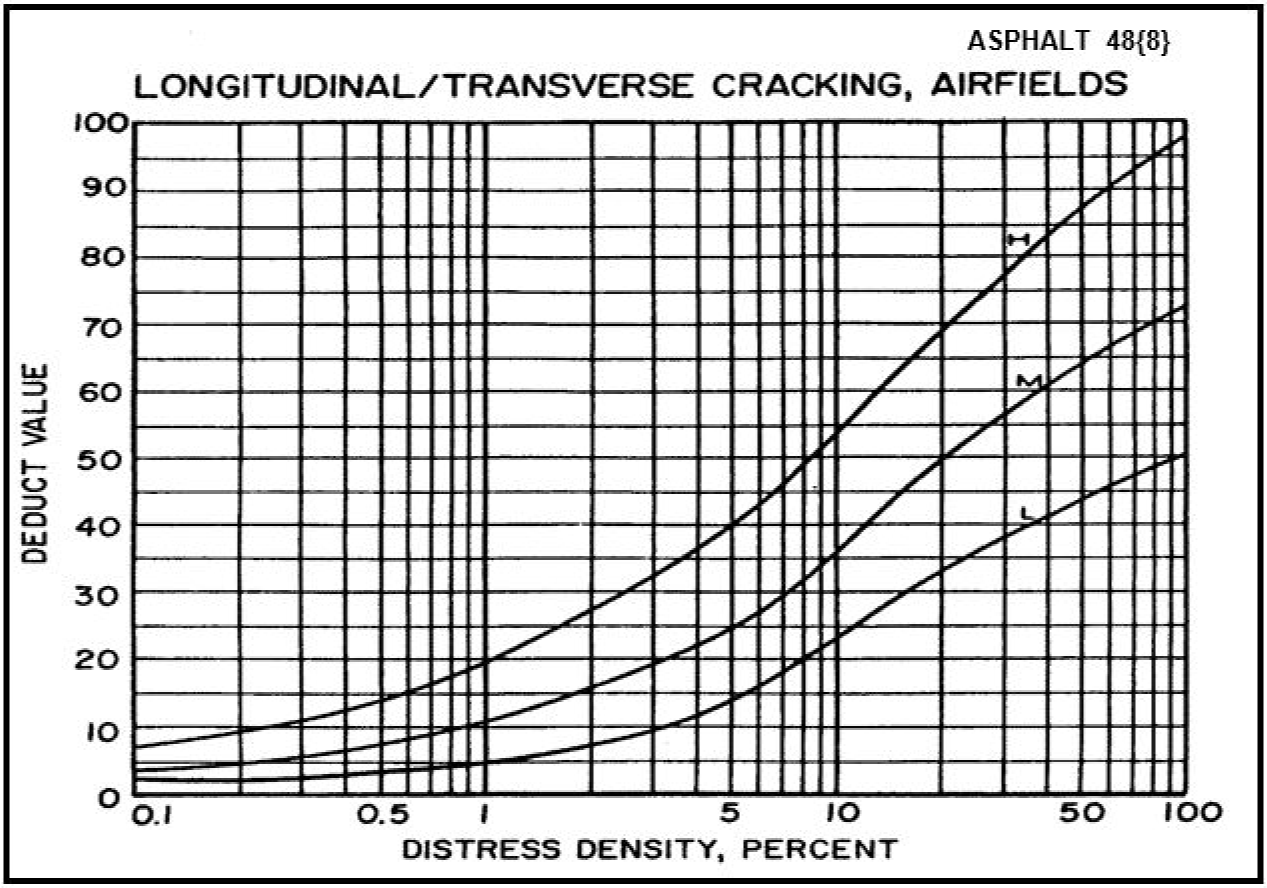


Figure C-10 Deduct Curves for Longitudinal/Transverse (48- Metric Units) {8}

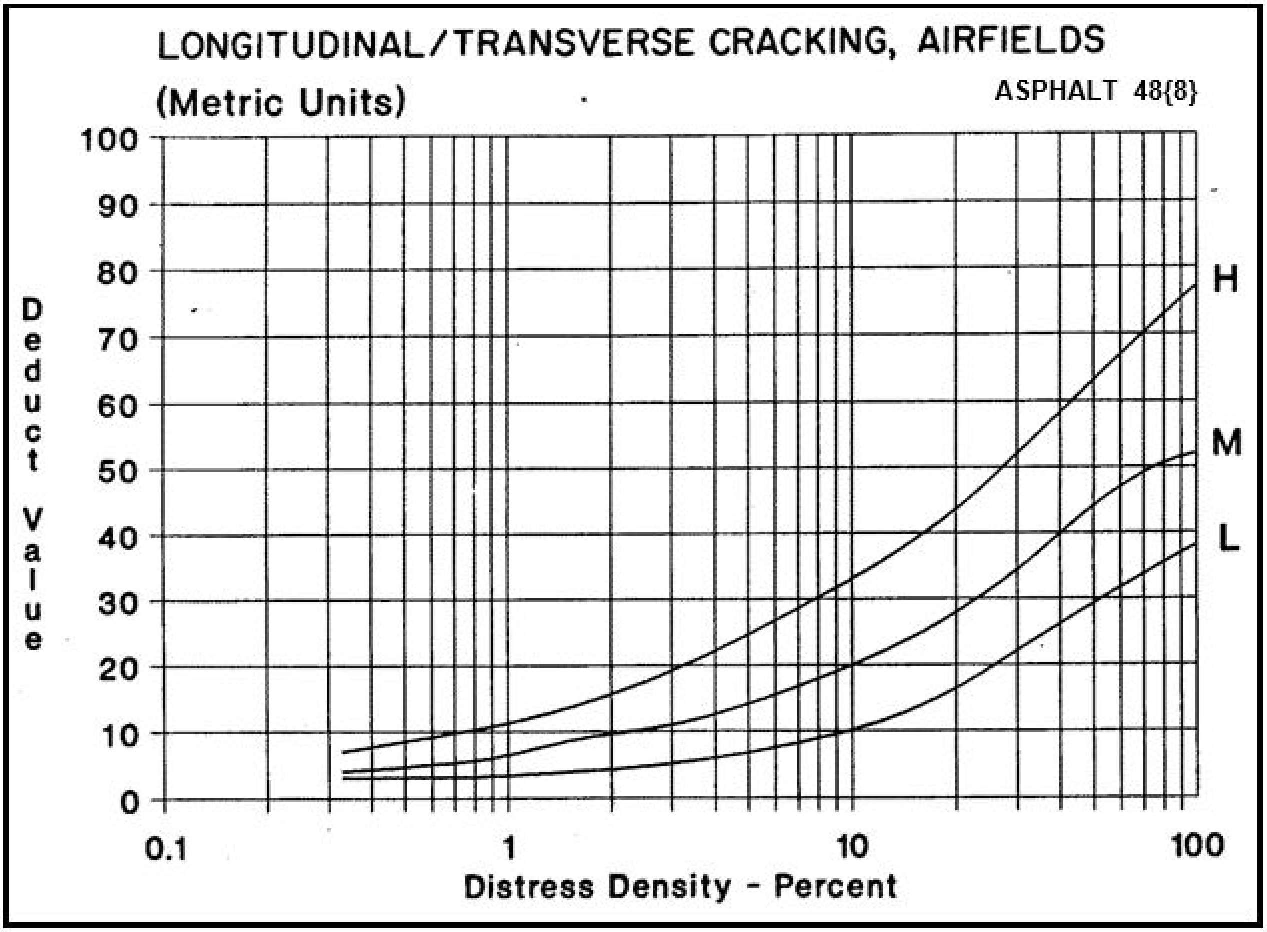


Figure C-11 Deduct Curve for Oil Spillage (49) {9}

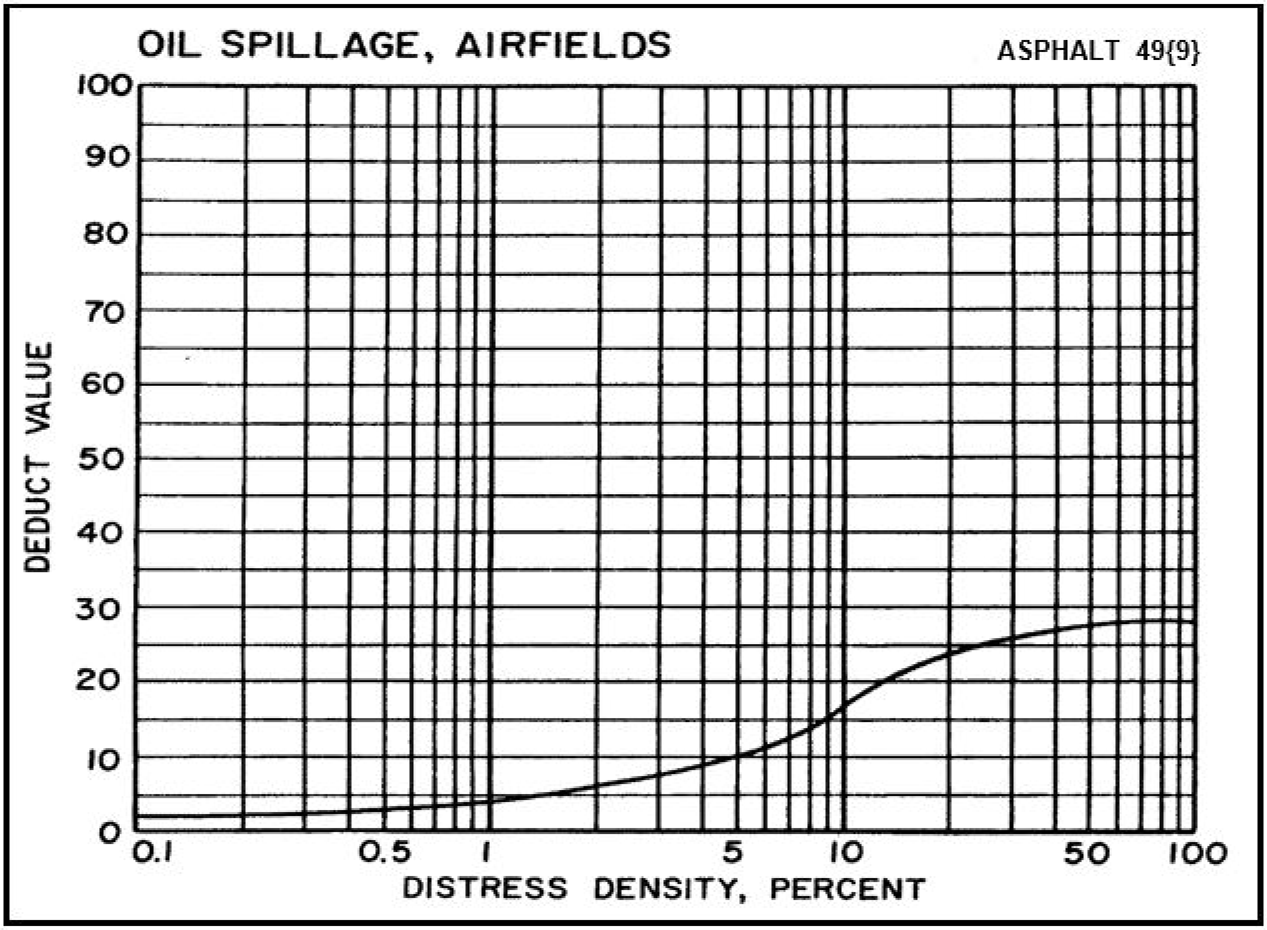


Figure C-12 Deduct Curves for Patching/Utility Cut (50) {10}

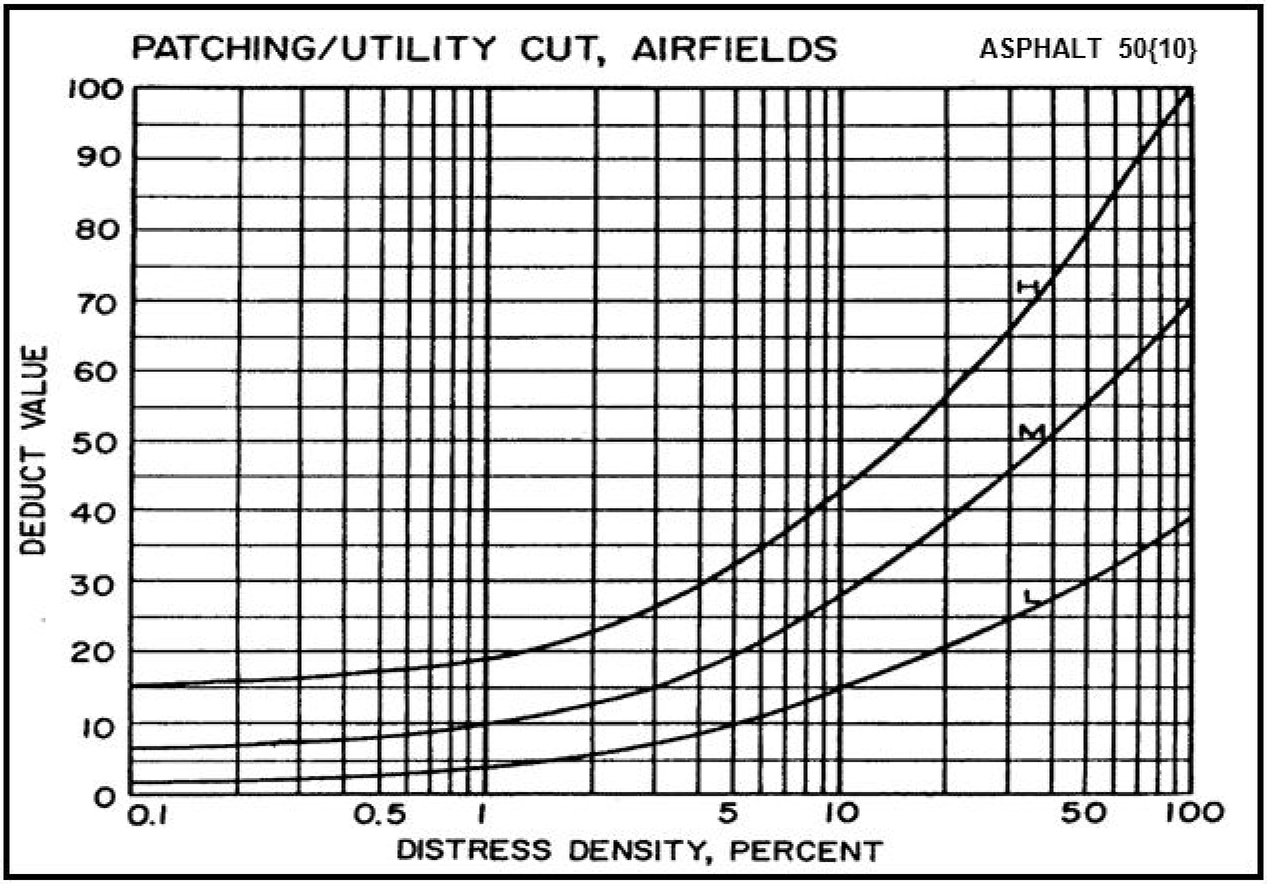


Figure C-13 Deduct Curve for Polished Aggregate (51) {11}

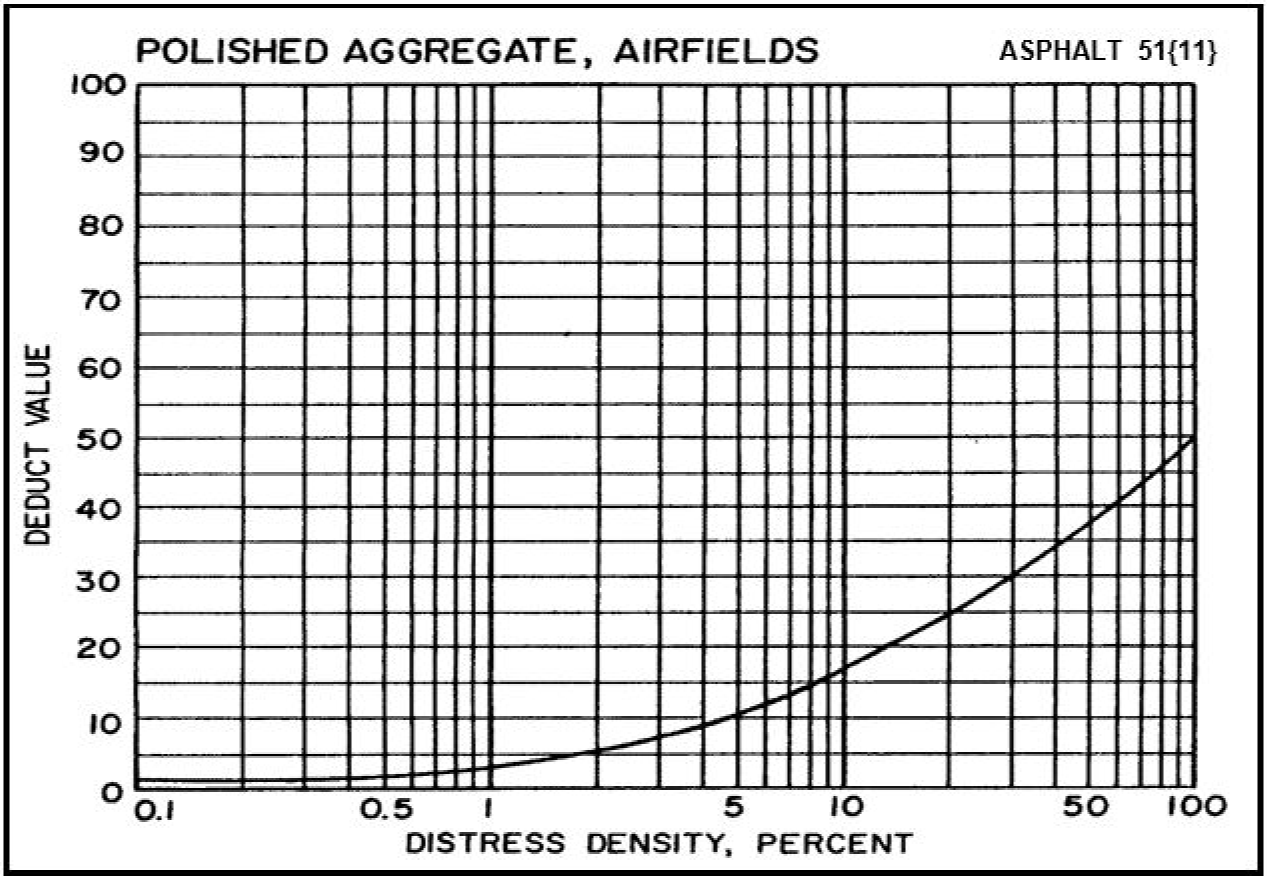


Figure C-14 Deduct Curves for Raveling (52) {12}

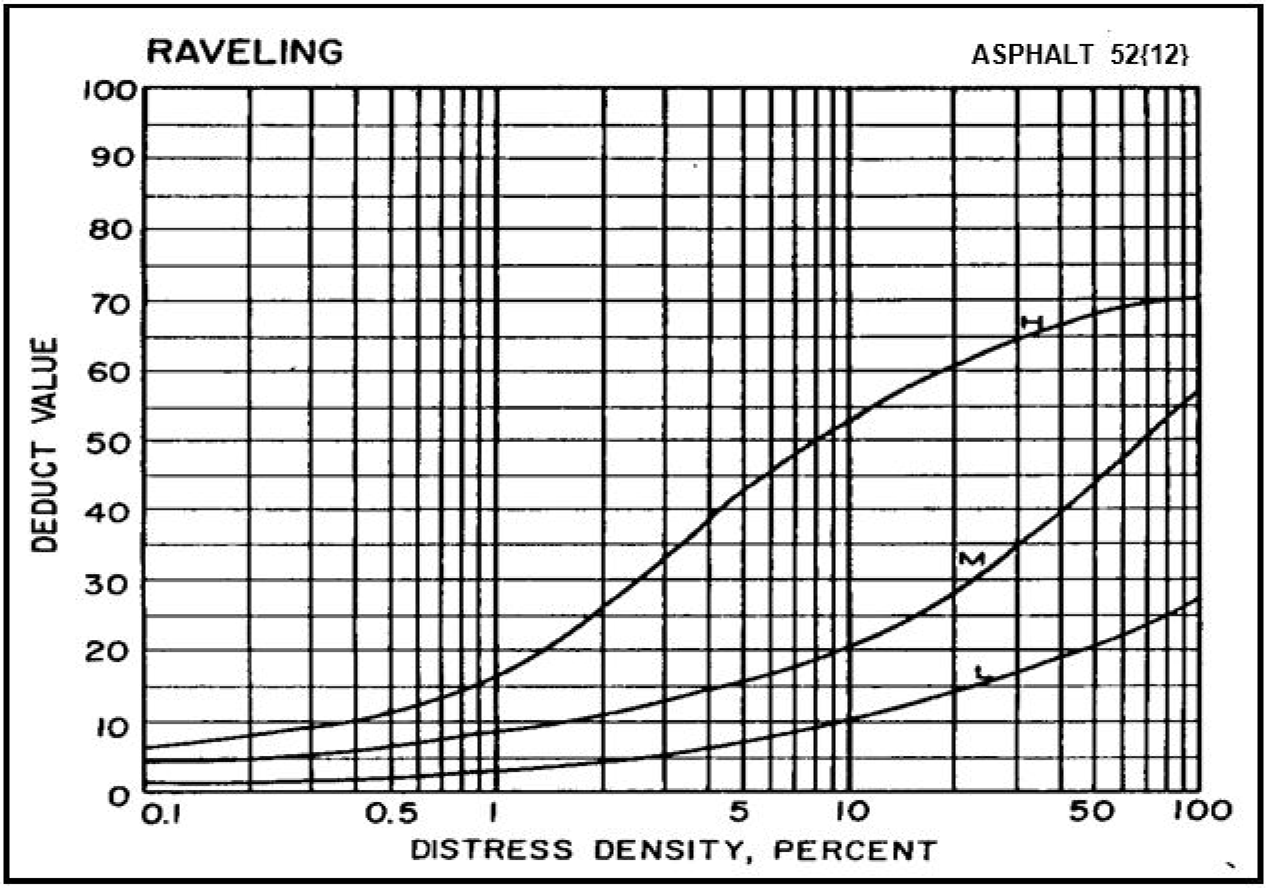


Figure C-15 Deduct Curves for Rutting (53) {13}

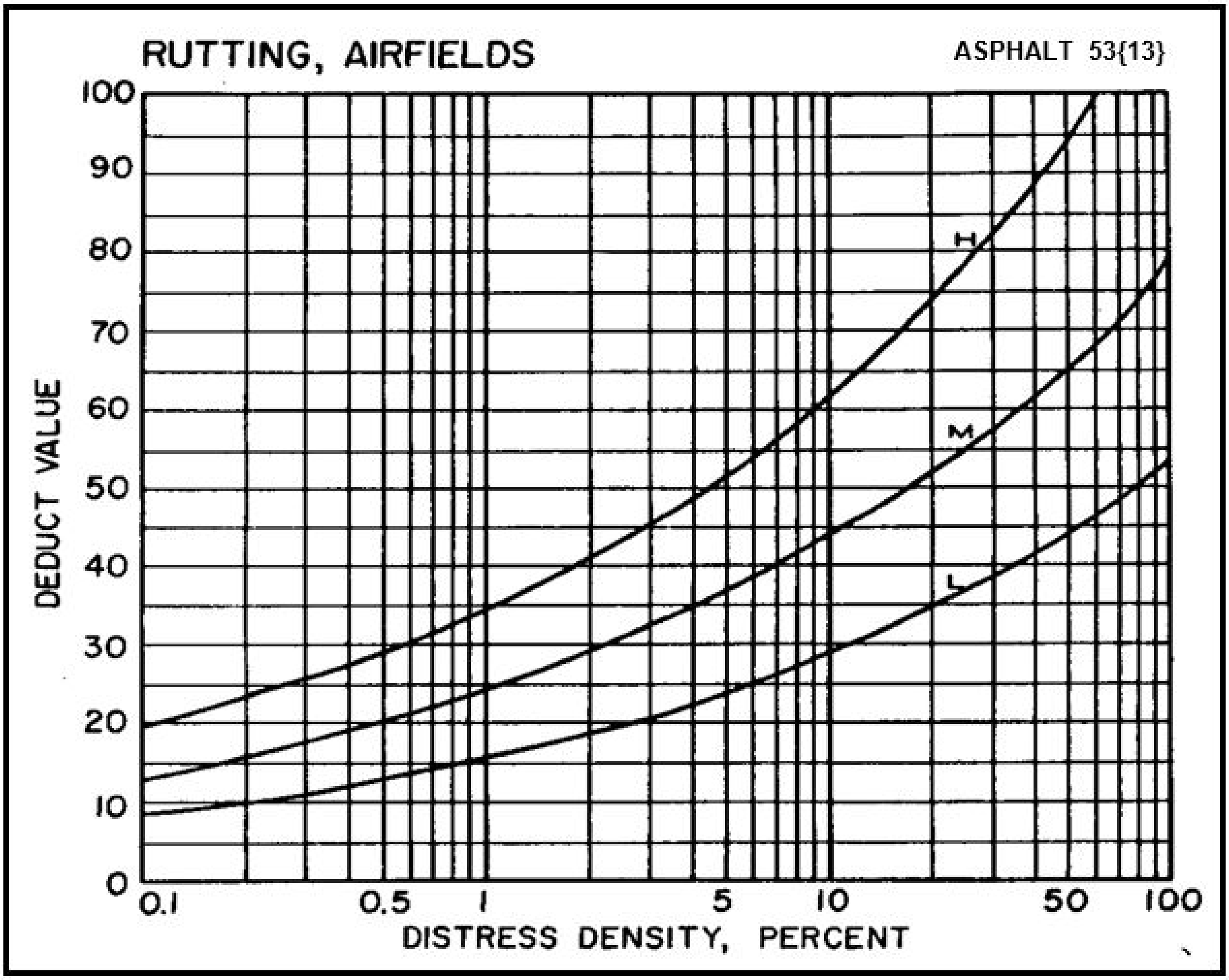


Figure C-16 Deduct Curves for Shoving (54) {14}

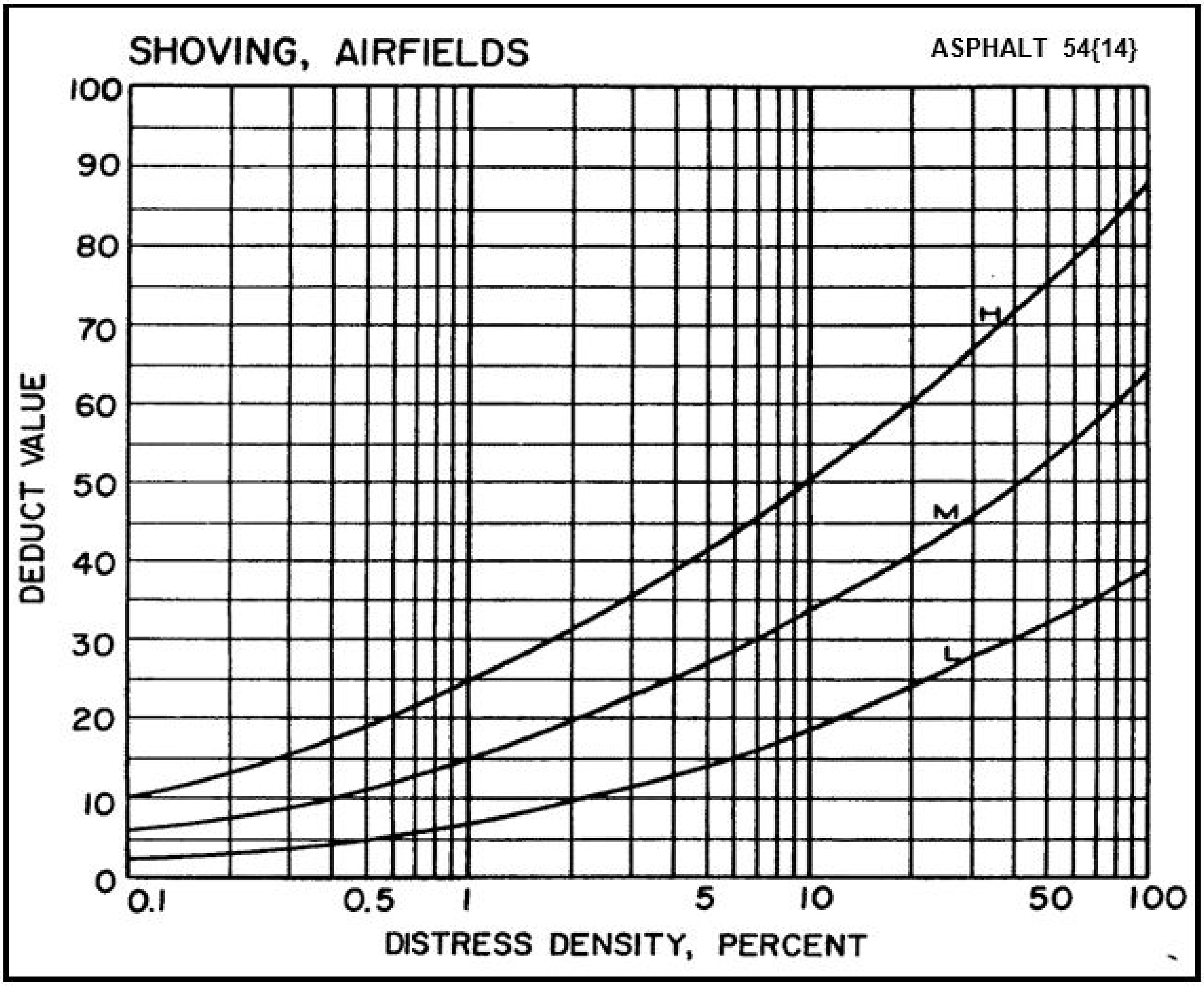


Figure C-17 Deduct Curve for Slippage Cracking (55) {15}

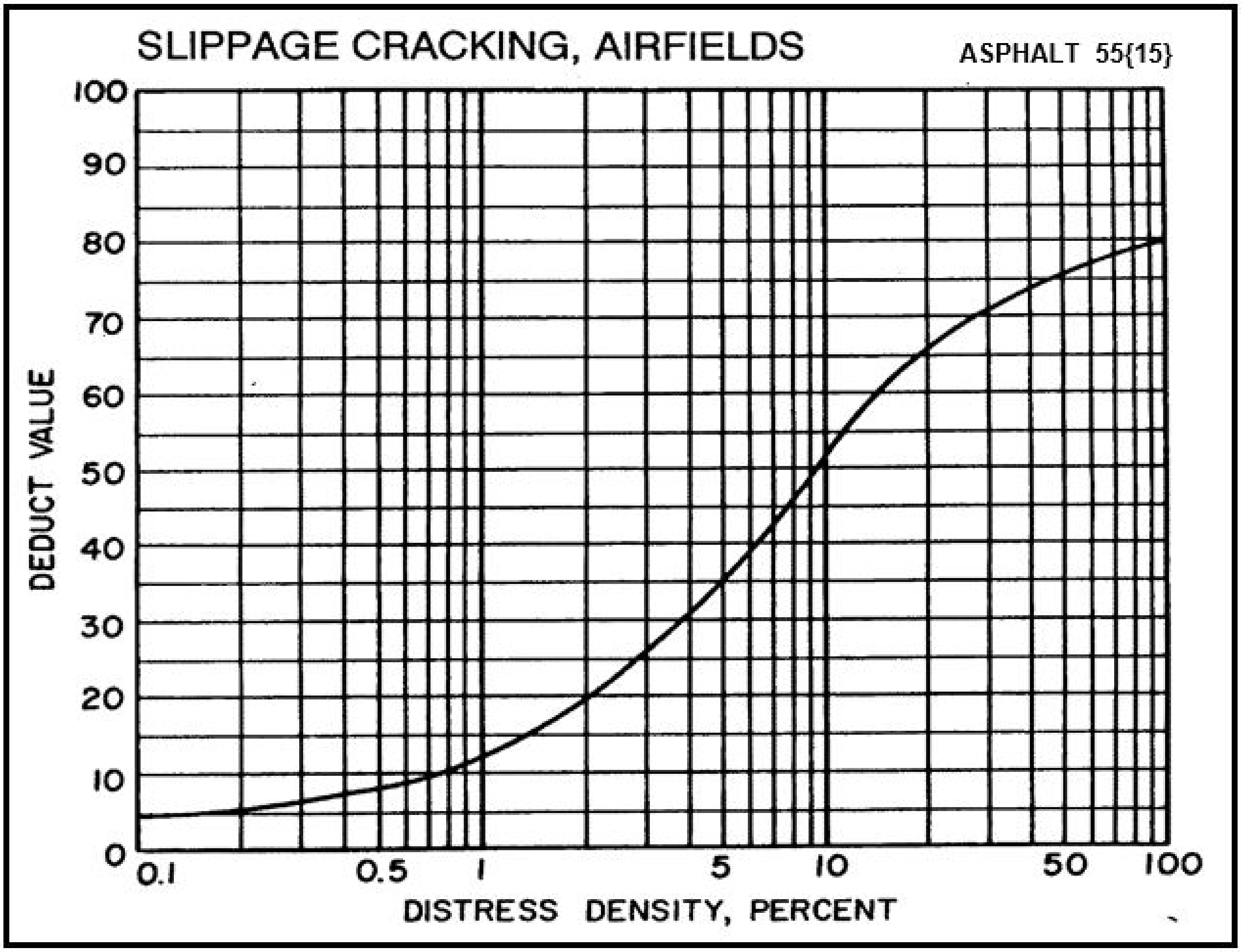


Figure C-18 Deduct Curves for Swell (56) {16}

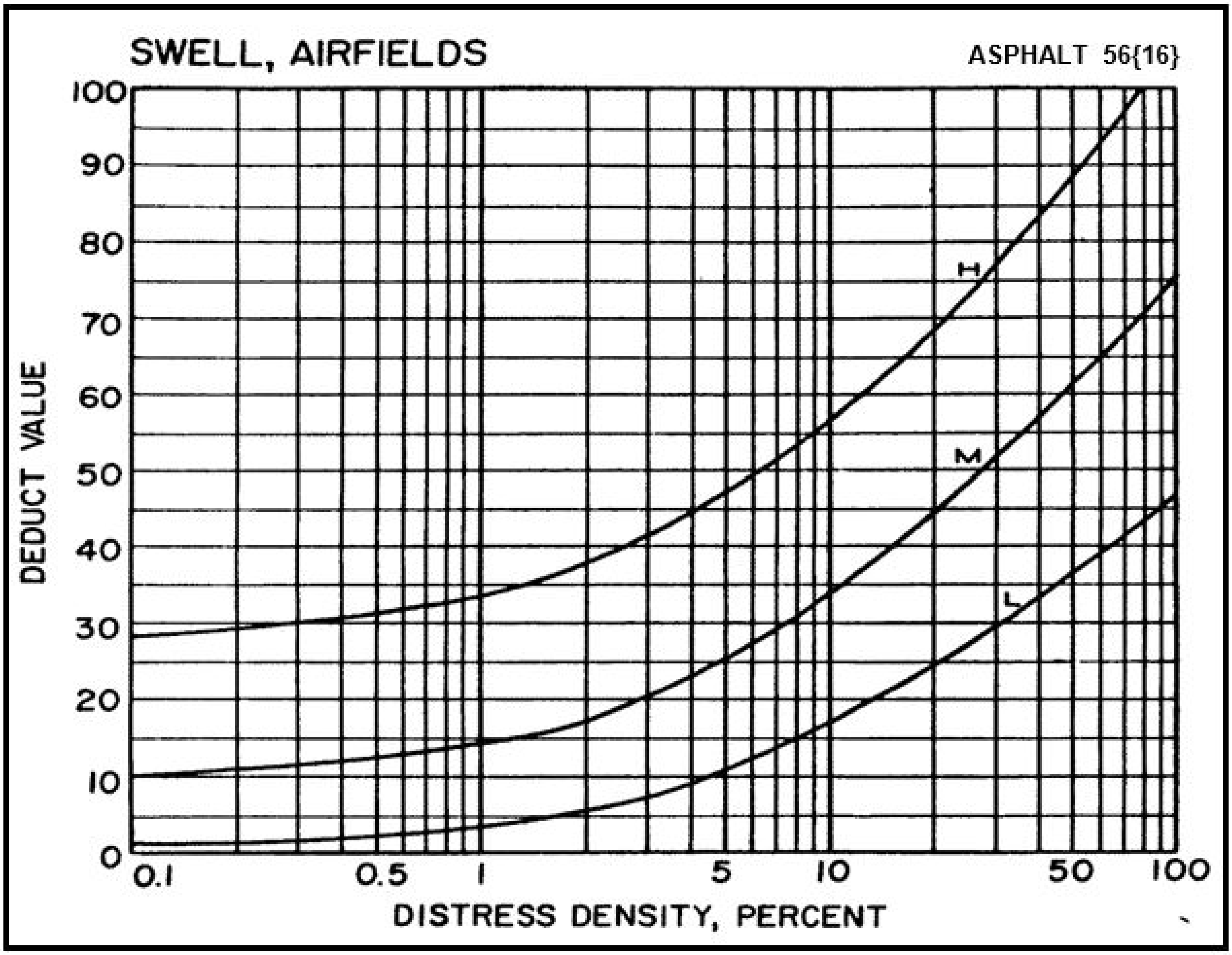


Figure C-19 Deduct Curves for Weathering (57) {17}

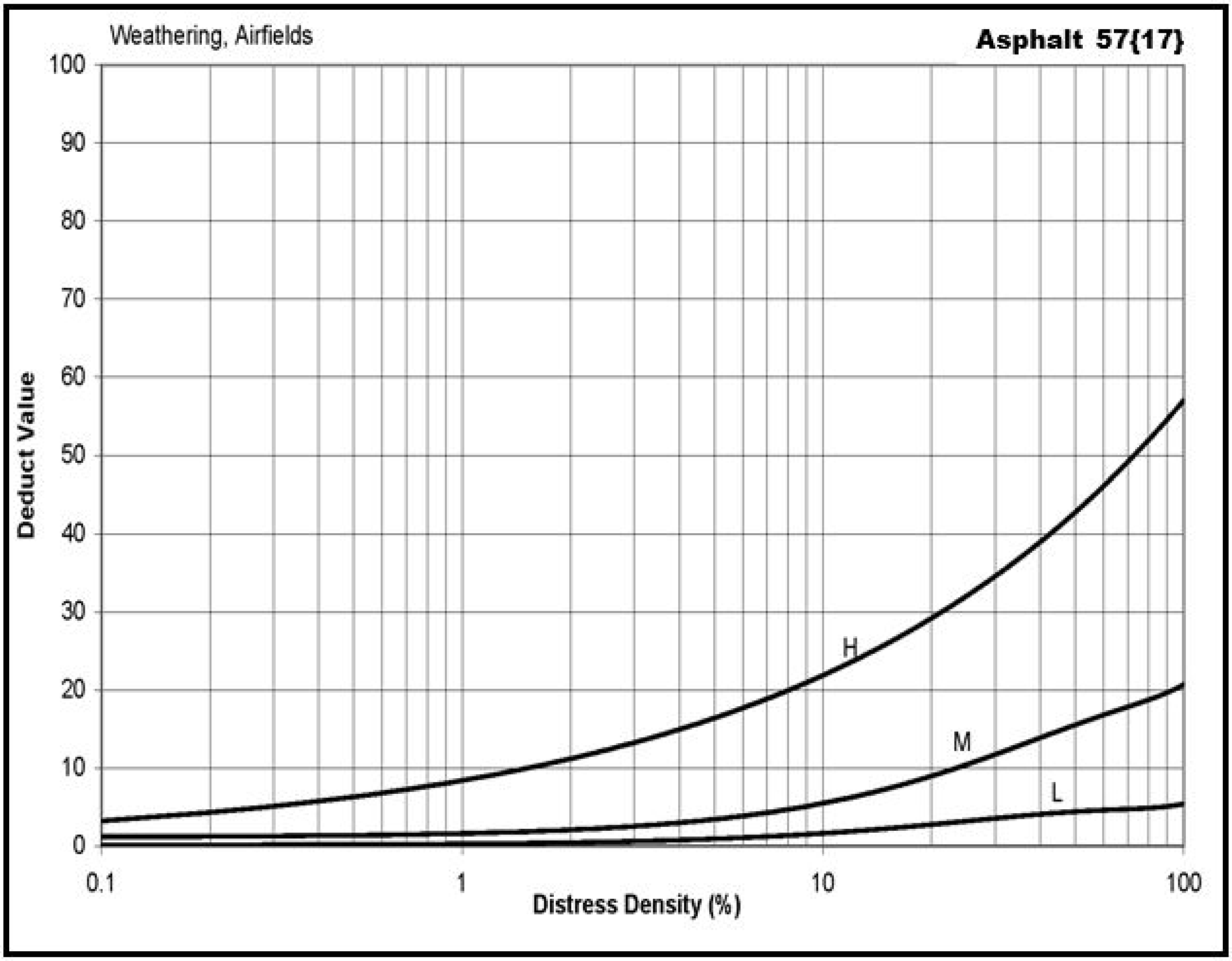
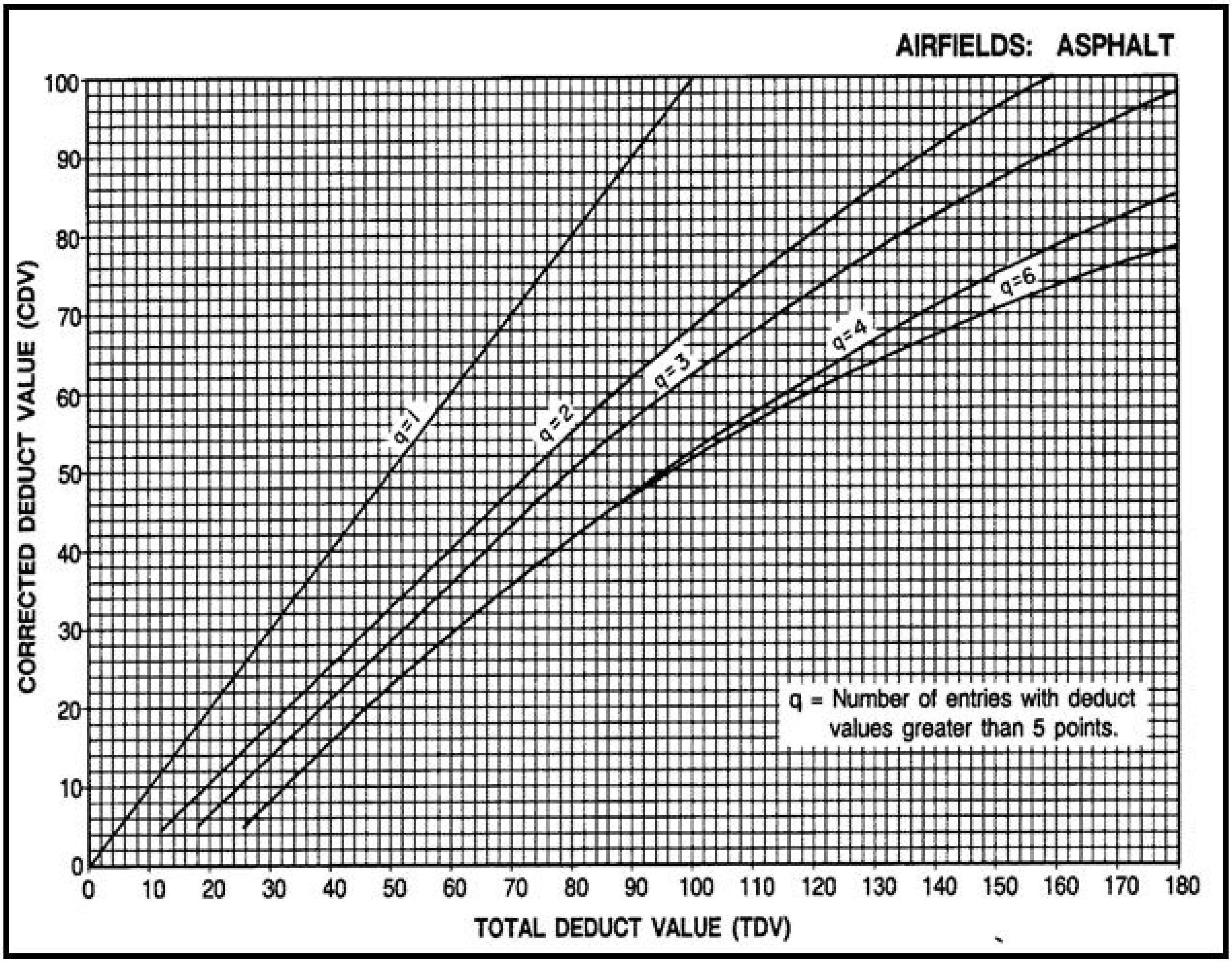


Figure C-20 Correct Deduct Curves for Asphalt Airfields



APPENDIX D DEDUCT CURVES FOR CONCRETE AIRFIELD PAVEMENTS

Figure D-1 Deduct Curves for Blowup (61) {1}

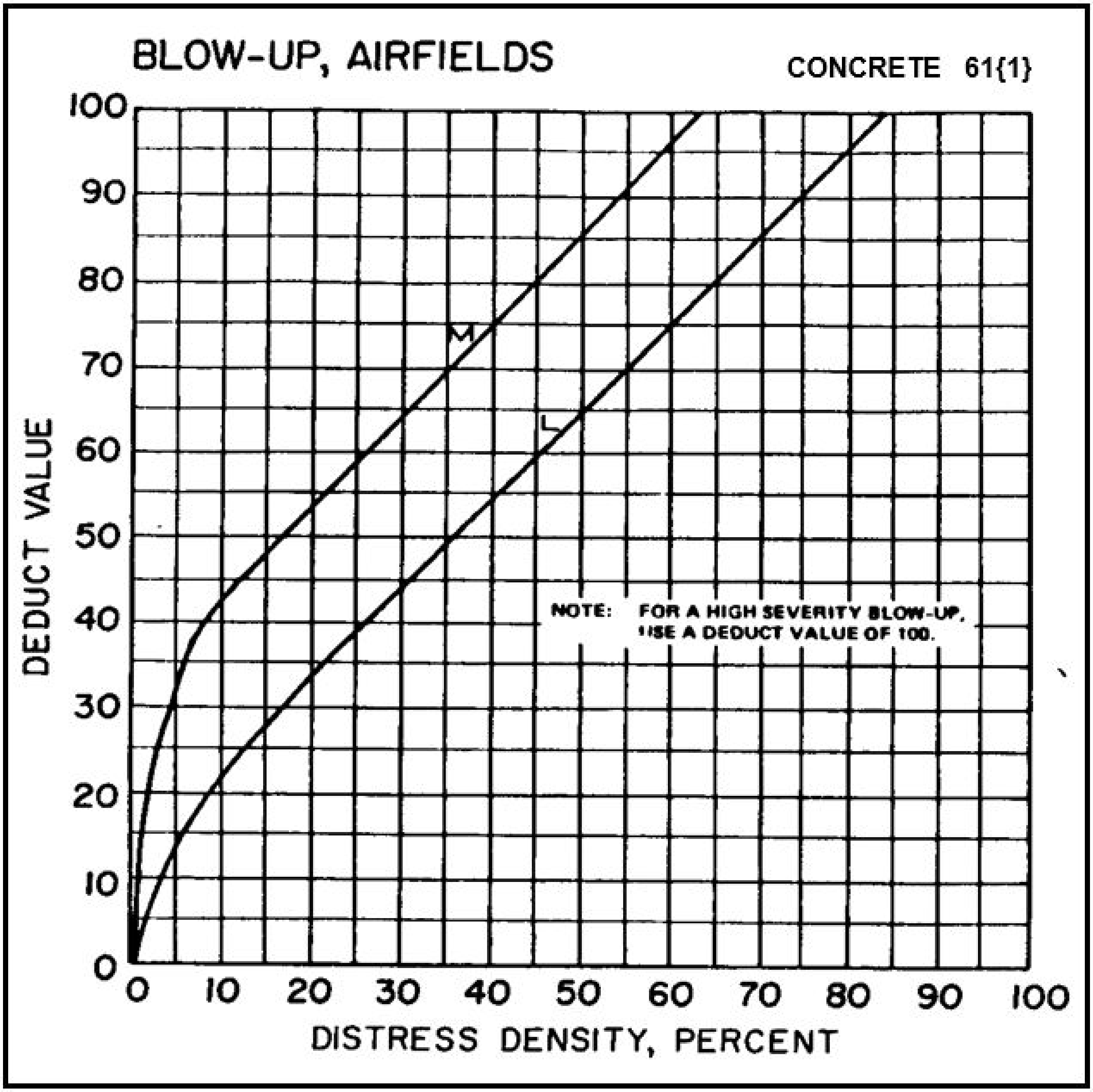


Figure D-2 Deduct Curves for Corner Break (62) {2}

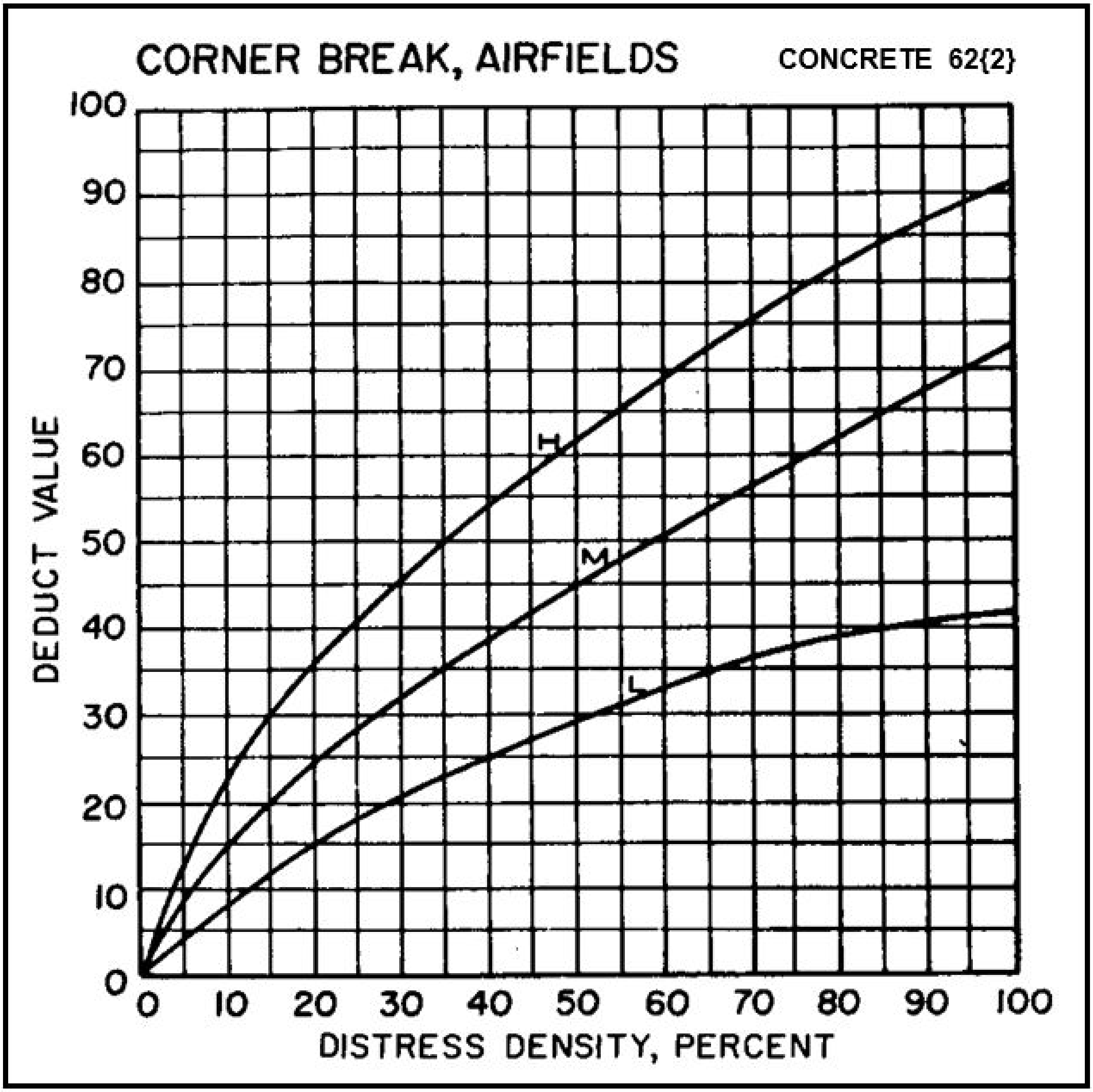


Figure D-3 Deduct Curves for Cracking (63) {3}

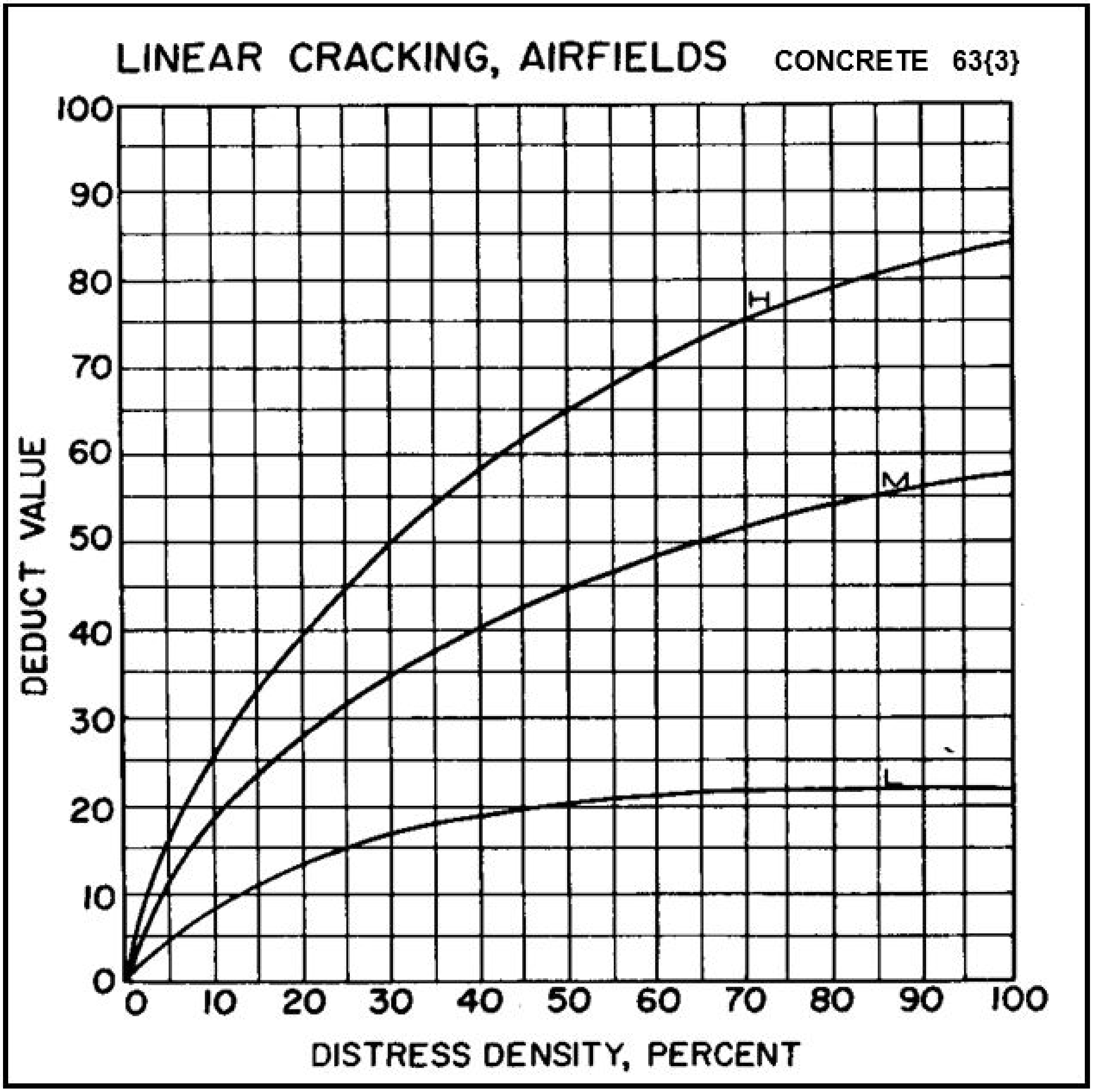


Figure D-4 Deduct Curves for Durability Cracking (64) {4}

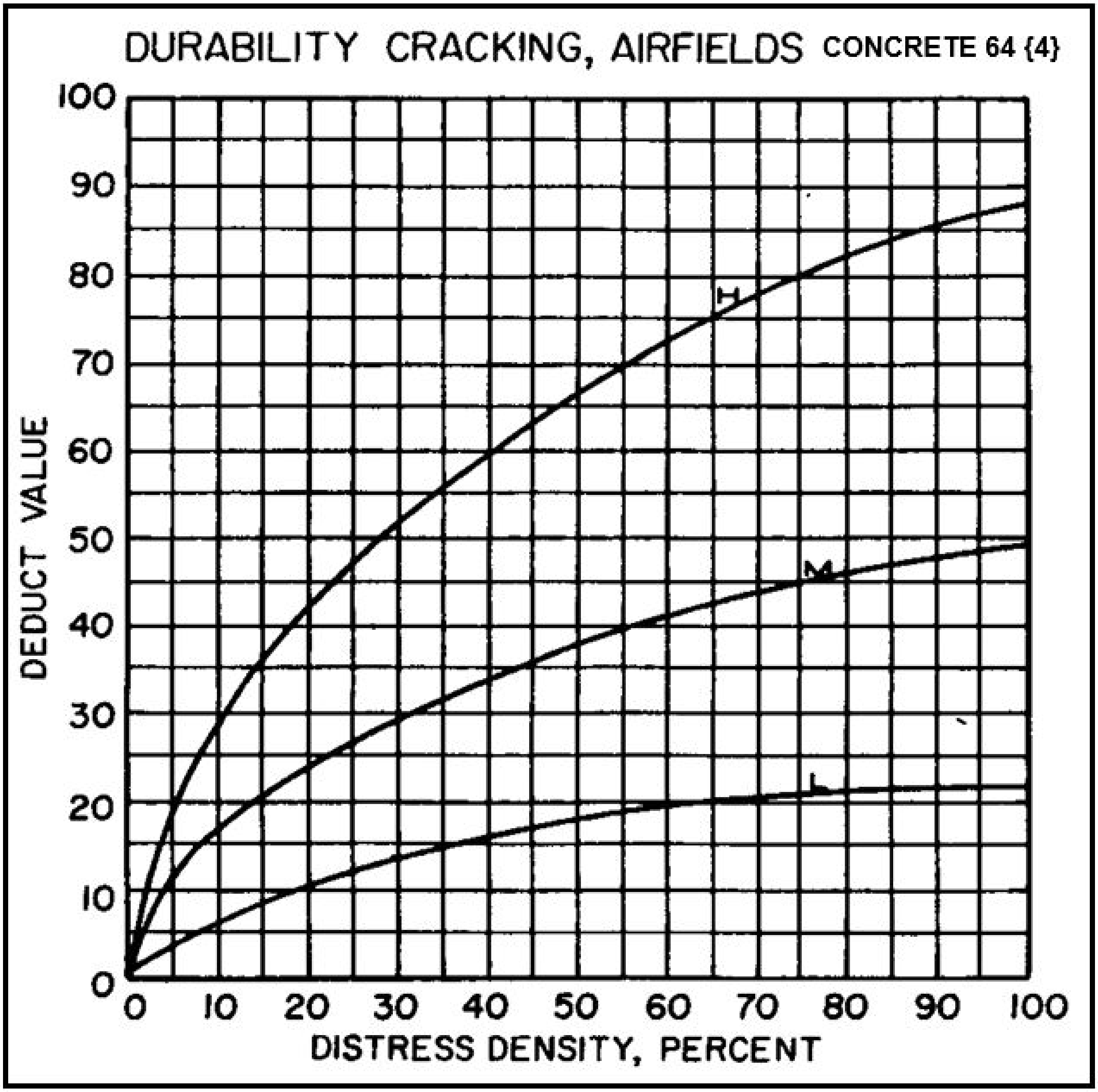


Figure D-5 Deduct Values for Joint Seal Damage (65) {5}

JOINT SEAL DAMAGE

Concrete 65 {5}

Joint seal damage is not rated by density. The severity of the distress is determined by the sealant's overall condition for a particular section.

The deduct values for the three levels of severity are as follows:

1. High Severity - 12 Points
2. Medium Severity - 7 Points
3. Low Severity - 2 Points

Figure D-6 Deduct Curves for Small Patch (66) {6}

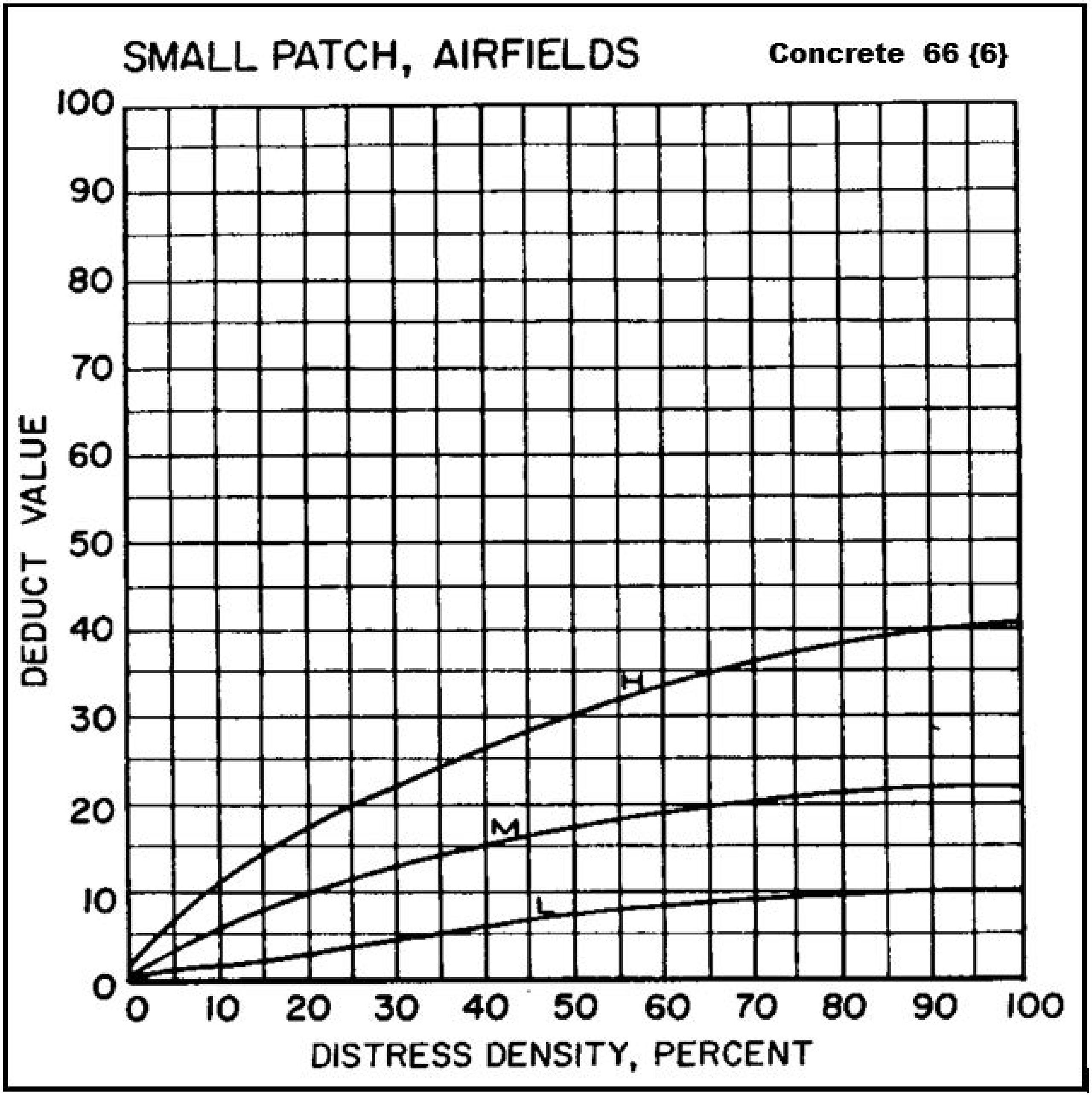


Figure D-7 Deduct Curves for Patching/Utility Cut (67) {7}

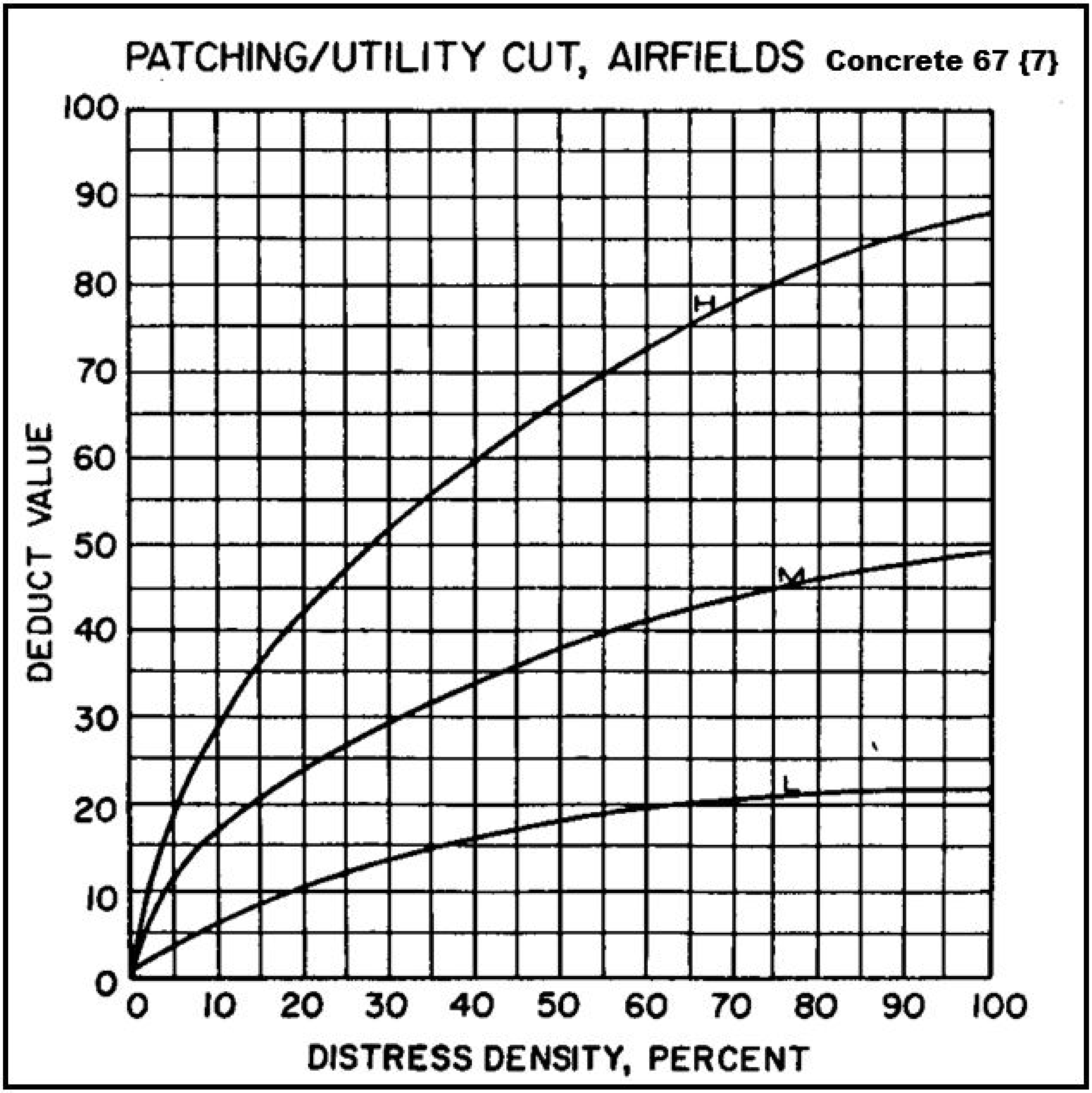


Figure D-8 Deduct Curve for Popouts (68) {8}

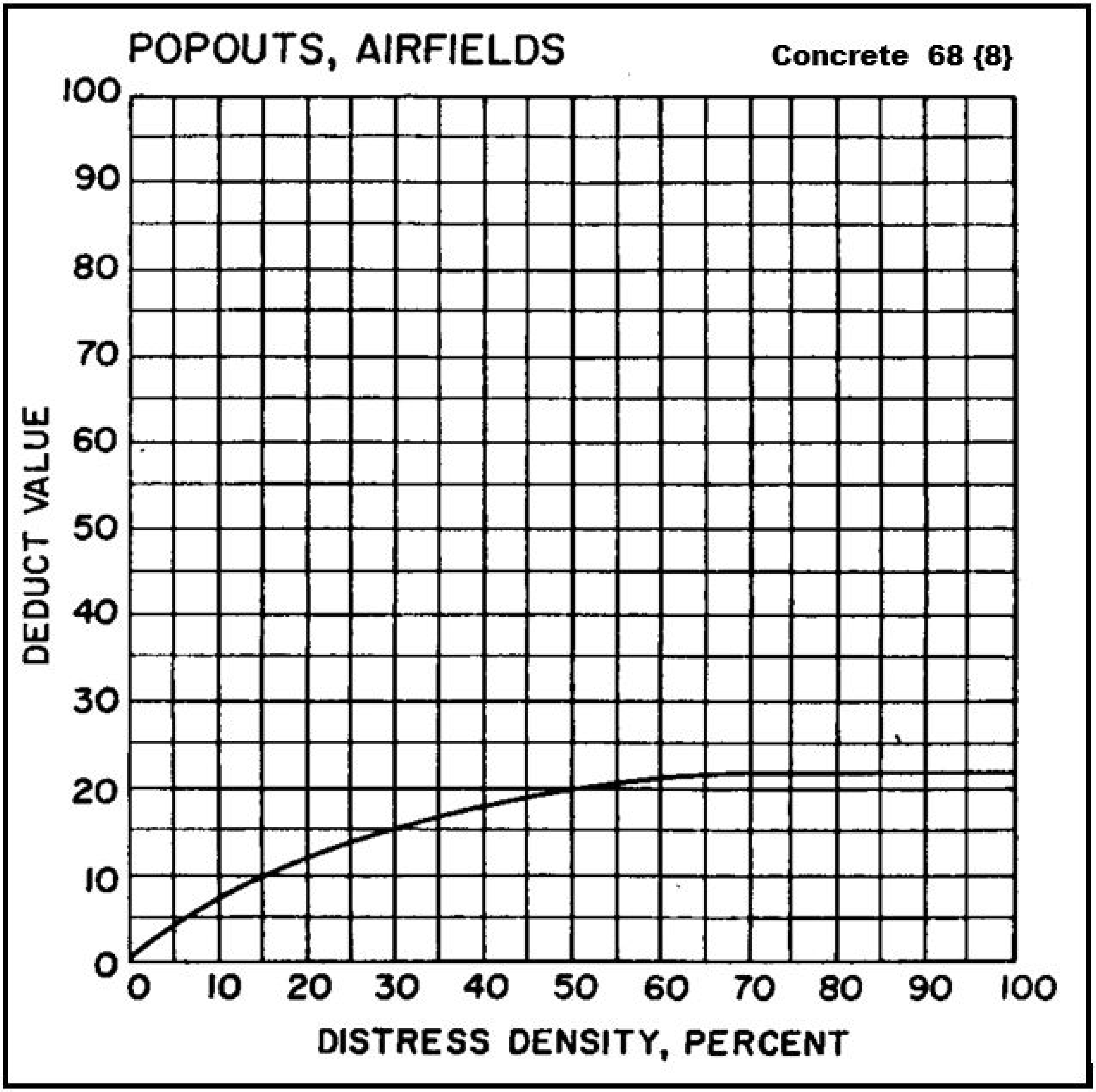


Figure D-9 Deduct Curve for Pumping (69) {9}

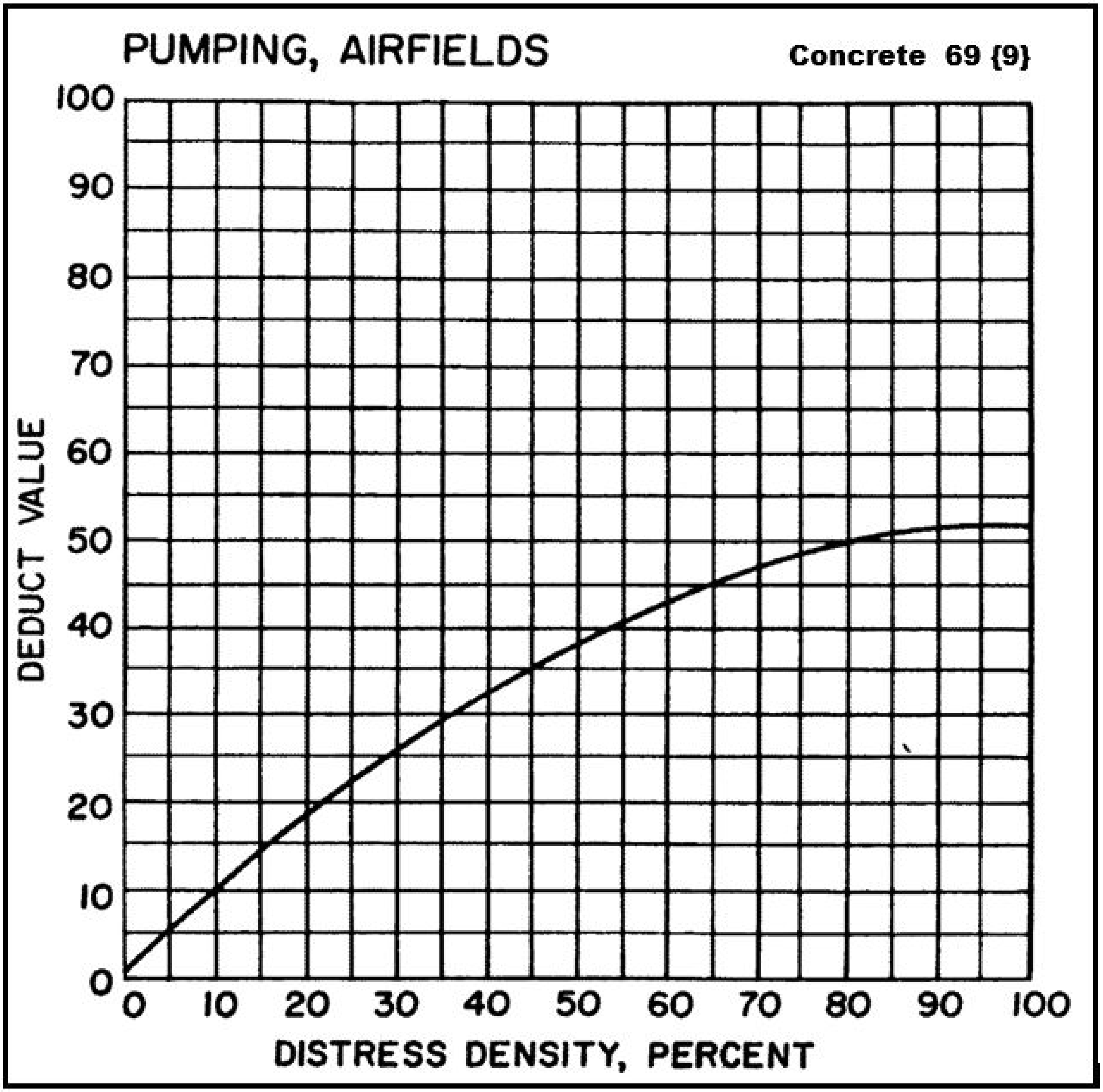


Figure D-10 Deduct Curves for Scaling (70) {10}

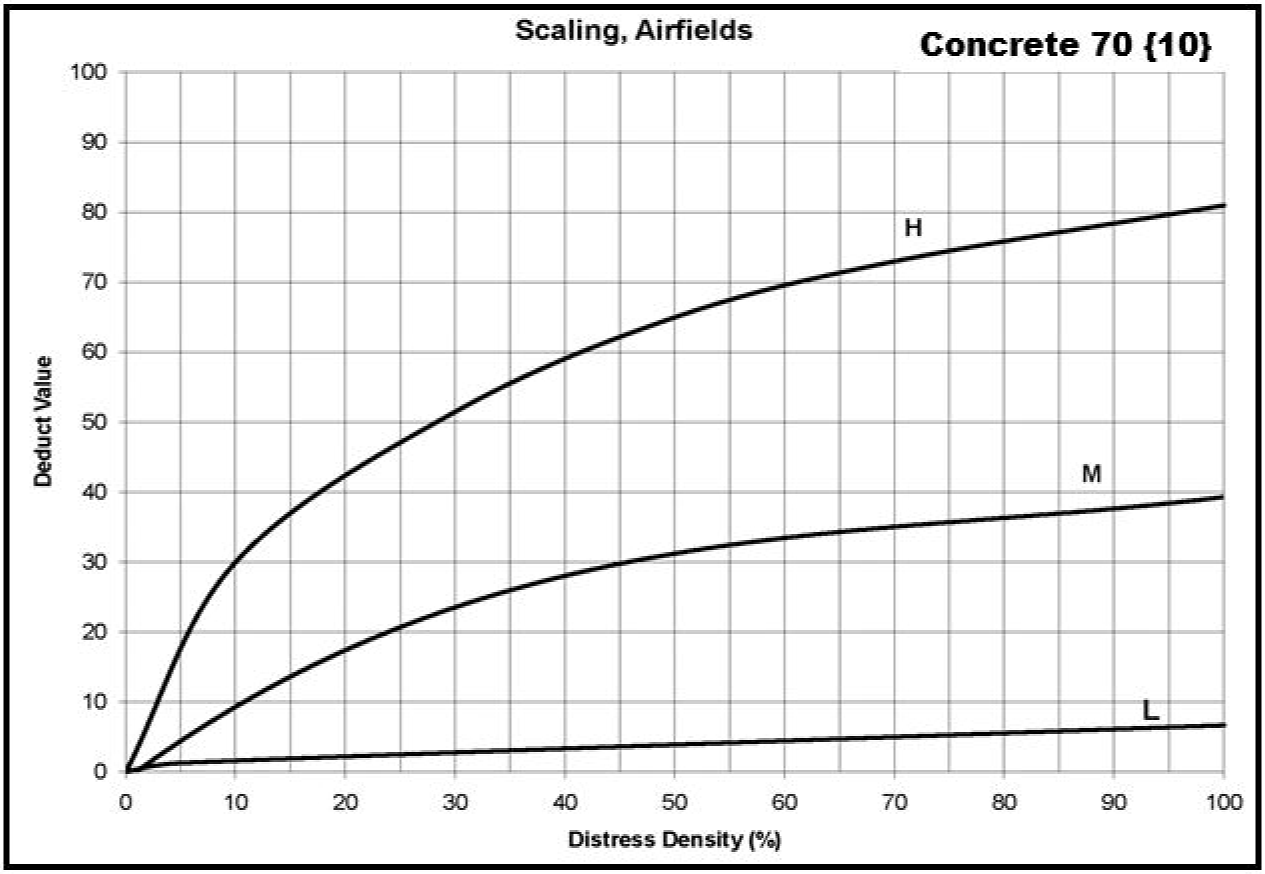


Figure D-11 Deduct Curves for Settlement (71) {11}

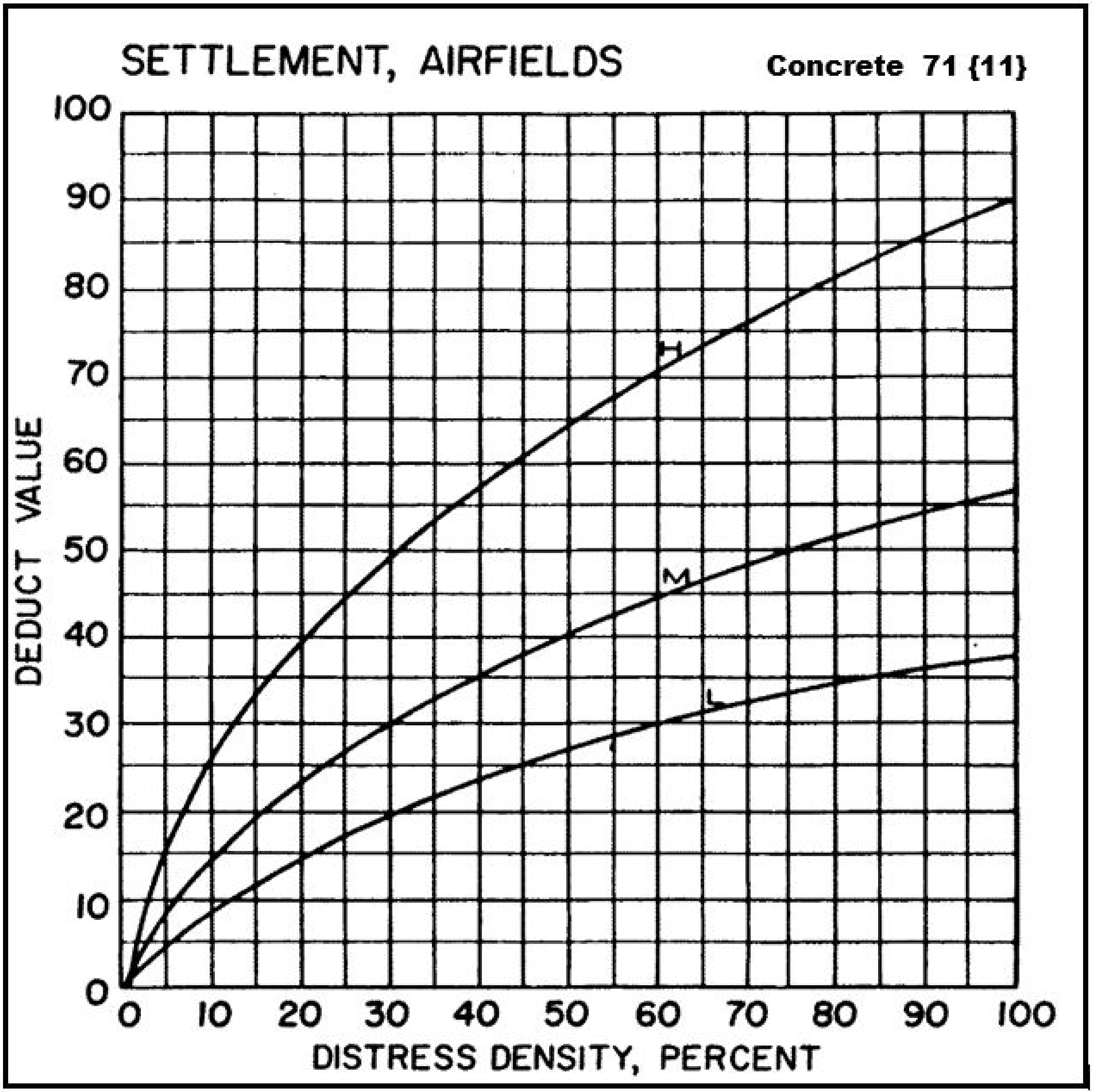


Figure D-12 Deduct Curves for Shattered Slab (72) {12}

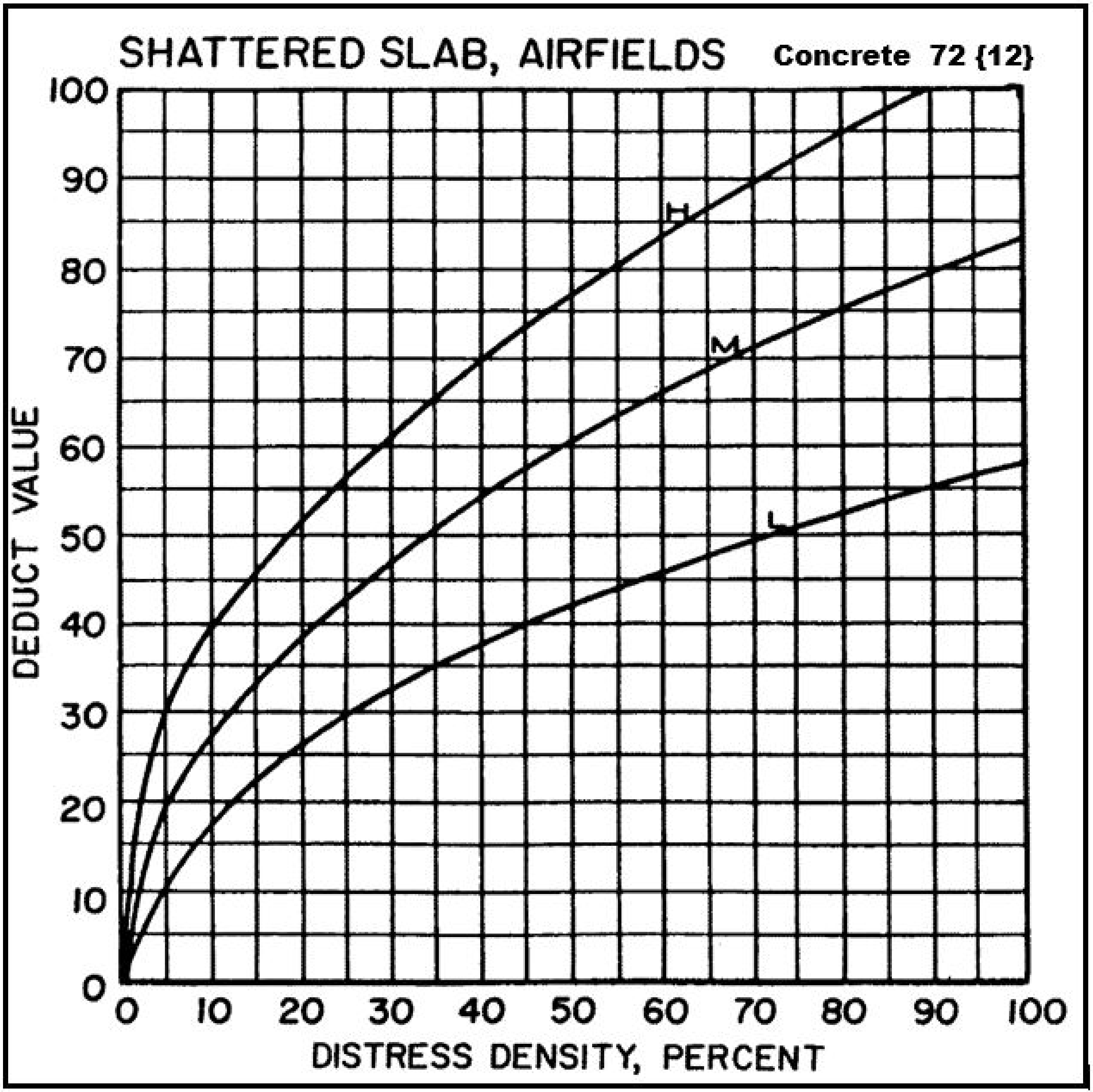


Figure D-13 Distress Curve for Shrinkage Cracks (73) {13}

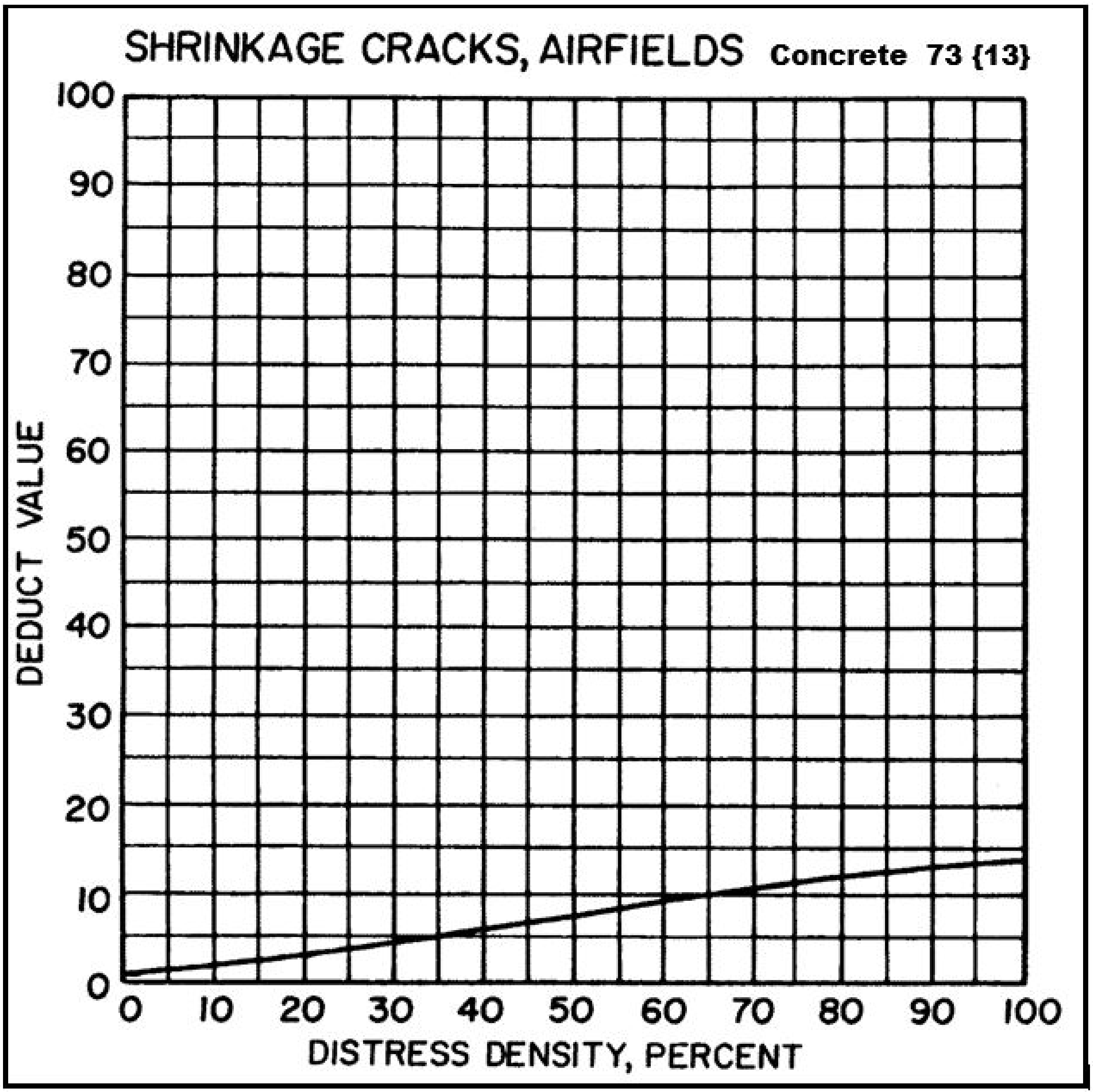


Figure D-14 Deduct Curves for Joint Spall (74) {14}

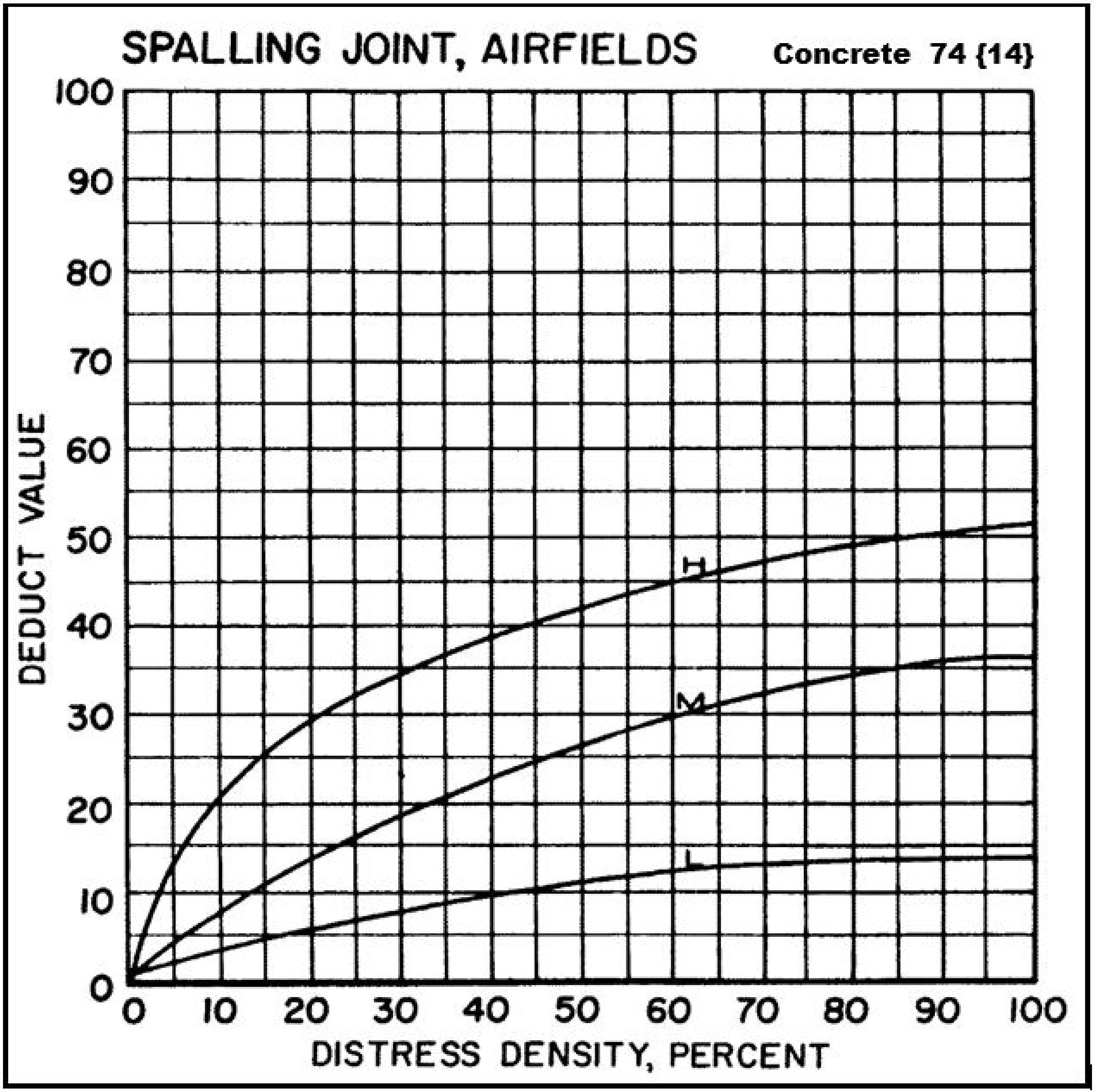


Figure D-15 Deduct Curves for Corner Spalling (75) {15}

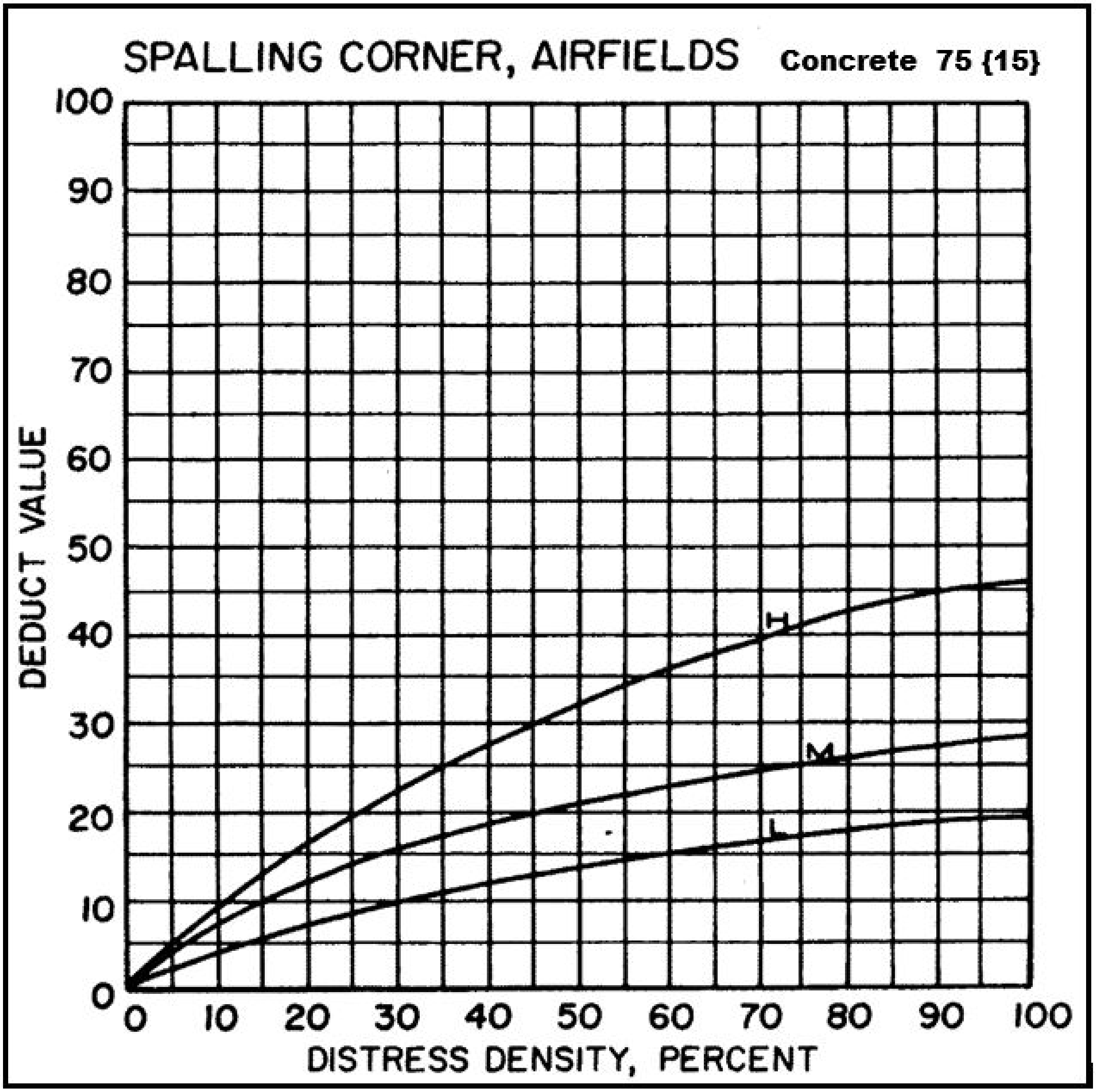


Figure D-16 Deduct Curves for ASR (76) {16}

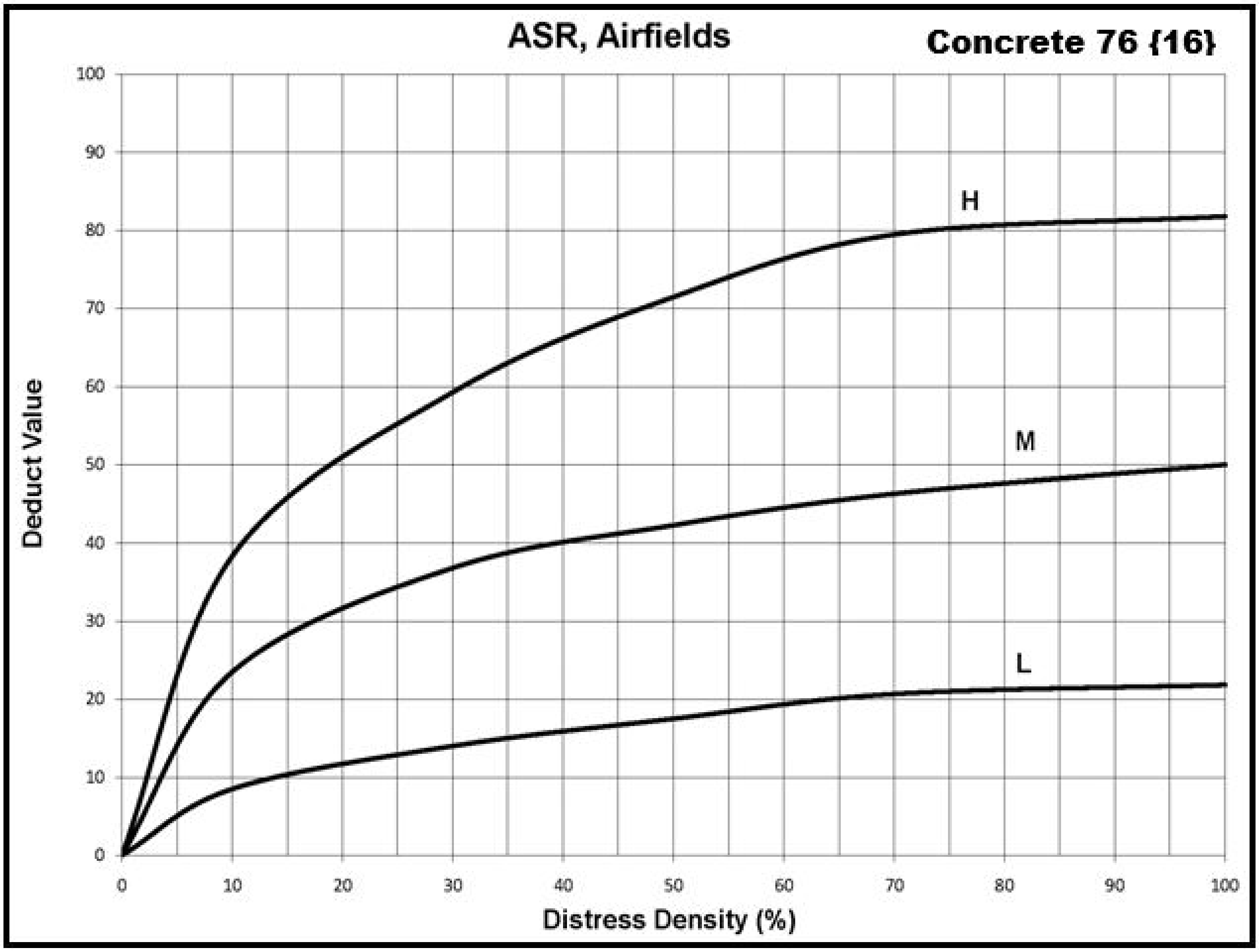
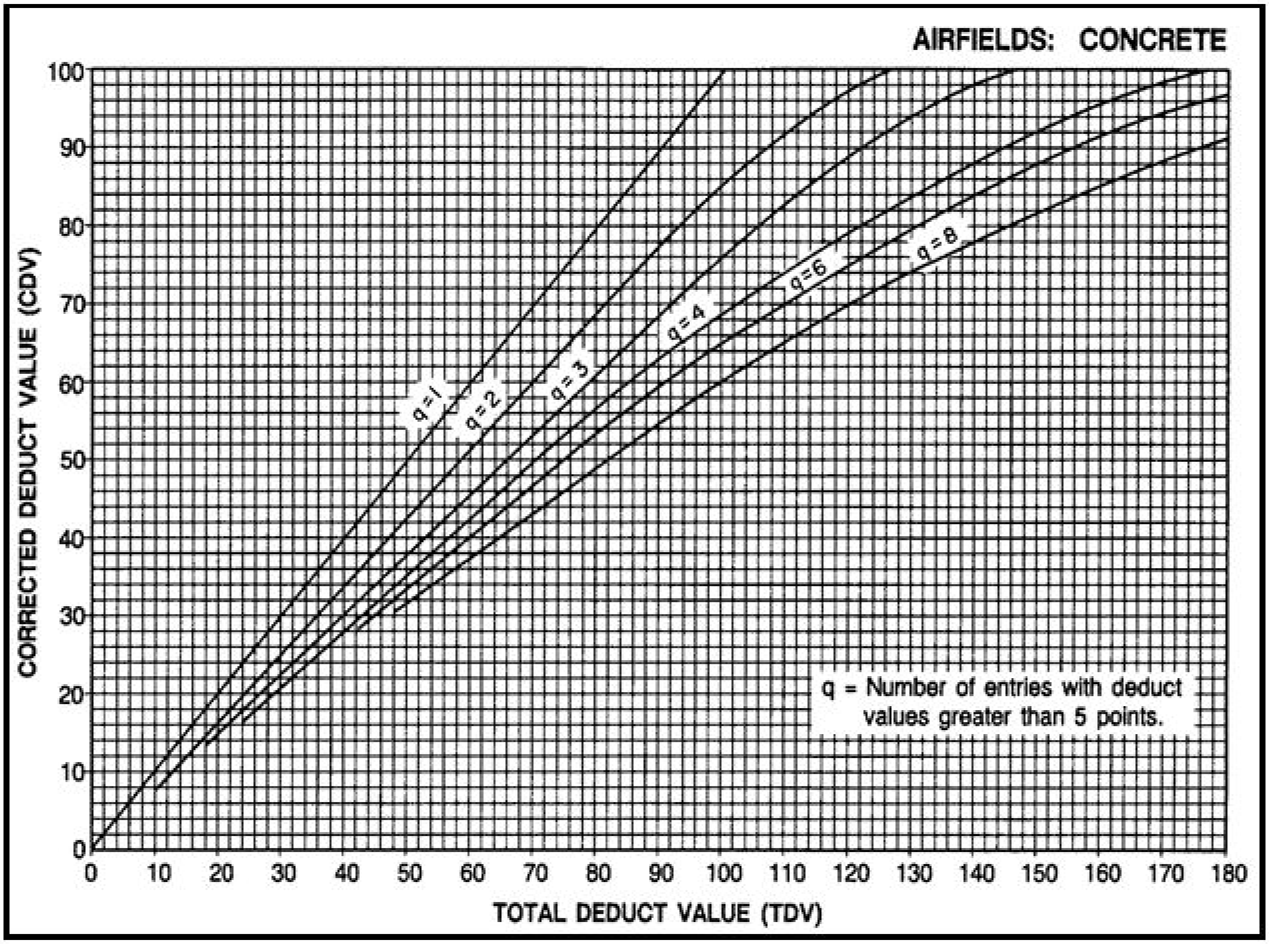


Figure D-17 Corrected Deduct Value Curves for Concrete



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APPENDIX E BLANK FORMS.

Figure E-1 Airfield Asphalt Pavement Condition Data Survey Sheet (Manual)

AIRFIELD ASPHALT PAVEMENT CONDITION SURVEY DATA SHEET (MANUAL)		SKETCH:
SURVEYED BY	SAMPLE UNIT	
SECTION	SAMPLE AREA	

41. Alligator Cracking (Area) {1}	45. Depression (Area) {5}	49. Oil Spillage (Area) {9}	53. Rutting (Area) {13}	57. Weathering (Area) {17}
42. Bleeding (Area) {2}	46. Jet Blast (Area) {6}	50. Patching (Area) {10}	54. Shoving From PCC (Area) {14}	
43. Block Cracking (Area) {3}	47. JT. Reflection (PCC) (Length) {7}	51. Polished Aggregate (Area) {11}	55. Slippage Cracking (Area) {15}	
44. Corrugation (Area) {4}	48. Long. & Trans. Cracking (Length) {8}	52. Raveling (Area) {12}	56. Swell (Area) {16}	

DISTRESS SEVERITY	Quantity (Area or Length) [ ] Metric [ ] English								TOTAL	DENSITY %	DEDUCT Value

Figure E-2 Airfield Concrete Pavement Condition Data Survey Sheet (Manual)

AIRFIELD CONCRETE (PCC) PAVEMENT CONDITION SURVEY DATA SHEET (MANUAL)
FOR SAMPLE UNIT

BRANCH	SECTION	SAMPLE UNIT
SURVEYED BY	DATE	SAMPLE AREA (Number of Slabs)

Distress Types

61. Blowup {1}	69. Pumping {9}
62. Corner Break {2}	70. Scaling {10}
63. Cracks {3}	71. Settlement/Faulting {11}
64. Durability Cracking {4}	72. Shattered Slab {12}
65. Joint Seal Damage {5}	73. Shrinkage Cracks {13}
66. Patching, Small < 0.5 m (< 5 ft) {6}	74. Spalling, Joints {14}
67. Patching, Large/ Utility Cut {7}	75. Spalling, Corner {15}
68. Popouts {8}	76. ASR {16}

DISTRESS TYPE	SEVERITY	NUMBER of SLABS	DENSITY %	DEDUCT VALUE

SKETCH:

Figure E-3 AC Airfield Pavement Condition Survey Data Sheet (Automated)

AC Airfield Pavement Condition Survey Data Sheet (Automated)			
PID		INSPECTOR NAME	
FROM		BRANCH USE	DATE INSPECTED
TO		SECTION WIDTH	SECTION LENGTH

AC Surfaced Distress Codes			
41. Alligator Cracking {1}	46. Jet Blast {6}	51. Polished Aggregate {11}	56. Swell {16}
42. Bleeding {2}	47. JT. Reflection (PCC) {7}	52. Raveling {12}	57. Weathering {17}
43. Block Cracking {3}	48. Long. & Trans. Cracking {8}	53. Rutting {13}	
44. Corrugation {4}	49. Oil Spillage {9}	54. Shoving From PCC {14}	
45. Depression {5}	50. Patching {10}	55. Slippage Cracking {15}	

SAMPLE NUMBER		SAMPLE AREA		SKETCH/COMMENTS
DISTRESS CODE	L	M	H	

Figure E-4 PCC Airfield Pavement Condition Survey Data Sheet (Automated)

AC Airfield Pavement Condition Survey Data Sheet (Automated)			
PID		INSPECTOR NAME	
FROM		BRANCH USE	DATE INSPECTED
TO		SECTION WIDTH	SECTION LENGTH
AC Surfaced Distress Codes			
41. Alligator Cracking {1}	46. Jet Blast {6}	51. Polished Aggregate {11}	56. Swell {16}
42. Bleeding {2}	47. JT. Reflection (PCC) {7}	52. Raveling {12}	57. Weathering {17}
43. Block Cracking {3}	48. Long. & Trans. Cracking {8}	53. Rutting {13}	
44. Corrugation {4}	49. Oil Spillage {9}	54. Shoving From PCC {14}	
45. Depression {5}	50. Patching {10}	55. Slippage Cracking {15}	

SAMPLE NUMBER		SAMPLE AREA		SKETCH/COMMENTS
DISTRESS CODE	L	M	H	

Figure E-5 PCI Calculation Form

<table>
<tr><td colspan="14">PCI CALCULATION FORM</td></tr>
<tr><td colspan="3">BRANCH</td><td colspan="5">SECTION</td><td colspan="6">SAMPLE UNIT</td></tr>
<tr><td colspan="3">CALCULATED BY</td><td colspan="5">DATE</td><td colspan="6"></td></tr>
<tr><td colspan="14">Adjustment of the Number of Deduct Values (1 Minimum, 10 Maximum):</td></tr>
<tr><td>ITERATION NUMBER</td><td colspan="10">DEDUCT VALUES (Arrange Values from Highest Value to Lowest Value)
* Do not list more values than the Adjustment Number of Deduct Values (round to the next higher integer if a fraction/decimal)
** The last (lowest) value listed may be a fraction of one of the DEDUCT VALUES in the Condition Survey Data Sheet</td><td>DEDUCT TOTAL</td><td>Number of Deduct Values Greater than (but not equal to) 5.0
q</td><td>Corrected Deduct Value
CDV</td></tr>
<tr><td>1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td>10</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="13">MAXIMUM CDV =</td><td></td></tr>
<tr><td colspan="13">Corrected Pavement Condition Index (PCI) = 100 - MAXIMUM CDV =</td><td></td></tr>
</table>

Figure E-6 Section/Branch Report Form

Section/Branch Report									
Branch	Section	Section Location	Section Size	Type Pavement	# Sample Units	Sample Units Inspected*	Sample Unit PCI	weighted average PCI	PCR

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APPENDIX F GLOSSARY

F-1 ACRONYMS.

AC	asphalt concrete
ASR	alkali-silica reaction
CDV	corrected deduct value
DOD	Department of Defense
FOD	foreign object damage
ft	foot
ft^2	square foot
HDV	highest deduct value
in.	inch
L&T	longitudinal and transverse
m^2	square meter
mm	millimeter
PCC	portland cement concrete
PCI	pavement condition index
PFC	porous friction course
UFC	Unified Facilities Criteria

F-2 DEFINITIONS OF TERMS

Additional sample — a sample unit inspected in addition to the random sample units to include non-representative sample units in the determination of the pavement condition. This includes very poor or excellent samples that are not typical of the section and sample units that contain an unusual distress such as a utility cut, oil spillage, or jet blast. If a sample unit containing an unusual distress is chosen at random, it should be counted as an additional sample unit and another random sample unit should be chosen. If every sample unit is surveyed then there are no additional sample units.

Asphalt concrete (AC) surface — aggregate mixture with an asphalt cement binder. This term also refers to surfaces constructed of coal tars and natural tars for purposes of this test method. Sometimes referred to as a flexible pavement.

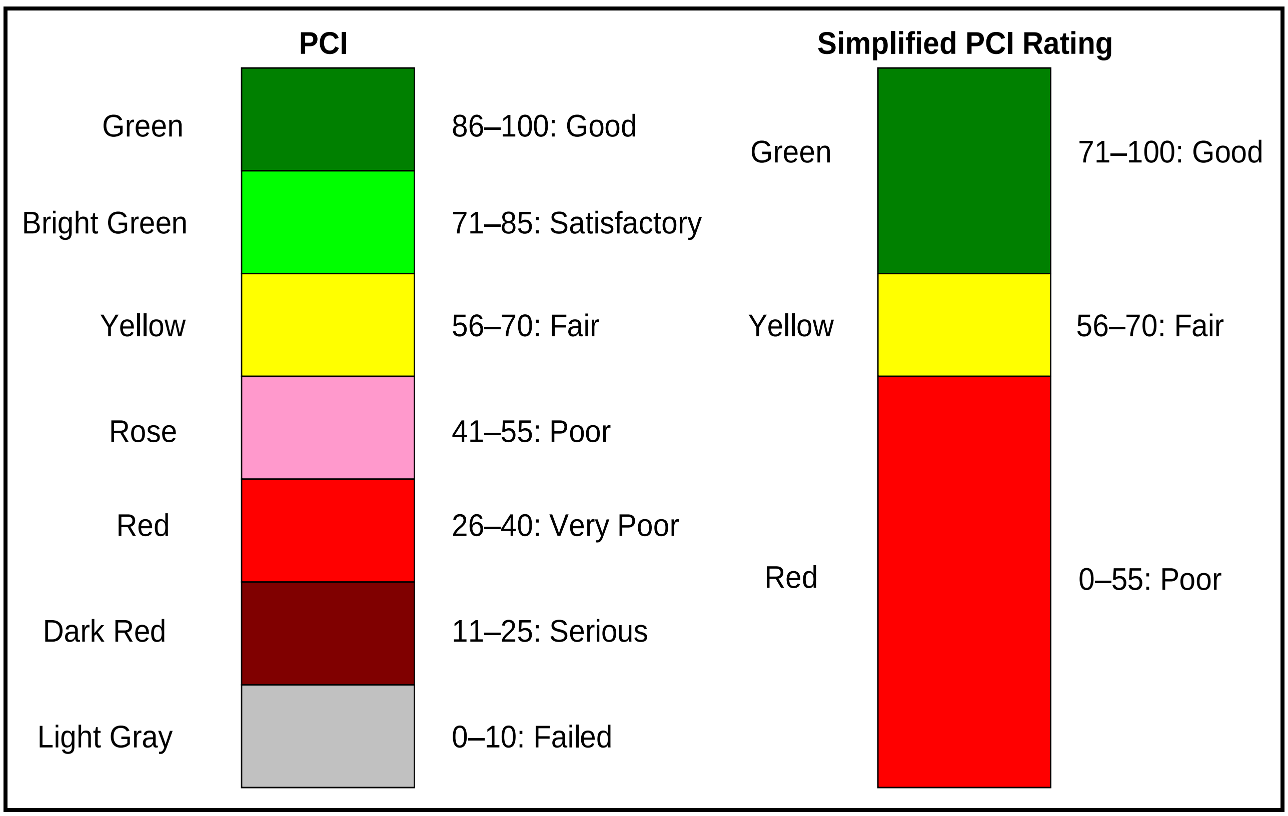
Deduct value (DV) — a number from 0 to 100, with 0 indicating the distress has no impact on pavement condition and 100 indicating an extremely serious distress that causes the pavement to fail.

Pavement branch — a branch is an identifiable part of the pavement network that is a single entity and has a distinct function. For example, each runway or taxiway is a separate branch.

Pavement condition index (PCI) — a numerical rating of the pavement condition that ranges from 0 to 100 with 0 being the worst possible condition and 100 being the best possible condition.

Pavement condition rating (PCR) — a verbal description of pavement condition as a function of the PCI value. This AEP establishes a standard color code for the seven condition codes developed by DOD and also for a corresponding simplified PCI rating system of Good (PCI = 71 to 100), Fair (PCI = 56 to 70), and Poor (PCI = 0 to 55), as depicted in Figure F-1. This system was adopted by and is also described in ASTM D5340.

Figure F-1 Pavement Condition Index (PCI) and Simplified PCI Rating Scales



Pavement distress — external indicators of pavement deterioration caused by loading, environmental factors, construction deficiencies, or a combination thereof. Typical distresses are cracks, rutting, and weathering of the pavement surface. Distress types and severity levels detailed in Appendix A for AC and Appendix B for PCC pavements must be used to obtain an accurate PCI value.

Pavement sample unit — a subdivision of a pavement section that has a standard size range: 20 slabs (±8 slabs if the total number of slabs in the section is not evenly divided by 20, or to accommodate specific field condition) for PCC pavement, and contiguous 5000 square feet ± 2000 square feet (465 square meters ± 185 square meters) if the pavement is not evenly divided by 5000 (or to accommodate specific field condition) for AC pavement.

Pavement section — a pavement area having uniform construction, maintenance, usage history, and condition. A section should have the same traffic volume and load intensity.

Portland cement concrete (PCC) pavement — aggregate mixture with portland cement binder including non-reinforced and reinforced jointed pavement. Sometimes referred to as a rigid pavement.

Random sample — a sample unit of the pavement section selected for inspection by random sampling techniques such as a random number table or systematic random procedure.

Primary Pavement — mission-essential pavements such as runways, parallel taxiways, main parking aprons, arm-disarm pads, alert aircraft pavements, turnabouts (hammer heads), and overruns (when the overrun is used as a taxiway or for takeoff roll). In general, only pavements that have aircraft use on a daily basis or frequently used transient taxiways and parking areas are considered primary.

Secondary Pavement — mission-essential but occasional-use airfield pavements, including ladder taxiways, infrequently used transient taxiway and parking areas, overflow parking areas, and overruns (when there is an aircraft arresting system present). In general, any pavements that do not have daily use by aircraft are secondary.

Tertiary Pavement — includes pavements used by towed or light aircraft, such as maintenance hangar access aprons, wash racks, overruns (when not used as a taxiway or to test aircraft arresting gear), and paved shoulders. In general, any pavement that does not support aircraft taxiing under their own power, areas where jet blast is limited, or is used only intermittently by aircraft is considered a tertiary pavement.

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APPENDIX G REFERENCES

DEPARTMENT OF DEFENSE

STANAG 7181 Ed. 1, *Standard Method for Airfield Pavement Condition Index (PCI) Surveys*, 2009, Executive Agent for the Defense Standardization Program Office, 8725 John J. Kingman Rd, Stop 5100, Fort Belvoir, VA, 22060-6220, http://www.assistdocs.com/

AIR FORCE

Development of a Pavement Maintenance Management System, Vol. I-V, 1976-1977, Shahin, M.Y., Darter, M.I., and Kohn, S.D., U.S. Air Force Engineering Services Center (AFESC), Tyndall AFB, Florida, www.dtic.mil

ASTM INTERNATIONAL

ASTM D5340, *Standard Test Method for Airport Pavement Condition Index Surveys*, https://www.astm.org/

UFC 3-260-17
22 May 2018
Change 1, 26 April 2023

UNIFIED FACILITIES CRITERIA (UFC)

O&M MANUAL: STANDARD PRACTICE FOR DUST CONTROL ON ROADS, AIRFIELDS, BASE CAMPS, AND ADJACENT AREAS

UNIFIED FACILITIES CRITERIA (UFC)

O&M MANUAL: STANDARD PRACTICE FOR DUST CONTROL ON ROADS, AIRFIELDS, BASE CAMPS, AND ADJACENT AREAS

U.S. ARMY CORPS OF ENGINEERS (Preparing Activity)

NAVAL FACILITIES ENGINEERING SYSTEMS COMMAND

AIR FORCE CIVIL ENGINEER CENTER

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

Change No.	**Date**	**Location**
1	26 April 2023	Paragraph 4-2.2; paragraph 4-2.11.2; paragraph 5-1.3; Appendix A, Army references; paragraph B-2.1; Table B-1; Table B-2

This UFC supersedes UFC 3-260-17, dated 16 January 2004, and Air Force ETL 09-3, dated 3 March 2009.

FOREWORD

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

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale should be sent to the respective service proponent office by the following electronic form: Criteria Change Request. The form is also accessible from the Internet sites listed below.

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

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

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

AUTHORIZED BY:

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Office of the Assistant Secretary of Defense
(Energy, Installations, and Environment)

UNIFIED FACILITIES CRITERIA (UFC)
REVISION SUMMARY SHEET

Document: UFC 3-260-17, *O&M Manual: Standard Practice for Dust Control on Roads, Airfields and Adjacent Areas*

Superseding: UFC 3-260-17, *Dust Control for Roads, Airfields and Adjacent Areas*, dated 16 January 2004, and Air Force ETL 09-3, *Chemical Dust Control for Contingency Roads, Base Camps, Helipads, and Airfields*, dated 3 March 2009.

Description: This UFC provides guidance for dust control materials and methods that are used successfully on roads, airfields, base camps, and areas adjacent to these structures to reduce airborne dust. This UFC applies to Army, Navy, and Air Force installations.

Reasons for Document:

The primary reason for the document update was to bring the document in compliance with UFC 1-300-01, *Criteria Format Standard*. A number of editorial changes were also needed to improve readability and correct typographical errors.

Impact:

Cost impact is negligible; improved guidance typically results in improved performance and reduced lifecycle cost.

Unification Issues:

None.

Disclaimer: Use of the name or mark of any specific manufacturer, commercial product, commodity, or service in this publication does not imply endorsement.

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FIGURES

TABLES

CHAPTER 1 INTRODUCTION

1-1 PURPOSE AND SCOPE.

This UFC provides guidance for dust control materials and methods used on roads, airfields, base camps, and areas adjacent to these structures to reduce airborne dust. Dust develops naturally in unpaved, denuded, or sparsely vegetated areas. Dust is created in unsurfaced areas subjected to concentrated foot or vehicular traffic and is a problem on shoulders of surfaced aircraft areas. Dust control improves health, safety, and wellness, limits increased costs associated with damage and maintenance on vehicles and other equipment, and minimizes dust signatures during military operations.

This UFC discusses dust control methods and materials that have proven effective to reduce dust; provides suggestions for rates and methods of application of materials for various soil types and environmental conditions; and discusses factors, such as availability, curing time, durability, logistics, and economics, which are significant in the ultimate choice of material. Agronomic, topical, and admixture methods are discussed; however, the primary focus is on dust palliatives. Appendix B addresses the specific problem of dune sands and how they may be partially controlled.

1-2 APPLICABILITY

This UFC applies to all military Service elements and contractors involved in the planning, design, construction, maintenance, repair, or preservation of DOD pavements worldwide. This UFC provides guidance for dust control materials and methods that are used successfully on roads, airfields, base camps, and areas adjacent to these structures to reduce airborne dust. This UFC outlines standard practices and will result in better oversight of work and help identify problem areas during application of the maintenance and repair (M&R) process.

1-3 REFERENCES.

Appendix A contains a list of references used in this UFC. The publication date of the code or standard is not included in this UFC. In general, the latest available issuance of the reference is used.

1-4 GLOSSARY.

Appendix C contains acronyms, abbreviations, and terms.

1-5 DEFINITION AND CAUSE.

The term “dust” is defined as particles of soil that have become airborne. Dust consists mainly of soil particles finer than 0.003 inch (0.074 millimeter) (i.e., passing the No. 200 sieve as described in ASTM E11). Dust is produced whenever the outside force(s) acting on a soil particle exceeds the force(s) holding it in place. Dust may occur naturally from the force of wind, although the production of dust is accelerated in areas of soil experiencing actual physical abrasion caused by the environment, vehicles, or activity. Dust is reduced by ground covers (such as grass, mulch, and geotextiles) that prevent wind forces from acting on the soil grains. Another mechanism is by adhesion between fine soil grains due to surface tension from liquids (such as water) or a physical bonding agent (such as portland cement). Agglomeration of fines increases the effective particle size, limiting the ability to become airborne. Other terms unique to this UFC are listed and defined in the following paragraphs.

1-5.1 Traffic Areas.

Traffic areas include roadways and vehicle parking areas; walkways; open storage areas; construction sites; runways, taxiways, shoulders, overruns, and parking areas of airfields and heliports; and tank trails.

1-5.2 Non-Traffic Areas.

Non-traffic areas include graded construction areas prior to turfing; graded construction areas that remain dormant for an extended period of time; denuded areas around the periphery of completed construction projects; areas bordering all airfield or heliport complexes; protective petroleum, oil, and lubricant (POL) dikes; magazine embankments of ammunition storage barricades; bunkers and revetments; cantonment, warehouse, storage, and housing areas, excluding walkways and roadways; unimproved grounds; and areas experiencing windborne sand (see Appendix B).

1-5.3 Occasional-Traffic Areas.

Occasional-traffic areas include shoulders and overruns of airfields used by propeller or jet aircraft; shoulders, hover lanes, and peripheral areas of heliports and helipads; and non-traffic areas where occasional traffic becomes necessary.

1-5.4 Dust Palliative.

A dust palliative is a material applied to soil to prevent soil particles from becoming airborne. Other terms used to indicate a dust control material include dustproofer, soil stabilizer, soil waterproofer, and dust control agent.

1-5.5 Pre-Wet.

Pre-wetting is the initial application of water on a soil surface prior to applying a liquid surface penetrant. This action primes the soil, improving the penetration and coverage of water-based palliatives.

CHAPTER 2 FACTORS FOR CONSIDERATION

2-1 GENERAL.

A wide selection of dust palliatives for dust control is available to the engineer; however, no one material is singled out as being the most acceptable for all situations. The successful control of dust and erosion in an area depends on several factors, the most important of which are:

- Influencing factors
- Environmental factors
- Expected traffic
- Topography
- Soil type
- Soil surface feature(s)
- Climate

2-2 FACTORS INFLUENCING DUST.

The presence of dust-size particles in a soil does not indicate a dust problem or severity of the dust problem that results in various situations. Many factors contribute to the formation, severity, and endurance of dust, including soil texture and structure, soil moisture content, soil density, presence of salts or organic matter in the soil, smoothness of the ground surface, vegetative cover, wind velocity and direction, and humidity. Depending on these factors, an external force imposed on a ground surface generates volumes of dust of varying density, size, and height above ground which are referred to as dust clouds. Figure 2-1 shows three typical dust clouds rising from military vehicles. Dust clouds are generated by drafts of moving air from windstorms, aircraft engines, or ground vehicles, which not only produce drafts of moving air but also abrade the soil surface.

2-3 ENVIRONMENTAL FACTORS.

For the selection and use of control methods and dust palliatives, consider applicable local safety, health, and environmental requirements. In the United States, material compliance with existing Environmental Protection Agency (EPA) rules and regulations is required.

Figure 2-1 Three Examples of Typical Dust Clouds

2-4 EXPECTED TRAFFIC.

The areas requiring treatment are divided according to the amount of traffic expected: those with no traffic, with occasional traffic, and with channelized traffic (i.e., roadway or taxiway). Where the extent of traffic is predicted or regulated, savings in time and material(s) is realized by adjusting the type and amount of treatment an area receives according to use.

2-4.1 Non-Traffic Areas.

These areas require treatment to withstand the effects of airblast due to wind or nearby vehicle operations and are not subjected to actual traffic of any kind. If traffic is applied, the treated area typically is damaged and repairs are required. In the majority of cases, establishing vegetative ground cover is the best solution for long-term dust and erosion control. However, for the short term, intermittent dust control is needed following construction or other activities that disturb the soil.

2-4.2 Occasional-Traffic Areas.

Besides resisting wind, helicopter rotor downwash, aircraft propwash, and airblast from jet engines, these areas also are subjected to occasional traffic by vehicles, aircraft, or personnel. Treatment for jet airblast is more involved than that required for helicopter and aircraft propellers; however, treatment for either is adequate to support occasional, non-channelized, vehicular traffic. If traffic conditions change and multiple passes or repeated crossings along the same path occur, the treated area has the potential to be damaged and repairs required. As with non-traffic areas, establishing vegetative ground cover is the best solution for long-term dust and erosion control.

2-4.3 Traffic Areas.

These areas require treatment to withstand regular channelized traffic by vehicles, aircraft, or personnel. Areas treated to withstand regular channelized traffic typically withstand airblast from aircraft and helicopters when applicable.

Perform an economic analysis of the cost to maintain an unsurfaced road versus the costs associated with a paved surface road on a case-by-case basis. Give consideration to the amount of maintenance required, level of traffic, ease of construction, and local costs. Where these areas are considered permanent, treat as specified in existing guidance publications.

2-5 TOPOGRAPHY.

2-5.1 Distinction Between Flat and Hillside Areas.

Consider the overall topography of the area as either flat or hillside. “Flat” is defined as an average ground surface slope of 5 percent or less while “hillside” refers to an average ground surface slope steeper than 5 percent. Place emphasis on the fact that the entire topography of the area to be treated is considered and not specific spot areas. Spot areas are given special attention as needed.

2-5.2 Dust Control for Flat and Hillside Areas.

Dust control depends on the type of traffic expected, etc.; however, the final dust palliative selected is affected by the slope. Liquid dust palliatives flow instead of penetrate on sloped surfaces. Tilling the dust palliatives, either liquid or powder, is recommended on hillside surfaces.

2-6 SOIL TYPE.

The soil type is one of the key features used to determine which method and material is used for dust control. Soils to be treated for dust control have been placed in five general descriptive groupings based on the Unified Soil Classification System (USCS) (see ASTM D2487).

- G = Gravel
- S = Sand
- M = Silt
- C = Clay
- O = Organic

2-6.2 Silts or Clays (High Liquid Limit).

The relatively impervious, plastic, fine-grained soils encompass USCS types CH, OH, and MH.

2-6.3 Silts or Clays (Low Liquid Limit).

The moderately permeable, low- to medium-plasticity, fine-grained soils encompass USCS types ML, CL, ML-CL, and OL.

2-6.4 Sands or Gravels (With Fines).

The moderately permeable, coarse-grained soils contain an appreciable amount of fines, encompassing USCS types SM, SC, SM-SC, GM, GC, GM-GC, and GW-GM.

2-6.5 Sands (With Little or No Fines).

The highly permeable sands or gravelly sands contain little or no fines, encompassing USCS types SW-SM, SP, and SW.

2-6.6 Gravels (With Little or No Fines).

The highly permeable gravels or sandy gravels contain little or no fines, encompassing USCS types GP and GW.

2-7 SOIL SURFACE FEATURES.

Soil surface features refer to both the state of compaction and degree of saturation of the soil in the area being considered.

2-7.1 Loose and Dry or Slightly Damp.

The surface consists of a cover, 0.25 to 2 inches (6 to 51 millimeters) thick, of unbound or uncompacted soil overlying a relatively firm subgrade and ranging in moisture content from dry to slightly damp. This surface is acceptable for treatment where no traffic or only occasional traffic is expected.

2-7.2 Loose and Wet or Slurry.

A surface condition consists of a cover, 0.25 to 2 inches (6 to 51 millimeters) thick, of unbound or uncompacted soil overlying a soft to firm subgrade and ranging in moisture content from wet to slurry consistency. Soil in this state cannot be treated until it is dried to the condition defined in either paragraph 2-7.1 or paragraph 2-7.3.

2-7.3 Firm and Dry or Slightly Damp.

The surface condition consists of a less than 0.25-inch (6-millimeter) -thick layer of loose soil, ranging in moisture content from dry to slightly damp, overlying a bound or compacted firm soil subgrade. This surface is acceptable for treatment for dust control regardless of the expected traffic.

2-7.4 Firm and Wet.

This surface condition is similar to that defined in paragraph 2-7.3 but has a wet surface. Soil in this condition cannot be treated until it is dried to the condition defined in paragraph 2-7.3.

2-8 CLIMATE.

2-8.1 Adverse Effects.

The climate in the area where dust control is desired could adversely affect the dust palliative(s) during storage (prior to placement), during placement (the construction and/or cure period), and after placement. The climate at the time of placement and after placement is considered when selecting a palliative. Agronomic methods are initiated at the onset of the growing season, which in some cases is limited to a few weeks.

2-8.2 Weather Extremes.

Weather extremes accelerate the aging and/or deterioration of most materials, and dust palliatives are no exception. Salts become ineffective during extended periods of no rainfall and when the relative humidity falls below 30 percent. Other palliatives (e.g., salts, polysaccharides) may leach from the soil during rain.

2-8.3 Freezing Effects.

Store, place, and permit liquid dust palliatives to cure at temperatures above 40 degrees Fahrenheit (4.4 degrees Celsius). Water-based palliatives (e.g., emulsions) are subject to freezing, which has detrimental effects on the physical properties, performance, and placement equipment. Some dust palliatives become brittle when exposed to extreme cold; therefore, do not traffic (if possible).

2-8.4 Storage of Liquids.

Storage of liquids may result in the settling of some components in the liquid. Mix concentrated liquid stabilizers by recirculating or mechanically stirring the material within the container. At temperatures above 90 degrees Fahrenheit (32.2 degrees Celsius), some bituminous products become tacky. Emulsions stored in containers in the sun can dry to a film in the headspace above the liquid. Once dried, the film does not re-disperse in the liquid. If the film dislodges into the liquid, it clogs spray nozzles, causing significant problems if proper filtering is not employed.

CHAPTER 3 DUST CONTROL METHODS

3-1 GENERAL.

This chapter describes three readily available types of dust control methods and the type of traffic areas where a dust palliative is applicable. Each dust control method is considered in relation to the specific job requirements. The dust control treatment methods commonly used are:

- Agronomic
- Topical application
- Admixtures

The agronomic method requires knowledge of the indigenous vegetation and access to farm-type equipment. Topical applications are the easiest to apply. Topical application requires a material placement procedure (i.e., spreading aggregate or geotextile over the area) or a material-spraying procedure. One of these two methods suffices for the majority of dust control cases. The admixture method requires standard road-building techniques using construction equipment. The agronomic and admixture methods are more complex and require more time and equipment to implement. These methods require specific handling, equipment, and procedures. When using any chemicals, adhere to the manufacturer's precautions for the use of personal protective equipment (e.g., masks, safety glasses, gloves) as required.

3-2 AGRONOMIC METHODS.

This method consists of establishing or extending and preserving vegetative cover, mulch, windbreaks, and rough tillage. It includes tasks such as seeding, sprigging, sodding, adding topsoil, fertilizing, mulching, and disking. Agronomic methods are not prescribed for traffic areas. Large areas are cleared for most construction projects, stripping the project area of the existing vegetation and all topsoil. Keep the extent of stripping to a minimum and the stripped topsoil with vegetative residue stockpiled for later use.

3-2.1 Vegetative Cover.

Vegetative cover is considered the most satisfactory form of dust palliative based on aesthetic aspects, durability, cost, and maintenance. This is the preferred method wherever it can be economically established and maintained. Areas of application are best limited to nontraffic areas. Where vegetative cover is to be ultimately established, select any dust palliative used for immediate surface protection with a view to minimize impairment to subsequent plant growth. While dense vegetation is certainly the most effective cover, more sparse native vegetation typical of semiarid and arid regions is a fully effective dust palliative under natural wind conditions so long as it is not damaged by traffic or other causes.

3-2.2 Mulch.

Use mulch only for non-aircraft applications due to the potential for damage to aircraft. A well-anchored mulch of vegetative material is used to stabilize soil against wind and water erosion in low- or non-traffic areas. Mulch refers to any substance, such as straw, hay, or other vegetative material, which is spread over the ground surface to protect it from the wind. Vegetative mulches are effective for one year and applied during any season.

Hydroseeds and hydromulches/fibrous mulches (blends of water, organic fibers, fertilizer, seed, and adhesive) are common and effective materials used for establishing vegetation. Bonded fiber matrix is a specialized method of hydroseeding that is hydraulically applied. A hydroseeder equipped with a spraying mechanism is used to place hydroseeds and hydromulches.

3-2.3 Windbreaks.

Any barrier of hedges, shrubs, or trees high and dense enough to protect facilities and unsurfaced soil areas is considered to be a windbreak. Windbreaks are placed at right angles to the direction of the prevailing wind. Several parallel windbreaks are required for high wind velocities; the higher the average wind velocity, the closer they are spaced. Their practical applicability solely for dust control is limited. Windbreaks supplement other dust control measures by reducing wind velocity. The use of windbreaks is recommended wherever they do not interfere with intended area activities.

3-2.4 Rough Tillage.

Chisels and turning plows are used to till strips across non-traffic areas that are sources of dust. Several strips are placed in parallel as an emergency measure to control dust in semiarid regions. Ensure the soil is cohesive enough to produce soil clods (lumps of earth with a minimum dimension of 1 inch [25 millimeters] measured in any direction). Strips are tilled at 25- to 100-foot (7.6- to 30.5-meter) intervals at right angles to the prevailing wind. As the strips become smooth through erosion, new strips are plowed adjacent to the earlier ones. The success of this method depends upon the formation of a cloddy, rough surface that breaks up the sweep of soil particles. Tillage of dry soil typical of desert areas is sometimes harmful rather than beneficial to dust control if a cloddy surface is not produced. Rough tillage is considered a temporary control measure to be followed by permanent vegetative cover, but it is sufficient as the only treatment if traffic is excluded from the area and the existing vegetation is capable of regeneration. Disk-type tillage tools are not used for rough tillage as they tend to pulverize the soil (i.e., soil clods are not formed). However, if long, narrow grooves are created, resulting in channelized runoff water, lay out the tillage on horizontal contours to prevent water damage.

3-3 TOPICAL APPLICATIONS.

3-3.1 Surface Penetration.

In the surface penetration method, a liquid dust palliative is applied directly on the soil surface by spraying or sprinkling and allowed to penetrate and/or seal the surface. This is the most common method of dust control due to the lower cost and ease of application compared to the admixture method. This method provides satisfactory—although temporary—dust abatement when significant penetration of the surface is achieved. However, if proper penetration is not achieved, a thin surface crust results, which is easily disturbed by traffic, allowing the underlying material to produce dust. Surface crusts are also more detrimental to aircraft than the dust itself, as larger particles and sheets of material become dislodged under airblast, presenting serious foreign object debris (FOD) potential. This is a concern in sandy and/or unprepared soils. A penetration depth of at least 1 inch (25 millimeters) is recommended for polymer emulsion products to minimize FOD potential. This recommendation is extended to all types of liquid dust palliatives applied topically.

Surface penetration applications are placed with a liquid pressure distributor, by a gravity-flow water distributor, or by hand-held devices. Position the spray apparatus 8 to 14 inches (203 to 355 millimeters) directly above the area being treated to preclude winddrift. Runoff is avoided by decreasing the application rate or applying the dust palliative at one-half the manufacturer's recommended rate and repeating the treatment before curing of the palliative begins.

3-3.1.1 Effectiveness.

The effectiveness of the surface penetration method depends on the depth of penetration, which is a function of the viscosity, surface tension of the liquid, and the permeability of the soil. This is a problem on compacted soils typical of most roads and airfields. Numerous products are designed with low viscosities, surfactants, and other surface-tension-reducing additives to improve penetration. For water-based palliatives, penetration is facilitated by lightly pre-wetting the surface with water before applying the dust palliative. This procedure reduces surface tension, which improves penetration and helps assure uniform coverage. Rapid-setting emulsions are particularly susceptible to forming surface crusts and are more suitable for the admixture method. Humectants require contact with air, having a relative humidity above 30 percent to absorb moisture into the soil; thus, they are well-suited for topical applications.

Surface penetrants require reapplication as they leach during rainfall, penetrate further into the soil over time, age, and wear from traffic. Reapplication rates vary between locations due to soil type, climate, rainfall, and traffic.

Surface penetration is well-suited for non-traffic areas and is temporarily effective for heavy or occasional traffic areas, provided the soil has adequate strength or has been conditioned for the stated use.

3-3.1.2 Types of Materials.

Types of materials used as surface penetrants:

- Humectants (calcium and magnesium salts, organic humectants)
- Petroleum products
- Polymer emulsions
- Synthetic fluids
- Plant resins (binders and natural oils)
- Biopolymers and polysaccharides

3-3.2 Surface Cover.

This method includes the use of aggregates, mats (i.e., AM-2 landing mat), or geotextiles (membranes or meshes) to create a surface cover or membrane for dust control. Geosynthetics/geotextiles and mats require extensive anchoring to be used around aircraft. Standard construction equipment is used effectively to place any of the systems applicable to the surface cover method.

In arid areas where most vegetative covers do not survive because of low rainfall, crushed or uncrushed gravel, slag, or tone aggregate (2 inches [51 millimeters] maximum size) is used as a dust palliative on nontraffic or occasional traffic areas. Aggregate is not recommended in close proximity to aircraft traffic because gravel particles can potentially be picked up and thrown by airblast, with possible damage to aircraft and ground personnel. Spread aggregate in a layer 2 inches (51 millimeters) thick and ensure it contains a minimum 80 percent by weight of particles retained on the 1.25-inch (32-millimeter) screen. Traffic over aggregate-covered areas presses the material into the soil and pulverizes the surface; therefore, this treatment is not recommended where channelized traffic is expected.

3-3.2.1 Effectiveness.

The surface cover method is applicable to nontraffic, occasional traffic, and heavy traffic areas, provided the soil has adequate strength or has been conditioned for the stated use. Aggregate and geotextiles are easy to place and withstand considerable rutting. Once a surface cover treatment is torn or otherwise compromised and the soil exposed, subsequent traffic or airblast increases the damage to the exposed soil. Begin repairs (maintenance) as soon as possible to protect the material in place and keep the dust controlled.

3-4 ADMIXTURE METHOD.

In the admixture method, the dust palliative is blended with the soil to produce a uniform mixture. This method takes more effort, time, and equipment than the penetration and surface cover methods; however, it also increases soil strength and improves performance of the additives. An admixture method is used when it is necessary to improve the soil and provide dust control. Emulsions and powdered additives are well-suited for the admixture method.

For in-place mixing, the surface soil is graded and loosened (if necessary) to a depth 1 to 2 inches (25 to 51 millimeters) greater than the design thickness of the treated layer. The dust palliative is added and blended with the loosened surface soil and the mixture is compacted. Powders may be spread by hand, by bag, or by a mechanical spreader; apply liquids with spray devices. The recommended mixing equipment includes rotary tillers and reclaimer-stabilizers. A grader, when used, is slow and inefficient at blending the additive with the soil. Ensure blending results in a uniform color of soil, both horizontally and vertically. Use compaction equipment and procedures for in-place mixing uses and soil-stabilization procedures (see UFC 3-250-11) for changing soil characteristics and soil strength used in road construction. For dust control on a nontraffic area, compaction is achieved by trafficking the entire surface with a 5-ton dual-wheel truck.

3-4.1 Depth of Treatment.

A minimum treatment of 3 inches (76 millimeters) is satisfactory for all nontraffic areas. To provide a dustproof surface in traffic areas, a minimum treatment depth of 4 inches (102 millimeters) is required. Mixing is accomplished in-place or offsite and is adaptable to a large variety of soil types. (The admixture method is not suitable for areas where a vegetative cover is to be established.)

3-4.2 Offsite Mixing.

Offsite mixing is used where in-place mixing is not desirable and/or soil from another source is needed to meet design requirements. Offsite mixing is accomplished with a stationary mixing plant or by windrow mixing with graders in a central working area. Processing the soil and dust palliative through a central plant produces a more uniform mixture than in-place mixing. The disadvantage in any offsite operation is having to transport and spread the mixed material.

3-4.3 Effectiveness.

The admixture method is effective for dust palliatives that provide increased soil strength, such as portland cement, asphalt and polymer emulsions, natural resins, and synthetic fluids (with binder).

3-4.4 Pertinent Areas.

The admixture method is applicable to nontraffic and occasional-traffic areas but is limited for traffic areas due to costs and manpower associated with construction.

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CHAPTER 4 DUST PALLIATIVES

4-1 GENERAL.

4-1.1 Dust Palliative Categories.

This section describes the different categories of chemical dust palliatives. The objective of a dust palliative is to prevent soil particles from becoming airborne. Dust palliatives are required for controlling dust on nontraffic or traffic areas, or both. For nontraffic areas, a palliative is needed that resists the maximum intensity of air impingement caused by weather or nearby aircraft. For traffic areas, ensure dust palliatives withstand the abrasion of wheels, tracks, or airblast. Although a dust palliative provides resistance against air impingement, it is unsuitable as a wearing surface. An important factor limiting the applicability of a dust palliative in traffic areas is the extent of surface rutting that occurs under traffic. Rutting occurs if the bearing capacity of the soil is such that the soil surface depresses or compacts as a result of vehicle traffic. The effectiveness of a dust palliative treatment is destroyed by rutting and abrasion and any remaining dust palliative is quickly stripped from the ground surface. Some palliatives tolerate deformations better than others, but ruts 1 inch (25 millimeters) or greater result in the destruction of any treatment method.

4-1.2 Hard or Soft Crust.

Dust palliatives either form a hard crust or soft crust on the soil surface. There are advantages and disadvantages to both types of crusts. Hard crust palliatives cause soil particles to form brittle physical bonds, which is stable, but apply the product so there is sufficient penetration (2 to 3 inches [51 to 76 millimeters]) to prevent punctures of the crust during traffic. A soft crust palliative coats the soil particles but does not create a brittle crust, which is advantageous in that punctures caused by traffic do not create loose pieces.

4-1.3 Waterproofing Soils.

Often, a dust palliative also functions to waterproof the soil. When this occurs, the dust palliative not only prevents dust but also helps preserve soil strength during wet weather conditions. Ensure dust palliatives are not harmful to existing vegetation and/or make it difficult to establish vegetation in treated areas.

4-1.4 Materials General Overview.

The descriptions of materials in this chapter are intended to provide an overview of the various categories of products commercially available. There are numerous manufacturers of dust palliatives and some products do not fall clearly into the listed category. The guidelines given for use in this UFC are general for that category. Follow manufacturers’ suggested guidance where there are differences.

4-2 DETAILED DUST PALLIATIVE DESCRIPTION.

4-2.1 Water.

Water sprinkled on the soil surface is a temporary measure for reducing dust. As long as the ground surface remains moist or damp, soil particles resist becoming airborne. Depending on the soil and climate, frequent treatment may be required. Do not apply water to clay soil surfaces in such quantity that puddles form, since a muddy or slippery surface results where the soil remains wet.

4-2.2 Chloride Salts.

Salts (sodium, calcium, and magnesium chloride) are used extensively as dust palliatives due to their low cost. These salts are purchased as a powder, pellet, flake, or water solution. They absorb moisture from the air (deliquescence) or from dew and rainfall (hygroscopic), holding it in the soil. Calcium and magnesium chlorides are used more frequently than sodium chloride and retain soil moisture when the relative humidity is 30 percent or greater. A secondary effect of chlorides is a weak cement action when dry due to crystallization. All chlorides are soluble in water and leach from the soil surface over time, depending on the soil permeability and amount of rainfall; thus, maintenance is eventually required. Continued applications of salt solutions ultimately build up a thin, crusted surface that is hard and free of dust. **1**\ Do not use chloride salts within 25 feet (7.6 meters) of airfield pavements subject to aircraft traffic to reduce the possibility of corrosion to aircraft and airfield metals. /**1**/ Calcium chloride and magnesium chloride require relative humidity levels to be a minimum of 30 percent for adequate results. Sodium chloride requires humidity levels greater than 50 percent and is much less frequently used. Ensure the dust palliative selected and the quantity used meets manufacturer’s instructions and does not exceed local environmental protection regulations.

4-2.3 Petroleum Products.

4-2.3.1 Asphalt Emulsions.

Emulsified asphalts are a bituminous product used for dust control. Emulsified asphalts provide dust mitigation by binding surface particles and are used to treat both traffic and nontraffic areas. Bituminous materials impart waterproofing to the treated area that remains effective as long as the treatment remains intact but are sensitive to weather extremes. Do not place emulsions in the rain or when rain is expected.

Asphalt emulsions are a blend of asphalt, water, and an emulsifying agent, and are available either as anionic or cationic emulsions. Ambient temperature, relative humidity, and wind speed affect the rate at which emulsions cure. Do not place emulsions at temperatures below 50 degrees Fahrenheit (10 degrees Celsius). Heating emulsions reduces curing time. Never exceed the upper heating limit of 185 degrees Fahrenheit (85 degrees Celsius) because the asphalt and water separates (breaks), resulting in material damage. Under favorable ground temperature and weather conditions, emulsions are sufficiently cured in eight hours. The slow-setting (SS) anionic emulsions of grades SS-1 and SS-1h are diluted with one to five or more parts water to one part emulsified asphalt by volume prior to use. A three-parts-water-to-one-part-emulsion dilution meets most manufacturers' recommendations. The cationic slow-setting (CSS) emulsions of grades CSS-1 and CSS-1h are used without dilution. If dilution is required, ensure the water used is free of any impurities, minerals, or salts that might cause separation (breaking) of the emulsion within the distribution equipment.

4-2.3.2 Cutback Asphalts.

Diesel fuel, cutback asphalts, motor oil, and road tars are rarely used due to environmental concerns; however, they may still be in use in some areas of the world that have not implemented strict environmental regulations and where asphalt emulsions are not available.

A cutback asphalt is a blend of an asphalt cement and a petroleum solvent. Cutbacks are classified as rapid curing (RC), medium curing (MC), and slow curing (SC), depending on the type of solvent used and its rate of evaporation. Each cutback is further graded by its viscosity. The RC and SC grades of 70 and 250, respectively, and MC grades of 30, 70, and 250, are generally used. Regardless of classification or grade, the best results are obtained by preheating the cutback. Spraying temperatures range from 120 degrees to 300 degrees Fahrenheit (48.9 to 148.9 degrees Celsius). The actual range for a particular cutback is much narrower; therefore, request the actual range from the supplier at the time of purchase. The user is cautioned that some cutbacks are heated above their flash point for spraying purposes so no smoking or open flames is permitted during application or cure. MC-30 grade is sprayed without being heated if the temperature of the asphalt is 80 degrees Fahrenheit (26.7 degrees Celsius) or above. A moist soil surface assists penetration. Curing time for cutbacks varies with the type. Under favorable ground temperature and weather conditions, RC cures in one hour, MC in three to six hours, and SC in one to three days. In selecting the material for use, consider local environmental protection regulations.

4-2.4 Lignins.

Lignin and lignin derivatives are byproducts of the manufacture of wood pulp. They provide dust control by physically binding soil particles. They are soluble in water and therefore readily penetrate soils. Do not use gray or salt water for dilution. Its solubility also makes it susceptible to leaching from the soil; thus, application is repeated as necessary after rainfall.

4-2.5 Polymer.

Polymer emulsions are excellent products for soil stabilization and dust control. These materials have good adhesive characteristics and provide stiffness, toughness, and water resistance. Do not mix polymer emulsions with gray or salt water for dilution. Soils stabilized with polymer emulsions are similar to those that can be stabilized by bitumen.

Polymer emulsions used for dust control are generally vinyl acetate or acrylic-based copolymers suspended in water by surfactants. They consist of 40 to 60 percent solid particles by weight of emulsion. Once they are applied, the polymer particles begin to coalesce as the water evaporates from the system, leaving a soil-polymer matrix that prevents small dust particles from escaping the surface. The polymers used for dust control typically have excellent tensile and flexural strength, adhesion to soil particles, and resistance to water. Immediately rinse equipment used to apply polymers to prevent damage. Polymer products are limited by a short shelf life (less than two years). Due to some vendors diluting polymer emulsion products in the past, it is recommended that random samples of the bulk product be tested to ensure the bulk product includes at least 40 percent solids according to ASTM D2834.

Polymer products can also be purchased in the form of a water-soluble powder. The polymer undergoes a chemical reaction upon curing and forms a water-resistant film that binds soil grains.

4-2.6 Synthetic Fluids.

Synthetic fluids are hydrocarbon-based liquids that are clear, odorless, non-corrosive, and applied without water dilution. The fluids act by agglomerating soil particles. They are non-curing, re-workable, and are regraded and re-compacted if the road or airfield surface needs smoothing. They are applied with standard spray equipment at a wide range of temperatures, even well below freezing. The re-workable binder is ready for immediate use upon application and maintains effectiveness for several months, depending on traffic level and surface conditions at time of placement. Because synthetic fluids do not harden, they are recommended for expedient helipads due to their minimal curing time and low probability of FOD generation.

4-2.7 Polysaccharides.

Polysaccharides are solutions or suspensions of sugars, starches, and surfactants in water. They may be diluted with water, depending on the intended use. Polysaccharides provide dust abatement by encapsulating soil grains and providing a binding network in the ground. Many polysaccharides are humectant (absorb water from the air) and hygroscopic (hold water after wetting); therefore, they are best used in climates with average relative humidity above 30 percent and with occasional rainfall. They are considered to be biodegradable materials and may leach from the soil with exposure to precipitation.

4-2.8 Cementing Materials.

Cementing type powders (portland cement, hydrated lime, and fly ash) are primarily used to improve the strength of soils (see UFC 3-250-11); however, when they are mixed with soils in relatively small quantities (2 to 5 percent by dry soil weight), the modified soil becomes more resistant to dusting. Portland cement is generally suited for all soil types, provided uniform mixing is achieved, whereas hydrated lime is better suited for soils containing a high percentage of clay. Fly ash may be used in combination with either portland cement or lime. Keep the compacted soil surface moist for a minimum of seven days prior to traffic.

4-2.9 Polyacrylamides.

Polyacrylamides are water-soluble polymers that provide dust control through moisture retention. These materials are used as super-absorbents in baby diapers, chemical spill containment, and other applications. They are generally applied in powder or granular form because polyacrylamides cause very large increases in viscosity when dissolved in water. The solution has the consistency of mayonnaise and is difficult to apply to soil. Polyacrylamides swell when they come in contact with water and may cause volume changes in the soil. For this reason, they are not recommended for use on roads.

4-2.10 Alternative Materials.

New commercial off-the-shelf products are continually introduced to the market. Some examples of different products are blends including glycerin, vegetable oils, surfactants, or other polymers. Test sections for new products are always recommended before using the products. The glycerin blend and vegetable oil products do not harden on the surface and provide dust control when FOD is of concern.

4-2.11 Vendor Summary and Selection.

4-2.11.1 Potential Vendors.

A list of potential vendors is summarized in Appendix B-2, Table B-1.

4-2.11.2 Logical Considerations.

Make logical considerations, such as duration of effectiveness, equipment required, shipping, storage, and shelf life, when determining which chemicals to use for dust control. In cases where water is not available, either use products that do not require dilution or water should be shipped. **1**\ Salts (such as calcium and magnesium chloride) cause corrosion to vehicles and aircraft, which is a reason to select a different, possibly more expensive, product. /**1**/

4-2.11.3 Emulsified Products.

Emulsified products have limited shelf lives. They consist of finely dispersed hydrophobic particles suspended in water. This dispersion is relatively unstable and results in the settling of solid particles. Normal mixing procedures do not allow these particles to go back into solution, and the product will not perform as designed. Keep emulsions from extreme heat, ultraviolet light, and freezing temperatures. Chloride salts, powdered polymers, and synthetic fluids do not have limitations on shelf life.

4-2.11.4 Choosing a Dust Palliative.

Choosing a dust palliative is ultimately governed by the existing need for dust control. Some products work better for helipads, while others are more effective on roads or airfields. Use soft crust palliatives on helipads to prevent FOD generation. Consider each type of palliative's benefits and limitations before selecting a product.

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CHAPTER 5 DUST PALLIATIVE APPLICATION

5-1 GENERAL APPLICATION INFORMATION.

The following section describes the primary considerations and methods for applying the recommended dust palliatives.

5-1.1 Soil Type.

The soil type affects the performance of dust palliatives. Fine-grained soils present a larger problem with dust generation and are more difficult to control. These soils require greater quantities of product to treat. Penetration is also hindered by the small pore sizes between soil grains. Multiple applications are required to treat fine-grained soils (silts and clays) to prevent ponding or surface runoff. Coarse-grained soils (sands and gravels) have higher infiltration rates to minimize ponding or runoff. Soil type is classified according to ASTM D2487.

5-1.2 Application Equipment.

Select application equipment based upon the types available and the application method. Projects occurring on or near military installations are more likely to have a broader range of choices for equipment types. Expeditionary missions in active theaters preclude the use of many types of machinery. The ultimate goal is to use equipment that allows the most efficient progress for placing dust palliatives. Larger areas need dispersion systems with large capacities. Liquid discharge is usually not the most time-consuming process. A hydroseeder can be used to spray over 100 gallons per minute. Other systems using a distribution bar spray around 50 gallons per minute. The time required to empty any tank at this rate is relatively small. The process dominating the construction time (for topical applications) is transporting and filling the equipment. For large jobs, it is important to use methods that reduce these steps. For treating small areas, time may not be as critical of a factor.

Rinse all equipment with water after transferring dust palliatives. Additionally, it is important to flush all distribution systems with water after applying dust palliatives. Film-forming products (polymers, lignosulfonates) coagulate within the distribution system and clog equipment. Cleaning the equipment after this occurs typically requires significant disassembly. Organic solvents may also be required to completely remove remaining polymer. It is important to rinse equipment after spraying chloride salts because of their tendency to corrode metal and initiate rust formation. Rinsing may be optional when using synthetic fluids for dust control. They tend to lubricate equipment and have not been found to generate problems. Cleaning is necessary if other types of liquids are to be placed in the equipment for other purposes.

5-1.3 Application Rates.

Choose application rates according to the soil type, the intended use of the treated area, and the necessary duration of use. Target a penetration depth of 1 inch (25 millimeters) for most applications where subjected to traffic. Dust palliatives applied to areas subjected to traffic are applied at a rate of 0.8 to 1.2 gallons per square yard (3.6 to 5.4 liters per square meter) and a lower rate used for nontraffic areas. **1**\ Synthetic fluids are applied at lower rates because they contain 100 percent active ingredients (often 0.4 gallon per square yard). /**1**/ Polymeric emulsions require application rates of greater than 1 gallon per square yard (4.5 liters per square meter) in areas of heavy traffic or for helipads. For example, using polymer emulsions on helipads requires an application rate of 1.2 gallons per square yard (5.4 liters per square meter) to produce thicker surface crusts to reduce FOD potential. Note that higher application rates are required if the polymer emulsions/polysaccharides are pre-diluted by the vendor as evidenced by less than 40 percent solids as measured according to ASTM D2834. Trial and error is necessary to achieve proper application rates.

Reapplication of dust palliatives is necessary as product effectiveness diminishes over time. Areas treated with chloride salts or synthetic fluids are rejuvenated by applying more palliative at half the original application rate. Troublesome areas or exposed, untreated soils require site preparatory work before spraying. Existing polymer film, if left undisturbed, typically repels the emulsion and prevents penetration of additional product.

5-1.4 Dilution Ratios.

Some products require dilution with water. These are typically any emulsified products (asphalt and polymer). Diluting the emulsion reduces the viscosity and improves penetration. In general, three parts water is added for each part product. Note that the recommended dilution ratio needs to be reduced if the palliatives have been pre-diluted by the vendor to less than 40 percent solids as measured according to ASTM D2834.

5-1.5 Topical Method.

Topical applications are the most commonly used technique for dust control. Spraying the surface of the soil with a dust palliative temporarily solves most dust problems. Alternative methods are used when the area to be treated is structurally deficient for the anticipated traffic or when greater durability is needed. Do not apply hard crust palliatives topically where heavy traffic is expected; soft crust palliatives can be applied topically on roads with sufficient bearing capacity. Topical applications are accomplished by spraying the dust palliative onto the native or prepared soil surface. It is imperative to maintain uniformity while dispersing the liquid. Application quantities are determined by estimating the area of ground surface to be treated and multiplying that area by the manufacturer's recommended application rate.

5-1.6 Admixture Method.

Admixture methods are designed to incorporate dust palliatives deeper into the soil and to provide longer-lasting dust abatement. These methods are usually necessary when heavy repetitive loading is introduced to the soil. Roads and airfields (runways, taxiways, or parking aprons) generally require admixture applications to achieve the desired results. Admixture depths for roads are typically a minimum of 3 inches (76 millimeters). The spray/till/compact/spray procedure (Figures 5-1 through 5-4) is recommended for incorporating the dust palliative into the soil.

1. Grade the soil using a motor grader (Figure 5-1).
2. Spray half of the total palliative application rate onto the soil surface.
3. Blend into top 3 inches (76 millimeters) of soil using a rotary mixer (Figure 5-2).
4. Compact using a steel-wheeled vibratory compactor until no significant change in density of the road surface is observed (Figure 5-3).
5. Spray remaining product onto compacted surface (Figure 5-4).

This method provides optimal performance of most palliatives; however, for more in-depth details and information on soil stabilization, consult UFC 3-250-11. Note that some palliatives do not provide any strength increase and may decrease the bearing capacity of the soil, which is important for airfield dust control.

Figure 5-1 Grading Road Surface Prior to Treatment

Figure 5-2 Applying Product with Hydroseeder and Mixing into Road Surface with Rotary Mixer

Figure 5-3 Compacting Road Surface After Mixing

Figure 5-4 Applying Final Spray to Seal Road Surface After Compaction

5-2 DISTRIBUTION EQUIPMENT.

A variety of distribution equipment is used to spray apply the palliatives. Appendix B, Table B-2, lists some manufacturers of spray equipment used for placing a variety of dust palliatives.

5-3 DETAILED APPLICATION GUIDANCE.

This section provides detailed guidance for treating helipads, roads, base camps, and fixed-wing airfield facilities.

5-3.1 Dust Abatement on Helipads.

This paragraph provides guidance for mitigating dust on unsurfaced helipads. A 150-foot by 150-foot (45.7-meter by 45.7-meter) helipad size is recommended for cargo helicopters, and a 100-foot by 100-foot (30.5-meter by 30.5-meter) helipad size is recommended for utility and attack helicopters. The equipment requirements may be modified, depending upon availability and mission requirements. Synthetic fluid is used as an example for the following procedures; however, the general types of equipment and process are similar for other liquid dust palliatives.

5-3.1.1 For dust abatement on helipads, provide and use the following:

- Motor grader for initial grading

- Vehicle(s) to haul the chemical totes, pumps, etc., and tow the distribution equipment
- Hydroseeder or other spray distribution system compatible with the selected chemical
- Dust palliative (synthetic fluid), typically in 275-gallon (1041-liter) totes (two to four required)
- Centrifugal pump and hoses with quick-connect ends to transfer the material from the tote to the distributor if the distributor does not include a pump
- Personnel (three)

5-3.1.2 The following steps will treat an expedient helipad:

1. Survey and visibly establish the area to be treated.
2. Place the synthetic fluid into the hydroseeder/distributor (Figure 5-5).
    - 450 gallons (1703.4 liters) for 100-foot by 100-foot (30.5-meter by 30.5-meter) helipad for smaller rotary-wing aircraft
    - 1000 gallons (3785.4 liters) for 150-foot by 150-foot (45.7-meter by 45.7-meter) helipad for larger rotary-wing aircraft
    - Quantities will be larger for treating with a polymer emulsion as an alternative solution; follow manufacturer’s dilution/application guidance
3. Position the hydroseeder/distributor on the edge of the helipad.
4. Use the tower gun and a long-distance nozzle to spray half of the product on half of the helipad. A hose attachment may also be used (Figure 5-6).
5. Move to the opposite side of the helipad and spray the remaining product.
6. If the distributor does not have standoff spray capability, it may be necessary to traverse the helipad ensuring spray overlap. **Note:** If the helipad ruts significantly under the distributor, smooth and re-treat the ruts by a hand wand to keep the ruts from acting as erosion focal points during aircraft operations.
7. Helicopters can land immediately on areas treated with synthetic fluids; however, best results occur after 24 hours (Figure 5-7). If a polymer emulsion is used as the alternative solution, allow the material to cure for a minimum of 24 hours prior to allowing traffic on the helipad.

Figure 5-5 Filling Hydroseeder from Material Tote

Figure 5-6 Topical Application from Hydroseeder Tower Gun (Top) or Hose (Bottom)

Figure 5-7 UH-1 Rotary-Wing Aircraft Operating on Treated Helipad

5-3.2 Dust Abatement on Roads.

5-3.2.1 Topical Application or Admixture Methods.

Complete dust abatement on roads using a topical application or admixture methods. Performing only a topical application provides dust abatement on aggregate roads with a high load-bearing capacity; however, when applying dust palliatives to unimproved roads, topical applications may not allow for manufacturer-recommended penetration. Thin surface crusts are prone to disintegration with increased traffic, allowing the underlying material to produce dust. Using a rotary mixer or soil stabilizer to incorporate dust palliatives into the soil is recommended. It is not necessary that the road be tilled prior to spraying the product. As long as runoff of the product does not occur, mixing can be performed after spraying onto the existing road surface to minimize construction efforts. Disturb the surface if the product does not readily soak into the road or if working on an inclined or crowned surface.

5-3.2.2 Equipment.

Modify the equipment requirements, depending upon availability and mission requirements. Polymer emulsion is used for the following example at a 3:1 water/emulsion mixing ratio. However, the types of equipment and process are similar for other types of liquid palliatives.

5-3.2.3 Supplies.

Provide and use the following:

- Motor grader for initial grading
- Vehicle(s) to haul the chemical totes, pumps, etc., and tow the distribution equipment
- Hydroseeder or other chemical distributor compatible with products
- Polymer emulsion mixed with water in appropriate amounts
- Rotary mixer
- Steel-wheeled vibratory compactor
- Personnel (three)

5-3.2.4 Application Procedures.

The application procedures using a diluted polymer emulsion are as follows:

1. Determine the length of road that can be treated per tank (hydroseeder/distributor capacity):

$$length\ (yd) = \frac{tank\ capacity\ (gal)}{[application\ rate\ (gsy) \times road\ width\ (yd)]}$$

$$length\ (m) = \frac{tank\ capacity\ (liter)}{[application\ rate\ (lsm) \times road\ width\ (m)]}$$

2. Place 675 gallons (2555 liters) of water into hydroseeder/distributor (minimum 900-gallon [3406-liter] capacity). For smaller distribution equipment, compute quantities to match the manufacturer recommended dilution ratio.
3. Add 225 gallons (852 liters) of polymer emulsion.
4. Mix for five minutes, using mechanical agitation.
5. Apply to the road surface for the determined length using a distribution bar or wide fan nozzle on the tower gun.
6. Immediately till the road surface to a 3-inch (76-millimeter) depth, using a rotary mixer (Figure 5-2).
7. Grade the road to establish grade requirements and correct distresses.
8. Compact the soil until the desired density is achieved (Figure 5-3).
9. Repeat steps 2 through 8, as needed.
10. Spray a light application (0.2 gallon per square yard [0.9 liter per square meter]) over the compacted road surface (Figure 5-4).
11. Repeat steps 1 through 10 for subsequent road lengths to be treated.

5-3.3 Dust Abatement in Base Camps and Other Non-Traffic Areas.

5-3.3.1 This paragraph provides guidance for mitigating dust in general base camp areas and other non-traffic areas. The topical application method is recommended. This method is less robust but cost-effective since the surface is subjected to lower loading requirements; thus, do not use this guidance for areas directly exposed to vehicle traffic. Synthetic fluid is used as an example for the following procedures. Modify the equipment requirements, depending upon availability and mission requirements.

5-3.3.2 Provide and use the following:

- Vehicle(s) to haul the chemical totes, pumps, etc., and tow the distribution equipment
- Hydroseeder or other chemical distributor compatible with products
- Dust palliative (synthetic fluid*)
- Personnel (three)

* Calculate quantities based upon recommended application rate of 0.4 gallon per square yard (1.8 liters per square meter) and the area to be treated.

5-3.3.3 The application procedures are as follows:

1. Determine the area of road that can be treated per tank (hydroseeder/distributor capacity):

$$area\ (yd^2) = \frac{product\ (gal)}{application\ rate\ (gsy)}$$

$$area\ (m^2) = \frac{product\ (liter)}{application\ rate\ (lsm)}$$

2. Fill the distribution equipment with synthetic fluid.
3. Apply to the road surface using a distribution bar, wide fan nozzle on tower gun, or hand wand/hose.
4. Repeat steps 1 through 3, as needed.

5-3.4 Dust Abatement Around Fixed-Wing Airfields.

5-3.4.1 Safety.

Due to safety concerns associated with surface friction requirements, dust palliatives are not recommended for use on any primary operating surface of the airfield. These areas are treated as a soil stabilization issue. Additionally, since the shoulders of unsurfaced airfields are designed to support occasional aircraft loading, it is also not recommended that the products be used on the shoulders of unsurfaced airfields; thus, the use of chemical dust palliatives is limited to the graded areas of unsurfaced airfields. For paved airfields, dust palliatives are used on any unpaved area around the perimeter of the pavement, including unpaved shoulders and graded areas. Due to potential FOD concerns, use synthetic fluids for this application. If a polymer emulsion or hard crust palliative is used, mix the material into the soil to minimize FOD potential. Polymer emulsions or other crust-forming stabilization additives cannot be topically applied around fixed-wing airfields due to the potential to form thin crusts capable of generating FOD. Modify the equipment requirements, depending upon availability and mission requirements; however, the types of equipment and process are similar to the previous section on dust abatement in base camps and other non-traffic areas.

5-3.4.2 Size Consideration.

Consider the size of the area to be treated around fixed facilities. The width of treatment along the perimeter is not an issue; however, the length of treatment for airfields can range from 1 to 3 miles (1.6 to 4.8 kilometers) per side of the runway. The resulting treatment area accumulates quickly. An analysis of the propeller/jet airblast was performed for the C-130 and C-17, respectively, to develop recommendations for the width of the treated area. The minimum treatment width is based upon the wingspan of the aircraft and the highest intensity plume, while the optimum treatment width is based upon the distance required to reduce the exhaust plume to a maximum velocity of 50 feet per second (15.2 meters per second) or 35 miles per hour (56 kilometers per hour). The treatment widths along each side of the runway and around any turnarounds or aprons are:

- C-130 minimum treatment width: 27 feet (8.2 meters)
- C-130 optimum treatment width: 50 feet (15.2 meters)
- C-17 minimum treatment width: 50 feet (15.2 meters)
- C-17 optimum treatment width: 100 feet (30.5 meters)

For unsurfaced fixed-wing facilities, begin the treatment at the edge of the shoulder and apply outward into the graded area and transition area. For paved fixed-wing facilities, begin the treatment at the edge of the paved surface and extend outward to the recommended width.

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CHAPTER 6 ECONOMICS

6-1 GENERAL.

Dust control is based on many factors and methods. More than one dust palliative is found to meet the needs for the method selected. Consider economics to determine the dust palliative selected for use.

6-2 ECONOMIC FACTORS.

Economic factors include, but are not limited to, the following items:

- Initial cost of the dust palliative(s) at site
- Equipment and labor costs (by method if applicable)
- Maintenance costs (see paragraph 6-2.3.4)
- Material storage costs (if applicable)
- Shipping costs
- Equipment acquisition/modification costs
- Area preparation (clearing and grubbing is expected at all sites)

6-2.2 Initial Cost.

The initial cost of the dust palliative is typically not the governing factor in making the selection. Consider any suitable dust palliative already on hand, especially when placement equipment is available.

6-2.3 Equipment and Labor Costs.

6-2.3.1 Agronomic Method.

Costs associated with this method closely parallel the local turf seeding or landscape planting operational costs in the area where dust control is desired (UFGS 32 05 33). Landscape contractors or similar firms are a source to provide rough estimates for planning purposes.

6-2.3.2 Surface Penetrant and Surface Cover.

Both of these methods recommend some spray-on dust palliatives, which are placed with an asphalt distributor or hydroseeder. Aggregate and membrane costs are taken from the supplier(s) near the area where dust control is planned. Labor costs associated with these two methods vary according to method type.

6-2.3.3 Admixture Method.

This method is probably the most expensive method described but is the most effective long-term. It requires equipment and manpower similar to that associated with soil stabilization techniques. The admixture method requires a rotary tiller mixer or reclaimer/stabilizer mixer to blend the admixture into the soil and other equipment used for pavement construction (e.g., motor grader, compactor). The material cost; cement, lime, or bituminous material is determined from the local supplier(s) nearest the area where dust control is desired (see UFC 3-250-11).

6-2.3.4 Maintenance.

No dust control method or dust palliative provides a maintenance-free solution. When frequent maintenance is required, order enough material for initial application plus an equal amount for 12 months' maintenance. In the case of trafficked areas, maintenance is minimized by prohibiting quick stops and sharp turns for all using vehicles and limiting traffic to essential vehicles only. Tanks and other tracked vehicles will obliterate most dust control methods employed.

6-2.3.5 Material Storage Costs.

Consult the manufacturer prior to purchase for storage information/requirements. Provide theft-proof storage for all dust palliatives until they are applied. Protect the liquid dust palliatives from freezing temperatures. Powders such as lime and cement are typically stored in a dry place with low humidity.

6-2.3.6 Shipping Costs.

Shipping or transportation costs are incurred directly or indirectly with all dust palliatives.

6-2.3.7 Area Preparation.

Most sites require some preparation. As a minimum, remove all large rocks (> 6 inches [152 millimeters]) and all large sticks and stumps.

6-3 FINAL SELECTION.

Some of the economic factors outlined in paragraph 6-2 are difficult to determine with certainty, especially where placement crews have no prior experience with dust palliative placement or the expected traffic use is not known; however, by considering these factors the final selection of a dust palliative is reasonably made.

APPENDIX A REFERENCES

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ASTM D2487, *Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)*

ASTM D2834, *Standard Test Method for Nonvolatile Matter (Total Solids) in Water-Emulsion Floor Polishes, Solvent-Based Floor Polishes, and Polymer-Emulsion Floor Polishes*

APPENDIX B BEST PRACTICES

B-1 CONTROL OF WINDBORNE SAND.

B-1.1 Introduction.

Many factors, including low rainfall, high evaporation, sparse vegetation, and seasonal winds, contribute to rock weathering and sand movement. Methods for controlling sand movement have met with varying degrees of success. This section summarizes the latest available information on windborne sand control and lists recommended methods for sand movement stoppage and diversion. Marine and river sand movement control are not discussed.

B-1.2 Wind, Wind Direction, Crosswind.

Wind is defined as any natural movement of air, whether of high or low velocity, or great or little force. Most regions have a predominant wind direction, some section of the compass from which the wind blows most often and with the greatest velocity. Crosswinds are winds directed at some angle to the predominant wind direction.

B-1.3 Forms of Dunes.

A dune is defined as a mound or ridge of windblown material, usually sand, formed in arid regions. Local conditions under which dunes are developed vary widely and, consequently, there is a broad range in their shape and size. The shape may assume almost any configuration and the size may vary from an insignificant lone sand pebble to mounds higher than 100 feet (30.5 meters). Some coastal dune formations have reached 1000 feet (304.8 meters) in height. The three general types of sand dunes are described below; only the third type (moving sand dunes) requires control.

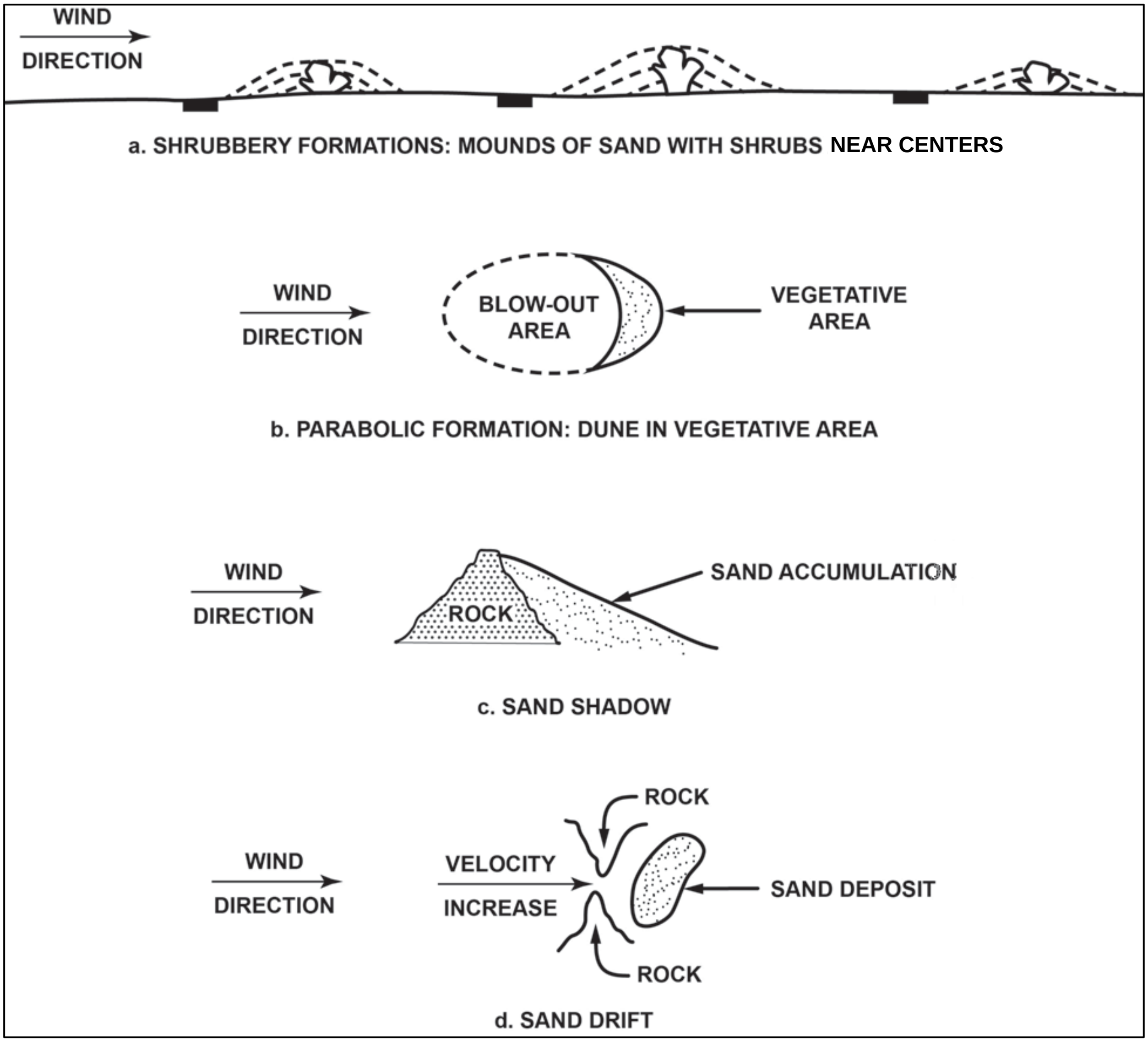
B-1.3.1 Sand Sheets.

These sheets occur in a generally flat, barren area with a predominant wind direction. They present no control problems because the sand does not accumulate.

B-1.3.2 Fixed Sand Dunes.

These dunes result from the accumulation of sand particles adjacent to fixed obstructions such as hills, cliffs, shrubs, and buildings. Fixed sand dunes may range in size from an accumulation around small shrubbery to sand shadows more than 50 feet (15.2 meters) deep. Because the fixed sand dune is immobile, it typically does not present a control problem. Figure B-1 shows types of fixed sand dune formations.

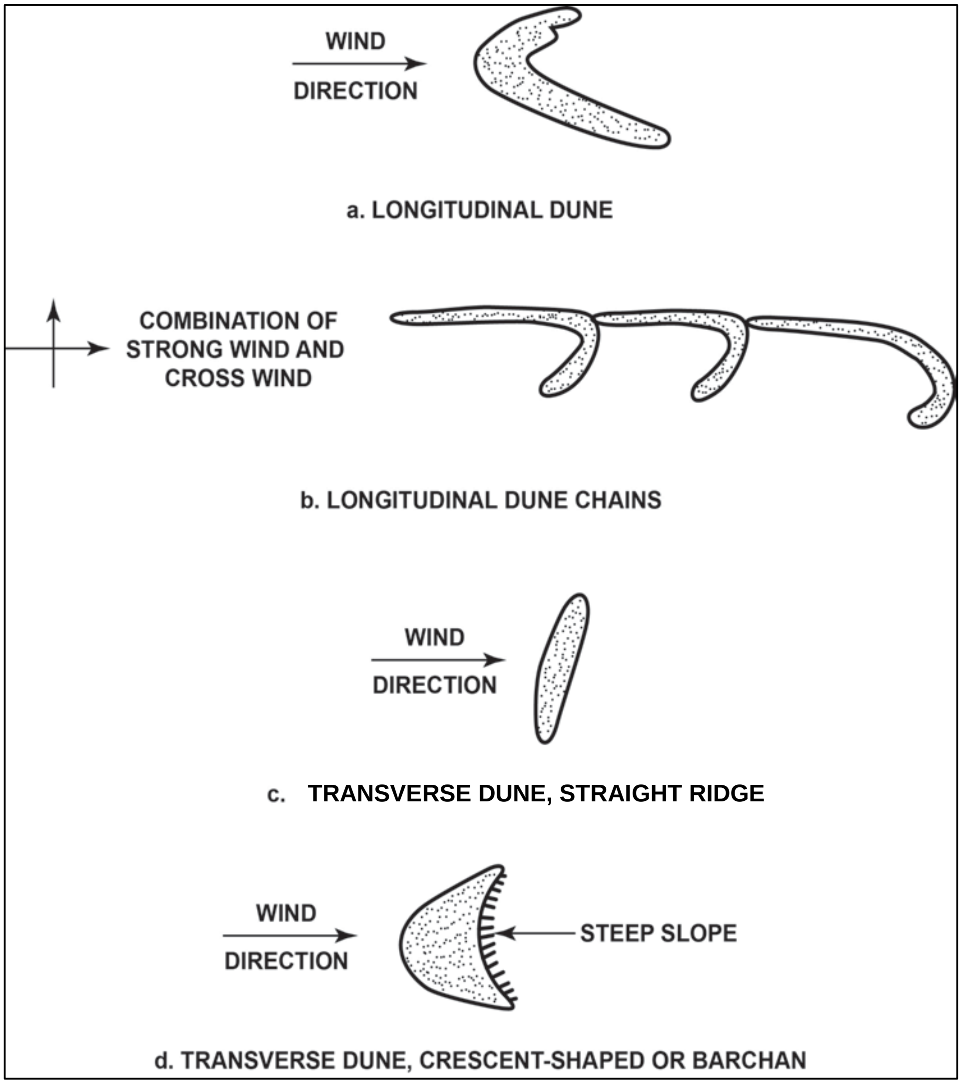
Figure B-1 Types of Fixed Sand Dunes



B-1.3.3 Moving Sand Dunes.

This type of sand mass exists independent of fixed surface features and may move from place to place, maintaining its initial form. Moving sand dunes are common in vast areas of sand with little or no vegetation. The control methods described below are applicable for this type of dune. With relation to predominant winds, moving sand dunes are classified either as longitudinal or transverse (Figure B-2). Longitudinal dunes are distinct ridges elongated in the direction of the predominant wind. A combination of predominant winds and crosswinds will produce a regular succession of dunes (longitudinal dune chains). Transverse dunes are formed by winds of steady direction blowing across an extensive source of loose sand, such as a sandy beach, and building ridges transverse to the wind direction. Low-velocity winds form straight parallel ridges and stronger winds form the more typical crescent-shaped or barchan transverse dune.

Figure B-2 Types of Moving Sand Dunes



B-1.4 Migration of Dunes.

After a dune is formed, the predominant wind may blow sand over the crest to the leeward slope. By this migration of particles, the dune then moves forward at a rate depending on wind velocity, topography, size of dune, and other factors. For example, along the Bay of Biscay on the west coast of France, dunes travel at rates up to more than 100 feet (30.5 meters) per year.

B-1.5 Sand Control.

There are many methods of sand control, with certain advantages and disadvantages in each method. The methods described below for the stabilization and/or destruction of windborne sand dunes are the most effective. These methods may be used alone or in combination.

B-1.5.1 Fencing.

This method of control employs flexible, portable, inexpensive fences to destroy the symmetry of a dune formation. The fence need not be a solid surface and may even have 50 percent openings, as in snow fencing. Any material such as wood slats, slender poles, stalks, or perforated plastic sheets bound together in any manner and attached to vertical or horizontal supports will be adequate. Rolled bundles that can be transported easily are practical. Prefabricated fencing is desirable because it can be erected quickly and economically. Because the wind tends to underscour and undermine the base of any obstacle in its flow path, the fence should be installed 1 foot (0.3 meter) above ground level. To maintain the effectiveness of the fencing system, a second fence should be installed on top of the first fence on the crest of the sand accumulation. The entire windward surface of the dune should be stabilized with dust-control materials, such as bituminous material, prior to erecting the first fence. The old fences should not be removed during or after the addition of new fences. Figure B-3 shows a cross-section of a stabilized dune with porous fencing. As long as the fences are in place, the sand will remain trapped. If the fences are removed, the sand will soon move downwind, forming an advancing dune. The proper spacing and number of fences required to protect a specific area can only be determined by trial and observation. Figure B-4 illustrates a three-fence method of control. If the supply of new sand to the dune is eliminated, migration is accelerated and dune volume decreases. As the dune migrates, it may move great distances downwind before it completely dissipates. An upwind fence may be installed to cut off new sand supply if the object to be protected is far downwind of the dune. This distance usually should be at least four times the width of the dune.

Figure B-3 Cross-Section of Dune Showing Initial and Subsequent Fences

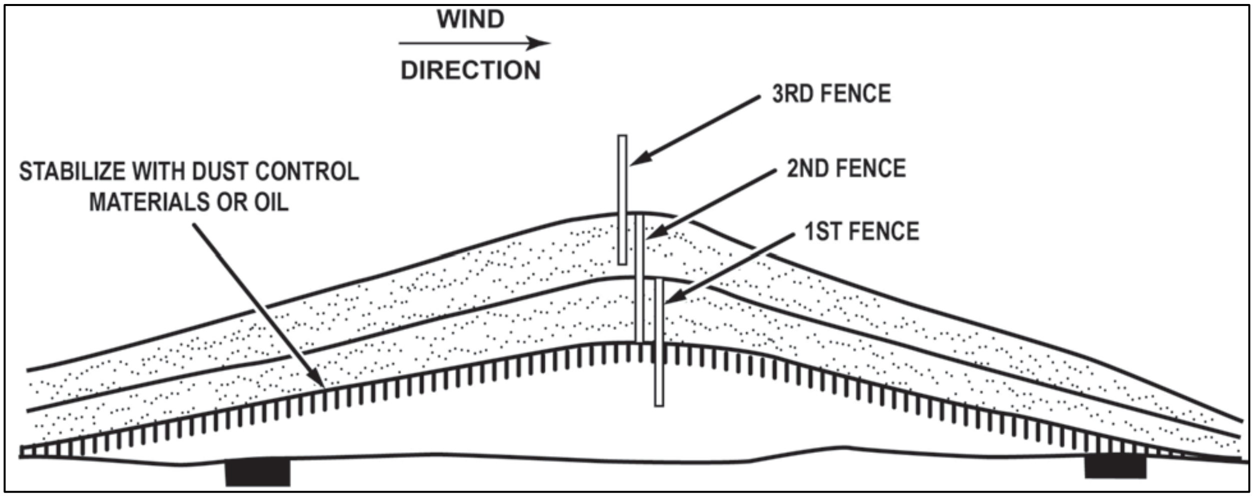
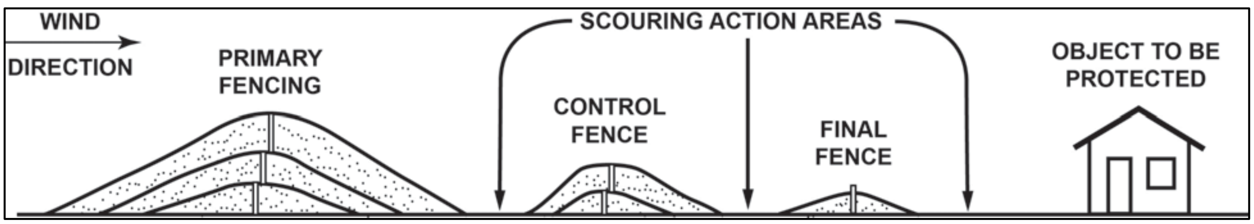


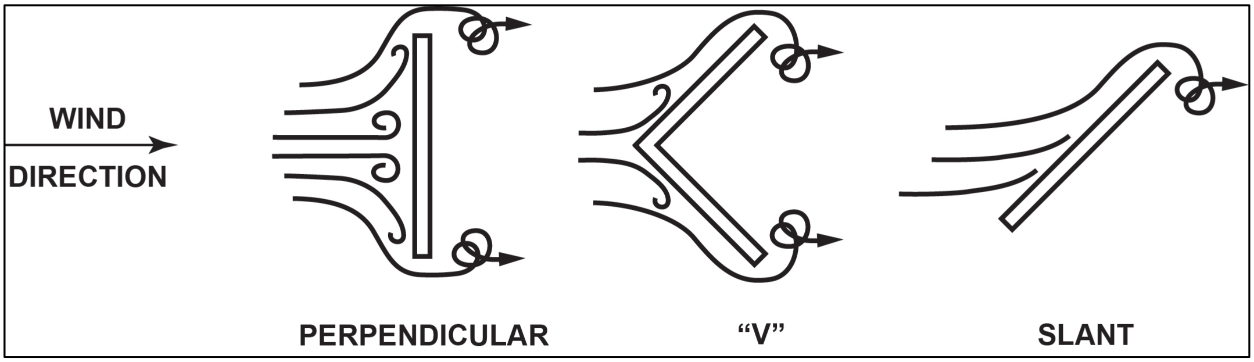
Figure B-4 Three Fences Installed to Control Dune Formation



B-1.5.2 Paneling.

Solid barrier fences of metal, wood, plastic, or masonry can be used to stop or divert sand movement. To stop sand, the barriers should be constructed perpendicular to the wind direction. To divert sand, the panels should be placed obliquely or nearly parallel to the wind. They may be single slant or “V” in pattern (Figure B-5). When first erected, paneling appears to give excellent protection; however, panels are not self-cleaning. Promptly remove the initial accumulations by mechanical means. If the accumulation is not removed, sand will begin to flow over and around the barrier and soon submerge the object to be protected. Mechanical removal is costly and endless. This method of control is unsatisfactory because of inefficiency and expense and should be employed only in conjunction with a more permanent control, such as planting, fencing, or using dust palliatives. Equally good protection at less cost is achieved by the fencing method.

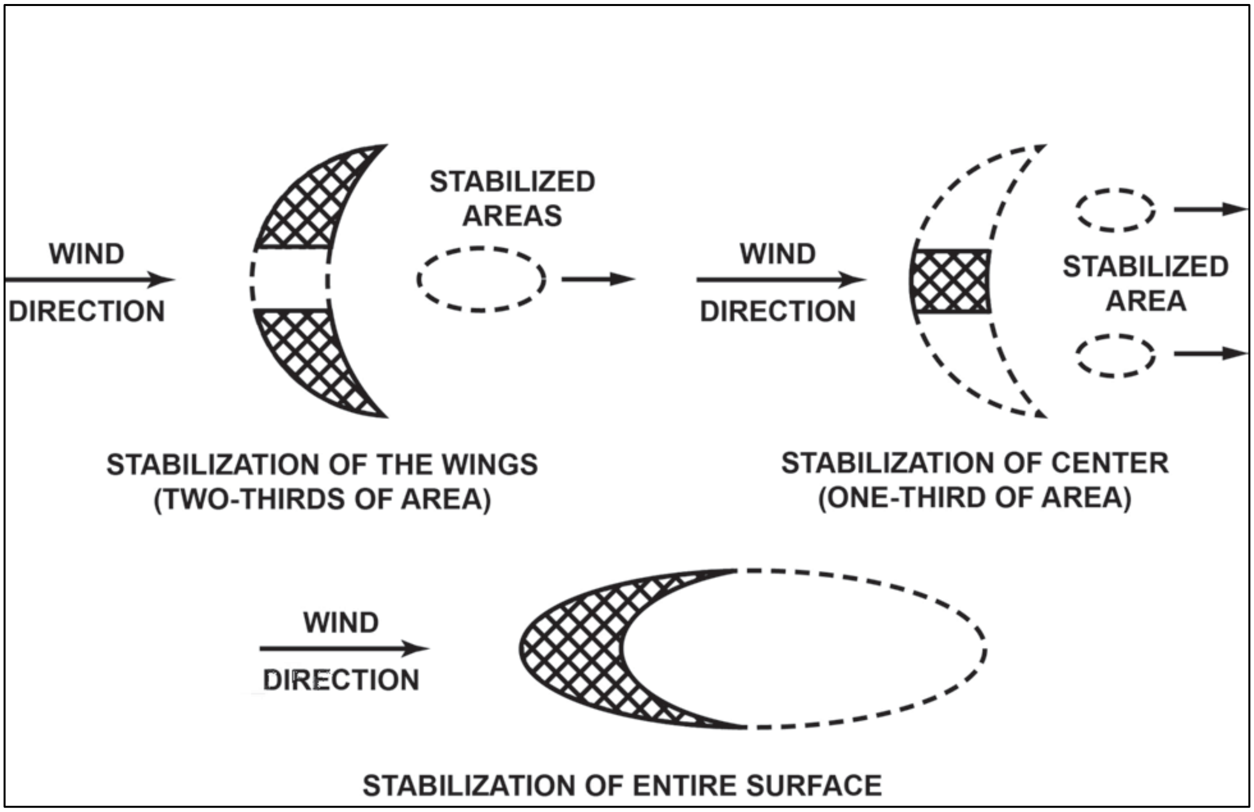
Figure B-5 Three Types of Solid Fencing or Paneling for Control of Dune Formation



B-1.5.3 Bituminous Materials.

Destruction of dune symmetry by spraying bituminous materials at either the center or the ends of the dune is an inexpensive and practical method of sand control. Petroleum resin emulsion and asphalt emulsions have been found to be effective. The desired stickiness of the sand is obtained by diluting one part petroleum resin emulsion with four parts water and spraying at the rate of 0.5 gallon per square yard (2.3 liters per square meter). Generally, the object to be protected should be downwind a distance of at least twice the tip-to-tip width of the dune. The center portion of a barchan dune can be left untreated or can be treated and the unstabilized portions allowed to reduce in size by wasting. Figure B-6 shows destruction of a typical barchan dune and stabilization, depending on the area treated.

Figure B-6 Schematic of Dune Destruction or Stabilization by Selective Treatment



B-1.5.4 Vegetative Treatment.

Vegetative cover is an excellent method of sand stabilization. Ensure vegetation to be established is drought-resistant and adapted to the climate and soil. Most vegetative treatments are effective only if the supply of new sand is cut off. On the upwind side, water, fertilizers, and mulch are liberally used. To prevent the engulfment of the vegetation, the upwind boundaries are protected by fences or dikes and the seed may be protected by mulch sprayed with a bituminous material. Seed on slopes may be anchored by mulch or matting. Oats and other cereal grasses may be planted as a fast-growing companion crop to provide protection while slower-growing perennial vegetation becomes established. Typically, the procedure is to plant clonal plantings, followed by shrubs used as an intermediate step, followed by the planting of long-lived trees. There are numerous suitable vegetative treatments for use in different environments. The actual type of vegetation selected should be chosen by qualified individuals familiar with the type of vegetation that thrives in the affected area. Stabilization by planting has the advantages of permanence and environmental enhancement wherever water can be provided for growth.

B-1.5.5 Mechanical Removal.

In small areas, sand may be removed by heavy equipment, but conveyor belts and power-driven wind machines are not recommended because of their complexity and expense. Mechanical removal may be employed only after some other method has been used to prevent the accumulation of more deposits. Except for its use in conjunction with another method of control, the mechanical removal of sand is not practical or economical.

B-1.5.6 Trenching.

A trench may be cut either transversely or longitudinally across a dune to destroy its symmetry. If the trench is maintained, the dune will be destroyed by wastage. This method has been used successfully in the (Yuma Desert) Arizona highway program, but it is expensive and requires constant inspection and maintenance.

B-1.5.7 Water.

Water may be applied to sand surfaces to prevent sand movement. It is widely used and an excellent temporary treatment. Water is required for establishing vegetative covers. The need for frequent reapplication and an adequate and convenient source constitute two major disadvantages of this method.

B-1.5.8 Surface Covers.

Any material that forms a (semi) permanent cover and is immovable by the wind will serve to control dust. Solid covers, though expensive, are excellent protection and can be used over small areas. This method of sand control accommodates pedestrian traffic as well as a minimum amount of vehicular traffic. Surface covers may be made from bituminous or concrete pavements, prefabricated landing mat, membrane, aggregate, seashells, and saltwater solutions. After placement of any of the above-listed materials, a spray application of bituminous material may be required to prevent cover decomposition and subsequent dust.

B-1.5.9 Salt Solutions.

Water saturated with sodium chloride or other salts can be applied to sand dunes to control dust. Rainfall will leach salts from the soil in time. During periods of no rainfall and low humidity (below 30 percent), artificial moisture in the form of water may have to be added to the treated area at a rate of 0.1 to 0.2 gallon per square yard (0.5 to 0.9 liter per square meter) to activate the salt solution.

B-2 POTENTIAL VENDORS AND DISTRIBUTION EQUIPMENT.

B-2.1 Potential Vendors.

A list of potential vendors is summarized in Table B-1 to assist in the procurement of products. It is not intended to be a complete listing of vendors as there are numerous large and small companies that provide a wide range of materials for dust abatement. **\1** The USDA (United States Department of Agriculture) maintains a product list for BioPreferred and Certified Biobased dust suppressants in the Construction section of the BioPreferred Catalog at:

https://www.biopreferred.gov/BioPreferred/faces/catalog/Catalog.xhtml. /**1**/ Inclusion on this list does not represent endorsement of any kind. The list is provided to assist the Soldiers, Sailors, Marines, and Airmen working in the field. **1**\\ Additional information on products and practices are available in the ERDC/GSL Technical Reports in Appendix A. /**1**/ Complete a small test section prior to using each product to evaluate the effectiveness and determine the placement details.

1\\

Table B-1 Product and Vendor Information for Dust Palliatives

Vendor	Products	Website
American Distributing	calcium ligosulfonate	https://americandistributing.com/services/
C-Gear	geotextile	https://www.cgear-outdoor.com.au/multimat.html
Deschamps Mat Systems	geotextile	https://defense.mobi-mat.com/
Dirt Glue	polymer emulsions	https://globalenvironmentalsolutions.com/
Enviroflo Engineering	surfactants, humectants, organic binders, foams	http://www.envirofloeng.com/
Enviroseal	polymer emulsions	https://www.enviroseal.com/
Envirotac	polymer emulsions	https://www.eparhino.com/
Envirotech Services, Inc.	polymer emulsions, humectants	https://envirotechservices.com/
Midwest Industrial Supply	polymer emulsion, synthetic fluids, glycerin blends, humectants	https://midwestind.com/
Landlock	polymer emulsions	https://www.landlocknaturalpaving.com/polymer-military-road-construction
PennzSuppress	paraffin resin	https://pennzsuppress.com/
PolyPavement	polymer emulsion	http://www.polypavement.com
Propex	geotextile	https://propexglobal.com/
Soilworks	polymer emulsion, synthetic fluids, vegetable oil, and glycerin blends	https://soilworks.com/
USG, Inc.	bonded fiber matrix	https://www.usg.com/content/usgcom/en/products/industrial/reclamation-erosion-control/dust-

Vendor	Products	Website
		armour-environmental-gypsum.html

/1/

B-2.2 Distribution Equipment.

A variety of distribution equipment is used to apply the palliatives. Table B-2 lists some manufacturers of spray equipment used for placing a variety of dust palliatives. It is not intended to be a complete listing of vendors as there are numerous large and small companies that provide a wide range of equipment for dust abatement. Inclusion on this list does not represent endorsement of any kind. The list is provided to assist the Soldiers, Sailors, Marines, and Airmen working in the field.

\1\

Table B-2 Product and Vendor Information for Equipment

Vendor	Products	Website
Finn Corporation	Hydroseeder	https://www.finncorp.com/
TurfMaker	Hydroseeder	http://turfmaker.com/
Epic Manufacturing	Hydroseeder	https://www.epicmanufacturing.com/
SealMaster	Emulsion sprayers	https://sealmaster.net/
Caterpillar	Water distributor (613C-II)	https://www.caterpillar.com/

/1/

APPENDIX C GLOSSARY

C-1 ACRONYMS

AFJPAM	Air Force Joint Pamphlet
CSS	Cationic Slow Setting
ERDC/GSL	Army Engineer Research and Development Center, Geotechnical and Structures Laboratory
ETL	Engineering Technical letter
FHWA-CFL	Federal Highway Administration - Central Federal Lands Highway Division
FM	Field Manual
FOD	Foreign Object Debris
gsy	Gallons per Square Yard
MC	Medium Curing
RC	Rapid Curing
SC	Slow Curing
SS	Slow Setting
UFC	Unified Facilities Criteria
UFGS	Unified Facilities Guide Specification
USCS	Unified Soil Classification System

FC 3-260-18F
28 October 2015
Change 1, 02 August 2023

FACILITIES CRITERIA (FC)

AIR FORCE AIRCRAFT ARRESTING SYSTEMS (AAS) INSTALLATION, OPERATION, AND MAINTENANCE (IO&M)

FC 3-260-18F
28 October 2015
Change 1, 02 August 2023

FACILITIES CRITERIA (FC)

AIR FORCE
AIRCRAFT ARRESTING SYSTEMS (AAS)
INSTALLATION, OPERATION, AND MAINTENANCE (IO&M)

AIR FORCE CIVIL ENGINEER CENTER (Preparing Activity)

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

Change No.	Date	Location
1	02 Aug 2023	paragraphs 1-1.1, 4-7.1, 4-7.3, 4-8.1, 4-13.2, and Summary Sheet - replaced AFI 32-1043 with AFMAN 32-1040; paragraph 3-5 replaced AFI 32-1042 with UFC 3-260-04; Updated References Appendix

FOREWORD

Facilities Criteria (FC) provide functional requirements (i.e., defined by users and operational needs of a particular facility type) for specific DoD Component(s), and are intended for use with unified technical requirements published in DoD Unified Facilities Criteria (UFC). FC are applicable only to the DoD Component(s) indicated in the title, and do not represent unified DoD requirements. Differences in functional requirements between DoD Components may exist due to differences in policies and operational needs.

All construction outside of the United States is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA). Therefore, the acquisition team must ensure compliance with the most stringent of the FC), the SOFA, the HNFA, and the BIA, as applicable. Because FC are coordinated with unified DoD technical requirements, they form an element of the DoD UFC system applicable to specific facility types. The UFC system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applicable to the Military Departments, Defense Agencies, and the DoD Field Activities. The UFC System also includes technical requirements and functional requirements for specific facility types, both published as UFC documents and FC documents.

FC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQ USACE), Naval Facilities Engineering Command (NAVFAC), and the Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale should be sent to the respective service proponent office by the following electronic form: Criteria Change Request. The form is also accessible from the Internet site listed below.

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

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

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

AUTHORIZED BY:

RANDY E. BROWN, SES II, DAF
Director
Air Force Civil Engineer Center

FACILITIES CRITERIA (FC)
NEW SUMMARY SHEET

Document: FC 3-260-18F, *AIR FORCE AIRCRAFT ARRESTING SYSTEMS (AAS) INSTALLATION, OPERATION, AND MAINTENANCE (IO&M)*

Superseding: None

Description: Unless specified otherwise, requirements within this FC are mandatory and apply to all military, Department of Defense (DoD) or Department of Transportation (DoT) Federal Aviation Administration (FAA) civilians, or DoD contracted personnel who are tasked to install, operate, maintain, repair, or otherwise participate in or affect operation or use of an AAS owned or operated by the Air Force. This includes firefighters or other first-responder personnel and augmentees. Specifically, installation, maintenance and operation of all Air Force AAS must comply with the requirements provided in **\1** AFMAN 32-1040 *Civil Engineer Airfield Infrastructure Systems* **/1/** UFC 3-260-01, *Airfield and Heliport Planning and Design*, UFC 3-260-02, *Pavement Design for Airfields*, and UFC 3-535-01, *Design Standards for Visual Air Navigation Facilities.* Maintenance procedures, repair parts, and materials necessary to install, operate, and maintain each energy absorbing system, net engaging barrier, or hook cable support system, must comply with the requirements in this FC and in the appropriate and specific 35E8 Series Technical Order (T.O.) or approved Manufacturer's Manual.

Reasons for Document:

- Provide technical requirements for installation, operation, and maintenance of Aircraft Arresting Systems.
- Consolidate criteria located in multiple documents.
- Update information to reflect new and revised standards.

Impact: There are minor cost impacts associated with this FC. However, the following benefits should be realized

- Standardized guidance has been prepared to assist engineers in the development of the plans, specifications, calculations, and Design/Build Request for Proposals (RFPs).

Unification Issues

None

Note: Use of the name or mark of any specific manufacturer, commercial product, commodity, or service in this FC does not imply endorsement by the Air Force.

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FIGURES

TABLES

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CHAPTER 1 OBTAINING AIRCRAFT ARRESTING SYSTEMS

1-1 NEW SYSTEMS

1-1.1 For new systems refer to **\1** AFMAN 32-1040 *Civil Engineer Airfield Infrastructure Systems* **/1/**.

1-2 TEMPORARY SYSTEMS (CONSTRUCTION PROJECTS, AIR SHOWS, EXERCISES)

Submit requests for temporary use of expeditionary Aircraft Arresting Systems (AAS) to HQ AFIMSC/IZB at least two months before the system must be in place and operational. (Air National Guard units request support through the Air National Guard Civil Engineer Technical Support Center [NGB/A7OC], Minot, ND).

1-2.3 Information Required

Give the following information in all requests:

- Number of systems needed.
- Reason the systems are needed, including the type of aircraft that will be using the systems.
- Geographic location of the requirement including the Stock Record Account Number (SRAN).
- Date the systems need to be operational.
- Date the systems can be removed.
- Points of contact and telephone numbers for the AAS Shop, Airfield Management, Safety, and Fire Department.

1-2.4 Operations and Maintenance Personnel

With the request for temporary AAS support for a mission, specify the intended source and the number of personnel who will operate and maintain the expeditionary system(s) at the site, including qualification levels.

1-2.5 Funding Source

The requesting activity must provide a fund citation to cover all costs associated with supporting the expeditionary installation. Including costs for:

- Shipment of the equipment.
- Transportation and per diem for temporary duty personnel.

- Expendable materials such as tapes, cables, and repair materials and parts including fuels, oils and lubricants.
- Repair or replacement of damaged items.
- Installation costs for equipment, materials, and other supplies.

1-2.6 Where to Send Requests

Send the information to the appropriate MAJCOM Civil Engineer at the appropriate address below (e-mail requests are encouraged):

AFIMSC Det 8 (ACC),

AFCENT/A7O,

NGB/A7OC,

AFIMSC Det 4 (USAFE),

AFIMSC Det 2 (PACAF)

1-2.7 Processing Time

The appropriate MAJCOM Civil Engineer evaluates each request on the basis of availability of personnel, equipment, and priority. It approves or disapproves requests within 10 working days.

CHAPTER 2 SITING SYSTEMS

2-1 INTRODUCTION

AAS and emergency overrun barriers are installed in several configurations. Typically, overrun barriers (nets such as MA-1A and BAK-15) and emergency arrestors such as E-5 chain gear (CHAG), Textile Brake, or soft ground arrestor systems (such as Engineered Material Arrestor Systems (EMAS) are installed as redundant systems for emergency recovery only. As such, they are installed in the overrun area of the runway. Operational arresting systems, such as BAK-12, are usually installed between the runway thresholds. This is necessary to allow pilots to touch down on the normal landing surface and stabilize the tail-hook before engagement. Fairlead beams or runway edge sheaves are used to direct the purchase tape path, and are installed on the runway shoulders to allow the energy absorber to be installed outside the mandatory zone of frangibility (at least 84 meters [275 feet] away from the runway centerline). Support ramps are constructed to lead up to exposed vertical surfaces of fairlead beams and tape tubes, allowing an aircraft to roll over them smoothly. Arresting gear that is installed on grade must have an "airfield friendly" structure built over it to protect the equipment from environmental degradation. The design should be in compliance with Typical Installation Drawings 67F2011A (on-grade with shelter) or 67F2012A (installed below grade within a vault), as applicable, this instruction, the applicable 35E8-series T.O., and the requirements detailed within UFC 3-260-01 (Chapter 3 and Appendix B13). Do not install any arresting system where the run-out will conflict with any other arresting system or any obstacle such as elevated airfield lights or signs. Although intervening taxiways may be within the run-out area, such cases should be avoided if possible to preclude blocking the intersection during an engagement, and increased wear to tapes caused by dragging them through the warped pavement interface between a centerline crowned taxiway and the runway. In cases where criteria cannot be met, a waiver must be established according to UFC 3-260-01 and/or the applicable 35E8-series T.O., as appropriate.

2-2 SITING OPERATIONAL SYSTEMS

The large rectangular pavement markings (fixed distance markings) located 300 meters (1000 feet) from the threshold represent the ideal aim point for pilots on approach to landing. Other visual landing aids, such as the visual glide slope indicator system, cue the pilot to touch down approximately 300 meters (1000 feet) from the threshold. This ensures a minimum threshold crossing height of at least 11 meters (35 feet). Since stabilizing the tail-hook after touchdown requires a distance of 150 to 240 meters (500 to 800 feet), the best location for an arresting system that accommodates approach end engagements is 450 to 540 meters (1500 to 1800 feet) from the threshold. Runways used extensively during instrument meteorological conditions may require that the system be sited as much as 670 meters (2200 feet) from the threshold; however, if aircraft that are not compatible with trampling the pendant must operate on the same runway, the installation commander may shift the installation site as close to the threshold as possible, but not closer than the distance that will allow an unobstructed runout with a standard BAK-12 system set-up (see paragraph 3.14 and T.O. 35E8-2-5-1, *Operation and Maintenance Instructions – Aircraft Arresting System Model BAK-12*). It is critical that the runout area for an aircraft engaging the system from either direction not conflict with other AAS components (cables or cross runway troughs) or other equipment such as threshold or runway end light fixtures. Other operating scenarios, such as northern tier locations with heavy snow or ice accumulation, may dictate that you place an additional system at the midpoint of the runway. The installation commander must approve installation of a midfield AAS after coordinating the plan with the host MAJCOM/A3, SE, and MAJCOM Civil Engineer.

2-3 SITING EMERGENCY SYSTEMS

Locate unidirectional AAS and barriers (nets) in the overrun area of the runway. The energy-absorbing device dictates the distance from the threshold because of the need to maximize system run-out. Do not locate unidirectional systems or net barriers closer than 11 meters (35 feet) from the threshold of the runway. Note: Runway threshold markings begin 6 meters (20 feet) inboard of the full-strength pavement; therefore, do not install a unidirectional system within 17 meters (55 feet) of the beginning of the longitudinal threshold markings. Do not mark AAS warning markings on the pavement in overruns, or install arresting gear marker (AGM) lighted signs adjacent to AAS in the overrun to identify the locations of these systems. Installation of these markings and signs might cause a pilot to attempt an approach end engagement with the system.

CHAPTER 3 INSTALLATION REQUIREMENTS

3-1 MANDATORY REQUIREMENTS AND WAIVERS

Comply with the following standards when locating, configuring, installing, or repairing an AAS. BCEs must obtain the installation commander's approval and coordinate with MAJCOM/A3, SE, and MAJCOM Civil Engineer before deviating from these standards. A waiver to UFC 3-260-01 or the applicable 35E8-series T.O. will be required if these standards cannot be met. See paragraph 3-10 for information with regard to systems installed under previous standards.

3-2 LOCATING ARRESTING SYSTEMS

The BCE's designated representative determines the configuration and location of arresting systems in cooperation with representatives from A3 and SE. Design must conform to the configuration criteria of the appropriate 35E8-series T.O., the Typical Installation Drawings, the requirements in this FC, and UFC 3-260-01. In cases where criteria cannot be met, a waiver must first be established and approved according to UFC 3-260-01 and/or the applicable T.O., as appropriate.

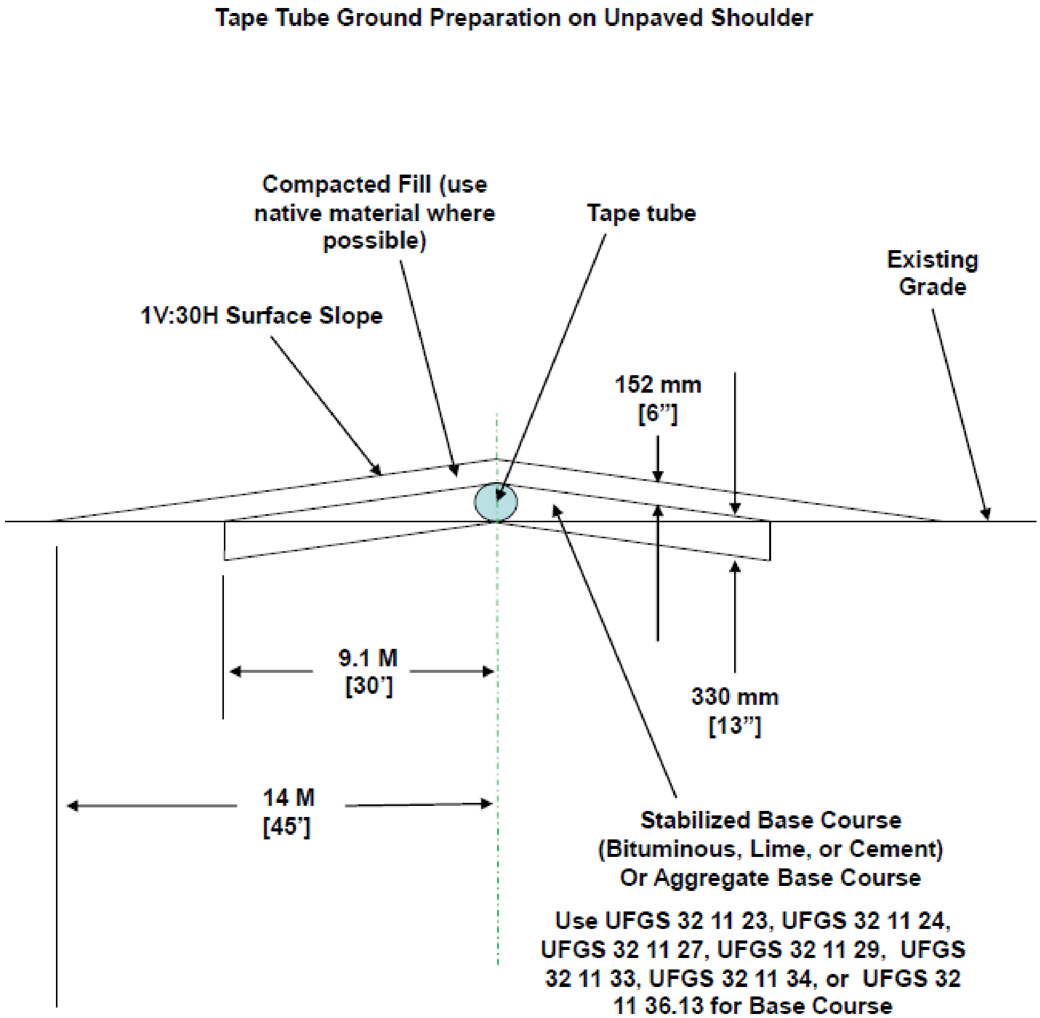
3-3 PLACEMENT OF ENERGY ABSORBERS

Locate all energy absorbers below grade or at least 84 meters (275 feet) from the runway centerline. (Exceptions: MA-1A and E-5 ship’s anchor chains and textile brake modules may be located along the runway overrun shoulders. Bi-directional textile brake modules may be located either along the overrun or runway shoulders.) Provide paved transitions and buried crushed stone ramps around the arresting system components and a paved service road to the site from the runway, as well as a location other than the runway (beyond the controlled movement area or outside the Runway Safety Area (RSA) on civil airfields). Pit-type installations may be sited closer to the runway as long as they meet the minimum split-distance required (15.2 meters (50 feet) for BAK-12); however, all above-grade appurtenances must be frangible, the transition to the pit cover must meet runway shoulder grade allowances given in Chapter 3 of UFC 3-260-01, and the pit cover and door must be designed to support wheel loads in accordance with UFC 3-260-01, Chapter 3, “Shoulders” (paved or unpaved, as applicable).

3-4 SHOULDER REQUIREMENTS

Where fairlead beams, edge sheaves, and tape tubes project above the grade of the existing runway shoulders, provide suitable fill materials and compaction next to or over these components to a finished grade of 1V:30H or flatter. Tape tubes must be steel or ductile iron. Tape tubes of other materials must be programmed for replacement and inspected monthly for signs of damage or degradation. For new installations, select tape tubes that are capable of supporting wheel loads in accordance with UFC 3-260-01, Chapter 3, “Shoulders” (paved or unpaved, as applicable). See Figure 3-1 for construction details.

Figure 3-1 Unpaved Runway Shoulder Construction Details Adjacent to Tape Tubes



3-5 OBSTRUCTION MARKING AND LIGHTING REQUIREMENTS

Provide obstruction marking and lighting and arresting system location marking and lighting according to the provisions of **\1** UFC 3-260-04, *Airfield and Heliport Marking* **/1/** and UFC 3-535-01, *Visual Air Navigation Systems*. This requirement also applies to temporary installations for construction or air shows unless waived within the temporary waiver by the Installation Commander or the designated authority. See UFC 3-260-01, Appendix B, Section 1. Do not mark AAS warning markings on the pavement in overruns, or install arresting gear marker (AGM) lighted signs adjacent to AAS in the overrun to identify the locations of these systems. Installation of these markings and signs might cause a pilot to attempt an approach end engagement with the system.

3-6 ABOVE-GRADE SYSTEM SHELTERS

Provide protective shelters constructed for on-grade installations must be constructed from lightweight framing materials and sheathing using connections that will allow the structure to break away or collapse if struck by an aircraft wing. See UFC 3-260-01, Appendix B, Section 13. Provide shelters with a removable roof or end wall, or a door opening to facilitate major maintenance or replacement of the equipment. Also provide proper ventilation and windows that will allow the operator to view the runway and tape sweep areas in both directions. See Typical Installation Drawing 67F2011A, Sheet 2, Note 3.

3-7 PAVEMENT ADJACENT TO CABLES

3-7.1 The center 23 meters (75 feet) of pavement extending out for 60 meters (200 feet) on both the approach and departure sides of the arresting system pendant are critical areas. Exception: 46 meter (150-foot) -wide runways with BAK-14 systems, the critical area is limited to the off-center engagement capability for the BAK-14 system, which is the center 18 meters (60 feet) of runway pavement. For wider runways, the critical area is the center 23 meters (75 feet) of runway pavement for BAK-14 or any other model AAS, regardless of the stated off-center engagement capability.

3-7.2 Within these critical areas, protruding objects such as centerline lights or reflectors, excessive paint build-up, and undulating surfaces are detrimental to successful tail-hook engagements and are not allowable. The maximum permissible longitudinal surface deviation in this area is ±3 millimeters (±0.125 inch) in 4 meters (12 feet). This does not apply to the channels in grooved pavement surfaces.

3-7.3 The prohibition on changes in pavement type does not apply to arresting system cables located in overruns because overruns are constructed of asphaltic pavement, and the first 305 meters (1000 feet) of runways are constructed from Portland cement concrete (PCC).

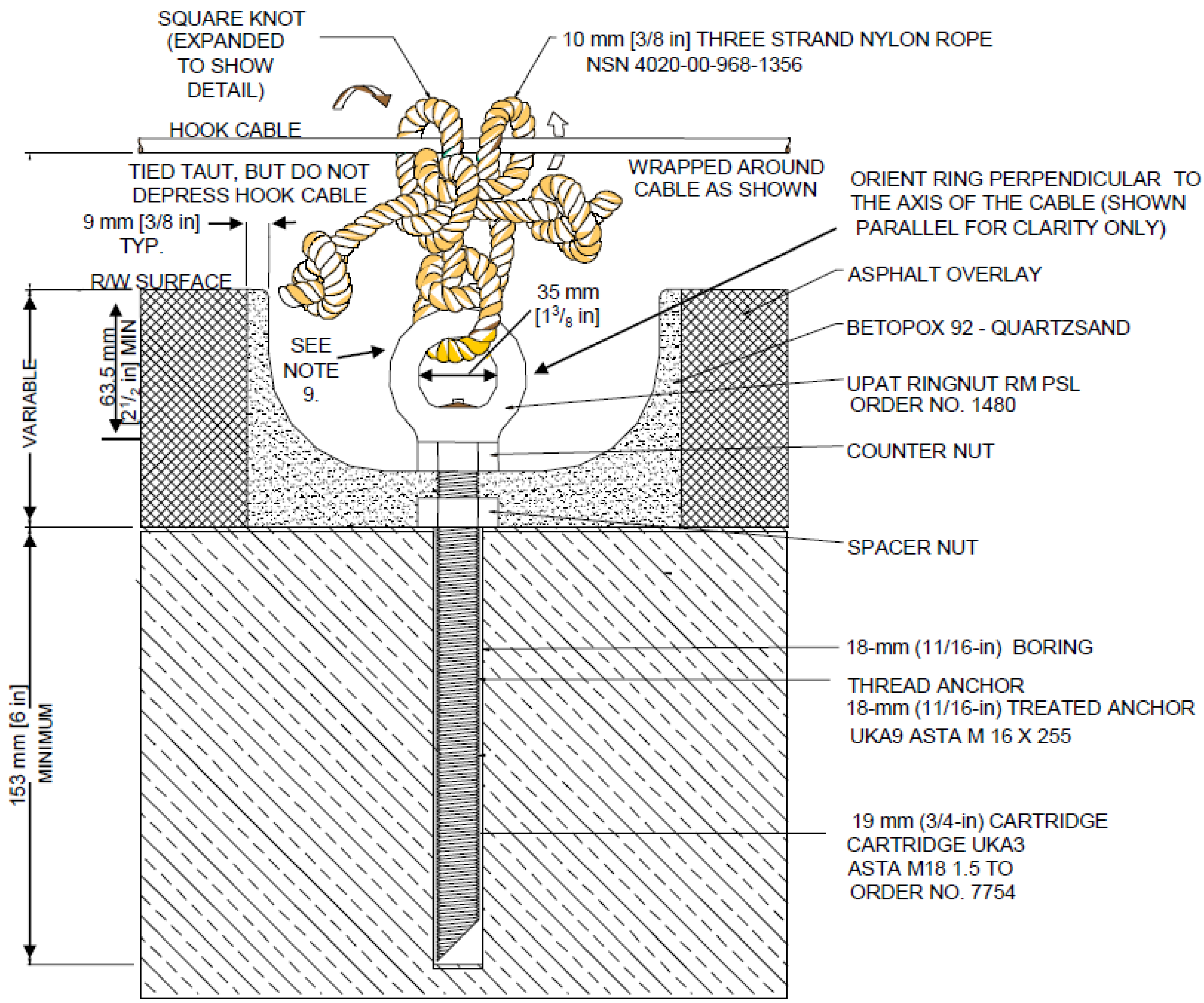
3-7.4 Grooves to improve surface drainage and surface friction characteristics are not permitted within 3 meters (10 feet) of arresting system cables due to potential for increased surface wear due to cable slap during trampling.

3-7.5 Changes in pavement type or an interface between rigid and flexible pavements are not permitted within 60 meters (200 feet) of arresting system cables in the center 23 meters (75 feet) of the runway. This does not apply to emergency systems located within overruns, sacrificial panels installed beneath cables, or to PCC anchor blocks installed for anchoring cable tiedowns in flexible pavement systems. These are not considered a change in pavement type because the individual foundations are not formed continuously from one tiedown to the next. This specifically prohibits rigid inlays from being used as a surface repair material beneath the cable in flexible runway pavement systems like hot mixed asphalt (HMA). This type repair causes high hook-skip potential when the flexible pavement consolidates, exposing the leading edge of the rigid pavement. However, rigid pavement must be used as a foundation under sacrificial panels installed beneath AAS cables in both rigid and flexible pavement systems. In these cases, no part of the rigid foundation can be used as a top-wearing surface.

3-8 CABLE ANCHOR INSTALLATION REQUIREMENTS

Install cable tiedown anchors for operational systems (systems located between the runway thresholds) to limit cable bounce and potential aircraft damage during aircraft rollover. Install eight anchors for all operational systems regardless of primary aircraft supported on the airfield. Program systems with four anchor points to be upgraded to eight anchor points. When using the Mobile Aircraft Arresting System (MAAS) or other expeditionary cable systems for other than an air show or a short-term construction project, add cable tiedowns to the runway to prevent aircraft damage during aircraft roll-over and engagements. This also applies at forward operating locations, but may have to be postponed until time and materials are available to accomplish the work. Install anchors at 3-meter (10-foot) intervals centered on the runway width for eight-point tiedowns. For rigid pavements, it is desirable that all anchor locations be offset at least 609 millimeters (24 inches) from pavement joints. The minimum offset from pavement joints for anchor locations is 300 millimeters (12 inches). If sacrificial panels will be installed, see paragraph 3-14 for anchor spacing. See Figures 3-2 through 3-6 for various cable tiedown designs and installation details. Any of the three styles of anchors may be used for flexible or rigid runway pavements but the anchor block details shown in Figure 3-6 and the Typical Installation Drawings 67F2011A and 67F2012A are specifically designed for flexible pavement systems.

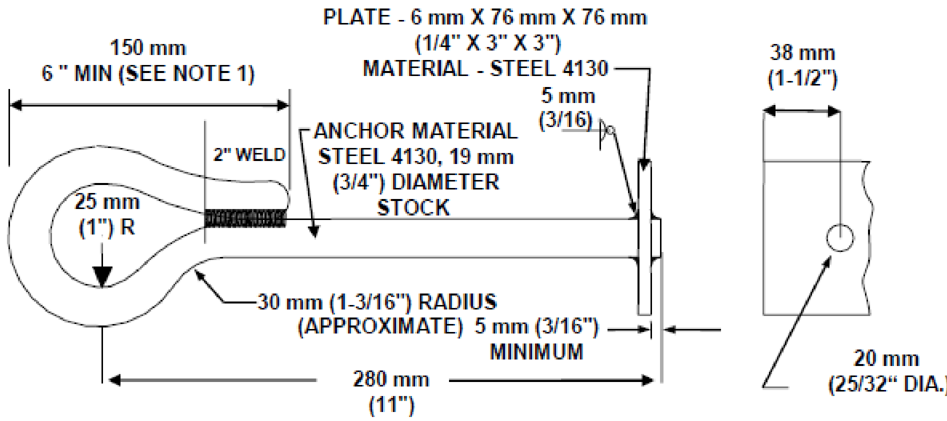
Figure 3-2 Designed Tiedown for Porous Friction Surfaces
(formerly "Alternate Cable Tiedown Anchor Installation")



NOTES:

1. See paragraph 3-8 on cable tie-downs and locations for number and placement of tie-downs.
2. Tie-down ropes will be approximately 1,200 millimeters (48 inches) long.
3. Ring nut shall be perpendicular to pendant cable.
4. Minimum anchor insertion into Portland cement concrete shall be 153 millimeters (6 inches).
5. Tie-down anchor bowl shall not exceed 127 millimeters (5 inches) in diameter.
6. Ring nut shall be tightened to full thread depth and locked to the anchor with a thread locking compound.
7. Threaded anchors shall be set with an impact type drilling machine.
8. See paragraph 3-8 for placement of anchors within 609 millimeters (24 inches)
9. Top of ring nut shall be recessed approximately 12 millimeters (0.5 inch) below the runway surface.

Figure 3-3 4130 Grade Steel Cable Tiedown Anchor



NOTE:

This area must be cadmium plated and conform to spec QQ-P-416 Class 1, Type 1.

Figure 3-4 Installation of 4130 Grade Steel Cable Tiedown Anchor

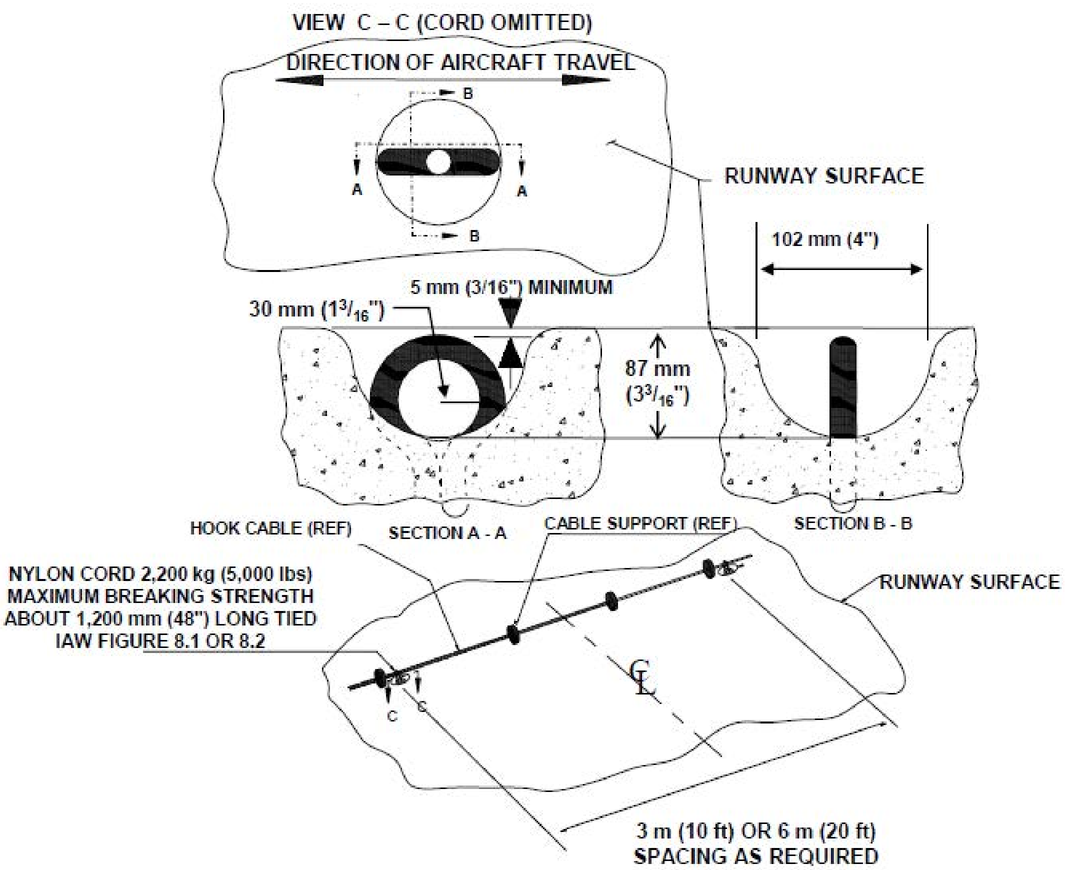
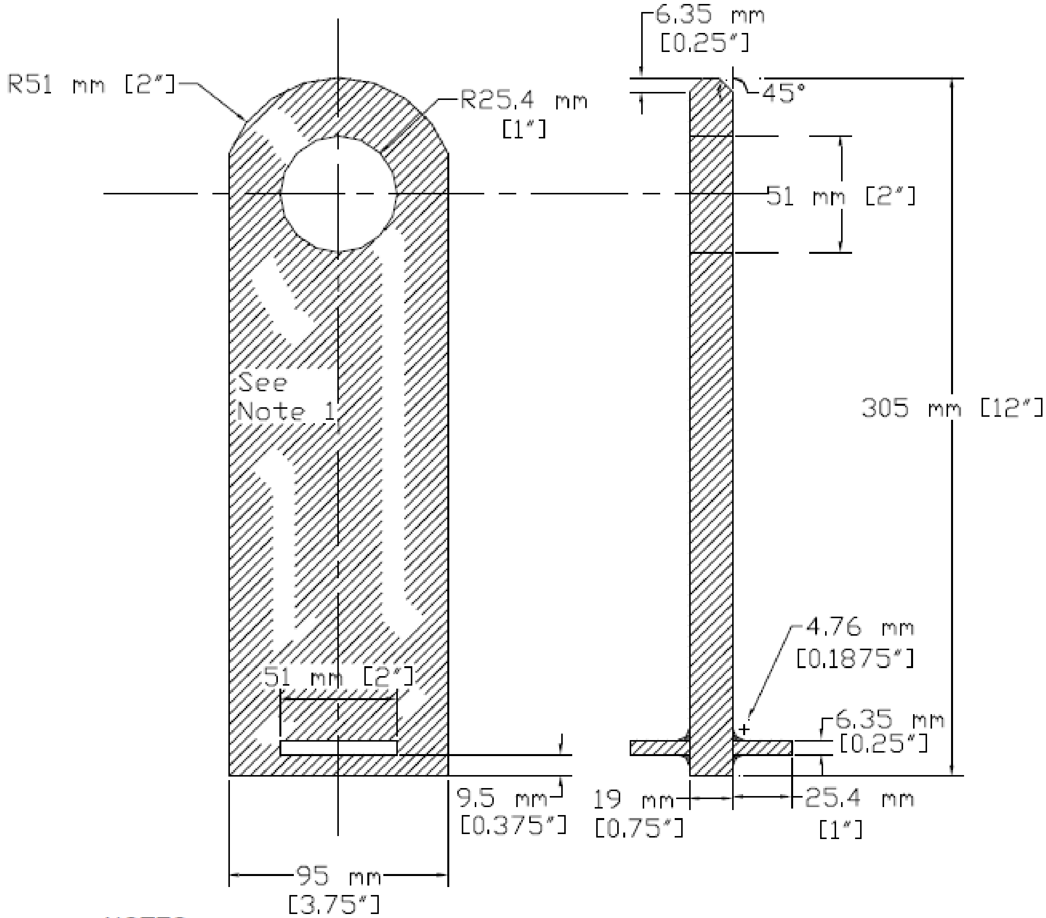


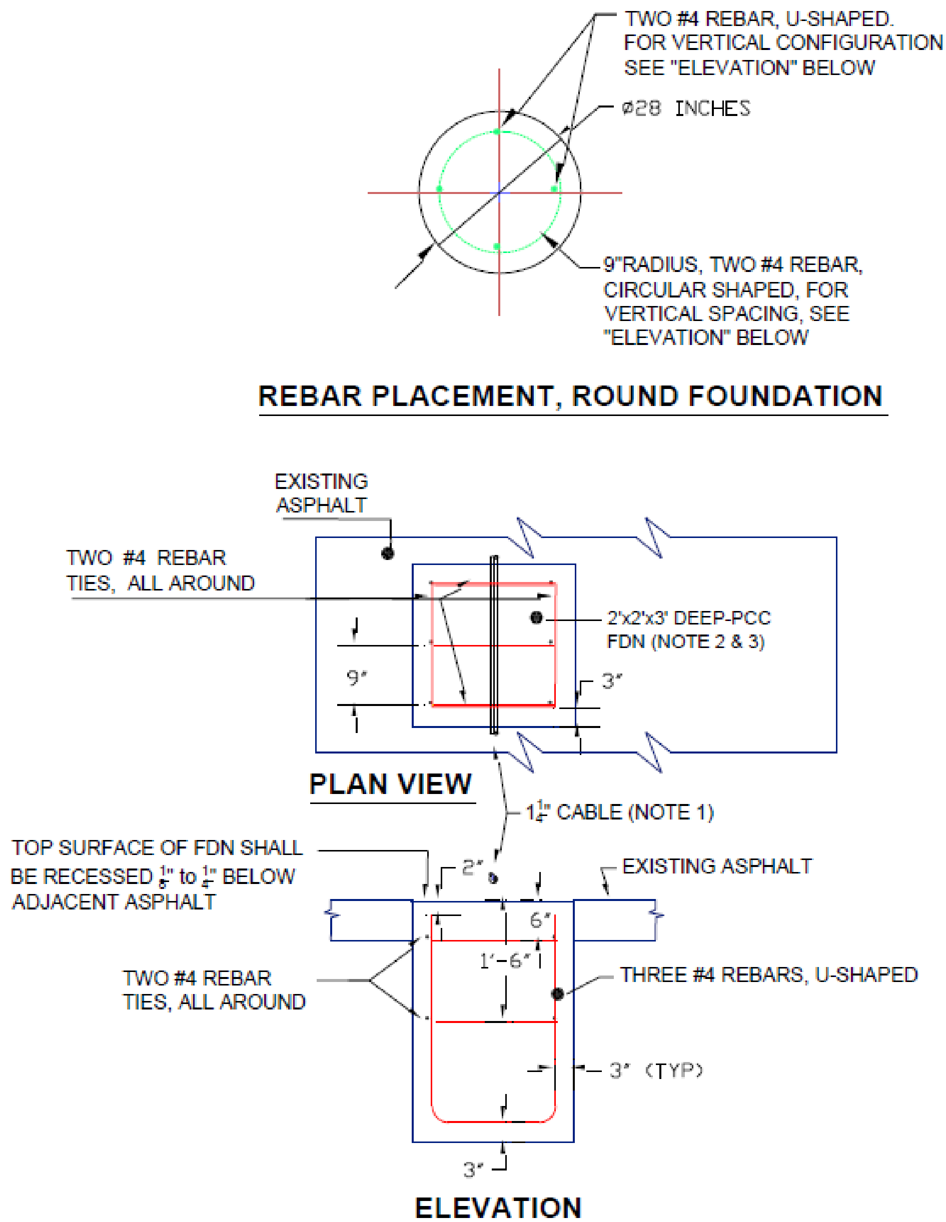
Figure 3-5 Locally Manufactured Cable Tiedown Anchor



NOTES:

1. Anchor stock is ASTM A36 steel, 19 mm [$\frac{3}{4}$"] by 95 mm [3.75"].
2. Anti-pull-out wings are 6.35 mm [1/4"] by 51 mm [2"] by 25.4 mm [1"] ASTM 36 flat bar with 4.76 mm [$\frac{3}{16}$"] fillet weld all around.
3. Chamfer top edges of anchor radius 6.35 mm [$\frac{1}{4}$"] at 45°.
4. Remove sharp edges from 52 mm [2"] diameter through hole.
5. Coat with cold galvanized coating or two-part epoxy paint suitable for marine applications.
6. Orient anchor with the hole aligned parallel with the cable.

Figure 3-6 Tiedown Foundation Detail for Flexible Pavement Systems



NOTES:

1. CENTER FOUNDATION UNDER CABLE.
2. LOCATE ANCHOR IN CENTER OF FOUNDATION.
3. CUT ASPHALT AS REQUIRED TO EXCAVATE FOR, AND PLACE PORTLAND CEMENT CONCRETE FOUNDATION. FOUNDATION MAY BE ROUND (28" DIAMETER) TO ALLOW USE OF AUGER FOR EXCAVATION.

3-10 GRANDFATHERED SYSTEMS

On-grade BAK-12 systems installed before 1 July 1977 that are sited at least 76.2 meters (250 feet) from the runway centerline do not have to be relocated to meet the minimum setback requirement of 84 meters (275 feet) from the runway centerline. All systems equipped with 2-roller edge sheaves or 2-roller fairlead beams must be programmed for retrofit with 3-roller fairlead beams or edge sheaves to eliminate the longitudinal wheel abutment along the runway shoulder. Replacement foundations must be constructed as described in paragraphs 3.3, 3.4, and Typical Installation Drawings 67F2011A or 67F2012A to comply with the 1V:30H (3.3 percent) maximum slope requirement along the runway shoulder (see UFC 3-260-01, Table 3.2). The unpaved shoulder areas adjacent to the tape tubes must be constructed to comply with Figure 3-1.

3-11 INSTALLING SYSTEMS AT JOINTLY-USED AIRPORTS

3-11.1 The FAA acts for and on behalf of the DoD Service component in operating arresting systems installed at jointly used civil airports for the primary use of U.S. military aircraft.

3-11.2 Site arresting systems on civil airports jointly used by civil and military aircraft according to FAA Advisory Circular (AC) 150/5220-9, *Aircraft Arresting Systems*.

3-11.3 To install an arresting system at a jointly used civil airport, the installation commander must first notify the airport manager (or authority) of the need. If the airport manager agrees, the installation commander submits the plan with sketches or drawings to the Air Force liaison officer at the FAA regional office. Refer any disagreement between the responsible officials to the next higher level within the chain of command.

3-11.4 If construction involves a lease agreement that does not allow placing additional structures on the leased premises, contact the MAJCOM Civil Engineer.

3-11.5 Third-party claims presented for damage, injury, or death resulting from FAA operation of the system for military aircraft or from the Air Force or Air National Guard maintenance of the system may be the responsibility of the Air Force. Process such claims under the appropriate Air Force regulatory guidance (AFI 51-502, *Personnel and Government Recovery Claims*).

3-11.6 The FAA is responsible for claims presented for damage resulting from FAA operation of the system for civil aircraft; therefore, separate agreements between DoD and FAA concerning liability for such damage are not necessary.

3-11.7 The MAJCOM negotiates the operational agreement with FAA for a jointly used civil airport. The MAJCOM may delegate this authority to the installation commander. The agreement describes FAA functions and responsibilities concerning the remote-control operation of arresting systems by FAA air traffic controllers. See Appendix C for a sample letter of agreement.

3-12 MILITARY RIGHTS AGREEMENTS FOR FOREIGN LOCATIONS AND USE BY NON-U.S. GOVERNMENT AIRCRAFT

3-12.1 Install these systems under the military rights agreement with the host government. The installation commander coordinates any separate agreements required with the local U.S. diplomatic representative and negotiates the agreement with the host nation. If the parties are unable to agree, refer the issue to the MAJCOM.

3-12.2 In an emergency, the pilot of a non-U.S. Government aircraft may request and use arresting systems at Air Force bases and jointly used airports within the CONUS and overseas.

3-13 STANDARD BAK-12 SYSTEM SETUP

3-13.1 For any of the three installation methods described within T.O. 35E8-2-5-1, site selection should be made to accommodate a standard system configuration for the allowable runout area.

3-13.2 For a 1200-foot (366-meter) runout, a standard system configuration for maximum BAK-12 runout includes a 1260-foot (384-meter) paved runout area (maximum runout plus aircraft length). Establish synchronization pressure, cam advancement, relief valve setting, tape stack height and cam gearbox drive sprocket size according to T.O. 35E8-2-5-1 Chapter 5. The system must also be equipped with a 1.25-inch (32-millimeter) -diameter pendant, supported by 6-inch (152-millimeter) -diameter support disks (donuts) or a BAK-14 or Type-H Hook cable support system.

3-13.3 For a 950-foot (290-meter) runout, a standard system configuration for a standard BAK-12 overrun runout includes a 1010-feet (308-meter) paved runout area (standard runout plus aircraft length).. Establish synchronization pressure, cam advancement, relief valve setting, tape stack height and cam gearbox drive sprocket size according to T.O. 35E8-2-5-1 Chapter 5. The system must also be equipped with a 1.25-inch (32-millimeter) -diameter pendant, supported by 6-inch (152-millimeter) -diameter support disks (donuts) or a BAK-14 or Type-H hook cable support system.

3-13.4 For a 900-foot (274-meter) runout, a standard system configuration for a 900-foot (274-meter) BAK-12 overrun runout includes a 960-feet (293-meter) runout area (standard runout plus aircraft length). Establish synchronization pressure, cam advancement, relief valve setting, tape stack height and cam gearbox drive sprocket size according to T.O. 35E8-2-5-1 Chapter 5 The system must also be equipped with a 1.25-inch (32-millimeter) -diameter pendant, supported by 6-inch (152-millimeter) -diameter support disks (donuts) or a BAK-14 or Type-H Hook cable support system.

3-13.5 For runway widths greater than 200 feet (61 meters), the control cam must be changed. Refer to T.O. 35E8-2-5-1 Table 5-5.

3-13.6 Once the site has been selected and the system installed, the Aircraft Arresting Systems Report (RCS: HAF-ILE [AR] 7150) must be submitted in accordance with paragraph 7, and a copy provided to the airfield manager. Information pertaining to location (with respect to runway thresholds) and runout must be published within the DoD Flight Information Program (FLIP). Once this has been reported and published, any change to the standard configuration (system runout, pendant cable diameter, or donut size) must not be made without an approved waiver from the Air Force Life Cycle Management Center (AFLCMC) and concurrence from the installation commander, and the MAJCOM Civil Engineer.

3-14 INSTALLATION OF ULTRA-HIGH MOLECULAR WEIGHT (UHMW) POLYETHYLENE PANELS BENEATH CABLES FOR HEAVILY TRAFFICKED PAVEMENTS

3-14.1 In cases where aircraft repeatedly trample donut-supported AAS cables, the pavement directly beneath the cable will erode to form a transverse groove in the pavement across the runway. This section provides procedures, material requirements, and other pertinent information for installation of UHMW polyethylene panels under AAS cables to prevent this damage. It also includes panel specifications and installation. Inspection guidelines are listed in Chapter 4.

3-14.2 Requirements of this FC are mandatory where UHMW panel installations are necessary. Designers should also consider a thickened slab under UHMW panels for new construction to ensure adequate runway pavement strength and sufficient anchoring depth is provided for panel studs and cable tiedown anchors. Installation of UHMW panels is also the preferred method of repair for existing pavements that are distressed from cable trampling. Other repair options such as installation of a hook cable support system (like BAK-14 or Type H) may be justified based on economy or mission.

3-14.3 AAS cables impact underlying pavement by eroding a groove in the pavement directly beneath the cable. The pendant support disks (donuts) must rest in the groove when the cable is in a pre-tensioned state, lowering the effective pendant height (EPH), and reducing the potential for a successful engagement. When the EPH is below 38 millimeters (1.5 inches) there is even higher potential the aircraft hook may not engage the cable, as well as a requirement to publicize the reduced engagement potential to aviators (see paragraph 4-5.2). These areas must be repaired to maintain a uniform pavement surface and the proper EPH to ensure reliability of the arresting system.

3-14.4 Materials must be easily installed and must be minimally susceptible to warping or rapid wear. They must also be cost effective. The Air Force has used numerous pavement repair materials under arresting system cables with varying performance, from satisfactory to very poor. Most of these repairs have been costly and/or eroded quickly. Therefore, the pavements subject matter experts have established that in cases where preformed panels are the best repair option, UHMW panels should be specified. Further, it is absolutely critical to keep panels flush with, or, preferably, slightly recessed 1.6 to 3.2 millimeters (0.0625 to 0.125 inches) below the adjacent pavement surface. Thermal compatibility of the panel material and pavement, security of the anchoring system, and elevation and smoothness of the adjacent pavement and joint seals are extremely important. If possible, plan to install the panels and sealant during average annual temperatures to allow for optimum sealant placement. If the panels are placed in cold weather the joints will tend to close completely in hot weather. If placed in hot weather the joints will tend to be too wide during cold weather. For this reason, it is desirable to use light-gray colored panels to help minimize thermal expansion and contraction (see some recommended panel colors in Figure 3-7).

Figure 3-7 Preferred Panel Colors from FED STD 595, *Colors Used in Government Procurement*

36173		Low solar absorbent gray #17
36231		Gray #23 (36231 replacement of MIL-MIL-DTL-700, Formula 20L)
36270		Low solar absorbent gray #27 (also with anti-stain properties)
36307		Gray #30 (Bulkhead gray)
36373		Low solar absorbent gray #37 (Light gray, color#26373)
36492		Gray #49 (Gull or pearl gray)

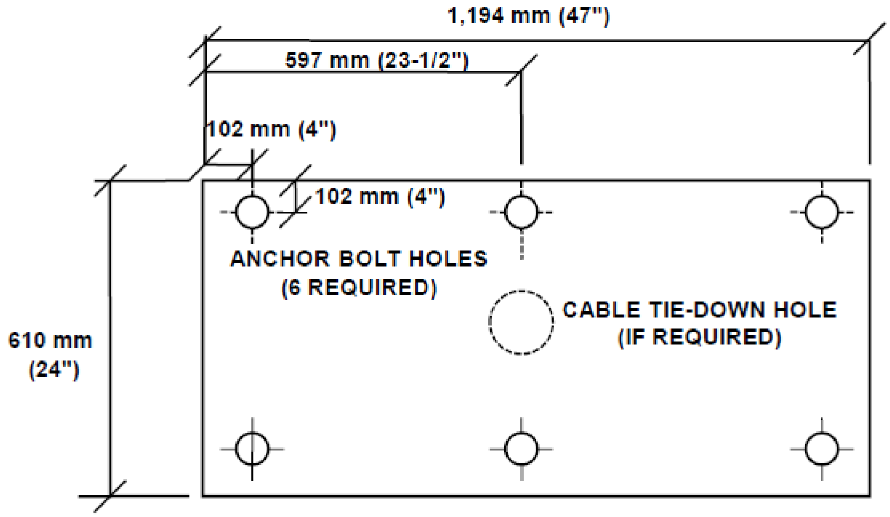
3-14.5 Generally, uncut panel stock is 1220 millimeters (48 inches) wide by 3048 millimeters (10 feet) long by 38 millimeters (1.5 inches) thick (panel stock must not be less than 36.5 millimeters (1.4375 inches) nor more than 38.1 millimeters (1.5 inches)). This allows five 1220 millimeter (48 inch) –long panels to be cut from the 3048-millimeter (10-foot) -long stock with minimal waste. To reduce panel warping and damage to joints from cable impact, panels should nominally be 610 millimeters (24 inches) wide for all installations. Cut panels in lengths so panel joints line up with runway pavement joints. Do not allow panels to overlap pavement joints. This prevents pavement, anchor, or panel failure due to thermal expansion or contraction. For runways with slabs sized in 1524-millimeter (5-foot) increments, such as those having 6-meter (20-foot) longitudinal paving lane joint spacing, panels should be 1207 millimeters (47.5 inches) long. Panels may be shorter but must never exceed 1219 millimeters (4 feet). Order prefinished panels in lengths to suit slab width(s) located beneath the AAS cable on the runway. Take care to ensure there will be no overlap of panels and pavement joints, and no panel anchors will be set closer than 4 inches from any joint. Overlap of joints will cause premature failure. Panels should be drilled and counter-bored for hold-down anchors, and a 4-inch hole cut in the center of panels for those that must accommodate a cable tiedown anchor.

3-14.5.1 Panel Dimensions. Order panels cut to 24 inches wide by 48 inches long or less. Tolerance on panel length and width will be ±3.2 millimeters (±0.125 inch). Panel thickness will be no greater than 38.1 millimeters (1.5 inches) or less than 36.5 millimeters (1.4375 inches).

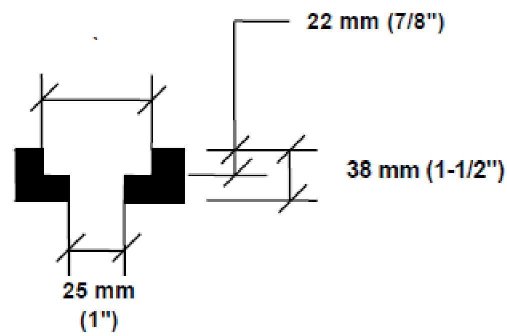
3-14.5.2 Anchor Stud Hole Locations and Dimensions. Each full-sized panel will have six anchor stud holes centered 102 millimeters (4 inches) from the edges of the panel corners and at mid-length. Each partial-sized panel will have four anchor stud holes centered 102 millimeters (4 inches) from the edges of the panel at each corner. The anchor stud hole will be 25.4 millimeters (1 inch) for the through hole and 51 millimeters (2 inches) for the countersink hole. The countersink hole will be 22 millimeters (0.875 inch) deep with square shoulders for a flat washer to lie against. Figure 3-9 shows dimensions and drilling details. Tolerances on dimensions for locations and diameters of anchor holes will be ±1.6 millimeters (±0.0625 inch).

3-14.5.3 Locating Cable Tiedown Anchor Holes. The agency ordering panels must specify the total number of panels required to be drilled to accommodate cable tiedown anchors (four or eight per inlay). The cable tiedown anchor hole must be 102 millimeters (4 inches) in diameter and drilled completely through the panel. Cable tiedown anchor holes will be located in the center of the panel. The location of the cable tiedown anchor hole is shown in Figure 3-8. Cable tiedowns must not be located closer than 305 millimeters (12 inches) from existing pavement joints. Install cable tiedown anchors for operational systems (systems located between the runway thresholds) to limit cable bounce and potential aircraft damage during aircraft rollover. Install eight anchors for all operational systems regardless of primary aircraft supported on the airfield. Program systems with four anchor points to be upgraded to eight anchor points (ref: paragraph 3-8).

Figure 3-8 Panel Dimensions and Anchor and Tiedown Locations



PANEL DIMENSIONS AND ANCHOR HOLE LOCATIONS



Detail of Anchor Hole

3-14.5.4 As indicated above, panel lengths must be sized to ensure panel joints do not overlap longitudinal pavement joints, or joints in the panel foundations. Lengths selected must also accommodate cable tiedown anchor spacing and minimize warping. To accomplish these goals, some slabs will require longer panels, mixed with some partial-length panels. These should be patterned to minimize the number of lengths needed, and spread uniformly across the runway width. Partial panels should never be used to accommodate a cable tiedown anchor. They should only be drilled at each corner. Tiedown anchors should only be placed in full length panels with six anchors. Figures 3-9 through 3-13 shows exact panel, and partial panel lengths, as well as appropriately adjusted spacing for cable tiedown anchors for various slab widths. The dimensions shown allow for 13-millimeter (0.5-inch) -wide joints between panels and pavement edges.

Figure 3-9 Cable Tiedowns for Panels Placed on 3.8-Meter (12.5-Foot) Slabs

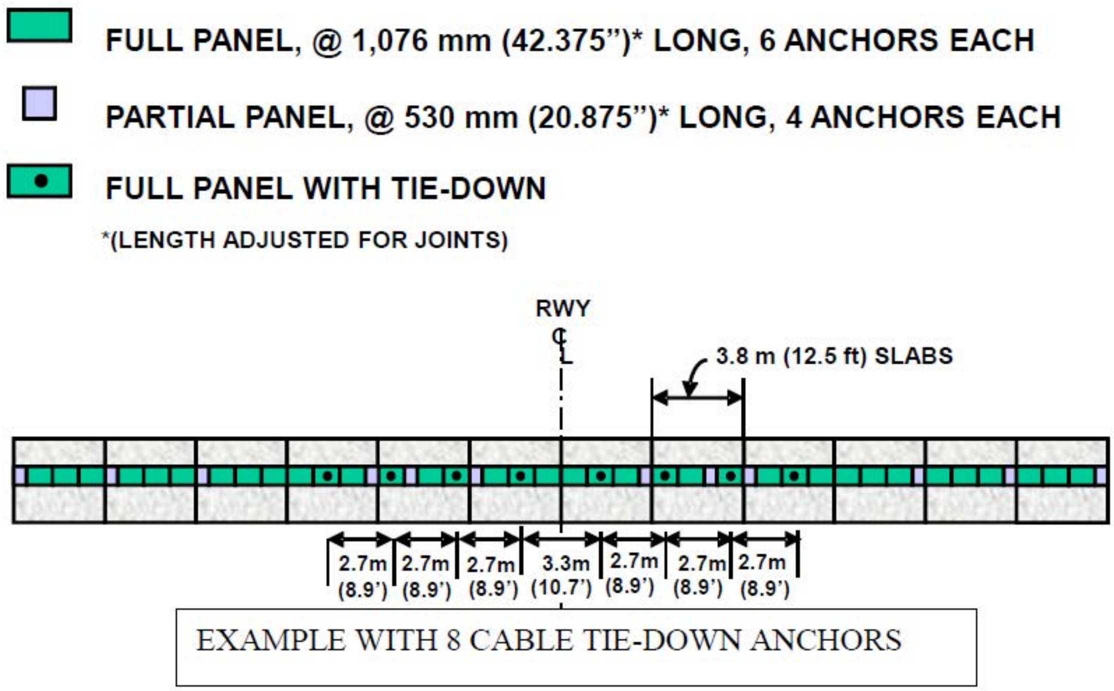


Figure 3-10 Cable Tiedowns for Panels Placed on 4.6-Meter (15-Foot) Slabs

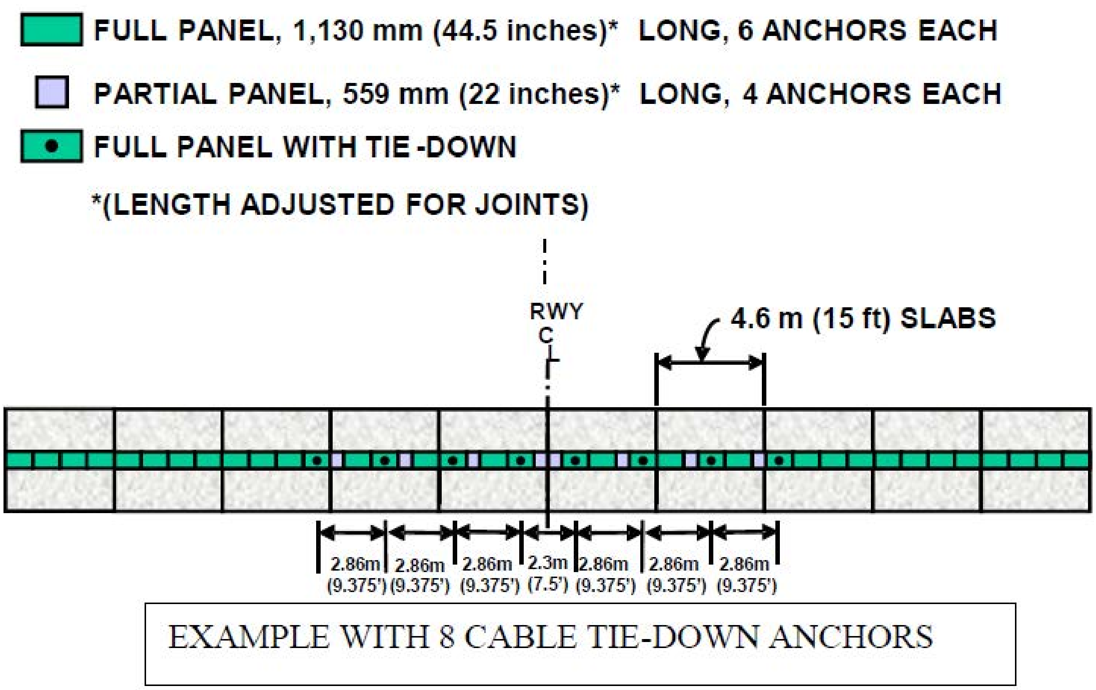


Figure 3-11 Cable Tiedowns for Panels Placed on 5.7-Meter (18.75-Foot) Slabs

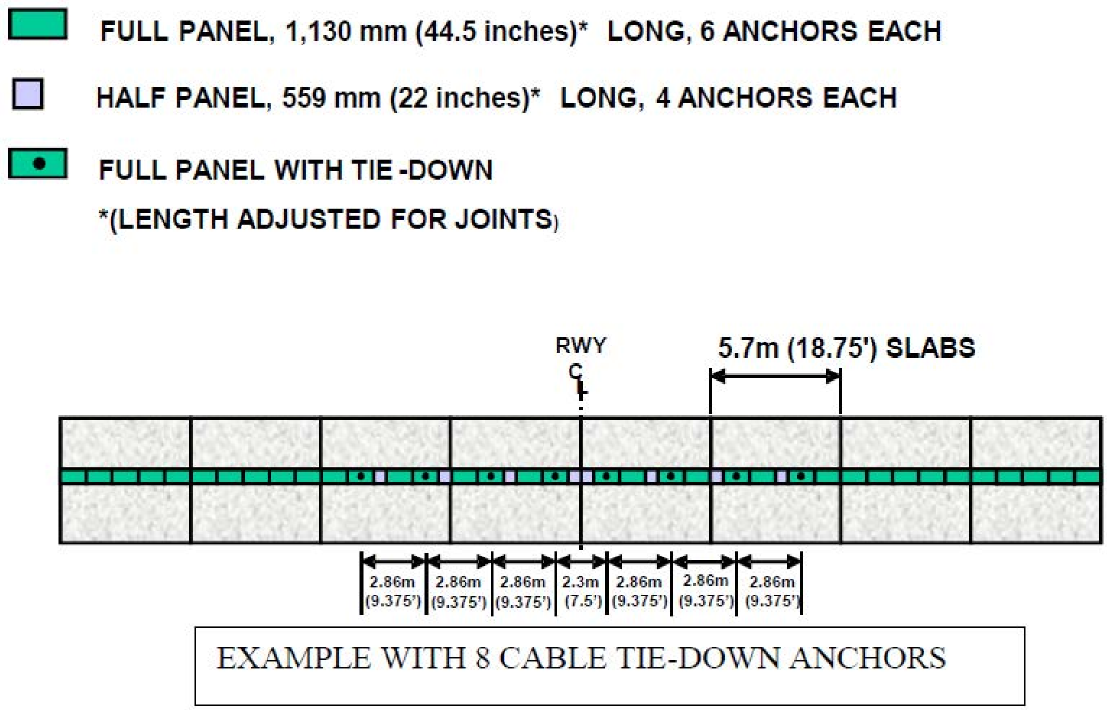


Figure 3-12 Cable Tiedowns for Panels Placed on 6-Meter (20-Foot) Slabs

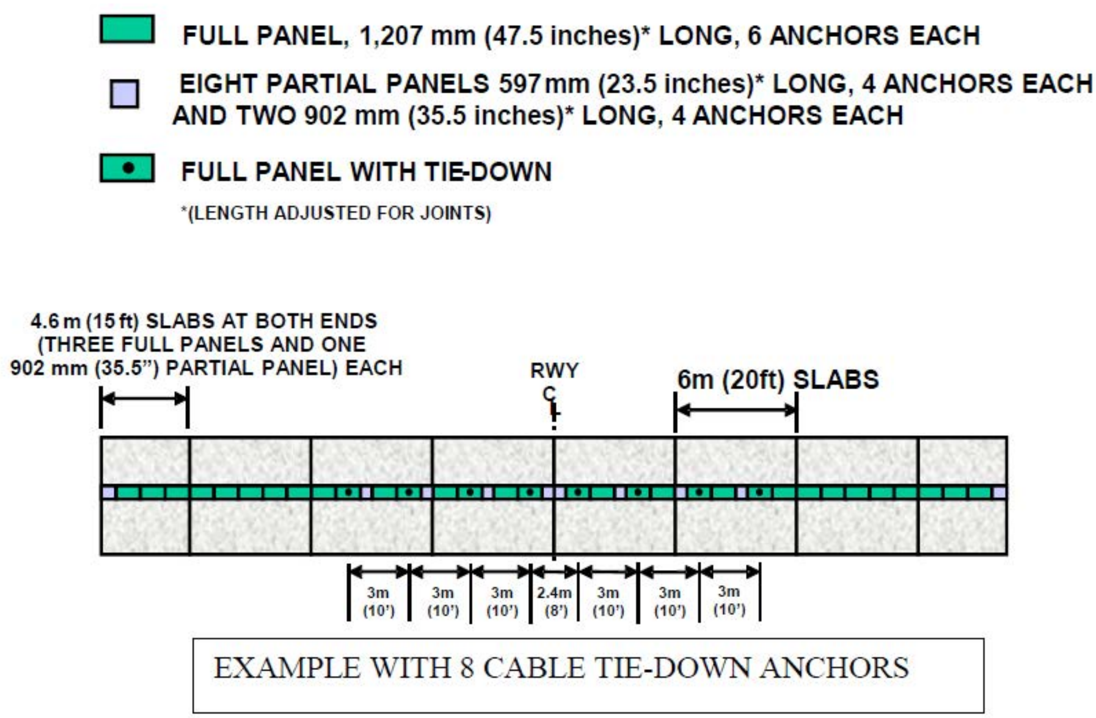
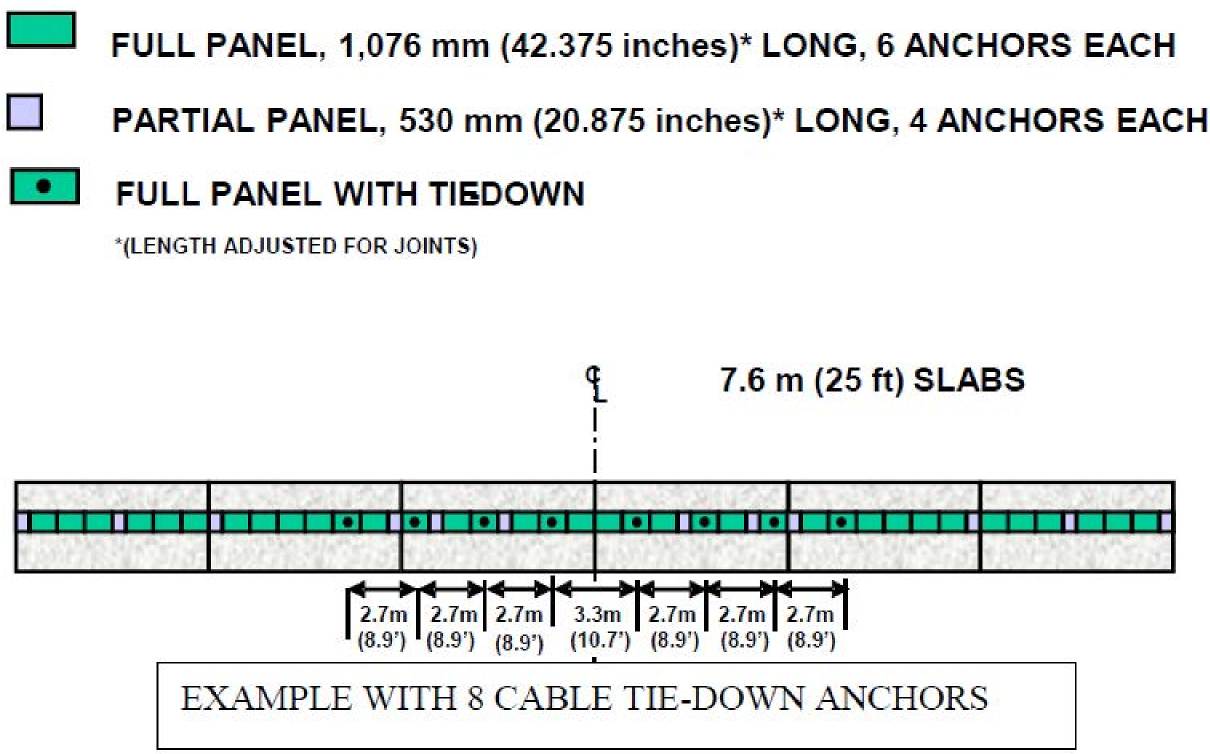


Figure 3-13 Cable Tiedowns for Panels Placed on 7.6-Meter (25-Foot) Slabs



3-14.6 The panels must be fabricated from virgin and/or recycled UHMW polyethylene and will be a variable shade of gray in color, and UV-stabilized. An antistatic additive must be added to the UHMW polyethylene and it must meet the physical requirements of Table 3-1.

Table 3-1 Physical Requirements for UHMW Polyethylene

Property	**Test Method**	**Requirement**
Density	ASTM D1505	0.92–0.94 g/cm
Tensile elongation at break	ASTM D638	300–400 percent
Tensile yield strength	ASTM D638	2800–4000 psi
Shore hardness "D"	ASTM C886	60–70
Coefficient of friction	ASTM D3028	0.2
Izod impact strength	ASTM D256, Method A (see Note)	>20 ft-lb/inch
Note: The test specimens must have two opposing 15-degree notches.		

3-14.7 When considering the installation of UHMW panels it is important to verify thickness of the existing pavement. The panels must be anchored in a sound concrete foundation. A typical anchor stud is 245 millimeters (9.625 inches) long and the foundation is drilled slightly deeper to ensure the anchor does not protrude above the panel when installation is completed. For this reason, a minimum slab thickness of 280 millimeters (11 inches) is needed to properly anchor the panels. If the existing concrete is not thick enough, you must remove and replace it with adequate thickness concrete prior to UHMW panel installation, or select alternative repair methods.

3-14.7.1 Flexible Pavement Systems

3-14.7.1.1 For installation in asphalt pavement:

- Saw-cut and remove a minimum 635-millimeter (25-inch) –wide transverse section of the asphalt and underlying materials to a depth of 915 millimeters (3 feet).

- Backfill the bottom of the trench with a well-graded crushed stone material and compact to a 305-millimeter (12-inch) thickness in 150-millimeter (6-inch) lifts.

- Place the 570 millimeters (22.5 inches) -thick concrete foundation for panel installation.

- Ensure the concrete foundation is finished on the same plane as the runway surface (matches transverse runway slope), and at the proper depth for the panel surface to be slightly below the adjacent pavement.

- Once the concrete is cured, proceed with installing and anchoring the panels as outlined in this section.

These instructions describe an installation procedure for an existing asphalt pavement. However, if installing UHMW panels in conjunction with construction of new flexible pavement (or reconstruction of an existing pavement), the above procedure is still recommended to allow uniform longitudinal compaction.

3-14.7.1.2 Installation in a Rigid Pavement System

For installation in Portland cement concrete (PCC) pavement:

- Prepare the receiving slot.
- Place a cementitious setting bed.
- Install the UHMW panels.
- Install panel anchor studs.
- Install new cable tiedown anchors.
- Seal the joints.

3-15 Step-by-Step Procedures for Preparing Installation of UHMW Panels

3-15.1 Prepare Receiving Slot

Prepare the receiving slot by first removing the concrete. The dimensions of the area of concrete removed depend upon the number of panels installed. For example, for a runway with 3.8-meter (12.5-foot) slabs, each full panel is 1076 millimeters (42.375 inches) long by 610 millimeters (24 inches) wide, and partial panels are 530 millimeters (20.875 inches) long and 610 millimeters (24 inches) wide, with 13-millimeter (0.5-inch) gaps between panels. Therefore, for a 22.86-meter (75-foot) -long inlay of 18 full panels and six partial panels across the runway (11.4 meters [37.5 feet]) on each side of the runway centerline, the saw cut area must be:

- 22.87 meters (75 feet, 0.5 inch) long
- 635 millimeters (25 inches) wide
- At least 64 millimeters (2.5 inches) deep

3-15.2 Saw Cut Perimeter of Inlay

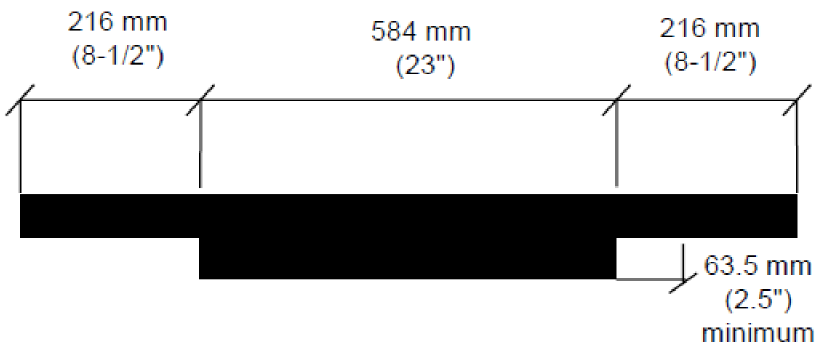
Perimeter saw cuts must be 76 millimeters (3 inches) deep and overlap at least 76 millimeters (3 inches) to ensure that corners are perfectly square when pavement is removed. Remove all loose, unsound concrete within the area. Additional saw cuts inside the perimeter will make removing the concrete easier (using chipping hammers) and result in a more uniform concrete profile

NOTE: For partial-runway-width installations, provide a means of drainage for the receiving slot to prevent damage from trapped water or dirt that may enter at leaks in the joint seals. Several saw cuts made to run from the ends of the inlay to the shoulders and cut at the same depth as the receiving slot will typically suffice.

3-15.3 Inspect Receiving Slot Following Concrete Removal

With a notched board (Figure 3-14), check the depth of the concrete within the recessed setting bed. Use a chipping hammer to remove any portions less than 64 millimeters (2.5 inches) from the surface of the adjacent pavement then visually check the concrete, sound it with a steel rod to identify any unsound portions, and remove all unsound concrete. Cut existing AAS cable tiedown anchors flush with the bottom of the concrete substrate before placing the setting bed.

Figure 3-14 Notched Board Used to Check the Receiving Slot



3-15.4 Remove Existing Tiedown Anchors

Cut existing AAS cable tiedown anchors flush with the bottom of the concrete substrate before placing the setting bed.

3-15.5 Clean Concrete Substrate

Upon removal of concrete from the slot, it is important to adequately clean the slot to ensure the new setting bed material will adhere to the substrate. Particular care should be taken to remove the laitance from the smooth faces of the saw cut walls; sandblast or use wire brushes, followed by compressed air.

3-15.6 Place a Setting Bed

Place a cementitious setting bed under the panels and allow the bed to cure before drilling and anchoring the panel anchor studs. Use ordinary PCC at airfield strength (34,474 kPa [5000 psi] compression/4482 kPa [650 psi] flexural strength in 28 days) when several hours' cure time is available. As a suggested mix, use:

- A lean seven-bag mix with 10-millimeter (0.375-inch) maximum size aggregate.
- Water-to-cement ratio not to exceed 0.3:1.
- Plasticizer admixture.
- Substitute fly ash for -50 sieve size sand as required.

This mixture will allow drilling within 18 to 24 hours. For short-cure-time applications, a prepackaged material such as Rapid Set® Concrete Mix is satisfactory. Rapid Set® Concrete Mix is packaged in 27-kilogram (60-pound) bags that yield approximately 0.014 cubic meters (0.5 cubic foot) of concrete when mixed with water (refer to Table 3-3 for ordering information). Placing a small test sample in a disposable pail the same depth as the setting bed may also serve as a helpful tool in determining adequate cure time for drilling operations

3-15.7 Positioning Mixing Equipment

Position two mechanical mortar or concrete mixers approximately 6 meters (20 feet) from the prepared inlay near the center of the runway. Transport mixed mortar in a wheelbarrow. Mortar mixers are preferred. Depending upon the type of material used, drum mixers may not agitate the material enough to produce the desired workability when the recommended amount of water is used.

3-15.8 Mixing and Placing Rapid Set® Concrete Mix

- Place 2.8 to 3.8 liters (3 to 4 quarts) of water in the mixer. In hot climates, using cold water can extend the setting time of the mix. In cold climates, using hot water and heating the substrate may shorten the setting time.
- Add one bag of Rapid Set® Concrete Mix and mix for two to three minutes. Note that this mix "wets" slowly. Do not add more water until the full mixing time has elapsed. Over-wetting will weaken the final mix. Place the material within 10 minutes after mixing. If temperature is above freezing, wet the substrate first. If below freezing, do not wet the substrate.

3-15.9 Finishing

Finish the material from the center of the bed to the edges to achieve proper bonding along the side walls of the excavation.

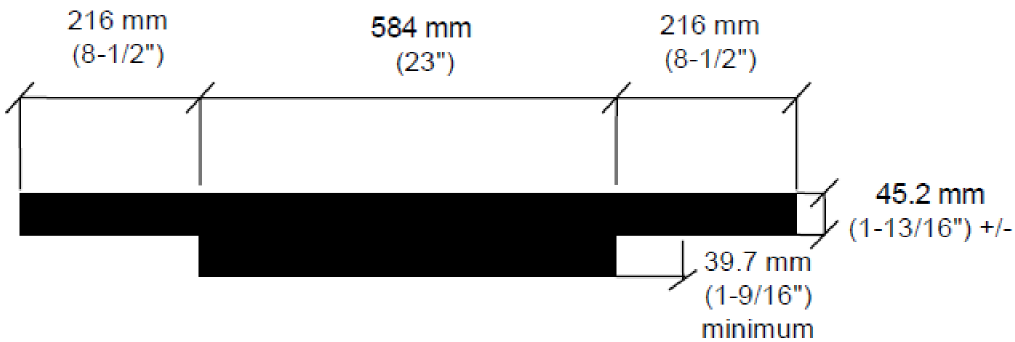
3-15.10 Curing

After initial set, when the surface becomes hard to the touch, fog- or spray-mist-cure with water for one hour. Do not add an excessive amount of water. Over-wetting will weaken the setting bed.

3-15.11 Leveling the Setting Bed

Mechanically vibrate the concrete before you screed to consolidate the mass. Even simple hand-tamping with a garden rake greatly reduces the percent of voids in the mix. Level the concrete to the proper depth in the setting bed using a notched screed board (Figure 3-15). Strike the screed periodically to ensure proper depth and uniform surface. The 39.7-millimeter (1.5625-inch) depth of the screed board is based upon a panel thickness of 38 millimeters (1.5 inches). Measure the actual thickness of each panel upon delivery to ensure they are all the same thickness and to establish the required screed dimensions. The setting bed must be level and of the proper depth to correctly support the panels. A properly-placed setting bed will help avoid a lot of aggravating manual labor. A setting bed that is not level or is placed at an improper depth requires excessive grinding of the pavement and/or shims, or may require grinding of the adjacent pavement surfaces. Shims should be used only as a last resort, not planned into the job. When required, the shim stock should be a nonferrous metal and should be sized to provide full surface support for the panel, not just point support at the anchor locations.

Figure 3-15 Notched Screed



3-15.12 Joints

Extend existing pavement joints through the setting bed by saw-cutting or using an expansion board. The saw cut should be a single blade-width and extend completely through the setting bed. Expansion boards must be set the full depth of the setting bed.

3-16 INSTALLATION OF UHMW PANELS

3-16.1 Allow the setting bed to harden (approximately 4 hours, depending on the type bed used) to the minimum strength that allows drilling without damage to the concrete.

3-16.2 Lay the panels in place and inspect to ensure that the top surface of the panel is at least 1.6 millimeters (0.0625 inch) lower than the adjacent pavement surface. Grind the bedding material or panel edges as necessary so that the panel surface is slightly recessed (1.6 to 3.2 millimeters [0.0625 to 0.125-inch]) below the adjacent pavement surface. Panel height is especially critical in the center half of the runway.

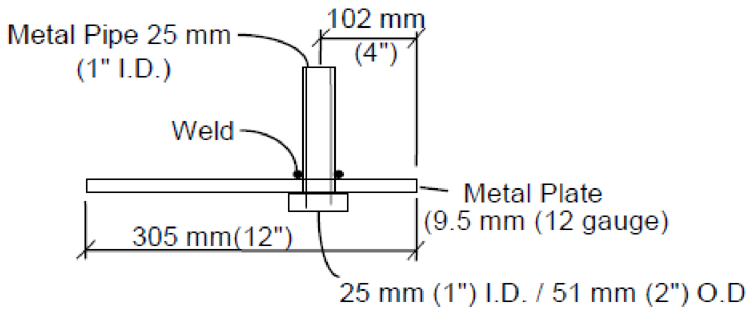
3-16.3 Set spacing between panels using 13-millimeter (0.5-inch) -thick shims and secure all panels in place with wood wedges (minimum four sets per panel) to prevent panels shifting during drilling of anchor stud holes. UHMW panels expand and contract greatly with temperature changes. The panels should be placed and anchored at the median annual temperature for the given location to allow for movement either way with temperature changes.

3-17 INSTALL PANEL ANCHOR STUDS

For a list of required tools and equipment, see Table 3-2.

3-17.1 Position the locally fabricated alignment tool (Figure 3-16) over each predrilled hole in the panel and drill 22-millimeter (0.875-inch) -diameter holes in the setting bed. Not all anchor studs are consistent in length as ordered, so check actual anchor stud lengths and drill to accommodate the longest stud. The depth of the hole is critical — if it is not deep enough, the stud will protrude above the panel surface and require excessive grinding; if it is too deep, the adhesive capsule will be positioned below the stud and not provide adequate coverage. Use a drill-mounted depth gage rod or mark a position on the drill bit shaft the length of the stud plus the depth of the alignment tool to ensure proper hole depth when drilling.

Figure 3-16 Drill Guide (Anchor Boring Alignment Tool)



3-17.2 Thoroughly clean debris from the drilled hole with a round wire brush and compressed air. A 9- to 13-millimeter (0.375- to 0.5-inch) -diameter tube attached to the compressed air line is necessary to remove all fines from the holes. Insert tubing to the bottom of the hole before purging to ensure all particles are removed. **CAUTION: Wear eye protection.**

3-17.3 Install each anchor stud as described below. To avoid work stoppage while the adhesive cures, plan to have at least 12 cap nuts available for setting anchors.

3-17.3.1 Insert an adhesive capsule into each hole with the rounded end facing the bottom of the hole. Screw a cap nut (or other manufacturer-provided adapter) onto the end of the anchor bolt and attach the unit to a heavy-duty drill (or rotary impact hammer). Insert a flat washer onto the threaded stud just below the adapter, or position the washer over the panel hole inside the counter-bore. Drive the anchor stud to the bottom of the hole to break the capsule(s) and mix the adhesive (in accordance with the manufacturer's instructions for drill speed and mixing time). Once the anchor stud is in position, do not disturb it until the adhesive has gelled. Allow the adhesive to cure as recommended by the manufacturer before the cap nut can be removed without disturbing the stud position.

3-17.3.2 Remove cap nut and flat washer; seal around stud with silicone sealant; reinsert flat washer and a thread-locking compound, then install a nut to the top of the anchor stud.

- Allow adhesive to fully cure according to the manufacturer's instructions and then torque the nuts to 81 newton meters (N•m) (60 pound feet [lb ft]).
- Grind off any portion of a stud that protrudes above the panel surface.

CAUTION—Take care to set anchors at the proper depth to avoid the need to grind the anchor rods. Excessive grinding will cause rapid build-up in the temperature of the anchor. Some epoxy manufacturers indicate heating the epoxy to 250^0 F or greater will degrade or destroy the strength of the epoxy bond.

3-18 INSTALL NEW CABLE TIEDOWN ANCHORS

Install cable tiedown anchors for operational systems (systems located between the runway thresholds) to limit cable bounce and potential aircraft damage during aircraft rollover. Install eight anchors for all operational systems regardless of primary aircraft supported on the airfield. Program systems with four anchor points to be upgraded to eight anchor points (ref: paragraph 3-8).

3-18.1 Each cable tiedown anchor hole will be located in the center of the appropriate panel. Refer to Figures 3-9 to 3-13 for location and spacing.

3-18.2 When installing cable tiedowns, ensure the top of the tiedown is at least 5 millimeters (0.1875 inch) to 13 millimeters [0.5 inch]) below the final panel surface height.

3-18.3 Depending on the location of existing runway pavement joints in relation to the runway centerline and the longitudinal joint spacing, UHMW panels may be installed with a panel joint or panel center falling on the runway centerline.

3-18.4 Figures 3-9 through 3-13 depict recommended cable anchor tiedown locations when installing standard full-sized and partial panels in various slab sizes. The partial panels are required to permit acceptable tiedown spacing and to avoid overlapping joints in the existing slabs. For installation in slabs sized other than those shown, consult the AAS engineer.

3-19 SEAL THE JOINTS

Use silicone sealant and apply joint seals in spacing between panels, around anchors and tiedowns, and between panels and pavement edges.

3-19.1 The joint surface must be recessed at least 6.35 millimeters (0.25 inch) below the panel top surface. Silicone sealants should be used in lieu of hot-pour asphalt or tar sealants.

3-19.2 The size of the backer rod must be carefully selected due to the expansion properties of the panels. The spaces between panels should be noted when the panels are in their contracted state to ensure an undersized backer rod is not used. Undersized backer rod may allow sealants to leak.

3-19.3 A non-shrinkable, non-absorbent, highly compressible foam backer rod should be used, sized to span the maximum expected gap but placed at the medium temperature and set at a depth to ensure a proper shape factor is created for the sealant reservoir.

3-20 INSTALLATION TOOLS, EQUIPMENT, AND MATERIALS

Table 3-2 provides a list of tools and equipment, with recommended quantities, needed to install a typical UHMW panel inlay for the full width of a 46-meter (150-foot) wide runway.

Table 3-2 Typical Tools and Equipment for Installation

Quantity	Unit	Description
1	each	Concrete saw, self-propelled
1	each	Hand-held portable saw
2	each	Saw blades
1	each	Water distributor
50	LF	Expansion board, asphalt impregnated, 102 mm x 13 mm (4 in x 0.5 in)
3	each	Mortar mixer, 4 cubic feet (two for use, one spare)
1	each	Sandblast unit for air compressor
3	each	Jackhammer, 40 kg (90 lb), with chisel and spade bits
1	each	Heavy-duty disc-type electric grinder
2	each	5 L (1.25 gal) containers for mixing water
3	each	Electric generators (1 per drill)
3	tons	Pea gravel (clean, washed gravel, 9 mm [0.375 in])
150	bags	Rapid Set® Concrete Mix repair material
4	buckets	5 gal size, for measuring aggregate
1	board	Notched screed, 51 mm x 102 mm x 1 m (2 in x 4 in x 40 in)
1	board	Notched depth gauge, 51 mm x 102 mm x 1 m (2 in x 4 in x 40 in)
As required (30 in this case)	panels	UHMW polyethylene, 610 mm (24 in) wide, sized, drilled and counter-bored.
As required (192 in this case)	each	Anchor studs, 19-mm (0.75-in) diameter, 245 mm (9.65 in) long, fully-threaded, with nuts, flat washers and vinyl ester resin vials (six per panel plus spares)
12 (min)	each	Cap nuts, 19-mm (0.75-in), 10 UNC
2	each	Magnesium floats
1	pair	Vice grips for cap nut removal
1	each	Screwdriver to help with cap nut removal
1	each	Concrete vibrator, small size

Table 3-2 Typical Tools and Equipment for Installation

Quantity	Unit	Description
2	each	Steel trowels
4	each	Shovels, square point
1	each	Electric drill, 13-mm (0.5-in) drive
1	each	Torque wrench to apply 81 N●m (60 lb ft) torque
1	each	TYMCO® airfield sweeper
1	each	Air compressor
1	each	Front end loader
2	each	Dump trucks
2	each	Wheelbarrow, 4 cu ft
2	each	Knives
1	each	Pickup truck
2	each	Hammer
2	each	Steel chisel, hand-held
1	each	Joint seal kettle with SS-S-1401 joint seal. **Note:** Silicone joint seal is also recommended and preferred. A recommended silicone joint seal is Dow Corning® 890-SL in 0.8-L (29-oz) tubes (96 tubes required) and a caulking gun for 0.8-lL (29-oz) caulk tubes.
3	each	Electric impact drill (Hilti HE72 or equivalent) with 22-mm (0.875-in) -diameter by 530-mm (21-in) -long masonry bits.
1	each	Gooseneck wrecking bar, 1220 mm (4 ft) long, minimum
1	each	Pick for debris breakout and removal
2	each	Wire brushes for slot cleaning
1	each	Roll of heavy cloth or plastic tape for marking drill bits for drilling depth
2	each	Alignment tools for drilling holes vertically
As req'd		Wood wedges to secure panels in position, minimum eight tapered wood wedges per panel
As req'd		Safety equipment including, but not limited to, dust masks, goggles, ear protectors, work gloves, and safety shoes *Ensure an eye wash is available.
As req'd		Wood spacers, approximately 13 mm (0.5 in) thick by 102 mm (4 in) by 76 mm (3 in), used to maintain spacing between panels during panel installation
As req'd		String line, spray paint, straightedge board, and a 30-m (100-ft) tape to measure and mark for saw cuts

3-21 MATERIALS AND SUPPLIES

Table 3-3 provides a list of materials, supplies and the recommended quantities needed to install a typical UHMW panel inlay for the full width of a 46-meter (150-foot) wide runway.

Table 3-3 Estimated Material Cost and Suggested Sources of Supply (150-Foot Wide Runway)

Quantity	Item	Suggested Source	Cost
30 each	UHMW polyethylene panels, predrilled with six counter-sunk anchor holes	Röchling Engineered Plastics http://www.roechling-plastics.us/ or Ultra Poly http://www.ultrapoly.com/	$16,900
192 each	Anchor studs, 19 mm (0.75 in) diameter, 245 mm (9.65 in) long, full-threaded (Hilti PN 068660) with vinyl ester bonding vials (Hilti PN 256702), nuts, and flat washers (Hilti HVA Adhesive Anchor System with HEA 19-mm [0.75-in] capsule and HAS 19-mm [0.75-in] rod)	Hilti Fastening Systems http://www.us.hilti.com/ or Williams Form Engineering Corporation http://www.williamsform.com/	$2,662
4 each	Drive sockets (PN 65279)	Hilti Fastening Systems	$74
4 each	Drive socket shafts (setting tool, square drive): SDS Max Connector, P/N 32221, **or** SDS Top Connector, P/N 332169		$484 $299
4 each	Masonry drill bits, 22 mm (0.875 in) diameter, 530 mm (21 in) long	Hilti Fastening Systems	$650
25 each	Cap nuts, 19 mm (0.75 in) diameter, 10 UNC (P/N 91855A036)	McMaster-Carr http://www.mcmaster.com/	$163

Table 3-3 Estimated Material Cost and Suggested Sources of Supply (150-Foot Wide Runway)

Quantity	Item	Suggested Source	Cost
150 bags	Rapid Set Concrete Mix	CTS Products www.ctscement.com or www.rapidset.com/rs Midwestern Regional Office 1211 South 6th Street St. Charles, IL 60174 Phone: (312) 773-4949 1-800-929-3030	$4,550
96 tubes	Silicone joint seal (Dow Corning 890-SL)	The Fred R. Hiller Company http://www.fredhiller.com/	$3,250
Note: Costs do not include shipping. Suggested vendors are provided to assist in locating sources. The use of the name or mark of any specific manufacturer, commercial product, commodity, or service in this FC does not imply endorsement by the Air Force.			

3-22 TYPICAL SCHEDULE OF EVENTS

Table 3-4 provides an example schedule of events for installing eight panels (partial width installation).

Table 3-4 Installation Schedule for Eight Panels

Day	Times	Event Description
1	1800–2200	Perimeter saw cutting, Runway 33. Crew size: 2 men. Saw cuts 76 mm (3 in) deep.
2	1500–1745	Excavation starts on Runway 33 inlay. Crew size: 9 men. Concrete removed using three 40-kg (90-lb) jackhammers and one cold milling cutter drum on a Bobcat 843 skid-steer loader. Debris loaded into dump truck using front-end loader. Large rubble removed by hand and shovel; small debris removed using the suction wand of the airfield sweeper.
2	1745–1915	Excavation complete. Slot cleaned with high-pressure air. Substrate sounded and delaminated (unsound, hollow) material removed. Approximate final slot size: 30 m (100 ft) long by 635 mm (25 in) wide by 76 mm (3 in) deep. Notched depth gauge board used to check depth in the center 12.2 m (40 ft) area where panels will be installed.
2	1915–2000	Final slot inspection. Loose hollow-sounding areas removed with jackhammer and pick. (Hand-held hammer and steel chisel may also be used.) Slot side walls cleaned with wire brushes. Slot cleaned and dried with high-pressure air.

Table 3-4 Installation Schedule for Eight Panels

Day	Times	Event Description
2	2000–2230	Mixing and placing of setting bed begins. Both concrete mixers used. Ten-person crew used. No bonding agent used or needed. Notched board used to keep setting bed at the correct level below the surrounding pavement surface.
2	2030–2242	Curing compound applied periodically as the setting bed is placed.
2	2242–2300	Cleanup accomplished and runway cleared. Approximately 90 bags of mortar placed.
3	0855–1030	Joints and cracks saw-cut through the mortar patches, both flush and recessed patch areas. Hand-held portable saw used for recessed setting bed cracks/joints and self-propelled pavement saw used for flush patches.
3	1015–1045	Panel placement begins. Panels positioned and tightly wedged into place using wood spacers and wood shims (wedges). (Panels as ordered for the job have predrilled anchor bolt holes.)
3	1050–1130	Drilling bolt holes begins. Three heavy-duty electric impact drills (two Hilti HE72, one Milwaukee) used and work well. Three minutes drilling time per hole required. Portable drill alignment tool used to keep drill bit positioned vertically to start hole. Drill bits marked with tape to control hole depth. Long slender tube inserted completely to bottom of bolt holes delivers compressed air to thoroughly clean holes. Recommended wire brushing of holes is not accomplished.
3	1130–1345	Panel anchor studs set in position using electric drill with adapter attachment. Anchor studs anchored into pavement with adhesive capsule inserted before inserting anchor stud in hole. Installation of anchors is delayed during first hour while new adapter is fabricated locally for anchor installation. After first adapter is tried and proven, two more adapters are fabricated. Anchor stud installation then progresses rapidly with most anchor studs installed in last hour. Applying oil on ends of studs aids adapter removal after stud installation.
3	1340–1400	Shims removed. Site cleaned with compressed air to remove all particles before sealing around panels with joint sealant.
3	1710–1730	Studs torqued to 81 N•m (60 lb ft) with torque wrenches. All studs torqued adequately but several stud ends protrude above panel surface.

Table 3-4 Installation Schedule for Eight Panels

Day	Times	Event Description
3	1810–1820	High studs ground down flush with surface using a heavy-duty disc-type electric grinder. **CAUTION—Excessive grinding will cause rapid build-up in the temperature of the anchor rod. Some epoxy manufacturers indicate heating the epoxy to 250^0 F or greater will degrade or destroy the strength of the epoxy bond. Take care to set anchors at the proper depth to avoid anchor failure.**
3	1720–1820	Sealant applied to joints around panels using kettle with hot-applied, single-component, non-jet-fuel-resistant sealant (SS-S-1401). Job complete.
3	1820–1830	Final inspection and job site cleanup completed.

CHAPTER 4 OPERATION, MAINTENANCE, CERTIFICATION, AND INSPECTION

4-1 INTRODUCTION

4-1.1 This chapter provides basic information on inspection, maintenance, certification, operation, maintenance records, and deficiency reporting for AAS. Information contained in this chapter is intended to be general in nature. Specific technical information may be found in the applicable 35E8-series T.O.s.

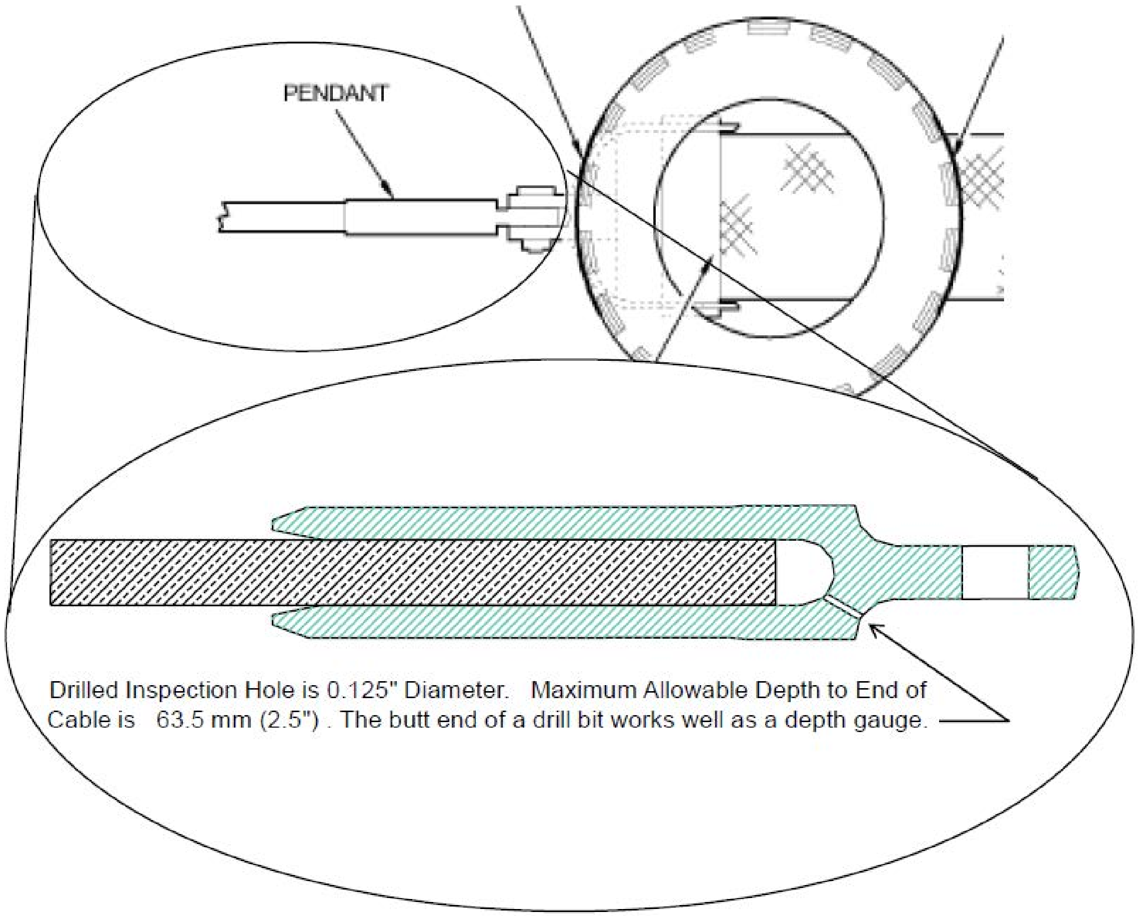
4-1.2 The BAK-12 T.O. provides alternate procedures for removing an aircraft from the cable after engagement. These alternate procedures are commonly referred to as a "slingshot" removal of the aircraft. Potential for aircraft damage is high when using these methods; therefore, use these procedures only during contingencies or in-flight emergencies that require rapid removal of an aircraft from a cable. The procedure must be approved by the installation commander before being used for routine disengagement of aircraft during local exercises or scheduled testing of the arresting system (e.g., certification).

4-2 CABLE (PENDANT) INSPECTIONS

4-2.1 Inspections must be performed in accordance with the applicable T.O., information contained within this instruction, and the 35E8-series work cards.

4-2.2 In-service pendant cables must be inspected daily and after each engagement. Use cable inspection criteria from BAK-12 or BAK-13 T.O.s for textile brake AAS. For all AAS cables (pendants), measure and record the swaged end cable insertion depth measurement in the maintenance records before placing any arresting system cross-runway pendant in service (see Figure 4-1). Do not install cables with swaged end depth measurement greater than 63 millimeters (2.5 inches). The previous requirements to mark the cable with paint or some other means of permanent marking and to perform post-arrestment measurements have been made optional at the discretion of the AAS shop supervisor. Spare pendants should be stored indoors or on their original shipping container.

Figure 4-1 Swaged End Measurement for Cable to Terminal End Fitting



4-3 EXPEDIENT TRIM PAD ANCHORING SYSTEM CABLE INSPECTIONS

4-3.1 Expedient trim pad anchoring systems can be installed using K-M anchoring components from the MAAS. Use ETL 06-4, *Expedient Trim Pad Anchoring Systems*, to install and inspect expedient trim anchors. Use the following guidance for cable inspection and disposition if AAS pendants are used to restrain the aircraft during trim operations.

4-3.2 Cables used with the expedient trim pad setup shall be kept separate from cables used for aircraft engagements, and shall only be used for trim operations (e.g., cables used for trim operations shall not be used for aircraft engagements, and cables that have been used for engagements shall not be used for trim operations).

4-3.3 Develop a use and inspection log for each new cable and record the date and pertinent details of each trim operation in the log. Maintain the log for the life of the cable. There is no limit to the number of trim operations that can be performed with a single cable within a 36-month period; however, all cables will be removed from service 36 months after their initial installation date unless they fail to meet the requirements stated below.

4.3.2.1 Before installing any cable, measure and record the swaged end cable insertion depth as prescribed above in paragraph 4-2.2. Also, inspect the cable in accordance with instructions in T.O. 35E8-2-5-1. Do not install cables with defects identified in the T.O. or if the insertion depth measurement exceeds 63 millimeters (2.5 inches).

4-3.2.2 After each trim pad operation, inspect the cable in accordance with instructions in T.O. 35E8-2-5-1. Also, measure and record the swaged end cable insertion depth for each end, or inspect for swaged end movement if the swaged end position has been marked as described in paragraph 4-2.2 above. Remove the cable from service if it fails to meet the inspection requirements of T.O. 35E8-2-5-1 or shows any change in the swaged end position on the cable.

4-4 TAPES, NETS, SUSPENSION STRAPS, AND BARRIER WEBBINGS

4-4.1 Crop exposed tape between the runway edge sheave (fairlead beam) and the tape connector on the BAK-12 according to the appropriate 35E8-series T.O. Crop the tape between the absorber base and the tape connector according to the appropriate 35E8-series T.O. on expeditionary systems if a tape tube is not used. Perform (end-for-end) on the tapes on all systems according to the appropriate 35E8-series T.O. No nylon tapes should be retained in service longer than T.O. requirements or if usage exceeds the maximum allowable for engagements, pull-outs or tape stack height in the applicable 35E8-series T.O. Due to the negative effects of UV light on nylon, every effort must be made to protect tapes from direct sunlight. For this reason, all spare nylon tapes must be stored indoors with the original protective seal in place.

4-4.2 For MA-1A and BAK-15, a new webbing assembly and suspension straps must be installed after each engagement according to the appropriate 35E8-series T.O. Inspect pendant cables and replace if required.

4-5 PAVEMENTS ADJACENT TO AND BENEATH AAS CABLES

4-5.1 Critical Pavements

The center 23 meters (75 feet) of pavement extending out for 60 meters (200 feet) on both the approach and departure sides of the arresting system pendant are critical areas. Protruding objects, excessive paint build-up, excessive joint sealant material, warped sacrificial panels, and undulating surfaces are detrimental to successful tail-hook engagements and are not allowed. This area of the runway must be visually inspected at least monthly for indications of the above noted conditions. Suspect areas, such as pavement cracks and joints, pavement, and panels beneath the cable must be inspected more closely, and when warranted, checked to ensure the effective pendant height is adequate for successful engagements. Increased attention will be necessary after each freeze-thaw cycle.

4-5.1.1 Problem areas must be immediately identified to the installation pavements engineer for a more thorough inspection and corrective action. The airfield manager must also be notified so that Notice(s) to Airmen (NOTAMs), local NOTAMs, and aircrew briefings can be issued to highlight the potential problem pending corrective action.

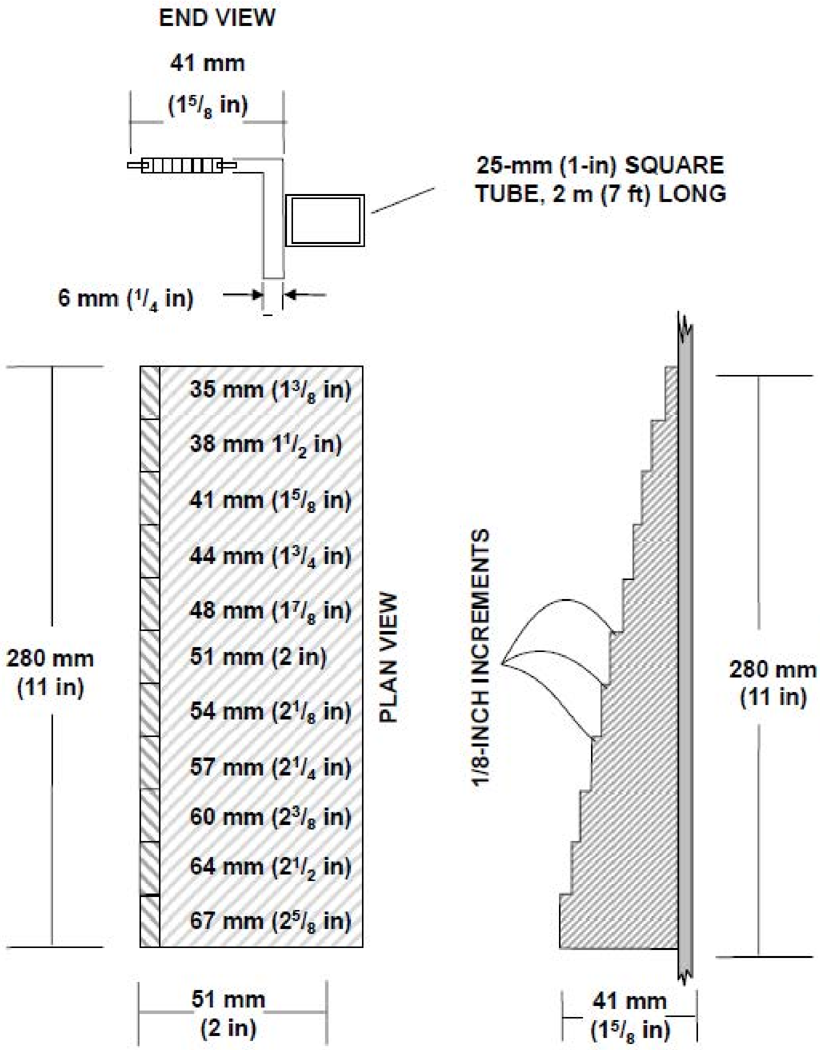
4-5.1.2 Perform more detailed inspections of suspect areas with a 4-meter (12-foot) straightedge. Begin on the runway centerline and check the pavement in the immediate area of the cable for high spots, depressions, or other undulations. Perform the inspection out to a point beyond the first transverse pavement joint on rigid pavements or for approximately 3 meters (10 feet) past the suspect area, or for a minimum longitudinal distance of 6 meters (20 feet), whichever is greater. Repeat this procedure within 1 meter (3 feet) on both sides of the runway centerline, and then at not more than 2-meter (6-foot) intervals across the runway, for a total distance of 11.5 meters (37.5 feet) on either side of the runway centerline. Grind flush any high spots exceeding 3 millimeters (0.125 inch). Report depressions exceeding 3 millimeters (0.125 inch) in depth to the installation pavements engineer for corrective action.

4-5.2 Effective Pendant Height (EPH)

The EPH is the vertical distance (in millimeters or inches) from the underside of the pendant to the pavement surface, or if worn, a projected surface representing the original plane of the runway surface beneath the cable. The EPH for an undamaged or non-grooved runway surface is approximately 60 millimeters (2.38 inches) for a 32-millimeter (1.25-inch) pendant cable. Maintaining this cable height as near to maximum as possible greatly increases the probability the aircraft tail-hook will successfully engage with the arresting system pendant cable. However, as the cable is trampled by aircraft, the rotational oscillations induced by roll-over cause the pavement to wear.

4-5.2.1 Measure the EPH along the center third of the runway width at 3-meter (10-foot) intervals or less using an EPH-measuring tool (see Figure 4-2). Manufacture the tool locally for use by the AAS shop. Perform measurements with AAS cable under tension. Ensure cable tiedowns are not pulling the cable towards the runway surface. Preferably perform measurements in the area between cable support disc.

Figure 4-2 EPH Stepped Feeler Gauge

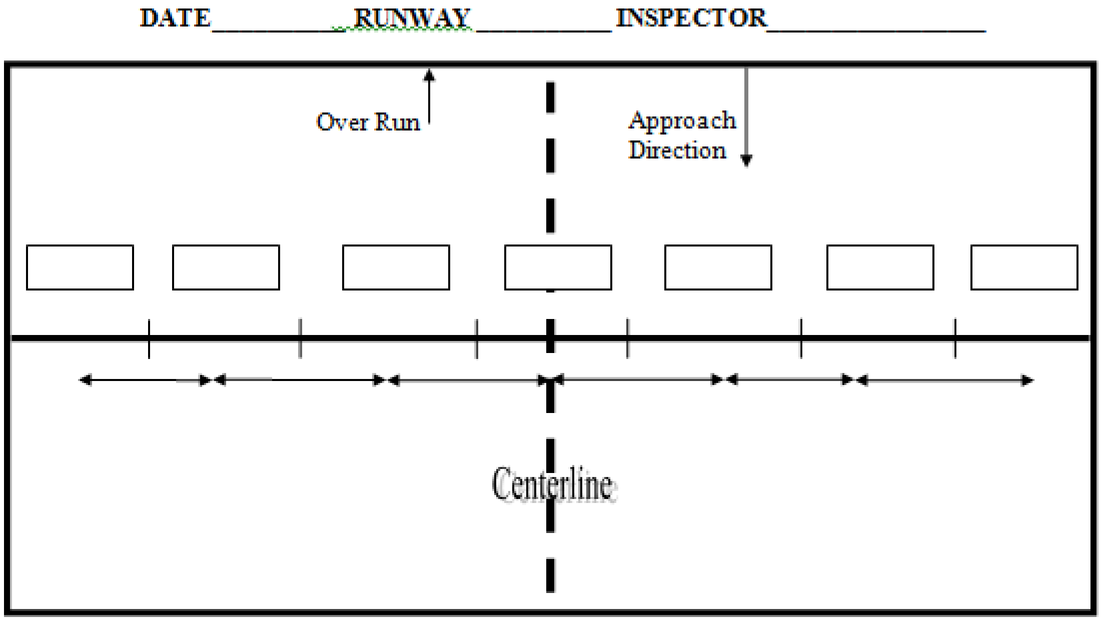


EPH MEASURING TOOL CONSTRUCTED FROM 51-mm (2-in) ANGLE STOCK
(NOT TO SCALE)

4-5.2.2 Start measuring when pavement erosion or grooving is noticed and repeat measurements at least monthly until repaired. As the EPH approaches 38 millimeters (1.5 inches), take and record measurements daily until repaired.

4-5.2.3 Record EPH measurements in the arresting system maintenance log, using a sketch to demonstrate the EPH values and the distance to the location where the measurement was taken (see Figure 4-3). Distance between measurements should not exceed 10 feet. Measurements should be taken in the center most point between cable support disk. Indicate the distance between measurements left and right of the runway centerline. Perform and record measurements while facing the runway approach for documentation consistency.

Figure 4-3 EPH Measurement Log Sample



4-5.2.4 AAS maintenance personnel must notify the local Pavements Engineer, MAJCOM representative and local Airfield Manager when EPH measurements become necessary. Provide status reports of changes to the EPH as they occur. Problem areas must be immediately identified to the installation pavements engineer for a more thorough inspection and corrective action. The Airfield Manager must also be notified so that Notice(s) to Airmen (NOTAMs), local NOTAMs, and aircrew briefings can be issued to highlight the potential problem pending corrective action.

4-5.2.5 Arrange for pavement repairs when any EPH measurement drops to 44 millimeters (1.75 inches) or less. Make the repair before the lowest EPH drops below 38 millimeters (1.5 inches). Perform emergency repairs (permanent or temporary) when any EPH measurement is less than 38 millimeters (1.5 inches).

4-6 ULTRA HIGH MOLECULAR WEIGHT (UHMW) POLYETHYLENE PANEL INSPECTION AND MAINTENANCE

Installations should establish formal procedures to ensure satisfactory performance of UHMW panels. UHMW panels should be inspected daily and monthly for effects of aircraft traffic and thermal movement (expansion/contraction/warping) in accordance with the following.

4-6.1 Daily Inspection. Panel inspection should be added to the daily arresting system inspection checklist for power production personnel. Visually check for panel buckling, warping, and surface variations. If disparity is found, initiate corrective measures.

4-6.2 Weekly Inspection. Check for panel buckling, warping, and surface variations by placing a steel straightedge on top of each panel parallel with the runway centerline at:

- Each joint between panels.
- At least two locations within each panel.
- Any other location that appears raised or irregular.

The straight edge must be long enough to overlap the pavement on each side of the panel by a minimum of 305 millimeters (12 inches). Immediately report raised edges or high spots exceeding 3.2 millimeters (0.125 inch) above the plane of the adjacent runway to the installation Pavements Engineer, local Airfield Manager and to the MAJCOM AAS engineer for further evaluation. Take color photographs to document findings.

4-6.3 Monthly Inspection. The installation pavements engineer should participate once each month in the daily inspections with the AAS personnel. Record all panel conditions, including (but not limited to):

- Erosion affecting a reduction in EPH.
- Distresses in the pavement or panels.
- Warping or edge curling.
- Soundness.
- Delamination.
- Anchor nuts and studs. (Note that anchor stud-nuts may be over-torqued if tightened repeatedly. If any are found loose, use a thread-locking compound such as Loctite® on the threads before tightening, then reseal.)
- Joint Seals.
- Spalling.

Report any deterioration or other problems to the appropriate AFIMSC Detachment for further evaluation.

4-6.4 Joint Maintenance. Joints should be resealed as needed, and just prior to onset of cold weather to prevent moisture accumulation and freezing below the panels. Ice formation beneath panels may cause panel failure, anchor failure, or excessive panel warping.

4-7 CERTIFICATION

4-7.1 All Air Force arresting gear (excluding MA-1A, E-5, BAK-15, textile brake, and soft ground arrestor systems) that have not been engaged at a speed sufficient to exercise the hydraulic system within the past 12 months must be certified by an aircraft engagement. *Refer to* **\1** *AFMAN 32-1040 Civil Engineer Airfield Infrastructure Systems* **/1/**. Report all engagements or missed engagements per **\1** AFMAN 32-1040 **/1/**.

4-7.2 Maintenance and recovery crews will also be evaluated during certification engagements. The following factors will be considered:

- Evaluate crew proficiency in disconnecting the aircraft and returning the AAS to service.
- Evaluate adequacy of maintenance, training records, established Special Levels of replacement parts and supplies, and engagement data.
- Evaluate availability of necessary tools, bench stock, and special equipment.

4-7.3 Responsibility for assuring that certification is accomplished according to this instruction, appropriate 35E8-serise T.O. and **\1** AFMAN 32-1040 *Civil Engineer Airfield Infrastructure Systems* **/1/** rests with the host command. AAS personnel must provide an information copy of each record of certification engagement or certification inspection report to airfield management for their file. Records of certifications will also be maintained in accordance with requirements for Maintenance Records in this FC.

4-8 OPERATION

4-8.1 Refer to **\1** AFMAN 32-1040 *Civil Engineer Airfield Infrastructure Systems* **/1/**, for unidirectional barrier net and pendant cables located in the overruns of the approach end of the runway.

4-8.2 Maintain operational arresting systems like BAK-12 and MAAS in the ready position on the approach and departure ends of the runway and in overruns (but not underruns) unless the installation commander directs otherwise.

4-8.3 AAS, Barriers and interconnected hook cables may be removed from the overrun and runway during snow and ice removal operations. However, coordinate removal with airfield management, then return the AAS, Barriers and interconnected hook cables to operational status as soon as possible.

4-8.4 Hook cable support and retraction systems are not designed to operate in the up position with repeated aircraft rollovers. Repeated high-speed rollovers will damage the system components, reduce system reliability, increase the chance of a missed engagement, and increase maintenance costs.

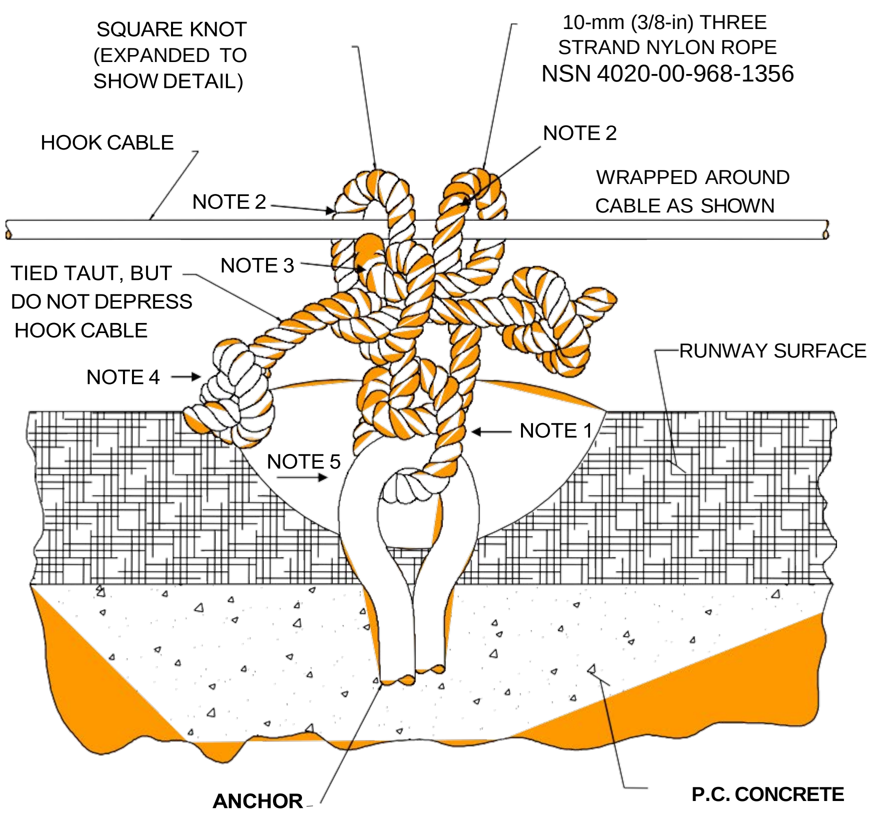
4-8.4.1 Low-speed taxi rollovers must also be kept to a minimum to prevent degradation of system performance.

4-8.4.2 If the AAS is not required to stop the aircraft, air traffic control (ATC) should lower the BAK-14 or Type H cable support system prior to aircraft rollover.

4-8.4.3 Local airfield operating instructions should include provisions for ensuring the BAK-14 or Type-H cable support system is lower prior to the arrival or departure of non-hook equipped or arrestment-capable aircraft

4-8.5 Secure the cable to the cable tiedown anchors with a length of 10-millimeter (0.375-inch) -diameter, three-strand nylon rope (nsn 4020-00-968-1356) approximately 1200 millimeters (48 inches) long (2200 kilograms [5000 pounds] maximum breaking strength). The rope must be fastened to the anchor with a simple overhand knot then tied to the cable with a square knot that is finished on the underside of the cable. Tie a simple overhand knot as close to the square knot as possible with the remaining rope. This will prevent the square knot from becoming loose. See Figure 4-4.

Figure 4-4. Securing Cable with Tiedown Rope



NOTES:
1. **Tie one half of a square knot on the anchor.**
2. **One end of the rope comes over the cable on the long side of the runway. The other end of the rope comes over the cable from the threshold side.**
3. **After the ropes are looped over the cable, tie a square knot underneath the cable.**
4. **Tie knots in ends of rope as close as possible to square knot.**
5. **Orient ring perpendicular to the axis of the cable. Shown parallel for clarity only.**

4-9 RADIO PROCEDURES AND STANDARD PHRASEOLOGY

When performing duties associated with AAS and barriers in the airfield environment, it will be necessary to communicate with ATC, ground control, fire emergency services, and airfield management by two-way radio. Follow local procedures established within the airfield operating instruction (AOI) and the base airfield driving regulations and program. General terms to be used for radio communication are provided in AFI 13-204, Volume 3, *Airfield Operations Procedures and Programs*, AFI 13-213, *Airfield Driving*, and Federal Aviation Administration (FAA) Order JO 7110.65T, *Air Traffic Control, "*Pilot/Controller Glossary." The most common terms for use and their definitions are provided below. Appendix B-2 also provides definitions for the various terms that relate specifically to the airfield and airfield operational areas, including the method used to designate the in-use runway. The phrase "clear" must not be used when communicating with tower personnel.

- "Acknowledge" — Request that you have received and understand the message.
- "Affirmative" — Yes.
- "Negative" — No.
- "Say Again" — Request to repeat the message.
- "Roger" — I have received and understand the last transmission.
- "Hold Short" — Do not proceed per the tower's instructions.
- "Wilco" — I have received and will comply with your message.

4-10 Reporting System Status

Report the status of an AAS or Barrier to the ATC using the terms "operational," "not operational," "in-service," "out of service" or "pendant cable disconnected and off the runway" consistently when reporting status to the airfield authority. These terms are easy-to-understand descriptions of AAS or Barrier status. The specific terms selected for each installation should be specified within the local AOI.

4-11 Reporting System Location

When communicating the location of an AAS on the active runway, use the active runway designation and refer to the system in question by approach, midfield, or departure end AAS, or approach or departure end barrier. In this case, it is important to differentiate between AAS and barriers. BAK-12 and BAK-14 systems are AAS systems, not barriers. Net systems such as MA-1A and BAK-15 systems are barriers. See the definition of terms in Appendix B-2 of this FC. The active runway (the runway in use) is identified by the numeric designation of the approach end of the runway. For example, for Runway 12/30, the active runway would be "Runway 12" when aircraft are taking off from or landing toward the end of Runway 12, or are on a 120-degree compass heading.

4-12 Hand Signals

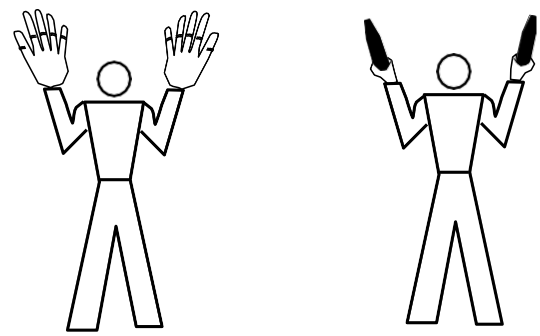
Standard hand signals for use between AAS crewmembers and aircrew members are provided in AFI 11-218, *Aircraft Operations and Movement on the Ground*. Standard hand signals for use between AAS crewmembers are shown in Figures 4-5 and 4-6. During night operations or restricted visibility, the ground crew will use a pair of same color light wands and done a Type III reflective vest.

Figure 4-5 Hand Signals for Rewind, Point Man to Pilot

	DAY	NIGHT

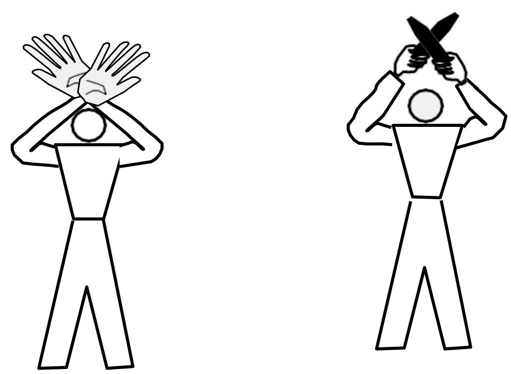
MOVE AHEAD

ARMS A LITTLE ASIDE, PALMS FACING BACKWARDS AND REPEATEDLY MOVED UPWARD BACKWARD FROM SHOULDER HEIGHT.



STOP

ARMS CROSSED ABOVE THE HEAD, PALMS FACING FORWARD



UP TAILHOOK

RIGHT FIST, THUMB EXTENDED UPWARD, RAISED SUDDENLY TO MEET HORIZONTAL PALM OF LEFT HAND

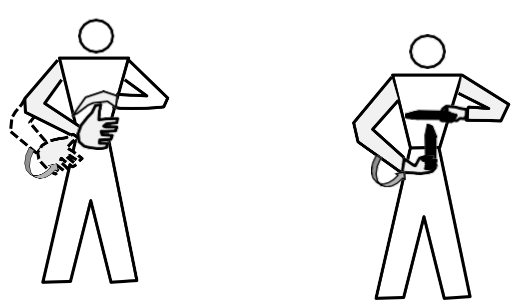
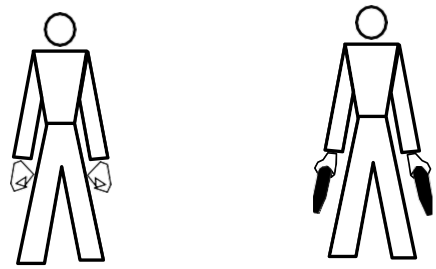


Figure 4-6 Hand Signals for Rewind, Point Man to Rewind Operator, Sheet 1

STOP (Both Units As Shown)

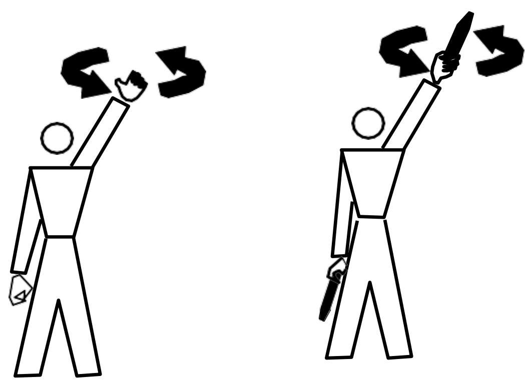
NIGHT - LIGHT WANDS TO SIDES, LIGHTS OFF

DAY - HANDS TO SIDES, FISTS CLENCHED



REWIND OR PRETENSION ONE UNIT

AS INDICATED BY HAND USED TO SIGNAL



REWIND BOTH UNITS

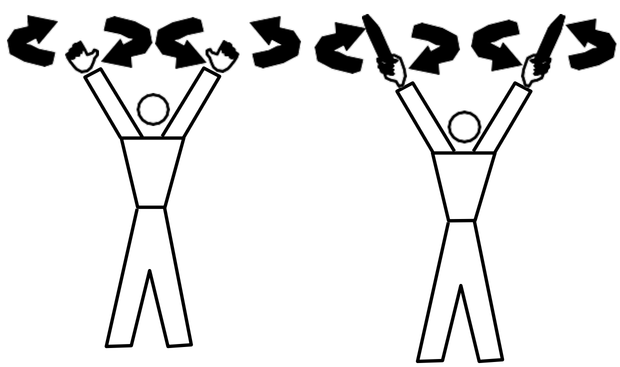
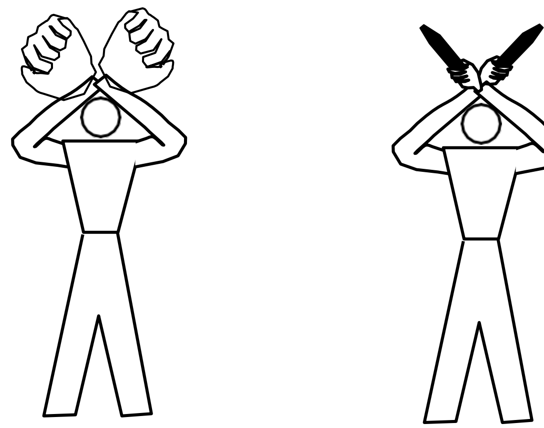
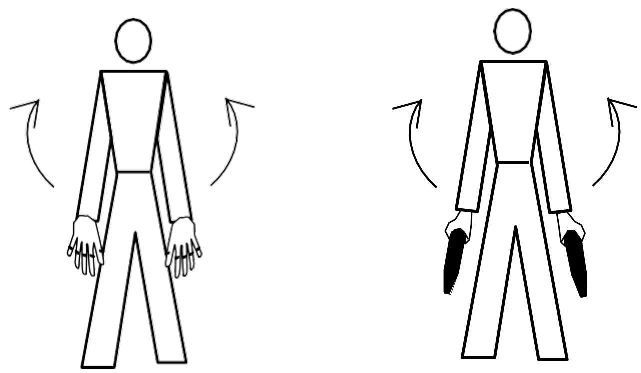


Figure 4-6 Hand Signals for Rewind, Point Man to Rewind Operator, Sheet 2

LOCK BRAKE



RELEASE BRAKE



REPEATE LAST SIGNAL

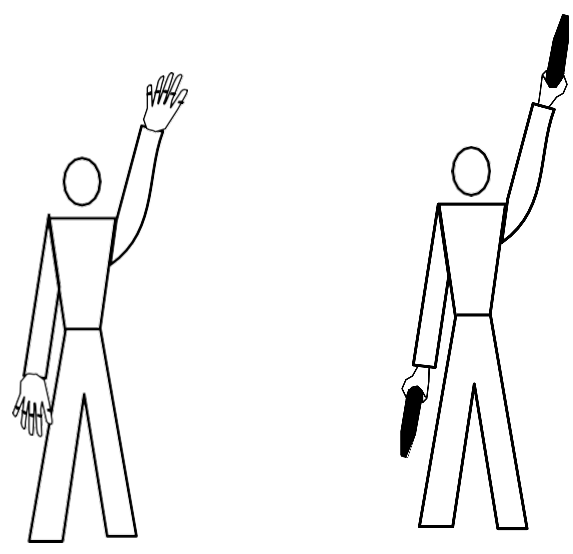
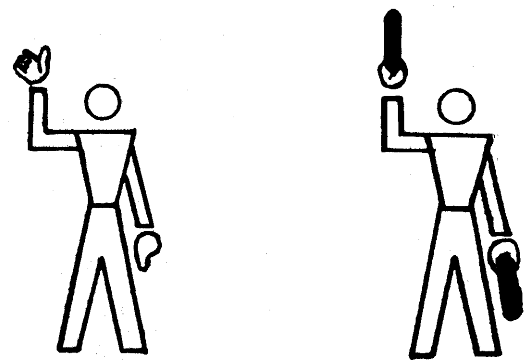


Figure 4-6 Hand Signals for Rewind, Point Man to Rewind Operator, Sheet 3

GENERAL
MESSAGE
AFFIRMATIVE
SIGNAL



4-13 MAINTENANCE DOCUMENTATION AND RECORDS

4-13.1 Document all activities (maintenance and inspections, etc) in a log book as soon as the task has been accomplished. Identify the time and date of the activity, location of the activity, all personnel performing the work and on the work site, as much information as is available for parts and materials used (including part number, manufacturer's name and CAGE Code, serial number (if any), contract number, batch, and date of manufacture) and status of the AAS or barrier.

4-13.1.1 Maintain the log book until all systems referenced are removed or replaced.

4-13.1.2 The AAS supervisor will ensure a record of inspections, repairs, and authorized modifications are kept in a log and that arresting system historical records are maintained in the AAS work center.

4-13.1.3 The AAS supervisor will review and sign the log daily except weekends or holidays. Work accomplished on weekends and holidays will be reviewed and signed off the next duty day

4-13.1.4 The AAS supervisor will perform quality assurance inspections on the installation and maintenance of AAS, historical records and the vehicles and tools used to perform AAS activities. Quality assurance inspections will be documented in the AAS log book.

4-13.1.4 Log books shall be retained and stored for 5 years from the date of the last entry.

4-13.2 Establish a historical maintenance record for each system for the overhaul service life of the system, and document, at a minimum, the following information in the record:

- AAS or Barrier type, date installed, location on airfield, and serial numbers (number of system engagements on BAK-12, and MAAS).

- Last overhaul date (including fairlead beams or edge sheaves).
- Last non-destructive inspection (NDI) date with results.
- Daily inspections.
- Weekly inspections.
- Monthly inspections.
- Quarterly inspections
- Semi-annual inspections
- Annual inspections
- Multi-year inspections
- Purchase Tape data (date installed, contract number, manufacturer, usage data for each tape and serial number of the AAS the purchase tape installed).
- Cable replacement data (date installed, manufacturers' identification code, serial number, and contract number).
- System certification and certification inspection records/reports. (Submit all engagement reports per **\1** AFMAN 32-1040 *Civil Engineer Airfield Infrastructure Systems* **/1/**
- Aircraft engagement reports.
- Replacement parts and/or materials (including part number, manufacturer's name and CAGE Code, serial number (if any), contract number, batch, and date of manufacture)

4-13.3 Historical records must be kept with the system for the life of the equipment to ensure they are returned to the overhaul facility when the system is changed out. This includes War Reserve Materiel (WRM) systems in storage, as well as systems designated for training use only, as applicable. Provide a copy of maintenance records to the overhaul facility or WRM location when the system removed.

The AAS supervisor will review and sign each historical record entry to verify accuracy of the entry. Work accomplished on weekends and holidays will be reviewed and signed off the next duty day

4-13.4 The AAS supervisor shall establish and maintain an AAS status board in the AAS work center that indicates at a minimum for all installed and stored AAS and/or barriers:

- Current status each AAS and/or barrier
- Current pendant or net system configuration
- Due dates for maintenance activities
- Current tape count, pendant count, and system count
- Date of installation for tapes, pendants and textile systems and nets
- Last engagement date

4-14 DEFICIENCY REPORTING

Report all deficiencies discovered with AAS and components to base supply according to T.O. 00-35D-54, USAF Material Deficiency Reporting, Investigation, and Resolution.

CHAPTER 5 SYSTEMS USED ON USAF INSTALLATIONS

5-1 DESCRIPTION

Aircraft arresting systems consist of engaging devices and energy absorbers. Engaging devices are net barriers such as MA-1A and BAK-15, disc-supported pendants (hook cables), and cable support systems such as BAK-14 and the Type H that raise the pendant to the battery position or retract it below the runway surface. Energy-absorbing devices are ships' anchor chains, rotary friction brakes (such as the BAK-12), tearing strap modules such as textile brake systems, and soft ground systems such as the Engineered Material Arresting System (EMAS). Tables 5-1 and 5-2 below show the leading particulars for Air Force energy-absorbing systems**.**

Table 5-1 USAF Aircraft Arresting System Energy Absorber Leading Particulars (Except Textile Brake)*

System Type	BAK-12 66-Inch Reel	Dual BAK-12 66-Inch Reel	MAAS 990-Foot Runout	MAAS 1200-Foot Runout***
Nominal Aircraft Weight (lb)	50,000	100,000	40,000	68,400
Energy Capacity (ft-lb)	85×10^6	170×10^6	40×10^6	98×10^6
Nominal Runout (ft)	1,200	1,200	990	1200
Tape Strength (lb)	105,000	105,000	105,000	105,000
Cable Strength (lb)	130,000	130,000	130,000	130,000
Maximum Speed (kn)**	180	180	150	180

* The operating characteristics given in this table are described in inch-pound units as reported by the original equipment manufacturers.

****** 190 knots is the dynamic limit for steel cables used in AAS. Random failures will occur at 190 knots and above; therefore, 180 knots is established as the working limit for cable-engagement systems.

******* MAAS configured for 1200-foot runout in the 31-stake, PCC, or set-back anchoring schemes having the same technical characteristics as a 66-inch BAK-12.

Table 5-2 USAF Textile Brake Aircraft Arresting System Leading Particulars*

System Type	MB 60.9.9.C	MB 100.10C
Cable diameter/strength	1.25 inches/130,000 lb	1.25 inches/130,000 lb
Stage 1 runout (length of available braking force)	551 feet	N/A
Energy capacity stage 1 (ft-lb)	26×10^6	N/A
Total system energy capacity (ft-lb)	52×10^6	44×10^6
System runout (total length of available braking force)	1000 feet	889 feet

Energy capacity calculated at 160 knots.

Note: Twelve percent increase in energy capacity when using a net.

* The operating characteristics given in this table are described in inch-pound units as reported by the original equipment manufacturers.

5-2 CHAIN ABSORBER ARRESTING GEAR (CHAG) SYSTEMS

5-2.1 MA-1A

The MA-1A emergency arresting system consists of a net barrier and cable system designed to engage the main landing gear of an aircraft (Figure 5-1). Because it is a unidirectional system, it must always be installed in the overrun area. Aircraft engaging this system above the speed and weight limits provided in Figure 5-3 (or Chart 1-1 of T.O. 35E8-2-2-1) will result in a runout greater than 305 meters (1000 feet) or cable failure. Most MA-1A systems employ ships' anchor chains as the energy absorber. These systems require a runout area of at least 259 meters (850 feet) plus the length of the aircraft. The chains lie on either side of the runway overrun, beginning at the barrier location and running in the direction of aircraft travel; however, some MA-1A systems use a BAK-9 instead of a ship's anchor chain as the energy absorber. These systems require a runout area of at least 290 meters (950 feet) plus the length of the aircraft. This configuration is an MA-1A/BAK-9.

5-2.2 MA-1A Modified

The MA-1A may also be complemented with a hook-cable interconnect to accommodate hook engagement. This arrangement is shown in Figure 5-2. The MA-1A is not currently in production as a system. Do not consider it for new installations unless you can salvage the necessary equipment from another facility. Obtain further technical information on this system from T.O. 35E8-2-2-1.

Figure 5-1 MA-1A Barrier

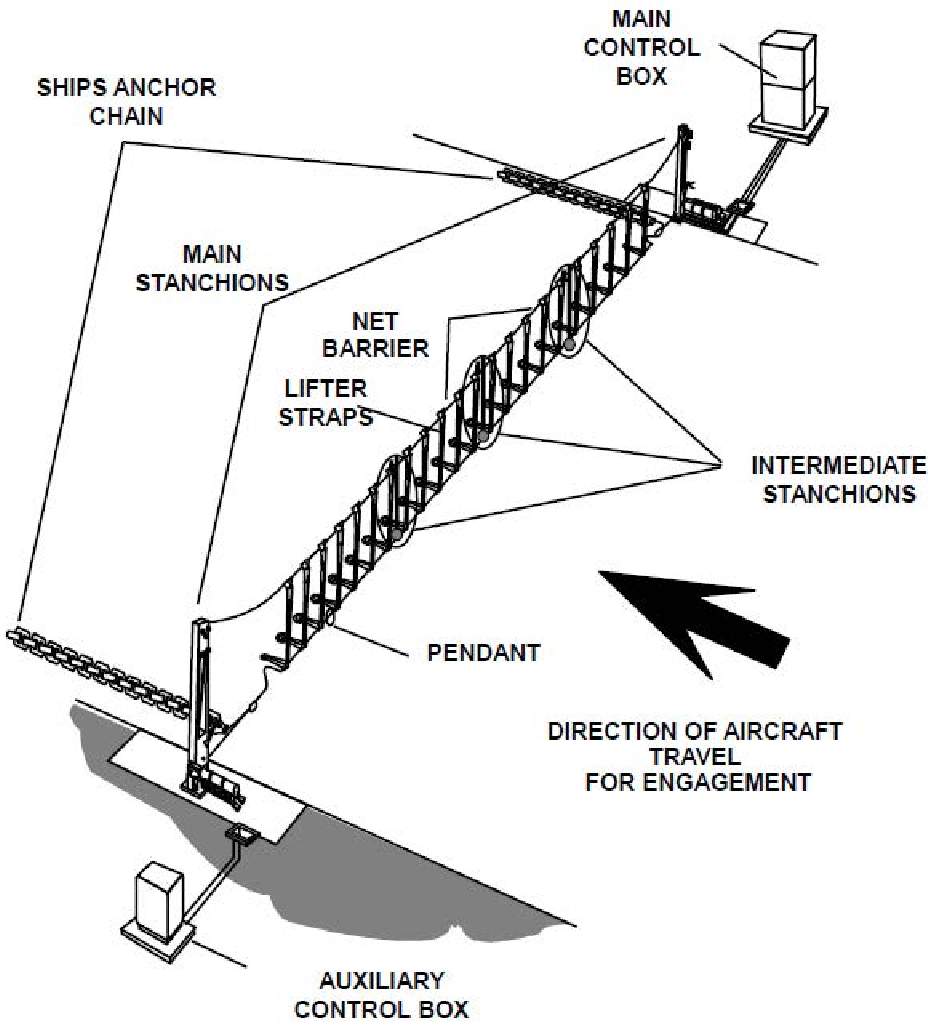


Figure 5-2 MA-1A Modified Barrier With Hook Cable Interconnect

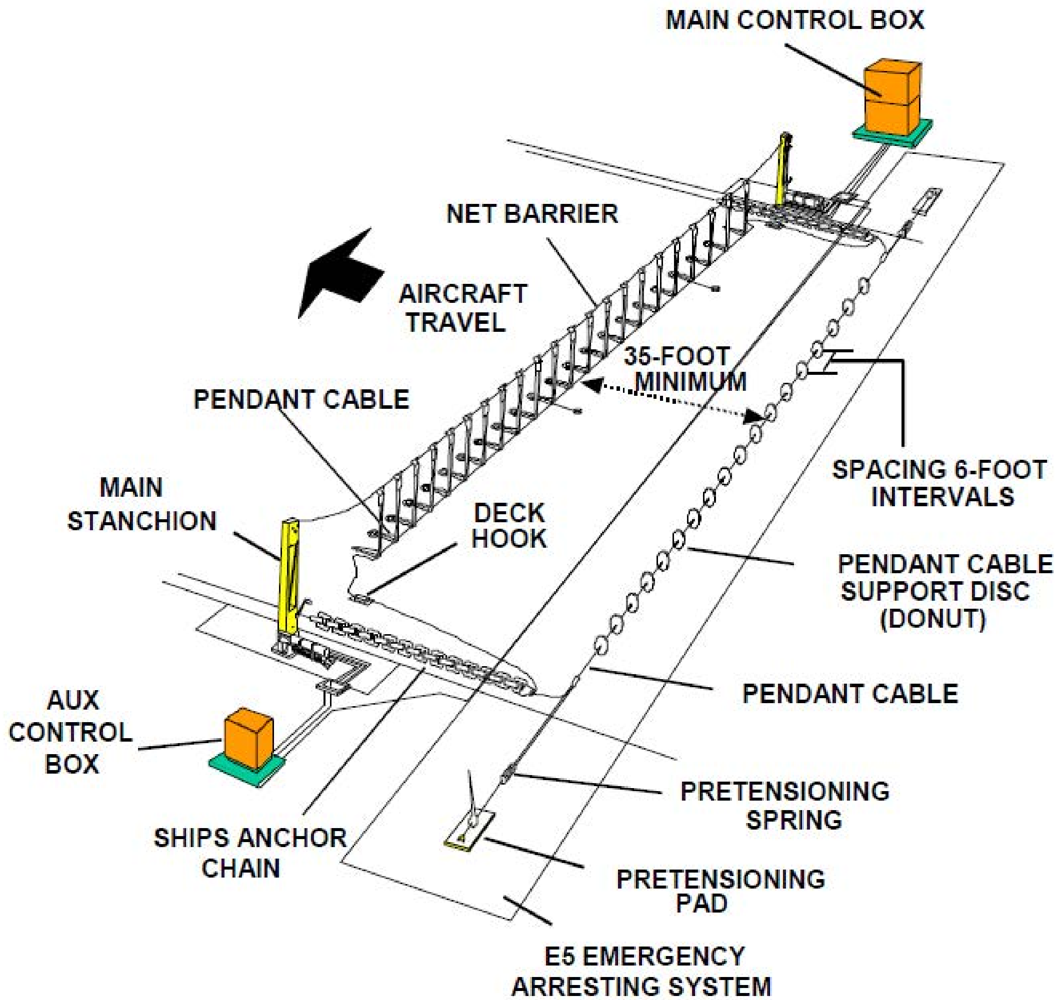
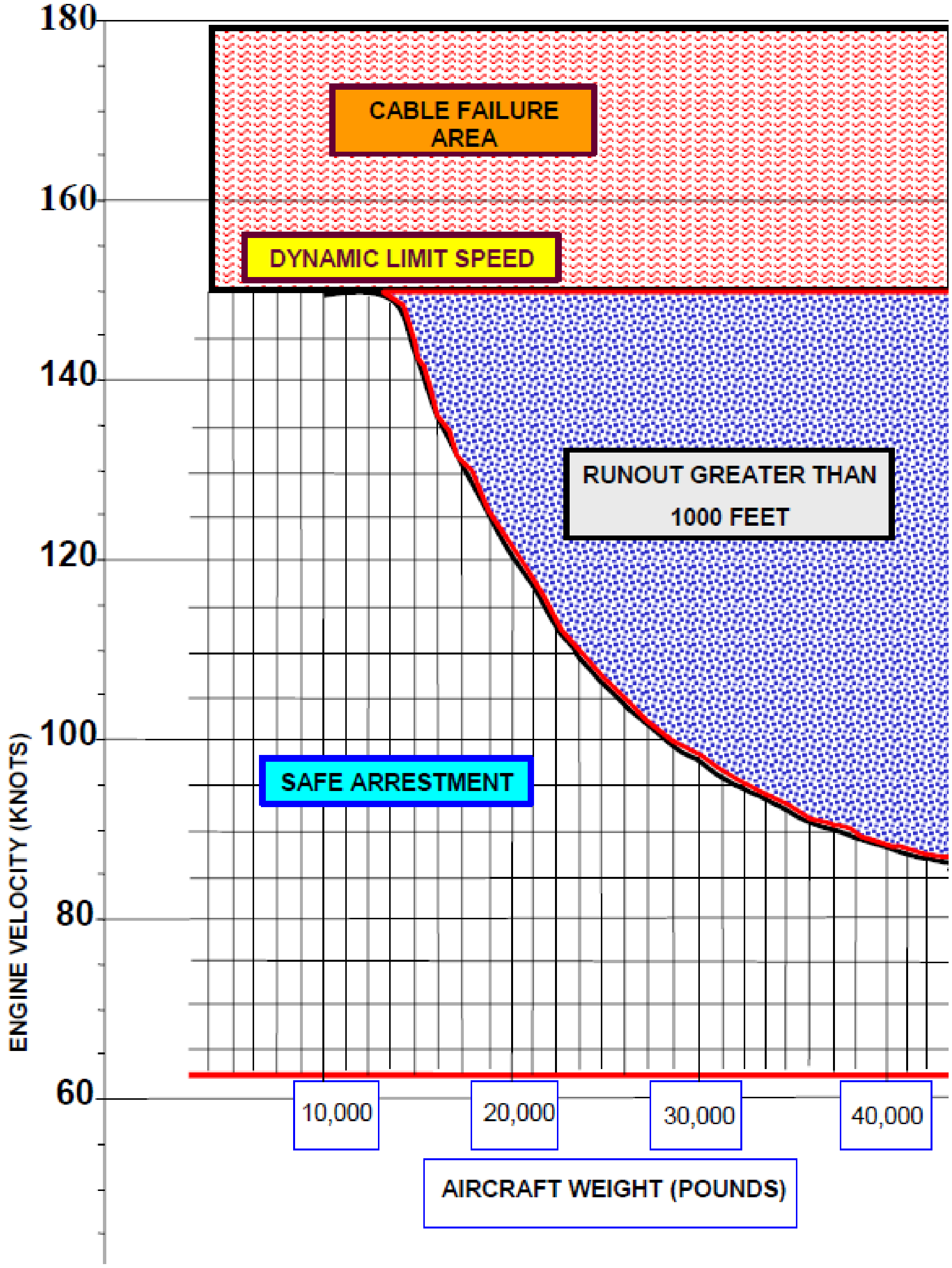


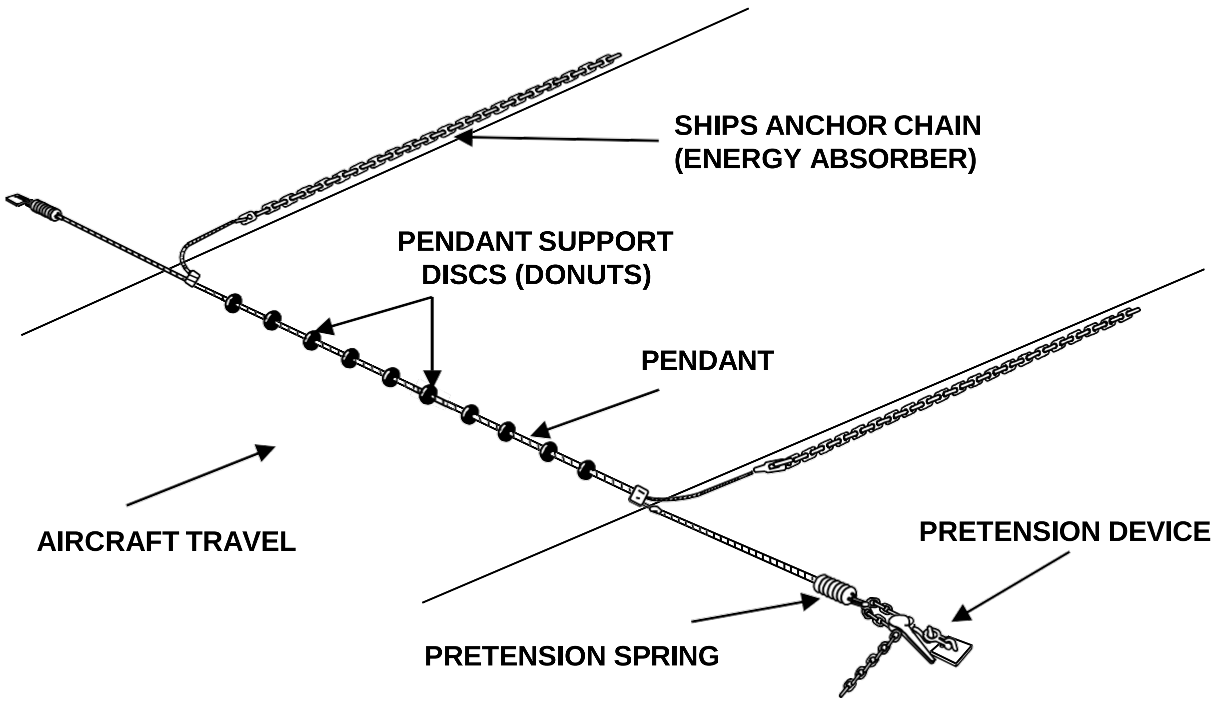
Figure 5-3 Speed and Weight Chart for Chain Gear



5-3 E-5

This unidirectional emergency arresting system is a U.S. Navy design and designation. Much like the MA-1A, this system uses several shots of ship's anchor chain as the energy absorber but these systems are never connected with a barrier (net). For the Navy or Marine Corps, these systems can have from one to four disc-supported hook cables, with designations of E-5 and E-5 Mod 1 through E-5 Mod 3. Obtain further technical information on the Navy configuration of this system from the Naval Air Warfare Center, Lakehurst, New Jersey. For the Air Force, these systems use only one pendant and are sited and maintained as described in the MA-1A T.O. (TO 35E8-2-2-1). They are designated as an E-5 (Figure 5-4).

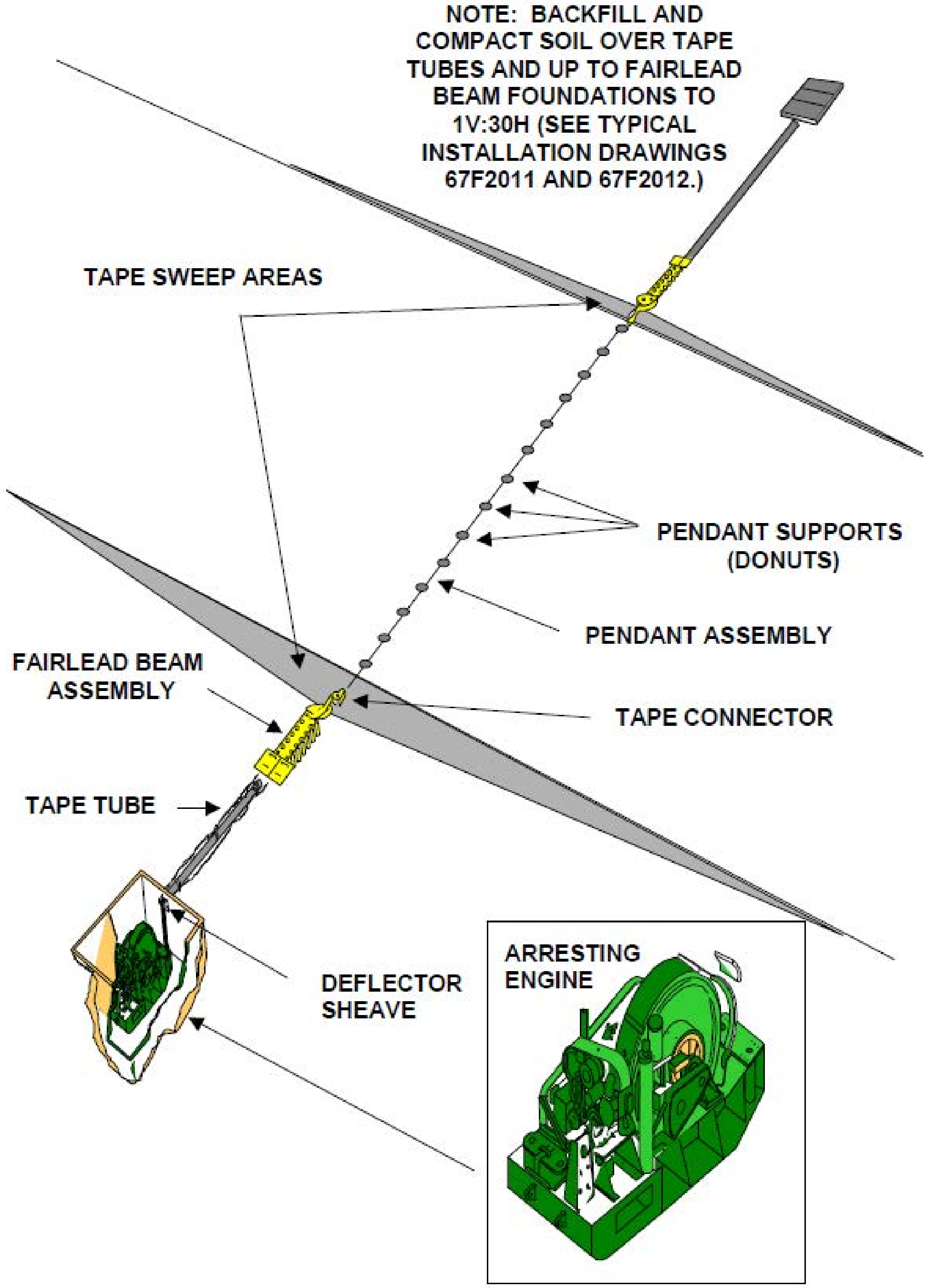
Figure 5-4 E-5 Hook Cable CHAG



5-5 BAK-12 Rotary Friction Brake Absorber

5-5.1 The BAK-12 (Figure 5-5) is the standard Air Force operational AAS. This bi-directional system employs two energy absorbers. Each absorber consists of two multi-disc rotary friction brakes mounted on either side of the purchase-tape reel on a common shaft. The energy absorbers are located on opposite sides of the runway or overrun, connected to a 32-millimeter (1.25-inch) disc-supported pendant by the purchase tapes. Ideally, the energy absorbers should be in a below-grade pit with a minimum split distance of 15.24 meters (50 feet). (Split distance is a measurement taken between the lead-on sheave of the fairlead beam or edge sheave, and the energy absorber.) Split distances of up to 91 meters (300 feet) are acceptable for all BAK-12 installations. You may also install BAK-12 systems above grade in one of two configure-tions, the selection depending upon site conditions and operational requirements. These are the expeditionary installation for periods of up to one year, and the semi-permanent installation, well-suited for long-term use and typically selected when site conditions will not allow a pit-type installation. Siting and grading requirements are in Section 3 of T.O. 35E8-2-5-1. *Typical Installation Drawings for pit-type installations (drawing number 67F2012A*) and permanent surface type installations (drawing number 67F2011A) are available from AFCEC/COS and the AFLCMC.

Figure 5-5 BAK-12 Aircraft Arresting System



5-5.2 Originally, BAK-12 energy absorbers were fitted with a 60-inch purchase-tape storage reel. This design allowed the maximum energy expected to be imparted during an aircraft engagement to dissipate within a runout of 290 meters (950 feet) plus the length of the aircraft. Designers have since improved the BAK-12 to meet increased demands of heavier and faster aircraft. The energy absorbers have been retrofitted with larger 66-inch or 72-inch tape storage reels to accommodate increased runout, thus increasing the total energy capacity of the system. These systems require 366 meters (1200 feet) plus the length of the aircraft for maximum runout. The 72-inch reel systems are special-purpose systems configured for 610 meters (2000 feet) of runout.

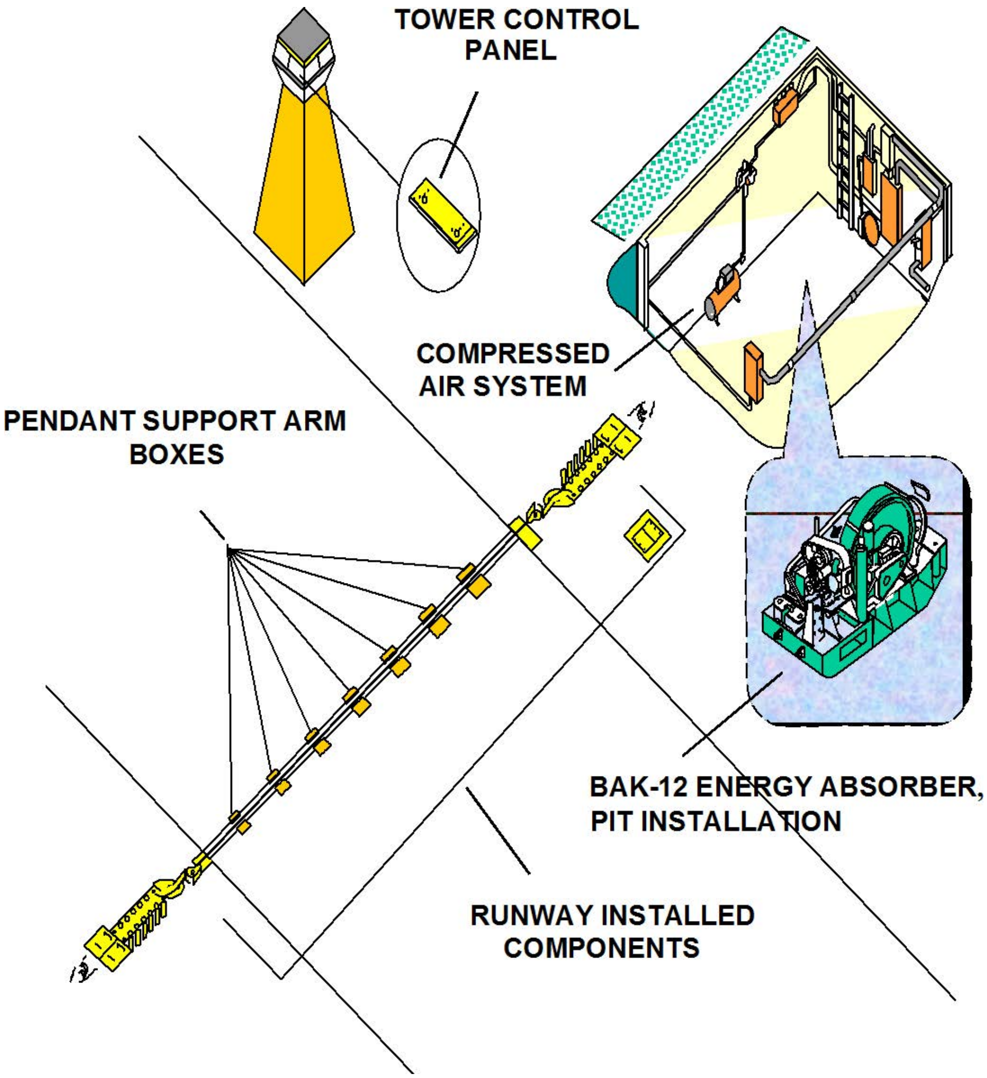
5-5.3 The standard BAK-12 is configured for cross-runway separations of up to 61 meters (200 feet) (distance between fairlead beams or edge sheaves). For installations with cross-runway spans exceeding 61 meters (200 feet), replace the BAK-12 control valve cam to accommodate full runout of the system. Refer to T.O. 35E8-2-5-1 to identify the part number for the correct replacement cam and installation procedures. Also select a pendant length of at least 80 percent of the distance between the fairlead beams to avoid adverse cable dynamics. Selected cable length should be at least 2 meters (6 feet) less than the total span between runway edge sheaves. This will allow sufficient exposed tape on each side of the runway (at least 0.6 meter [2 feet]), as well as an offset between the runway centerline and the center point of the cable, to further reduce cable dynamics by disrupting parity in the kink wave caused by the engagement.

5-5.4 Dual BAK-12 systems are special-purpose installations configured to accommodate high-energy engagements of aircraft ranging from 27,200 to 63,500 kilograms (60,000 to 140,000 pounds). These configurations consist of four BAK-12 energy absorbers arranged in pairs on either side of the runway. The energy absorbers may be standard BAK-12s, or be equipped with 72-inch-diameter tape storage reels to accommodate 610 meters (2000 feet) of runout. Special tape connectors and edge sheaves are needed for these installations. For details of these components and other special considerations, see Section VIII of T.O. 35E8-2-5-1.

5-6 BAK-14 AND TYPE H HOOK CABLE SUPPORT SYSTEMS

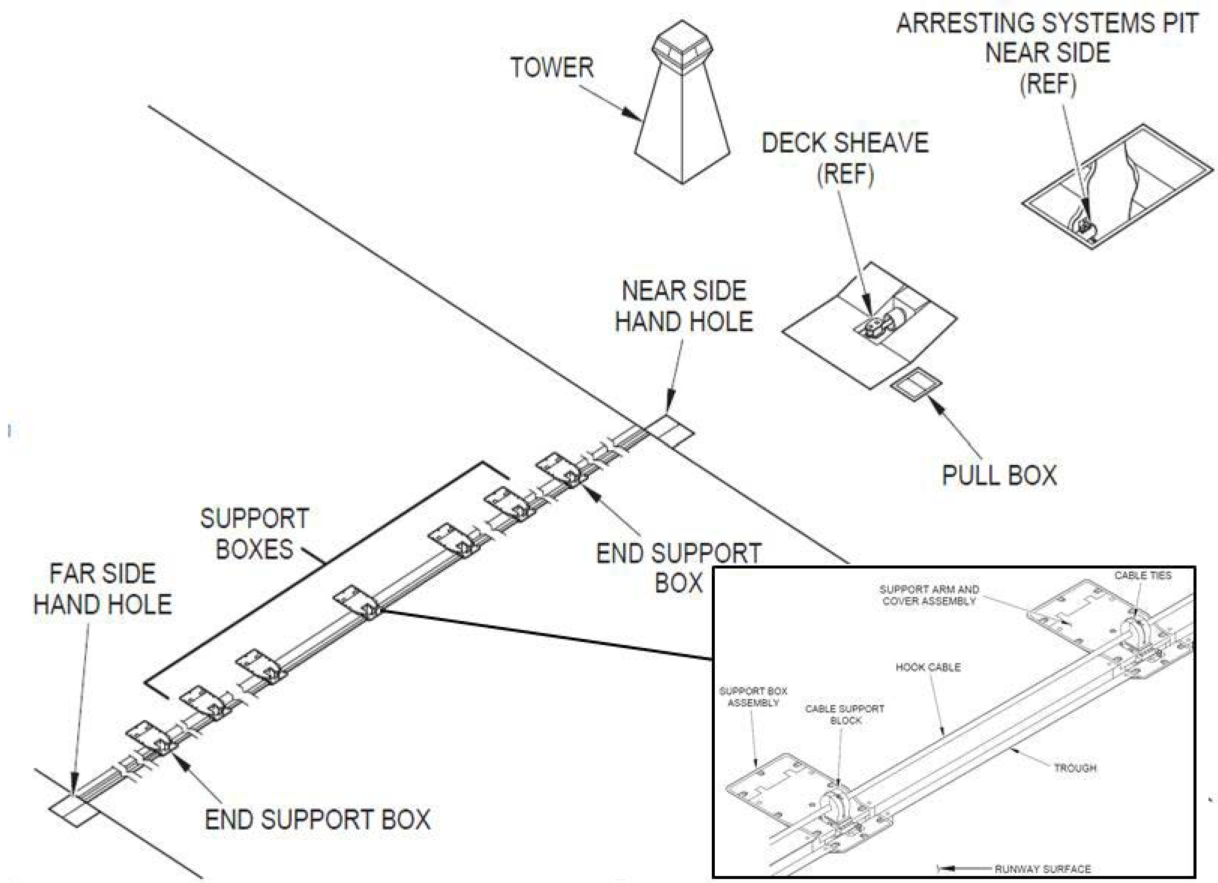
5-6.1 The BAK-14 hook cable support system (Figure 5-6) is a bidirectional hook cable (pendant) support system used in conjunction with the BAK-12, or a comparable pair of arresting system absorbers to engage and safely stop a hook-equipped aircraft. It provides the means to support the pendant at least 51 millimeters (2 inches) above the runway surface while giving Air Traffic Control the means to lower the pendant below the surface of the runway to prevent damage to low-undercarriage aircraft, the pendant, and the pavement below the pendant during trampling. These systems can accommodate 45-, 60-, and 90-meter (150-, 200-, and 300-foot) -wide runways, and can be ordered to suit the specific application. The control side BAK-12 pit or protective shelter and foundation must be enlarged to house the compressed air and control systems needed to operate these supplemental systems. The site and utility considerations for installation are in T.O. 35E8-2-8-1, *Operation, Maintenance, and Installation Instructions with Illustrated Parts Breakdown, Hook Cable Support System, Model BAK-14*.

Figure 5-6. BAK-14 Cable Support and Retraction System



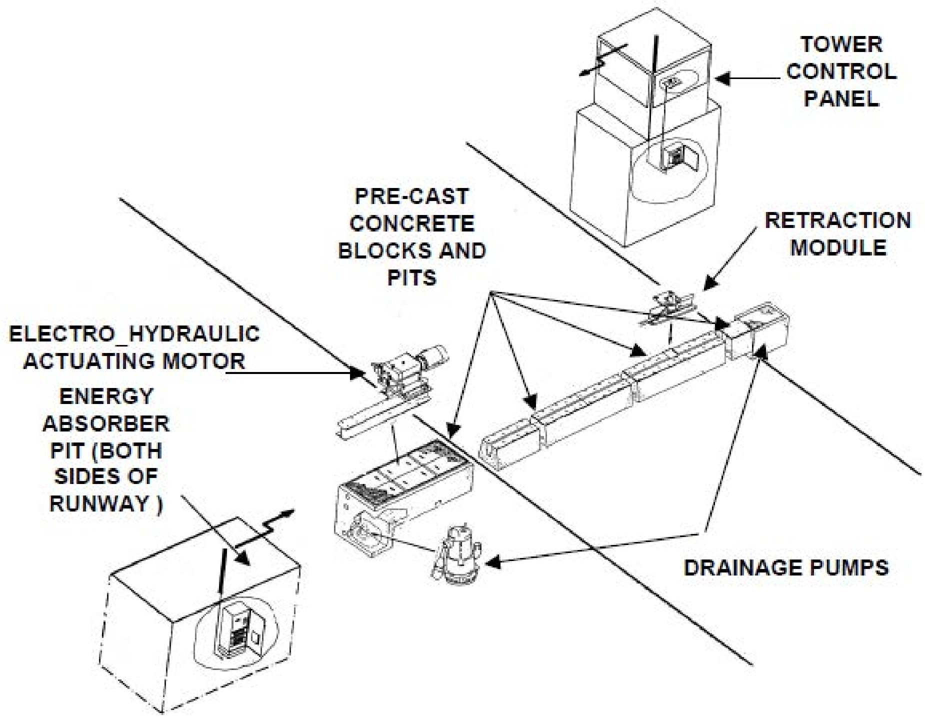
5-6.2 The BAK-14 Modified or BAK-14M (Figure 5-7) is a bidirectional hook cable (pendant) support system used in conjunction with the BAK-12, or a comparable pair of arresting system absorbers to engage and safely stop a hook-equipped aircraft. The system consists of either 14 or 20 support blocks which support the hook cable 3 inches (nominal) (two inches minimum) above the surface of the runway while giving Air Traffic Control the means to lower the pendant below the surface of the runway to prevent damage to low-undercarriage aircraft, the pendant, and the pavement below the pendant during trampling. The system can accommodate 45-, 60-, and 90-meter (150-, 200-, and 300-foot) -wide runways. The BAK-14M contains modified support box covers that provide easier maintenance access and rapid support box replacement. The site and utility considerations for installation are in T.O. 35E8-2-8-1-11, *Operations Manual for the BAK-14 Hook Cable Support Systems (Pit Mounted with Heaters)14 and 20 Box Systems.*

Figure 5-7. BAK-14M Cable Support and Retraction System



5-6.3 The Type H hook cable support system (Figure 5-8) is a bi-directional hook cable support system that can be used in conjunction with any type of energy- absorbing device. It provides a means to raise a cable at least 51 millimeters (2 inches) above a runway surface or lower it below the runway surface in less than 1.5 seconds. It can be supplied to accommodate runway widths of 46, 60, and 90 meters (150, 200, and 300 feet). A radio remote-control system provides Air Traffic Control the means to operate the system and to monitor its operational status. It typically consists of 14 to 18 (depending on runway width) retraction modules installed into pre-cast concrete blocks across the runway and connected together by metallic rods to form a rigid loop. This loop is actuated by an electro-hydraulic motor located in a concrete pit on one side of the runway. Detailed information (i.e., description, operation, maintenance, illustrated parts list), are provided in T.O. 35E8-2-8-12, *Type H45-200 Aircraft Arresting Cable Retraction System Abbreviated Component Maintenance Manual With Illustrated Parts List* and Aerazur Technical Manual 256-722, *Type H45-200* Component Maintenance Manual With Illustrated Parts List. Installation drawings are available from the manufacturer. It should be noted, three-phase power is needed at the Type H installation site to power the hydraulic pump actuator.

Figure 5-8. Type H Hook Cable Support System



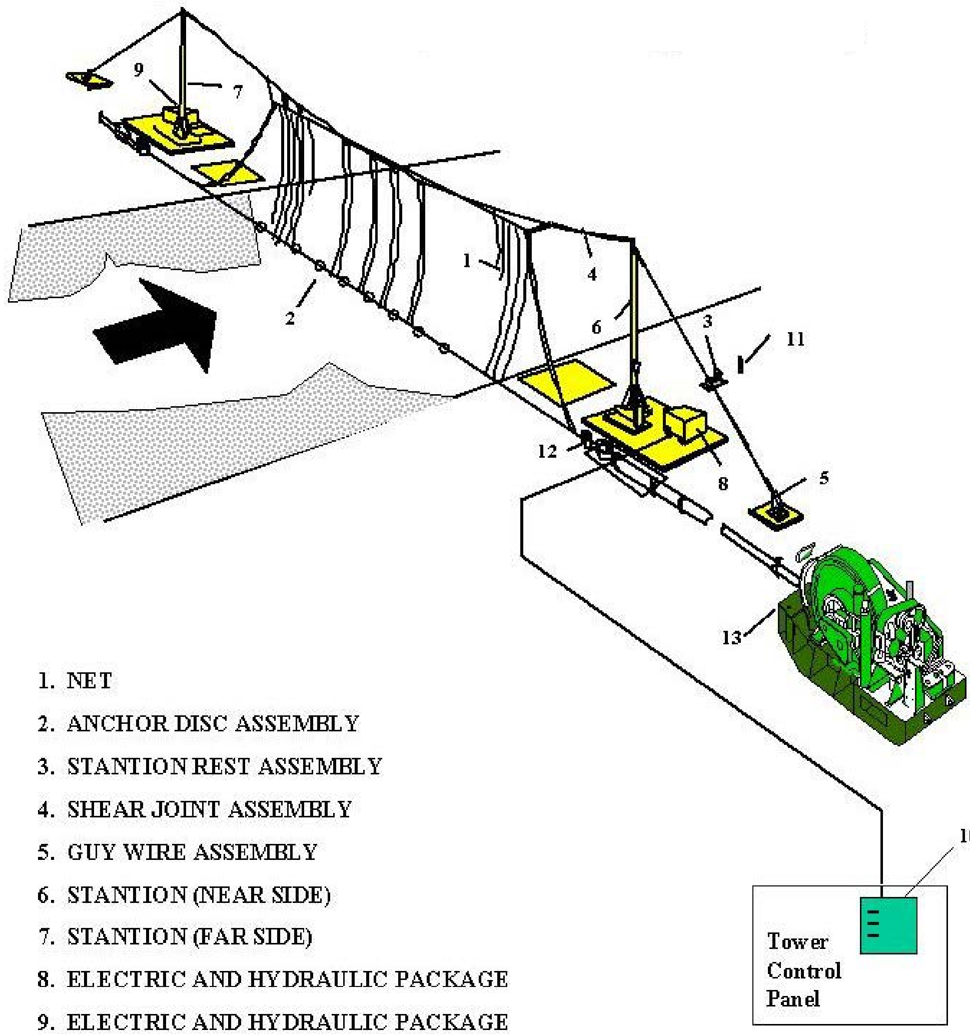
5-7 BAK-15 (61QSII)

5-7.1 The BAK-15 aircraft arresting barrier consists of a pair of electro-hydraulically powered steel masts that provide support and remote-controlled movement for a unidirectional nylon net barrier (Figure 5-9). The masts are installed on opposite sides of the runway overrun on concrete foundations. The ATC tower contains a remote-control panel which can be hard-wired, but most commonly is radio-controlled.

5-7.2 The barrier must be augmented with an energy-absorbing device such as a ship's anchor chain, BAK-12, or textile brake. During an aircraft engagement, shear links in the net suspension straps separate by the force of the aircraft engaging the net. The net then envelops the aircraft and seats on the leading edge of the wings, transferring the forward momentum of the aircraft to the energy-absorbing device.

5-7.3 The system can be complemented with a standard disc-supported pendant to accommodate tail-hook engagements through interconnect configuration hardware similar to that used for the MA-1A Modified. The hook cable interconnect kit is designated as the 62 NI (net interconnect). System operation and maintenance instructions are in T.O. 35E8-2-12-1, *Operation And Maintenance Instructions BAK-15 Aircraft Arresting Systems.* Obtain installation drawings from the manufacturer through the procuring activity at the time of procurement.

Figure 5-9. BAK-15 Net Barrier (Pictured with BAK-12 Absorbers, BAK-15/12)



1. NET
2. ANCHOR DISC ASSEMBLY
3. STANTION REST ASSEMBLY
4. SHEAR JOINT ASSEMBLY
5. GUY WIRE ASSEMBLY
6. STANTION (NEAR SIDE)
7. STANTION (FAR SIDE)
8. ELECTRIC AND HYDRAULIC PACKAGE
9. ELECTRIC AND HYDRAULIC PACKAGE
10. REMOTE CONTROL ASSEMBLY
11. ALIGNMENT ROD
12. TAPE CONNECTOR
13. ABSORBER

5-8 MOBILE AIRCRAFT ARRESTING SYSTEM (MAAS) CONFIGURATION

5.8.1 The MAAS (Figure 5-10) is essentially a BAK-12 AAS mobilized through installation on a specially developed trailer. It is configured for a maximum aircraft runout of 302 meters (990 feet). This system was initially developed and tested to accommodate recovery of fighter aircraft returning to a battle-damaged airfield. Such cases require rapid deployment and installation and may require that only the minimum essential anchoring hardware be installed to accommodate this scenario. When installed for this purpose, the MAAS is installed along the shoulder of the runway this configuration can be either unidirectional or bi-directional (upgrade kit required) engagement capability with a maximum aircraft weight and speed of 18,144 kilograms (40,000 pounds) at 150 knots

(Table 1-1). Installing the MAAS without a set-back configuration limits the system weight capabilities and the type of aircraft capable of operating on the airfield. For detailed instructions on this system, refer to T.O. 35E8-2-10-1, *Operation and Maintenance Instructions, Arresting Systems, Aircraft, Mobile*.

5.8.2 When the MAAS is installed in the set-back configuration it presents a significantly reduced profile on the runway edge allowing the airfield to accommodate wide body aircraft. The MAAS set-back configuration is accomplished with Mobile Runway Edge Sheave (MRES) (Figure 5-11) or Lightweight Fairlead Beam (LWFB) (Figure 5-12) and postures the MAAS in a bi-directional engagement capability for a maximum aircraft runout of 366 meters (1200 feet). The engagement capability in the set-back configuration is a maximum aircraft weight and speed of 31026 kilograms (68,400 pounds) at 180 knots. For detailed instructions on this system, refer to T.O. 35E8-2-10-1, *Operation and Maintenance Instructions, Arresting Systems, Aircraft, Mobile*.

5.8.3 The MAAS can be installed over soil, concrete, asphalt, and asphalt over soil or concrete. The MRES and LWFB can only be installed over soil and concrete. Careful planning should take place to fully understand the obstacles of the proposed installation site. The California Bearing Ratio (CBR) will be a determining factor when a MAAS is planned to be installed over soil. Expeditionary soil installation should not be used if the anticipated period of service is longer than one year. Waivers to extend use longer than one year are processed through AFLCMC. The preferred method of installation for an anticipated period extending beyond one year is concrete pads for the MAAS and MRES or LWFB. Contact AFCEC/COS for drawings.

Figure 5-10 Mobile Aircraft Arresting System (MAAS)

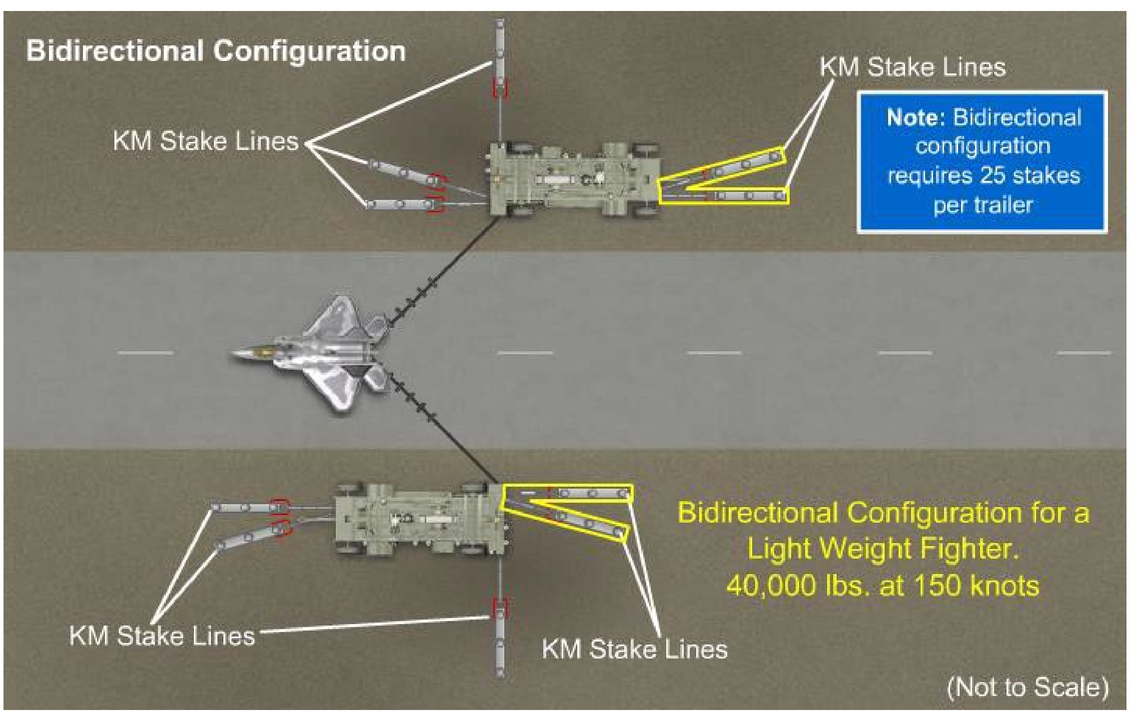


Figure 5-11 Mobile Aircraft Arresting System (MAAS) in Set-Back Configuration with Mobile Runway Edge Sheave (MRES)

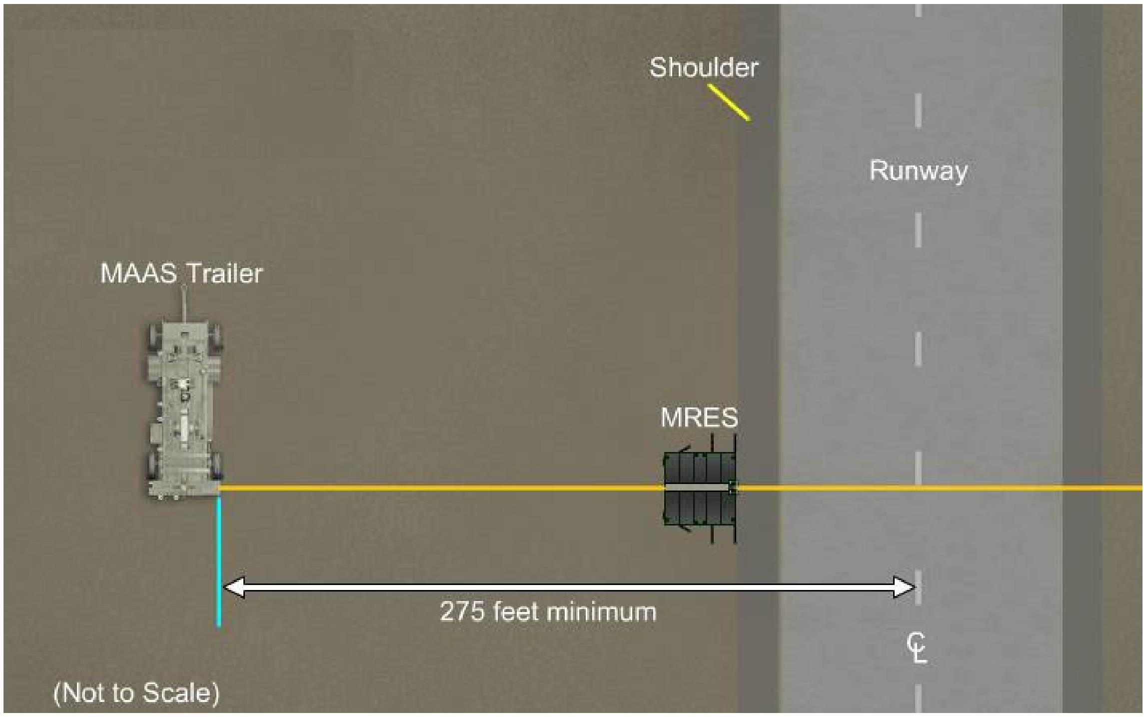
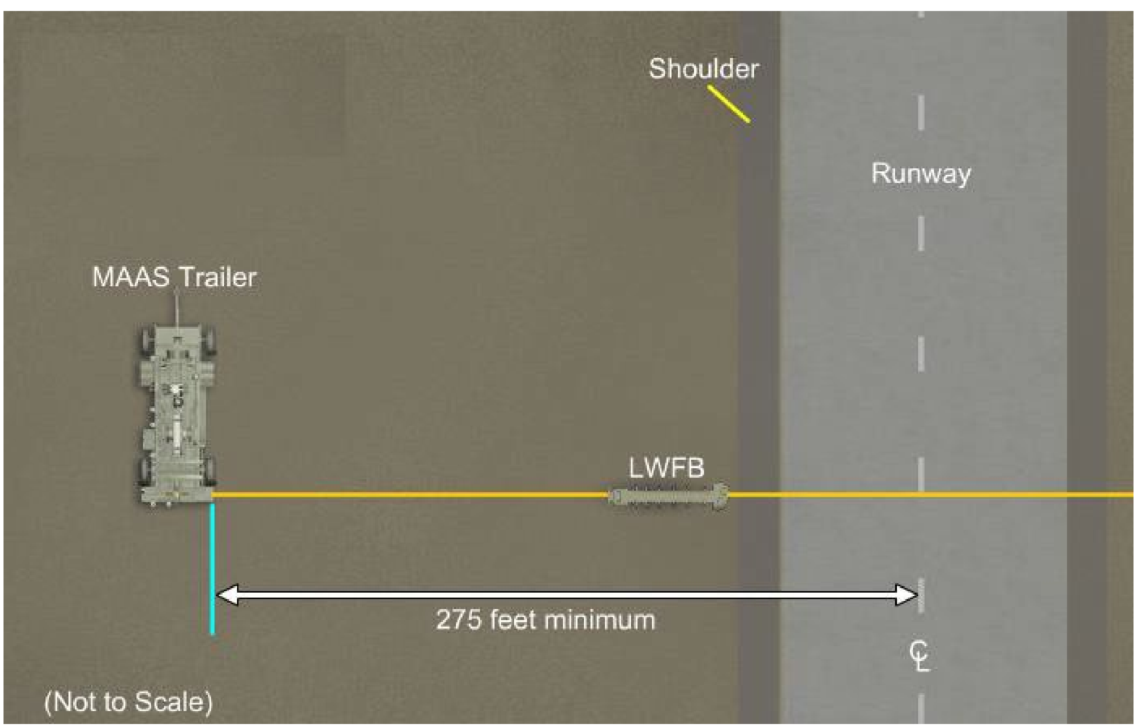


Figure 5-12 Mobile Aircraft Arresting System (MAAS) in Set-Back Configuration with Lightweight Fairlead Beam (LWFB)



5-9 TEXTILE BRAKE

5-9.1 This modular arresting system is primarily intended as an emergency back-up system for standard operational systems. It is composed of multiple modules arranged in equal numbers on both sides of the overrun (or runway if a bidirectional model) that contain specially woven textile tearing straps to absorb the kinetic energy generated during an engagement. One end of each module is anchored to the ground, and the other end is connected to a tensioned cable or barrier positioned across the runway to engage an aircraft. The system is available in a two-stage unidirectional configuration (Figure 5-13) see Table 5-2 and T.O. 35E8-2-13-1, *Operation, Service, Overhaul with Illustrated Parts Breakdown Textile Brake and Hook Cable Aircraft Arresting System, Type MB 60.9.9.C*, . For information on the single-stage bi-directional system (Figure 5-14) MB 100.10.C, see Table 5-2 and T.O. 35E8-2-14-1, *Operation and Service, Overhaul Instructions, Illustrated Parts Breakdown for Textile Brake and Hook Cable Aircraft Arresting System, Type MB 100.10.C*.

5-9.2 The advantages of the two-stage system (MB 60.9.9.C) over the MB 100.10.C bi-directional system are higher system capacity and lower costs for reconfiguration after low-energy engagements. The modules in a stage (breaking line) are expended upon aircraft engagement and must be replaced; however, a life cycle analysis indicates system costs are approximately 50 percent of the life cycle cost for a BAK-12 installed in the overrun area of a runway due to the low number of engagements that occur there. These systems are designed for tail-hook-equipped fighter aircraft but can also be complemented with a net barrier such as the BAK-15 or a net and cable interconnect system. They may also be configured for expeditionary or temporary installations.

5-9.3 If the bi-directional version of the textile brake arresting system is installed on the operational runway surface due to a non-standard length overrun, the arresting gear marker (AGM) signs should be blanked when viewed from the approach. This is because the system is a low-energy-capacity system (compared with BAK-12) and is not intended for approach end engagements.

Figure 5-13 Textile Brake, Model MB.60.9.9.C

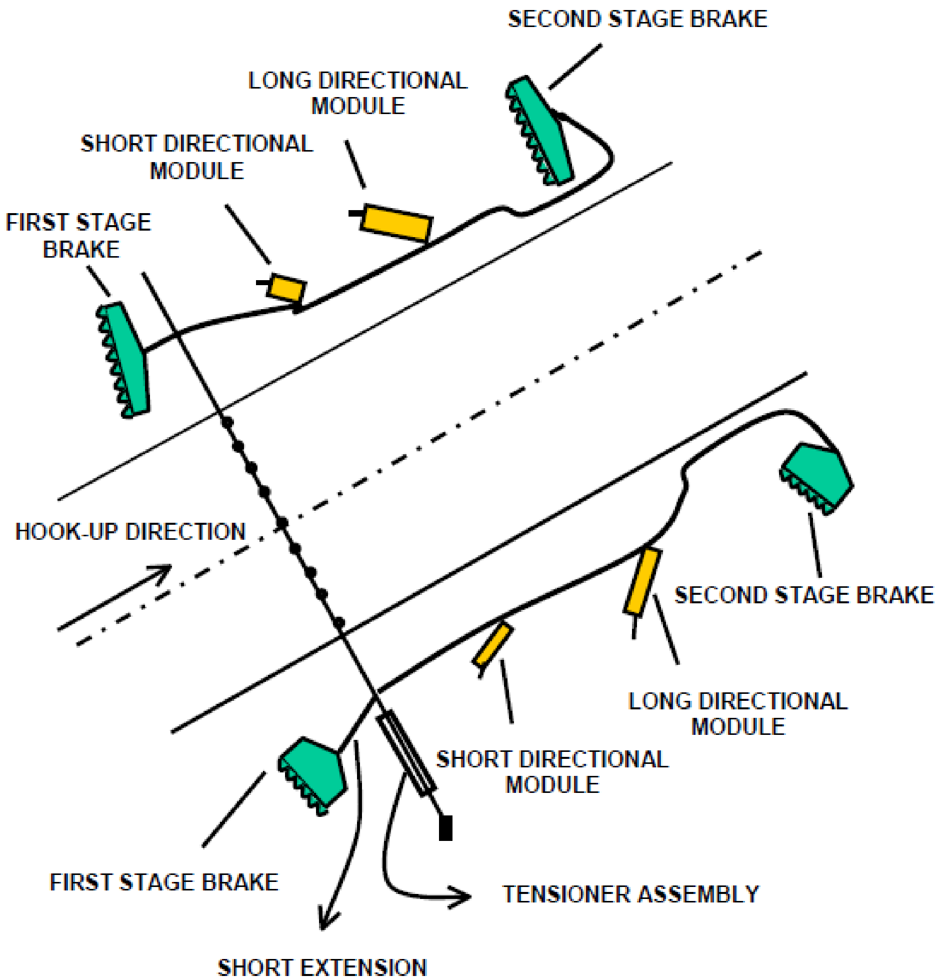
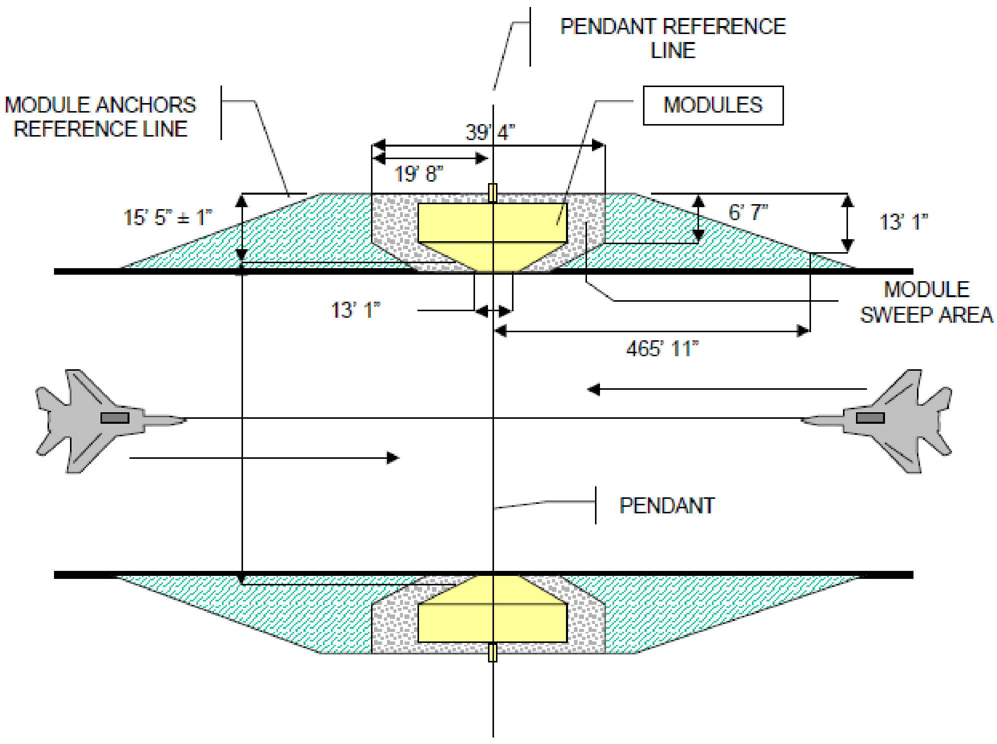


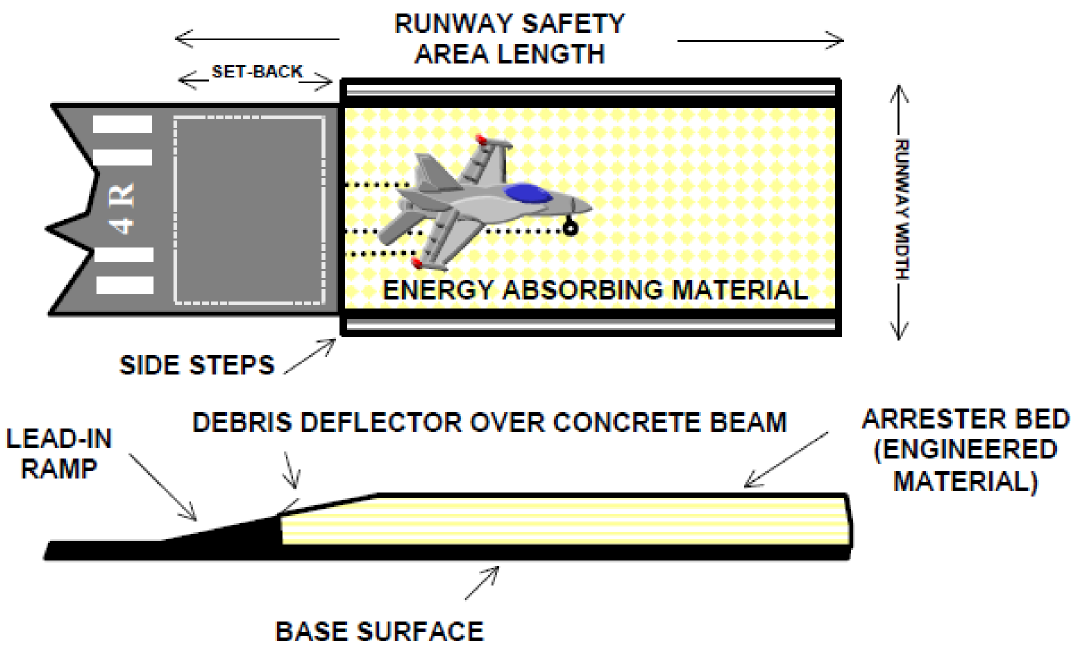
Figure 5-14 Textile Brake, Model MB.100.10.C



5-10 SOFT GROUND TYPE AAS

The Engineered Material Arresting System (EMAS) is an FAA-approved soft ground system normally used for civil airports to mitigate short safety areas (less than 305 meters [1,000 feet] long) at runway ends. The system is constructed of cellular foam concrete of specific strength and thickness to decelerate an aircraft that overruns the runway through rolling resistance. The design for each system is aircraft-specific, based upon the type of aircraft that will use the runway. FAA AC 150/5220-22, *Engineered Materials Arresting Systems (EMAS) for Aircraft Overruns*, provides the design basis. It is intended for use where it is impractical to obtain the standard 305-meter (1000-foot) overrun (FAA term Runway Safety Area (RSA)) and other alternatives are not feasible. See Figure 5-15 for layout of a typical soft ground type system. For purposes of design, the soft ground arrestor system can be considered fixed by function and frangible since it is designed to fail at a specific impact load; therefore, a soft ground system is not considered an obstruction under Federal Aviation Regulation (FAR) 14 Code of Federal Regulation (CFR) Part 77, Subpart C--*Standards for Determining Obstructions to Air Navigation or Navigational Aids of Facilities*. Soft ground systems are located beyond the end of the runway, centered on the extended runway centerline. They will usually begin at some distance from the end of the runway to avoid damage to the system due to jet blast or short landings. This distance will vary depending on the area available and the specific system design.

Figure 5-15 Typical Soft Ground Aircraft Arrestor System



CHAPTER 6 NUMBER AND TYPES OF SYSTEMS AUTHORIZED

6-1 Use the following examples for guidance, keeping in mind the primary mission aircraft, climatic region, and other operational factors dictate the total number, type, and location of AAS required on runways. The MAJCOM operating the tail-hook-equipped aircraft, or other aircraft compatible with net barrier or soft ground systems requiring support makes this determination through operational risk management (ORM), considering runway length and configuration, and proximity to other airfields and other factors.

6-2 The typical configurations described in paragraphs 6-2.1 through 6-2.3 for both runways and overrun systems may not necessarily be required in all cases.

6-2.1 A runway intended primarily for operating tactical or training tail-hook-equipped aircraft should typically have an emergency system in each overrun and an operational system at each end of the runway to provide a safety factor for possible missed engagements. However, some locations at forward operating bases or where snow and ice accumulation warrants, two operational systems may be necessary for each runway end, and a midfield installation may be needed as well.

6-2.2 Runways that are primary divert facilities for bases operating tactical or training tail-hook-equipped aircraft should typically have an emergency system in each overrun, and an operational system on each end of the primary runway.

6-2.3 Bases that are occasional hosts to arrestment-capable transient aircraft should have an emergency system installed in each overrun of the primary runway, or an operational system on each end of the primary runway.

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CHAPTER 7 AIRCRAFT ARRESTING SYSTEM LOCATION REPORT [REPORT CONTROL SYMBOL (RCS): HAF-ILE (AR) 7150]

7-1 DoD needs an accurate accounting of all AAS to determine worldwide operational capabilities. BCE representatives are responsible to ensure that the status and locations of their arresting systems are correct in the DoD FLIP. Report changes in the arresting system array promptly so that other agencies can validate and publish the addition or correction. Report all information in inch-pound units.

7-2 Submit arresting system location report information to the local installation airfield manager for inclusion in the DoD FLIP. Provide a courtesy copy to AFCEC/COS at the following address:

AFCEC/COS
Attn: Aircraft Arresting System SME
139 Barnes Drive, Suite 1
Tyndall AFB FL 32403-5319
afcec.co@us.af.mil (e-mail submissions are encouraged)

7-3 Submit the following information, along with a diagram similar to the diagram in Figure 7-1:

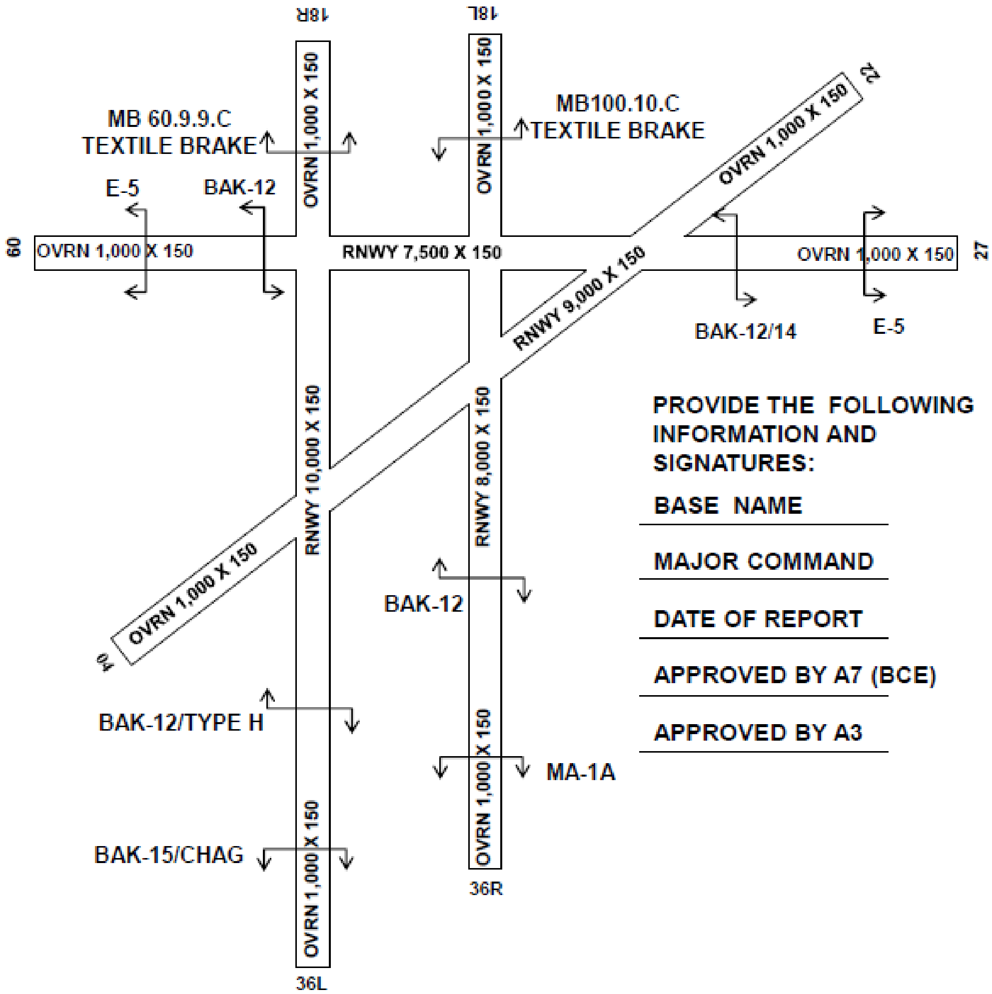
- Base name
- MAJCOM or sponsor
- Runway designations
- System type
- Length of runway to the nearest 100 feet (threshold to threshold)
- Width of runway, in feet
- Length of overrun, in feet (threshold to end of overrun)
- Longitudinal location of the arresting system with respect to the threshold, in feet (for example, “plus (+) 950" indicates that the system is 950 feet from the threshold on the runway; "minus (-) 35" indicates that the system is 35 feet from the threshold into the overrun)

7-4 Describe the arresting system installation characteristics for each system indicated on the airfield scheme using the following notations:

- AG — above ground
- BG — below ground
- EX1 — expeditionary system (BAK-12)

- EX2 — expeditionary system (MAAS)
- IC — barrier interconnected with a hook cable
- RR — remote radio control
- RH — remote hard-wired control
- MO — manually operated barrier net (raised and lowered)
- Z — owned by another service, country, or agency
- O — out of service, inoperative
- SR — 950-foot runout
- ER — 1200-foot runout
- NSR — nonstandard runout (indicate runout in feet following code entry)

Figure 7-1 Sample Airfield Diagram for Aircraft Arresting Systems Report



PROVIDE THE FOLLOWING INFORMATION AND SIGNATURES:

BASE NAME __________

MAJOR COMMAND __________

DATE OF REPORT __________

APPROVED BY A7 (BCE) __________

APPROVED BY A3 __________

NOTES:

1. Indicate runway and overrun lengths and widths for all runways as shown above.
2. Indicate runway designations as shown above.
3. Indicate arresting system locations as shown above.
4. Include remarks describing any non-standard configurations or conditions (attach additional sheets as necessary).

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APPENDIX A REFERENCES

UNIFIED FACILITIES CRITERIA

\1 https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc **/1/**

UFC 1-200-01, *General Building Requirements*

UFC 3-260-01, *Airfield and Heliport Planning and Design*

UFC 3-260-02, *Pavement Design for Airfields*

\1 UFC 3-260-02, *Airfield and Heliport Marking* **/1/**

UFC 3-535-01, *Visual Air Navigation Facilities*

AIR FORCE

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

AFI 11-218, *Aircraft Operations and Movement on the Ground*

AFI 13-204V3, *Airfield Operations Procedures and Programs*

AFI 13-213, *Airfield Driving*

\1 AFMAN 32-1040, *Civil Engineer Airfield Infrastructure Systems* **/1/**

AFI 51-502, *Personnel and Government Recovery Claims*

Electronic Technical Information Management System (ETIMS)
https://www.my.af.mil/etims/ETIMS/index.jsp

T.O. 00-35D-54, *USAF Deficiency Reporting and Investigating System*

T.O. 35E8-2-2-1, *Operation and Service Instructions - Runway Overrun Barrier, Types MA-1 and MA-1A*

T.O. 35E8-2-2-3, *Overhaul Instructions - Runway Overrun Barrier, Types MA-1 and MA-1A*

T.O 35E8-2-2-4, *Illustrated Parts Breakdown – Aircraft Arresting System Model MA-1 and MA-1A*

T.O. 35E8-2-5-1, *Operation and Maintenance Instructions – Aircraft Arresting System Model BAK-12*

T.O. 35E8-2-5-3, *Overhaul Maintenance with Illustrated Parts Breakdown - Aircraft Arresting System Model BAK-12*

T.O. 35E8-2-5-4, *Illustrated Parts Breakdown – Aircraft Arresting System Model BAK-12*

T.O. 38G1-113-3, *Diesel Engines Overhaul Instructions with Illustrated Parts Breakdown*

T.O. 35E8-2-8-1, *Operation, Maintenance, and Installation Instructions with Illustrated Parts Breakdown, Hook Cable Support System, Model BAK-14*

T.O. 35E8-2-8-1-11, *Operations Manual for the BAK-14 Hook Cable Support Systems (Pit Mounted with Heaters)14 and 20 Box Systems*

T.O. 35E8-2-8-12, *Type H45-200 Aircraft Arresting Cable Retraction System Abbreviated Component Maintenance Manual With Illustrated Parts List*

T.O. 35E8-2-12-11, *Operation and Maintenance Instructions BAK-15 Aircraft Arresting Systems.*

T.O. 35E8-2-10-1, *Operation and Maintenance Instructions, Arresting Systems, Aircraft, Mobile*

T.O. 35E8-2-10-3, *Overhaul Instructions, Arresting Systems, Aircraft, Mobile*

T.O. 35E8-2-10-4, *Illustrated Parts Breakdown, Arresting Systems, Aircraft, Mobile*

T.O. 35E8-2-13-1, *Operation, Service, Overhaul with Illustrated Parts Breakdown Textile Brake and Hook Cable Aircraft Arresting System, Type MB60.9.9.C*

T.O. 35E8-2-14-1, *Operation and Service, Overhaul Instructions, Illustrated Parts Breakdown for Textile Brake and Hook Cable Aircraft Arresting System, Type MB100.10.C*

Air Force Civil Engineer Center (AFCEC)

Typical Installation Drawing 67F2011A

Typical Installation Drawing 67F2012A

FEDERAL

Code of Federal Regulation (CFR) Part 77: Subpart C--*Standards for Determining Obstructions to Air Navigation or Navigational Aids of Facilities*

Federal Standard 595, *Colors Used in Government Procurement*, http://www.gsa.gov/portal/content/142623

FAA

FAA AC 150/5220-22, *Engineered Materials Arresting Systems (EMAS) for Aircraft Overruns*

FAA AC 150/5220-9, *Aircraft Arresting Systems*

FAA Order JO 7110.65, *Air Traffic Control*, “Pilot/Controller Glossary”

AMERICAN SOCIETY FOR TESTING AND MATERIALS

C886-98, *Standard Test Method for Scleroscope Hardness Testing of Carbon and Graphite Materials*

D256-10, *Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics*

D638-14, *Standard Test Method for Tensile Properties of Plastics*

D1505-10, *Standard Test Method for Density of Plastics by the Density-Gradient Technique*

D3028-95, *Standard Test Method for Kinetic Coefficient of Friction of Plastic Solids (Withdrawn 2000)*

INDUSTRY

Aerazur Technical Manual 256-722, *Type H45-200 Retractable Hook Cable System*

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APPENDIX B GLOSSARY

B-1 ACRONYMS

A7	Directorate of Installations and Mission Support
AAS	Aircraft Arresting System
AC	Advisory Circular (FAA)
AF/A4C	Air Force Director of Civil Engineers
AFCEC	Air Force Civil Engineer Center
AFCEC/COS	AFCEC Engineering Division
AFCEC/COSC	AFCEC Civil Branch
AFCENT	Air Forces Central (Command)
AFEMS	Air Force Equipment Management System
AFI	Air Force Instruction
AG	above ground (AAS installation notation)
AGM	Arresting Gear Marker
AOI	Airfield Operating Instruction
ASTM	American Society for Testing and Materials ATC Air Traffic Control
BAK	Barrier Arresting Kit
BCE	Base Civil Engineer
BEMO	Base Equipment Management Office
BG	below ground (AAS installation notation)
BIA	Bilateral Infrastructure Agreements
CAGE	Commercial and Government Entity
CE	Civil Engineer
CFR	Code of Federal Regulation

CHAG	Chain Absorber Arresting Gear
CONUS	Continental United States
cu ft	cubic foot
DoD	Department of Defense
DoT	Department of Transportation
EMAS	Engineered Materials Arresting Systems
EPH	Effective Pendant Height
ER	1200-foot runout (AAS installation notation)
EX1	expeditionary system (BAK-12) (AAS installation notation)
EX2	expeditionary system (MAAS) (AAS installation notation)
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FC	Facility Criteria
FLIP	Flight Information Publications
ft	foot
ft-lb	foot-pound
g/cm	gram per centimeter
gal	gallon
GSE	Government-Supplied Equipment
HMA	Hot Mix Asphalt
HNFA	Host Nation Funded (Construction) Agreements
HQ ACC	Headquarters Air Combat Command
HQ USACE	Headquarters United States Army Corps of Engineers
IC	barrier interconnected with a hook cable (AAS installation notation)
ICAO	International Civil Aviation Organization

In	inch
IO&M	installation, operation, and maintenance
kg	kilogram
kPa	kilopascal
L	liter
lb	pound
lb ft	pound foot
LF	linear foot
M	meter
M	meter
MAAS	Mobile Aircraft Arresting System
MAJCOM	Major Command
MAJCOM/A3	Major Command Directorate of Operations
MAJCOM/SE	Major Command Directorate of Safety
mm	millimeter
MO	manually operated barrier net (raised and lowered) (AAS installation notation)
N•m	Newton meter
NAVFAC	Naval Facilities Engineering Command
NI	net interconnect
NOTAM	Notice to Airmen
NSN	National Stock Number
NSR	nonstandard runout (indicate runout in feet following code entry) (AAS installation notation)
O	out of service, inoperative (AAS installation notation)
OCONUS	Outside the Continental United States

ORM	Operational Risk Management
oz	ounce
PACAF	Pacific Air Forces
PCC	Portland Cement Concrete
psi	pound per square inch
QDR	Quarterly Data Report
RCS	Report Control Symbol
RCS HAF-ILE	Report Control Symbol - Headquarters Air Force - Civil Engineer
RDS	Records Disposition Schedule
RH	remote hard-wired control (AAS installation notation)
RR	remote radio control (AAS installation notation)
RSA	Runway Safety Area (FAA term)
SBSS	Standard Base Supply System
SE	Safety
SOFA	Status of Forces Agreement
SR 9	50-foot runout (AAS installation notation)
SRAN	Stock Record Account Number
T.O.	Technical Order
U.S.	United States
UFC	Unified Facilities Criteria
UFGS	Unified Facilities Guide Specification
UHMW	ultra-high-molecular-weight
UNC	Unified National Coarse (thread pitch)
USAF	United States Air Force
USAFE	United States Air Forces in Europe

UV	ultraviolet
WR-ALC	Warner Robins Air Logistics Center
Z	owned by another service, country, or agency (AAS installation notation)

B-2 DEFINITION OF TERMS

Active Runway—One or more runway(s) used simultaneously for takeoff or landing operations on an airfield or airport. When multiple runways are used, they are all considered active runways.

Aircraft Arresting Barrier—A device, not dependent on an aircraft arresting hook, used to stop an aircraft by absorbing its forward momentum in an emergency landing or aborted takeoff. (Joint Publication 1-02, *Department of Defense Dictionary of Military and Associated Terms*)

Aircraft Arresting Cable—The part of an aircraft arresting system (AAS) that spans the runway surface or flight deck landing area and is engaged by the aircraft arresting hook.

Aircraft Arresting System (AAS)—A series of components used to engage and absorb the forward momentum of a routine or emergency landing or an aborted takeoff.

Arrestment-Capable Aircraft—Aircraft with flight manual procedures for an arrestment.

Cycle Time—A measure of time between engagement of an aircraft, and the point in time when the arresting system is certified fully operational and ready for another engagement.

Effective Pendant Height (EPH)—The vertical distance in inches from the underside of the pendant cable to a projected surface representing undamaged runway surface.

Energy Absorber—The component of the arresting system that dissipates the kinetic energy of the arrested aircraft.

Location Identification—A description identifying the location of arresting systems by the approach or departure end, runway designation, and position in hundreds of meters/feet from the threshold. For example, the location identification extended runout BAK-12 at +457.2 meters (+1500 feet) on approach runway 36 indicates a 365.7-meter (1200-foot) runout BAK-12 located 457.2 meters (1500 feet) beyond the threshold of runway 36.

Missed Engagement—Any unsuccessful attempt to engage an AAS hook cable with a successfully deployed aircraft tail-hook or Barrier System (net system).

Mobile Aircraft Arresting System (MAAS)—A self-contained, trailer-mounted BAK-12 AAS that accommodates rapid installation during contingencies.

Movement Area (USAF/FAA)—The runways, taxiways, and other areas of an airport/heliport used for taxiing/hover taxiing, air taxiing, take-off, and landing of aircraft, exclusive of loading ramps and parking areas. At airports/heliports with a tower, specific approval for entry onto the movement area must be obtained from Air Traffic Control (ATC). For USAF, the movement area is determined by the airfield operations flight commander and defined in the installation airfield operations and airfield driving instructions in accordance with AFI 13-204V3 and AFI 13-213.

Movement Area (ICAO)—That part of an airport used for the take-off, landing and taxiing of aircraft, consisting of the maneuvering area and the apron(s).

Overrun (USAF)—An area beyond the take-off runway designated by the airport authorities as able to support an airplane during an aborted take-off. The FAA/ICAO term for this is “stopway.” UFC 3-260-01 identifies this area as one that prevents serious damage to aircraft that overrun or undershoot the runway.

Pendant—The part of an AAS that spans the runway surface or flight deck landing area and is engaged by the aircraft tail-hook.

Reset Time—The time required to ready the arresting system for another engagement after aircraft release. (This does not include time to disengage the aircraft from the arresting system but does include the time required to inspect and certify the system as fully operational.)

Stopway (FAA/ICAO)—An area beyond the take-off runway designated by the airport authorities as able to support an airplane during an aborted take-off. The Air Force term for this is “overrun.”

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APPENDIX C LETTER OF AGREEMENT WITH THE FEDERAL AVIATION ADMINISTRATION (FAA)

In cases where a military activity needs to install an arresting system on a civil or jointly used airfield, the following example may be used as a guide in developing the agreement.

AGREEMENT: The [FAA office and address] and [designated MAJCOM] agree to the following provisions for the operation and use of aircraft arresting equipment installed on [designated runway, airport name, and address].

General Provisions:

This agreement describes FAA functions and responsibilities concerning the remote-control operation of arresting systems by FAA air traffic controllers. It governs use of arresting barriers and hook cable arresting systems for military aircraft and, in an emergency, at pilot request for civil aircraft.

The conditions and procedures described in this agreement become effective when it is signed and dated by the parties and the tower chief receives written notice from the installation commander that one of the following conditions exists:

> The arresting system has been accepted from the contractor and is commissioned and fully operational.
>
> The arresting system is available for emergency use only. If the arresting system has not been accepted from the contractor, this notification must come with a written statement from the contractor authorizing emergency use of the system and waiving any claim against the FAA for damage to the system as the result of such use.
>
> A NOTAM has been issued specifying one of the above conditions. Before receiving the letter from the installation commander, the military crew de-energizes the tower arresting system controls and the chief controller labels them "Inoperative." Tower personnel may not energize the controls under any circumstances.

Automatic arresting systems may be installed on the runway or in the overrun. Control tower personnel raise or lower the barrier or hook cable through a remote-control panel in the control tower.

Air traffic controllers operate the tower arresting system controls at the request of:

> The pilot of any military aircraft (regardless of the Service concerned, type of aircraft, or nature of the operation).
>
> The pilot of a civil aircraft in an emergency, when in commission or emergency use status as described above.
>
> A mobile control unit, the airfield manager, or a designated representative.

The military crew originates NOTAMs covering operational or outage status of a barrier or hook cable. During a NOTAM outage for repair or maintenance, tower personnel operate the controls, provided that the outage NOTAM contains the statement "available for emergency use" and the tower possesses a copy. Otherwise, the military crew deenergizes the tower controls and the chief controller labels them "Inoperative." In this event, tower personnel may not energize the controls under any circumstances.

During NOTAM outages due to failure of controls or when tower personnel advise of malfunction of the system, the military crew at the system site has full and final responsibility for operating the arresting device. The arresting system crew maintains a listening watch on air and ground frequencies and has transmitting and receiving capability with the tower on the ground control frequency keeping personnel informed of the position of the system.

Operations:

Typically, all military aircraft take off and land toward an operational arresting system in the "ready" configuration. The pilot asks the control tower operator to raise or lower the barrier or hook cable. For example, the pilot says "Duluth Tower, Joy 32 on base, gear down and locked, raise cable."

For normal landings, the request involves the approach-end cable.

For normal takeoffs, the request involves the departure-end barrier and cable.

When tower personnel receive a request to raise or lower the barrier or cable, they must inform the pilot of the intended barrier or cable position as part of takeoff or landing information. For example, they say "Joy 32 cleared for takeoff, barrier indicates up."

The pilot may request barrier or cable operating status at any time.

The barrier and cable controls are in the down position except when pilots or other authorized personnel request that either or both be raised.

Tower personnel raise the departure-end barrier and both approach- and departure-end cables for known or suspected radio failure landing by any military arrestment-capable aircraft. Activate the arresting system even if you doubt the aircraft's ability to engage the system.

The standard phraseology for emergency requests to raise the barrier is "barrier, barrier, barrier." The standard phraseology for emergency requests to raise the cable is "cable, cable, cable."

Tower personnel start normal crash procedures when an aircraft engages the barrier or cable if these procedures are not in progress.

When there is a malfunction of the barrier, hook cable mechanism, or remote control system, the tower personnel notify airfield management immediately.

Executed at ______________________________ Dated ____________________________________

For the FAA

____
(Signed)

____
(Title)

For the Air Force

____
(Signed)

____
(Title)

UFC 3-270-01
21 February 2018
Change 1, 17 March 2022

UNIFIED FACILITIES CRITERIA (UFC)

O&M MANUAL: ASPHALT AND CONCRETE PAVEMENT MAINTENANCE AND REPAIR

UFC 3-270-01
21 February 2018
Change 1, 17 March 2022

UNIFIED FACILITIES CRITERIA (UFC)

O&M MANUAL: ASPHALT AND CONCRETE PAVEMENT MAINTENANCE AND REPAIR

U.S. ARMY CORPS OF ENGINEERS (Preparing Activity)

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER CENTER

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

Change No.	**Date**	**Location**
1	7 March 2022	Added Chapter 22 on maintenance approach of specific areas critical to F-35B/C operations. Added Paragraph 21-3.6 Epoxy Coatings and 21-3.7 Joint Sealants. Updated third paragraph of 20-1, 21-1, 21-3, 21-3.1, 21-3.3, 21-4.4, 21-4.6, 21-5.1, and Appendix B References – Army.

This UFC supersedes UFC 3-270-01, dated 15 March 2001; UFC 3-270-02, dated 15 March 2001; UFC 3-270-03, dated 15 March 2001; UFC 3-270-04, dated 15 March 2001; UFC 3-250-06, dated 16 Jan 2004; Air Force ETL 96-4, dated 9 July 1996; Air Force ETL 97-2, dated 28 July 1997; Air Force ETL 02-7, dated 7 August 2002; Air Force ETL 02-8, dated 5 September 2002; Air Force ETL 11-26, dated 21 December 2011; and Air Force ETL 14-2, dated 21 November 2014.

FOREWORD

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

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale should be sent to the respective service proponent office by the following electronic form: Criteria Change Request. The form is also accessible from the Internet sites listed below.

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

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

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

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UNIFIED FACILITIES CRITERIA (UFC)
NEW SUMMARY SHEET

Document: UFC 3-270-01, *O&M: Asphalt and Concrete Pavement Maintenance and Repair*

Superseding: UFC 3-270-01, *Asphalt Maintenance and Repair*; UFC 3-270-02, *Asphalt Crack Repair*; UFC 3-270-03, *Concrete Crack and Partial-Depth Spall Repair*; UFC 3-270-04, *Concrete Repair*; UFC 3-250-06, *Repair of Rigid Pavements Using Epoxy Resin Grouts, Mortars, and Concretes*; ETL 96-4, *Temporary Joint Sealing Details and Procedures for Pavements;* ETL 97-2, *Maintenance and Repair of Rigid Airfield Pavement Surfaces, Joints and Cracks;* ETL 02-7, *Preventing Concrete Deterioration Under B-1 and F/A-18 Aircraft;* ETL 02-8*, Silicone Joint Sealant Specification for Airfield Pavements;* ETL 11-26, *Using Asphalt Surface Treatments as Preventive Maintenance on Asphalt Airfield Pavements;* and ETL 14-2, *Preventing and Repairing Concrete Deterioration Under MV-22 and CV-22 Aircraft*;

Description: UFCs 3-270-01, 3-270-02, 3-270-03, 3-270-04 and UFC 3-250-06 are hereby cancelled and combined into this UFC. To reflect the combination of these four UFCs into one document, the title of UFC 3-270-01 is changed from *Asphalt Maintenance and Repair* to *O&M Manual: Asphalt and Concrete Pavement Maintenance and Repair*. Many figures are updated and the document reviewed to ensure recent developments are included. In addition, the following Air Force Engineering Technical Letters (ETLs) are cancelled and incorporated into this UFC: ETL 96-4, ETL 97-2, ETL 02-7, ETL 02-8, ETL 11-26, and ETL 14-2.

Reasons for Document: This UFC provides engineers with information on the options for maintaining and repairing, as well as preserving and extending, the service life of pavements. It also provides information on which methods are appropriate to address observed pavement distresses. It also outlines materials, equipment, techniques, and cautions required to produce a cost-effective and durable pavement. The overlap in the five superseded UFCs and six cancelled ETLs made it difficult to ensure consistency between documents as modifications to each were added. Combining these UFCs and ETLs into one document facilitates user comprehension and maintains internal consistency during future updates.

Impact: These changes enhance user access to the technical guidance in the documents (one document instead of eleven). This effort reduces the cost to maintain this guidance by reducing ambiguity and reducing the number of documents. There is a potential decrease in initial and lifecycle costs due to increased options available to sustain the pavements throughout the life of the pavement and which will extend to the life of the pavement.

Unification Issues: There are no unification issues.

Disclaimer: Use of the name or mark of any specific manufacturer, commercial product, commodity, or service in this publication does not imply endorsement.

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CHAPTER 1 INTRODUCTION

1-1 PURPOSE AND SCOPE.

This UFC contains information on materials, equipment, and procedures for repairing and maintaining hot mix asphalt (HMA) and portland cement concrete (PCC) pavements. Typical maintenance and repair (M&R) methods, and problems that might be encountered in using these methods, are discussed. Guidance is provided for using each of these M&R methods. Additional information can be found in the references listed in Appendix A.

This UFC is intended for use as a field UFC for airfield and roadway pavement repair for all U.S. Navy, Army, and Air Force pavements. The described techniques are applicable for airfields, roads, parking lots, and other pavement uses. Probable causes of pavement problems are discussed and suggested M&R measures described in order to correct pavement surface problems at the source.

Not covered in this UFC are maintenance and repairs of surface water drainage systems, pavement markings, ground lighting, and unpaved margins.

1-2 APPLICABILITY.

This UFC applies to all military Service elements and contractors involved in the planning, design, and construction, maintenance, repair, or preservation of DOD pavements worldwide. This UFC is for the M&R of asphalt and concrete pavements. Follow standard practices to ensure good performance and to obtain required pavement service life. Projects where standard practices were not followed resulted in poor performance. In many cases, those providing oversight were not knowledgeable about standard practices. This UFC outlines standard practices and will result in better oversight of work and help identify problem areas during application of the M&R process.

1-3 GENERAL BUILDING REQUIREMENTS.

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

1-4 REFERENCES.

Appendix A contains a list of references used in this UFC. The publication date of the code or standard is not included in this UFC. In general, the latest available issuance of the reference is used.

1-5 GLOSSARY.

Appendix C contains acronyms, abbreviations, and terms.

CHAPTER 2 TYPES OF MAINTENANCE AND REPAIR FOR PAVEMENTS

2-1 INTRODUCTION.

The purpose of M&R of asphalt and concrete pavements is to extend the useful life of the pavement, maintain a smooth riding surface, reduce mission impact, and prevent water from entering the underlying soil.

2-1.1 Maintenance and Repair.

Typical maintenance on asphalt and concrete pavements consists principally of the care of joints, sealing of cracks, surface treatments, replacement of random broken slab panels, full-depth and partial-depth repairs, dowel bar restoration, diamond grinding, slab-jacking, sub-sealing, petroleum, oil, and lubricant (POL) contamination removal, and the correction of minor settlement and drainage faults. Repair consists of the work required to restore a distressed pavement so it may be used at its original designed capacity and/or accommodate the current mission as provided for by applicable Service instructions.

2-1.2 Pavement Management.

Use an effective pavement management and inspection system that provides timely M&R to keep a pavement in optimal condition. Identify the root cause of the pavement distress and address the underlying problem. To implement an effective pavement management and inspection program, use UFC 3-260-16FA, *Airfield Pavement Condition Survey Procedures*, and UFC 3-270-08, *Pavement Maintenance Management*. These UFCs describe all asphalt and concrete pavement distresses and severity levels.

2-1.3 Quality Control.

Perform quality control, whether work is performed in-house or by contract, to obtain effective durable maintenance and repairs. Use an independent certified testing laboratory, referred to herein as the QC lab. Quality control (QC) functions are performed by the QC lab, which are necessary to monitor the work. Mix designs, soil cement design, soils analysis for compaction control, and supporting construction process monitoring are performed by the QC lab. The minimum daily monitoring requirements are described in specified UFGSs. Submit QC lab qualifications for review and approval to the government contracting officer or their designated technical representative. The government contracting officer or their designated technical representative will review the qualifications of the laboratory and, if necessary, visit the QC lab. Include, as a minimum, local area industry standards, , ASTM C78, *Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading),* ASTM C1260, *Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method),* ASTM C1077, *Standard Practice for Agencies Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Testing*

Agency Evaluation, ASTM D3666, *Standard Specification for Minimum Requirements for Agencies Testing and Inspecting Road and Paving Materials*, and respective state highway department certifications, when applicable, in evaluation criteria used to determine the suitability of the QC lab.

Before proceeding with the work, construct a test section to demonstrate the capability to perform to the intent of the specification. Demonstrate within the test section the ability to do pavement removal, subgrade preparation, base placement, and concrete mixing, placing, and finishing for both partial- and full-depth repairs. Incorporate the construction of joints, protection of the work, and QC procedures into the test section. Use all procedures and materials used to construct an acceptable test section as the standard of evaluation for performing the work. Incorporate equipment, materials, and procedures used for the approved test section into the work.

2-2 PAVEMENT MATERIALS.

2-2.1 Safety.

Safety hazards, such as fire/explosion hazards, toxicity, and reactivity, are associated with pavement repair materials and equipment. Always provide a Material Safety Data Sheet (MSDS) from the manufacturer with the material. Review the MSDS for personal protective equipment (PPE) and other safety precautions before use.

2-2.2 Importance of Weather.

2-2.2.1 Weather Effects – Asphalt.

2-2.2.1.1 Preferably, perform patching or resurfacing work only during dry weather and on dry surfaces. Place courses only when the surface temperature of the underlying course is greater than 40 degrees F (4 degrees C) for course thicknesses greater than 3 inches (75 millimeters) and 45 degrees F (7 degrees C) for course thicknesses 3 inches (75 millimeters) or less. When hot asphalt mixtures are placed on cold pavements they may quickly cool, making adequate compaction difficult. Moreover, asphalt and asphalt mixtures do not bond adequately to damp surfaces.

2-2.2.1.2 Mixtures containing emulsified or cutback asphalt require more curing time in high humidity. Low temperatures also reduce the rate of evaporation of emulsified or cutback binders during curing. Cationic emulsions generally are less affected by the weather than anionic emulsions. As a result, many agencies specify cationic emulsions for M&R work. Cutback asphalts are now seldom used due to environmental concerns; however, cutback asphalt may be encountered outside of the US.

2-2.2.1.3 Moisture affects seal coats and other surface treatments in the first few hours after placement. Rainfall prior to the time the liquid asphalt solidifies allows the leaching away or separation of asphalt from the aggregate. This results in the loss of some or all of the applied surface treatments.

2-2.2.1.4 Repairs cannot always be made in warm, dry weather. Therefore, QC, quality assurance (QA), equipment, and procedures are required when repairs are made during poor weather conditions as the repairs are less likely to perform satisfactorily. Sometimes mission requirements take precedent, which requires repairs as soon as practical even though they may only be temporary. Further, delaying repairs may allow small surface defects to become major failures.

2-2.2.2 Weather Effects – Concrete.

2-2.2.2.1 Weather conditions at a job site, hot or cold, windy or calm, dry or humid, may be vastly different from the optimum conditions assumed at the time a concrete mix is specified, designed, or selected. Concrete can be placed in hot or cold weather conditions, provided adequate precautions are taken to alleviate the negative impacts of high or low ambient temperatures.

2-2.2.2.2 The precautions required to ensure a quality end product will vary depending on the actual conditions during concrete placement and the specific application for which the concrete will be used. Do not place concrete when the air temperature is below 40 degrees F (4 degrees C) in the shade. When the air temperature is likely to exceed 90 degrees F (32 degrees C), use concrete having a temperature not exceeding 90 degrees F (32 degrees C) when placed. Keep the surface of placed concrete damp with a water fog until the approved curing medium is applied.

In general, if the temperature at the time of concrete placement will exceed 77 degrees F (25 degrees C) or below 50 degrees F (10 degrees C), develop a plan to negate the effects of temperatures.

2-2.2.3 Hot Weather Effects on Concrete.

Any operation of concreting done at atmospheric temperature above 77 degrees F (25 degrees C) is termed hot weather concreting. The effect of hot weather may be as follows:

- A higher temperature of fresh concrete results in a more rapid hydration and leads to reduced workability/accelerated setting. This reduces the handling time of concrete.
- Concrete mixed, placed, and cured at higher temperature typically develops higher early strength than concrete produced and cured at normal temperature, but at 28 days or later the strength is generally lower.
- Rapid evaporation may cause plastic shrinkage and cracking and subsequent cooling of hardened concrete will introduce tensile stresses.
- Rapid drying of the existing repair surface will lead to premature failure due to poor or failed bond.

2-2.2.4 Cold Weather Effects on Concrete.

Any concreting operation done at a temperature below 50 degrees F (10 degrees C) is termed cold weather concreting. In the absence of special precautions, the effect of cold weather concreting may be as follows:

- When the temperature is falling to about 50 degrees F (10 degrees C) or below, the development of strength of concrete is retarded compared with development at normal temperature. Thus, the time period for removal of form work has to be increased as well as the time to allow for traffic.
- Permanent damage may occur when the concrete in fresh stage is exposed to freezing temperatures before hardening. Concrete may suffer irreparable loss in its properties to an extent that compressive strength may get reduced to 50 percent of what could be expected for normal temperature concrete.
- Large temperature differentials within the concrete member may promote cracking and adversely affect its durability.

2-2.2.5 Precautions.

Precautions may include some or all of the following for hot weather placement:

- Moisten subgrade, steel reinforcement, and form work prior to concrete placement.
- Erect temporary wind breaks to limit wind velocities and sunshades to reduce concrete surface temperatures.
- Cool aggregates and mixing water added to the concrete mixture to reduce its initial temperature. The effect of hot cement on concrete temperature is only minimal.
- Use a concrete consistency that allows rapid placement and consolidation.
- Protect the concrete surface during placement with plastic sheeting or evaporation retarders to maintain the initial moisture in the concrete mixture.
- Provide sufficient labor to minimize the time required to place and finish the concrete, as weather conditions substantially affect the times to initial and final set.
- Consider fogging the area above the concrete placement to raise the relative humidity and satisfy moisture demand of the ambient air.
- Provide appropriate curing methods as soon as possible after the concrete finishing processes have been completed.

- In extreme conditions, consider adjusting the time of concrete placement to take advantage of ambient temperatures, such as early morning or night time placement.

Note: With proper planning and execution, concrete can be successfully placed and finished to produce high-quality, durable concrete at hot or cold temperatures.

2-2.3 Asphalt Pavement Materials.

Asphalt concrete**,** commonly called asphalt, blacktop, or pavement**,** is a composite material commonly used to surface roads, parking lots, and airfields. It consists of mineral aggregate bound together with asphalt, laid in layers, and compacted. The terms "asphalt (or asphaltic) concrete," "bituminous asphalt concrete," and "bituminous mixture" are typically used in engineering and construction, which define concrete as any composite material composed of mineral aggregate adhered with a binder. The abbreviation "AC" is sometimes used for "asphalt concrete" but can also denote "asphalt content" or "asphalt cement," referring to the liquid asphalt portion of the composite material. A variety of specialty asphalt concrete mixtures have been developed to meet specific needs, such as stone-matrix asphalt, which is designed to ensure a very strong wearing surface, or porous asphalt pavements, which are permeable and allow water to drain through the pavement for controlling storm water. Mixing of asphalt and aggregate is accomplished in one of several ways described below.

2-2.3.1 Hot Mix Asphalt Concrete (HMAC).

Hot mix asphalt concrete (commonly abbreviated as HMAC or HMA) is produced by heating the asphalt binder to decrease its viscosity and drying the aggregate to remove moisture prior to mixing. Mixing is generally performed with the aggregate at about 300 degrees F (roughly 150 degrees C) for virgin asphalt, 330 degrees F (166 degrees C) for polymer modified asphalt, and asphalt cement at 200 degrees F (93 degrees C). Perform paving and compaction while the asphalt is sufficiently hot. In many countries, paving is restricted to summer months because in winter the compacted base will cool the asphalt too much before it is able to be packed to the required density. HMAC is the form of asphalt concrete most commonly used on high-traffic pavements such as those on major highways and airfields.

2-2.3.2 Superpave Mix Design.

One of the principal results from the Strategic Highway Research Program (SHRP) was the Superpave mix design method. Superpave, short for "superior performing asphalt pavement," is a pavement system designed to provide longer-lasting roadways. The Superpave mix design method was designed to replace the Hveem and Marshall methods. The volumetric analysis common to the Hveem and Marshall methods provides the basis for the Superpave mix design method. The Superpave system ties asphalt binder and aggregate selection into the mix design process, considers traffic and climate as well, and evaluates the finished product. The compaction devices from the Hveem and Marshall procedures have been replaced by a gyratory compactor and the compaction effort in mix design is tied to expected traffic.

2-2.3.3 Marshall Mix Design.

The basic concepts of the Marshall mix design method were originally developed by Bruce Marshall of the Mississippi Highway Department around 1939 and then refined by the U.S. Army. Currently, the Marshall method is used in some capacity by about 38 states. The Marshall method seeks to select the asphalt binder content at a desired density that satisfies minimum stability and range of flow values. The Marshall method continued to be refined through the 1950s, with various tests on materials, traffic loading, and weather variables. Today, the Marshall method, despite its shortcomings, is probably the most widely used mix design method in the world. It has become so widely used because it was adopted and used by the U.S. military all over the world during and after WWII and it is simple, compact, and inexpensive.

2-2.3.4 Stone Mastic Asphalt (SMA).

SMA can be used as wearing course for roads, paths, and other traffic surfaces. It is a standard method of construction on motorways, federal roads, and city streets with heavy and very high demand traffic. For maintenance of traffic surfaces, SMA is especially suited for thin layers. One of SMA's special advantages is that, within limits, it can be paved in different thicknesses to even out a surface without worrying about possible differences in post compaction.

Wearing courses made with SMA are especially stable and durable. They have proven their superior performance even in areas with heavy traffic and independent of any climatic influence. A wearing course made from SMA with the correct design and mix production as well as proper paving shows the following characteristics due to the high chippings content together with the mastic-like mortar:

- Better resistance to permanent deformation
- High-wearing resistance
- Less cracking due to cold or mechanical stress
- Coarse surface texture
- Good macro roughness
- Good long-term behavior

2-2.3.5 Porous Friction Course (PFC).

Porous or permeable friction courses (PFC) are HMA mixtures placed at the surface of a pavement structure in a thin layer to produce several benefits for the traveling public in terms of safety, economy, and the environment. It is a sacrificial wearing course consisting of an aggregate with relatively uniform grading, little or no fines and mineral filler, and it is designed to have a high air void content compared to dense-graded mixtures. Special repair procedures specifically applicable to these porous friction surfaces are presented and discussed in Chapter 10.

2-2.3.6 Warm Mix Asphalt (WMA) Concrete.

Warm mix asphalt concrete (commonly abbreviated as WMA) is produced by adding either zeolites, waxes, asphalt emulsions, or sometimes even water to the asphalt binder prior to mixing. This allows significantly lower mixing and laying temperatures and results in lower consumption of fossil fuels, thus releasing less carbon dioxide, aerosols, and vapors. Not only are working conditions improved, but the lower laying-temperature also leads to more rapid availability of the surface for use, which is important for construction sites with critical time schedules. The use of these additives in HMA (2.2.3.1 above) may afford easier compaction and allow cold weather paving or longer hauls. Use of WMA is rapidly expanding.

2-2.3.7 Cold Mix Asphalt Concrete.

Cold mix asphalt concrete is produced by emulsifying the asphalt in water with (essentially) soap prior to mixing with the aggregate. While in its emulsified state, the asphalt is less viscous and the mixture is easy to work and compact. The emulsion will break after enough water evaporates and the cold mix will, ideally, take on the properties of cold HMAC. Cold mix is commonly used as a patching material and on lesser-trafficked service roads.

2-2.3.8 Cut-back Asphalt Concrete.

Cut-back asphalt concrete is produced by dissolving the binder in kerosene or another lighter fraction of petroleum before mixing with the aggregate. While in its dissolved state the asphalt is less viscous and the mix is easy to work and compact. After the mix is laid down the lighter fraction evaporates. Because of concerns with pollution from the volatile organic compounds in the lighter fraction, cut-back asphalt has been largely replaced by asphalt emulsion.

2-2.3.9 Mastic Asphalt Concrete.

Mastic asphalt concrete or sheet asphalt is produced by heating hard-grade blown bitumen (oxidation) in a green cooker (mixer) until it has become a viscous liquid, after which the aggregate mix is then added. The bitumen aggregate mixture is cooked (matured) for around six to eight hours and, once it is ready, the mastic asphalt mixer is transported to the work site where experienced layers empty the mixer and either machine or hand lay the mastic asphalt contents on to the road. Mastic asphalt concrete is generally laid to a thickness of around 0.75 to 1.1875 inch (20 to 30 millimeters) for footpath and road applications, and around 0.375 inch (10 millimeters) for flooring or roof applications. In addition to the asphalt and aggregate, additives, such as polymers, and antistripping agents may be added to improve the properties of the final product.

Natural asphalt concrete can be produced from bituminous rock, found in some parts of the world, where porous sedimentary rock has been impregnated with upwelling bitumen.

2-2.4 Grading System for Asphalt Emulsions.

Most asphalt surface treatments contain an emulsified binder. Do not use solvent-based or cutback materials unless approved by the local environmental authority. Use emulsions appropriate for local conditions to ensure proper break and set time. Coal tar emulsions, usually used only as fuel-resistant sealers, are not discussed in this UFC.

Emulsions are classified (ASTM D977, *Standard Specification for Emulsified Asphalt*), on the basis of how quickly the asphalt droplets coalesce, resulting in "breaking" of the emulsion. RS, MS, QS, and SS refer to rapid-setting, medium-setting, quick-setting, and slow-setting, respectively. The breaking time increases from RS to SS. RS emulsions cannot be combined with aggregate. MS emulsions can only be mixed with coarse aggregate. QS and SS emulsions can be mixed with any aggregate. Designations 1 and 2 in emulsion nomenclature refer to the viscosity of the emulsion, with 2 being more viscous. The h designation refers to a base asphalt that is harder (lower penetration). Some emulsions have a HF designation, referring to high float. HF emulsions can provide a thicker asphalt film on aggregates, which is thought to enhance durability. Emulsions suspended by cationic surfactants are designated with a C. No designation refers to emulsions with anionic surfactants. Table 2-1 gives common emulsion grades for different types of surface treatments.

Table 2-1 Common Asphalt Emulsion Grades

Surface Treatment	Typical Asphalt Emulsion Grade Used
Liquid fog seal	RS-1, MS-1, HFMS-1, SS-1, SS-1h, CRS-1, CSS-1h, CQS-1h
Liquid and sand spray seal	RS-1, RS-2, HFRS-2, HFRS-2h, MS-1, HFMS-1, CRS-1, CRS-2, CRS-2h
Slurry seal	SS-1h, CSS-1h, CQS-1h
Microsurfacing	CQS-1h

2-2.4.1 Emulsion Breaking and Curing.

Breaking an asphalt emulsion refers to separating water from the asphalt and the evaporation of water. Some emulsions break when sufficient water has evaporated. Others break through chemical means. Breaking time is reduced by adding chemicals.

Curing asphalt emulsions involves the development of mechanical properties as the asphalt particles coalesce and the water is removed through evaporation. Typical curing times range from 30 minutes to 24 hours. Cure times are a function of environmental conditions, application rate, substrate properties, and product dilution ratios. Follow the manufacturer’s recommendations for closing the pavement to traffic.

2-2.4.2 Shelf Life.

Some asphalt materials have a limited shelf life; therefore, give particular attention to the manufacturer’s recommended shelf life when selecting a material. Shelf life typically ranges from three months to two years and depends on storage conditions, such as temperature, humidity, and packaging.

2-2.5 Concrete Pavement Materials.

A concrete pavement consists of a surface layer of concrete placed over a base (granular or stabilized) and subbase (typically granular) over the subgrade, which may incorporate a fill material. Concrete is a mixture of paste and aggregates. The paste, composed of cementitious materials and water, coats the surface of the fine and coarse aggregates. Through a chemical reaction called hydration, the paste hardens and gains strength to form concrete. The cementitious material primarily consists of portland cement but may also incorporate fly ash, slag cement (ground granulated blast furnace slag), silica fume (not common), or proprietary materials. Concrete is made with or without additives (e.g., air entraining, water-reducing) to achieve the required workability, strength, and durability properties. Concrete generally achieves its initial set within about one hour after water is added and will become fairly hard within six to eight hours of placement. Normal concrete will achieve about 90 percent of its long-term strength within about 30 days and will continue to gain strength at an ever-decreasing rate for many years as long as moisture is retained within the consolidated concrete mass and there is no adverse chemical reaction either internally or due to external action. Normal concrete is typically designed to achieve about 4,000 pounds per square inch (psi) (27.5 megapascals) compressive strength at 28 days. Rapid-set or high-early-strength concrete can be designed to achieve strengths of about 2,500 to 3,000 psi (17.2 to 20.7 megapascals) within 12 to 24 hours to allow for early opening of repair areas to traffic. Many rapid-set materials include proprietary cementitious materials.

2-2.5.1 Portland Cement Concrete (PCC).

PCC is generally accepted as the most appropriate material for the partial-depth repair of existing concrete pavements. Typical mixes combine Type I, Type II, or Type III portland cement with aggregate not larger than one-half the minimum repair thickness. Use a material that is a low-slump mixture of air-entrained concrete having a water-to-cement ratio not exceeding 0.44. Type I or Type II PCC can be used when the patch material can be protected from traffic for at least 24 hours. For faster-setting materials such as Type III cements, patches can be opened as soon as the material can withstand loads without plastic deformation. Type I or Type II portland cement, with or without admixtures, is more widely used than most other materials because of its relatively low cost, availability, and ease of use. In cooler weather, insulating layers can be used to retain the heat of hydration and reduce curing time.

Several proprietary portland cement-based repair materials are also available to achieve high early strength and can be used for partial-depth repairs.

2-2.5.2 Gypsum-Based Concrete.

Gypsum-based concrete (calcium sulfate) repair materials gain strength rapidly and can be used in any temperature above freezing. However, gypsum concrete may not perform well when exposed to moisture and freezing weather. Additionally, the presence of free sulfates in the typical gypsum mixture may promote corrosion of reinforcing steel in pavements.

2-2.5.3 Magnesium Phosphate Concrete.

Magnesium phosphate concretes set very rapidly and produce a high-early-strength, impermeable material that will bond to clean, dry surfaces. However, this type of material is extremely sensitive to water, either on the substrate or in the mix (even very small amounts of excess water can reduce strength). Furthermore, magnesium phosphate concrete is very sensitive to aggregate type (for example, some limestone aggregates are not acceptable). In hot weather (i.e., above 90 degrees F [32 degrees C]), many commonly available mixes experience short setting times (e.g., 10 to 15 minutes).

2-2.5.4 Calcium Aluminate Cement.

Calcium aluminate cements gain strength rapidly, have good bonding properties (on a dry surface), and very low shrinkage. However, due to a chemical conversion that occurs in calcium aluminate cement, particularly at high temperatures during curing, strength loss over time is likely to occur; consequently, these materials are not recommended for use as a patching material.

2-2.5.5 Polymer-based Concrete.

Polymer-based concretes are formed by combining polymer resin, aggregate, and an initiator. Aggregate is added to the resin to make the polymer concrete more thermally compatible with the existing concrete (which would otherwise lead to debonding), to provide a wearing surface, and for economy. The main advantage of polymers is that they set much quicker than most of the cementitious materials. However, they are expensive and can be quite sensitive under certain field conditions. Polymers used for pavement repairs can be classified into four categories: epoxies, methacrylates, polyester-styrenes, and urethanes.

When using polymeric materials for partial-depth repairs, use spall repair materials in accordance with TSPWG M 3-270-01.08-4, *Testing Protocol for Polymeric Spall Repair Materials*.

2-2.5.5.1 Epoxy Concrete.

Epoxy concrete repair materials are impermeable and have excellent adhesive properties. When used, it is important that the epoxy concrete be compatible with the concrete in the pavement. Differences in the coefficients of thermal expansion (CTE) between the repair material and the concrete can cause repair failures, but the use of thermally compatible aggregate increases the volume stability and helps reduce the likelihood of debonding. Place deep epoxy repairs in multiple lifts to control heat buildup.

2-2.5.5.2 Methyl Methacrylate (MMA) Concrete.

MMA concretes and high molecular weight methacrylate (HMWM) concretes have long working times, high compressive strengths, and good adhesion. Furthermore, they can be placed over a wide range of temperatures, from 40 to 130 degrees F (4 to 54 degrees C). MMA is manufactured with either an ultra-low viscosity, which is used as a penetrating crack sealer or to fortify extremely porous concrete substrates, or a medium viscosity, which is used as a neat mortar for grouting or thin patches and can be filled with pre-packaged coarse aggregate and used for partial or full-depth patching in a single pour. However, many methacrylates are volatile and may pose a health hazard to those exposed to the fumes for prolonged periods.

2-2.5.5.3 Polyester-styrene Polymers.

Polyester-styrene polymers have many of the same properties as MMA, except that they have a much slower rate of strength gain, which limits their usefulness as a rapid repair material. Polyester-styrene polymers generally cost less and are used more widely than MMA.

2-2.5.5.4 Polyurethane Resin

Polyurethane repair materials generally consist of a two-part polyurethane resin mixed with aggregate. Polyurethanes are generally very quick-setting (90 seconds), which makes a very quick repair. Some polyurethanes claim to be moisture-tolerant; that is, they can be placed on a wet substrate with no adverse effects. These types of materials have been used for several years with variable results.

2-2.5.6 Rapid-set Cement and Polymers.

There are a number of other polymeric materials available for partial-depth repairs, most of which exhibit rapid strength gain and a high degree of impermeability. Furthermore, some of these materials exhibit certain elastic properties that allow them to be placed across a joint without the need for an insert to maintain the joint.

Use rapid-set proprietary patching materials in compliance with the manufacturer's recommendations. This includes bonding, placing, time required before opening to traffic, and temperature ranges. Evaluate epoxy mortar and epoxy concrete mix designs in the laboratory before use. Precondition the epoxy resin catalyst before blending to produce a liquid blended between 75- and 90-degrees F (24- and 32-degrees C). Mix the epoxy components in compliance with the manufacturer's recommendations prior to adding aggregate. Blend the material in a suitable mixer until homogenous. Mix only the quantity of material that can be used within one hour (dependent on materials and air temperature, may be less than one hour) in each batch.

When using rapid-set cement and polymeric materials for partial-depth repairs, use spall repair materials in accordance with TSPWG M 3-270-01.08-2, *Testing Protocol for Rapid Setting Rigid Repair Material*.

Caution: **Use repair materials that are thermally compatible with the existing concrete. When an aggregate is used to extend the repair material, use aggregate that is thermally compatible with the aggregate in the existing concrete; otherwise, the risk of debonding will be high.**

2-2.5.7 Bonding Grout.

Bonding grout may be used when using cement-based repair material. The grout consists of one-part portland cement to one-part sand by volume with sufficient water to produce a mortar with a creamy consistency. The grout is applied as a light coat to the patch area. Place the concrete before the grout dries. If the grout dries or hardens prior to placement of this concrete, remove it by sandblasting. Do not place patches using normal-set concrete when the air temperature is below 50 degrees F (10 degrees C). At temperatures below 55 degrees F (13 degrees C), a longer curing period and/or insulation mats may be required. If the grout cannot be applied correctly, it is preferable not to use the grout and instead lightly dampen the repair area with water, including the vertical sides, just before application of the grout material in the repair area.

For rapid-set proprietary materials, follow the manufacturer's instructions regarding the use or non-use of the bonding grout. Remove all sandblasting residue using oil-free air-blowing equipment just prior to placing the bonding grout, if used. Apply the bonding grout using a stiff bristle brush and scrub into the patch area. Apply evenly in a thin coat (approximately 0.0625 inch [2 millimeters] thick).

Caution: **Irrespective of the type of bonding grout used, always apply it to a clean surface and never allow it to puddle or get dry before application of the repair material. If water is used to dampen the repair surfaces, the water is not allowed to pond on the repair surface.**

2-2.5.8 Recycled Concrete Pavement Material

Recycled concrete pavement material has many potential uses, which are addressed in UFC 3-250-07, *Standard Practice for Pavement Recycling*. When using recycled concrete pavement materials, consider testing the recycled materials to mitigate potential detrimental risks associated with harmful reactivity such as alkali-silica reaction (ASR), alkali-carbonate reaction (ACR), or sulfate attack.

2-2.6 Concrete Pavements Types.

2-2.6.1 Jointed Plan Concrete Pavement (JPCP).

JPCP may be doweled or not doweled at transverse joints; however, these pavements are always doweled along longitudinal construction joints. Transverse joint spacing used on airfields in the past ranged from about 15 feet (4.5 meters) to about 25 feet (7.5 meters), depending on slab thickness. Currently, the design joint spacing ranges from about 10 feet (3 meters) to about 20 feet (6 meters).

2-2.6.2 Jointed Reinforced Concrete Pavement (JRCP).

JRCP incorporates steel reinforcement and has longer transverse joint spacing, ranging from about 40 to 60 feet (12 to 18 meters) or longer. One or more transverse cracks may develop in each panel and the reinforcement keeps these cracks tight. The transverse joints are doweled. These pavements are not widely used anymore.

2-2.6.3 Continuously Reinforced Concrete Pavement (CRCP).

CRCP has not been widely used by the military. A higher level of reinforcement is used and transverse joints are not provided, except near structures. Use of the high level of reinforcement leads to the development of closely spaced cracking at about 3 to 6 feet (1 to 2 meters) and the steel holds the crack very tight.

2-2.6.4 Jointed Concrete Pavement.

Joints are created in jointed concrete pavements to control cracking locations and provide for unrestrained expansion and contraction of the concrete panels. If the panel contraction is restrained as a result of locked joints during service or improper joint-forming during construction, mid-panel cracking can develop. If the panel expansion is restrained during hot weather, joint spalling can develop and, in extreme cases, joint blow-up may result. Therefore, it is important to make sure that any joint repair activity does not restrict the contraction and expansion of the slab panels.

2-2.7 Cement Standards.

To ensure a level of consistency between cement-producing plants, certain chemical and physical limits are placed on cements. These chemical limits are defined by a variety of standards and specifications. For instance, portland cements and blended hydraulic cements for concrete in the U.S. conform to ASTM C150, *Standard Specification for Portland Cement*, ASTM C595, *Standard Specification for Blended Hydraulic Cement*, or ASTM C1157, *Performance Specification for Hydraulic Cements*.

Table 2-2 Cement Classification Standards

In the US, three separate standards may apply, depending on the category of cement. For portland cement types, ASTM C150 describes:	
Cement Type	**Description**
Type I	Normal
Type II	Moderate sulfate resistance
Type II (MH)	Moderate heat of hydration (and moderate sulfate resistance)
Type III	High early strength
Type IV	Low heat hydration
Type V	High sulfate resistance
For blended hydraulic cements (specified by ASTM C595) the following nomenclature is used:	
Cement Type	**Description**
Type IL	Portland-limestone cement
Type IS	Portland-slag cement
Type IP	Portland-pozzolan cement
Type IT	Ternary blended cement
However, with an interest in the industry for performance-based specifications, ASTM C1157 describes cements by their performance attributes:	
Cement Type	**Description**
Type GU	General use
Type HE	High early-strength
Type MS	Moderate sulfate resistance
Type HS	High sulfate resistance
Type MH	Moderate heat of hydration
Type LH	Low heat of hydration

2-2.7.1 Concrete Pavement Performance.

A concrete pavement provides a relatively long service life when properly designed, constructed, and maintained. In general, the service life of a pavement ends when, under the effects of traffic, weather, and/or lack of proper maintenance, the pavement breaks into small unstable sections, surface and joint problems develop, and extensive maintenance is required on a regular basis.

Properly designed and constructed concrete pavements do not exhibit significant distresses (e.g., cracking, joint faulting) for at least 15 years. As distresses develop, the service life of concrete pavements can be extended by timely maintenance, especially at joints and cracks. Maintaining the joints and cracks to minimize the infiltration of water and prevent the entry of incompressible material into the joint or crack is essential for long pavement service life. Frequent aircraft loadings greater than those for which the pavements were designed will cause early structural failure of the pavement.

2-2.7.2 Concrete Pavement Rigidity.

Concrete pavements are classified as rigid pavements. Concrete pavements bridge small, soft, or settled areas of a subgrade through their slab action or resistance to bending. Overloading of pavements can result from applied loads being greater than the design load, more passes than assumed in the design, or the foundation support being reduced as a result of pumping, excessive moisture, or settlement due to poor construction. Usually, once cracks develop in a panel, continued loading will cause additional cracking and/or panel breaks until the pavement is no longer functional.

2-2.7.3 Concrete Pavement Strength.

Military airfield and roadway concrete pavement design is based on limiting the concrete tensile stresses produced by aircraft or highway truck loads. Flexural strength of concrete is used in the design of concrete pavements. Loads applied to the pavement surface cause bending, with tensile stresses developing at the slab bottom (mid-slab locations) or at the slab top (corner locations, typically) and compressive stresses at the corresponding opposite surface. Since compressive strength of concrete is typically eight to ten times greater than the tensile or flexural strength, the ratio of load-induced tensile stresses at the bottom of the slab to the flexural strength of the concrete typically controls the structural behavior and performance of jointed concrete pavements.

The strength and durability of concrete is directly affected by:

- Quality of cementitious materials
- Water quality
- Cleanliness, durability, strength, and gradation of the aggregates
- Water-cementitious materials ratio
- Density (consolidation) of concrete

- Amount and types of admixtures
- Proportioning and mixing of materials
- Placement, finishing, and curing methods

2-3 PAVEMENT DISTRESSES.

Pavement distresses include items such as cracking, rutting, raveling, or other types of surface deterioration which indicate a decline in the pavement's surface condition or structural load-carrying capacity. Pavement distresses are discussed in detail in UFC 3-260-16FA. Having a pavement distress dictionary will improve communications within the pavement community by fostering more uniform and consistent definitions of pavement distress. Highway agencies, airports, parking facilities, and others with significant investment in pavements will benefit from adopting a standard distress language.

2-3.1 Asphalt Concrete (AC) Pavement Distresses.

1. Cracking
   a. Alligator or fatigue cracking
   b. Block cracking
   c. Edge cracking
   d. Joint reflection cracking
   e. Longitudinal cracking
   f. Slippage cracking
2. Patching and potholes
   a. Patching and utility cut patching
   b. Potholes
   c. Railroad crossing
3. Surface deformation
   a. Bumps and sags
   b. Corrugation
   c. Depression
   d. Rutting
   e. Shoving
   f. Swell

4. Surface defects
    a. Bleeding
    b. Polished aggregate
    c. Raveling
    d. Weathering
5. Miscellaneous distresses
    a. Lane/shoulder drop-off

2-3.2 Portland Cement Concrete (PCC) Pavement Distresses.

1. Cracking
    a. Corner break
    b. Divided slab
    c. Linear cracking
    d. Shrinkage cracking
    e. Spalling, corner
    f. Spalling, joint
2. Joint/crack related
    a. Faulting
    b. Joint/crack spalling
    c. Blowup/buckling
    d. Pumping
    e. Railroad crossing
3. Material related
    a. Alkali-silica reactivity (ASR)
    b. Durability (“D”) cracking
4. Surface distress
    a. Polished aggregate
    b. Popouts
    c. Patching, large and utility cuts
    d. Patching, small
    e. Scaling

5. Miscellaneous distresses
    a. Lane/shoulder drop-off

2-4 TYPES OF MAINTENANCE AND REPAIR.

A considerable investment is made in the construction of asphalt and concrete pavements and the vehicles/aircraft that use these surfaces. Therefore, costs decrease dramatically for every additional year of pavement use that does not cause vehicle/aircraft damage or require repeated patching or other repair activity. Routine periodic inspections and rapid pavement repair are essential for reducing the lifecycle costs of these pavements and maintaining the facility in an operation-ready status. A properly constructed and maintained pavement can last for many years and effectively meet the needs of the military.

The primary purposes of sealing cracks, repairing spalls, applying surface treatments, and carrying out other repairs in asphalt and concrete pavements is to reduce the costs associated with vehicle/aircraft damage due to foreign object damage (FOD), to extend the service life of the pavement, and to reduce the lifecycle costs for the pavement structure. Usually, there are multiple options for repairing a distress. First, determine the root cause of a distress then select a repair method to best resolve the cause. Do not apply repair options following pre-established intervals without taking the pavement’s condition into consideration. Pavement M&R is grouped into three categories;

2-4.1 Global Preventive Maintenance (PM).

Global PM is used to retard or slow pavement deterioration on a large scale, usually covering more than one section. Generally, global PM is effective at the beginning of pavement life and/or when the climatic-caused distresses have not started or the severity is low. Global PM may be performed periodically like localized PM, but is more commonly performed on a recurring schedule (i.e., at set time intervals).

2-4.2 Localized Preventive Maintenance (PM).

Localized PM consists of M&R actions performed on individual distresses to slow down the rate of pavement deterioration.

2-4.3 Operational Maintenance.

Also referred to as safety maintenance, stop-gap maintenance, and breakdown maintenance, operational maintenance is performed to mitigate distresses on pavements that are below the critical pavement condition index (PCI) to keep them operationally safe for use.

There are numerous types of M&R methods for asphalt and concrete pavements, which include patching, crack sealing, and surface treatments. This UFC presents basic M&R procedures along with relevant distresses. Overlays and new construction are covered under the UFC 3-250-XX pavement series. M&R procedures presented in this UFC include the following:

2-4.3.1 Summary of Asphalt Pavement Repairs.

The following concrete pavement repairs are discussed in this UFC:

- Chapter 3: Full-Depth Asphalt Patches
- Chapter 4: Procedural Steps (Partial-Depth Patch)
- Chapter 5: Sprayed Asphalt Surface Treatments
- Chapter 6: Bituminous Surface Treatment
- Chapter 7: Double Bituminous Surface Treatment
- Chapter 8: Asphalt Slurry Seals and Microsurfacing
- Chapter 9: Asphalt Crack Sealing
- Chapter 10: Porous Friction Surfaces
- Chapter 11: Diamond-Grinding Asphalt Concrete Pavements

Each of the above repair methods addresses specific distresses. Some of the repairs may be performed in combination.

2-4.3.2 Summary of Concrete Pavement Repairs.

The following concrete pavement repairs are discussed in this UFC:

- Chapter 12: Concrete Pavement Crack Sealing
- Chapter 13: Partial-Depth Repair of Concrete Pavements
- Chapter 14: Full-Depth Repair of Concrete Pavements
- Chapter 15: Concrete Pavement Slab Jacking
- Chapter 16: Subsealing Jointed Concrete Pavements
- Chapter 17: Concrete Pavement Diamond Grinding
- Chapter 18: Concrete Pavement Load Transfer Restoration
- Chapter 19: Concrete Pavement Retrofitted Edge Drainage
- Chapter 20: Maintenance of Heat-Resistant Concrete
- Chapter 21: Repair of PCC Damaged by POL

Each of the above repair methods addresses specific distresses. Some of the repairs may be performed in combination. Materials-related distresses, such as ASR and D-cracking, are not addressed in this UFC.

2-5 PAVEMENT REPAIR EQUIPMENT.

Inspect all equipment employed in the pavement repair operations before and during the repair project to ensure safe operation and proper application. Follow proper safety procedures in accordance with OSHA guidelines and standard practices for the protection of all project personnel. Make hand tools available for working in areas where machinery is not practical or allowed.

2-5.1 Equipment Inspection.

Inspect all repair equipment before and during actual construction. Inspection will determine if the equipment is being properly maintained, if all of the required safety devices are present, if the equipment and technique being used is damaging the pavement, and if the equipment is being operated correctly and safely.

2-5.2 Equipment.

Pavement repair equipment includes the following:

2-5.2.1 Router.

A router is used to create a sealant reservoir by enlarging meandering cracks to the desired depth and width. A vertical spindle router with a diamond bit is recommended to minimize damage to the pavement. However, an impact router may be used if it is equipped with carbide-tipped vertical-sided bits. Do not use impact routers not equipped with carbide-tipped bits or those equipped with V-shaped bits because they tend to chip and damage the pavement. When using a vertical spindle router, use a belt-driven router bit to help prevent injury to the operator and damage to the pavement if the bit jams in the crack. If damage to the pavement is observed, discontinue work until corrective action is taken. Such corrective action may require replacing worn router bits, changing operators, or replacing the equipment.

2-5.2.2 Concrete Saw.

A concrete saw with a water-cooled diamond blade or abrasive disk can be used to widen straight cracks to the desired width and depth. Concrete saws may be used in place of a router if the blade has a diameter of 6 inches (150 millimeters) or less. The 6-inch (150-millimeter) diameter blade allows the saw to follow slightly meandering cracks. However, a saw blade does not follow the meandering crack as well as a router. If a saw is used to widen the crack, a high-pressure water stream can be used to remove the debris created by the saw. Use care to avoid damaging the adjacent pavement when the saw is used.

2-5.2.3 Cold Milling.

Pavement milling (cold planing, asphalt milling, or profiling) is the process of removing at least part of the surface of a paved area such as a road, bridge, or parking lot. Milling removes anywhere from just enough thickness to level and smooth the surface to a full-depth removal. There are a number of different reasons for milling a paved area instead of simply repaving over the existing surface. Recycling of the road surface is one of the main reasons for milling a road surface. Milling is widely used for pavement recycling, where the pavement is removed and ground up to be used as the aggregate in new pavement. For asphalt surfaces, the product of milling is reclaimed asphalt pavement (RAP), which can be recycled in hot mix asphalt (HMA) (pavement) by combining with new aggregate and asphalt cement (binder) or a recycling agent. This reduces the impact that resurfacing has on the environment.

Milling can also remove distresses from the surface, providing a better driving experience and/or longer roadway life. Milling can remove the following issues:

- Raveling: Aggregate becoming separated from the binder and loose on the road
- Bleeding: The binder (asphalt) coming up to the surface of the road
- Rutting: Formation of low spots in pavement along the direction of travel, usually in the wheel path
- Shoving: A washboard-like effect transverse to the direction of travel
- Ride quality: Uneven road surface, such as swells, bumps, sags, or depressions
- Damage: Resulting from accidents and/or fires

It can also be used to control or change the height of part or all of the road. This can be done to control heights and clearances of other road structures, such as curb reveals, manhole and catch basin heights, shoulder and guardrail heights, and overhead clearances. It can also be done to change the slope or camber of the road or for grade adjustments, which can help with drainage.

2-5.2.4 Dimond Grinding.

Diamond grinding is one of the most cost-effective concrete pavement restoration (CPR) techniques. It consists of “grinding” 0.1875 to 0.25 inch (5 to 7 millimeters) of the surface of JPCP using closely spaced diamond saw blades. The result is a level, smooth, and generally quieter riding surface. The closely spaced grooves left after grinding give the riding surface excellent texture and frictional properties. The same technique and equipment is used for diamond grooving; however, while the purpose of grinding is mainly to restore ride quality and texture, grooving is generally used to reduce hydroplaning and accidents by providing escape channels for surface water. In terms of design, the main difference between grinding and grooving is in the distance between the grooves—about six times higher in the case of grooving. Diamond grinding can also be performed on asphalt pavement.

2-5.2.5 Water Blasting.

The water blasting equipment includes a trailer-mounted water tank, pumps, high-pressure hose, and wand with safety release cutoff control, nozzle, and auxiliary water resupply equipment. Provide and use the water tank and auxiliary resupply equipment of sufficient capacity to permit continuous operations. Provide and use hoses, wands, and nozzles capable of cleaning the crack faces and the pavement surface on both sides of the crack for a width of at least 0.5 inch (13 millimeters). Provide and use a pressure gauge mounted at the pump that shows the pressure in psi (kPa) at which the equipment is operating.

2-5.2.6 Hot Compressed Air (HCA) Heat Lance.

The HCA heat lance is used to warm, dry, and clean the crack when performing the sealing operation in less-than-desirable conditions. Such conditions occur following rain or when the pavement temperature is below 50 degrees F (10 degrees C). The heat lance can also be used to remove small amounts of vegetation from cracks. Heat lances are capable of producing heated air at 3,000 degrees F (1,650 degrees C) at velocities of up to 3,000 feet per second (915 meters per second); therefore, use extreme care or the asphalt adjacent to the crack can be damaged. Do not remain stationary with the heat lance over one spot but keep moving to ensure the asphalt is not overheated. Overheating will cause the pavement to become charred and brittle, resulting in premature sealant bond failure. Do not heat the cracks using direct flame methods. It is important to remove all debris from the crack but over-blasting could cause the pavement to ravel or create voids in the crack face.

2-5.2.7 Compressed Air.

Compressed air can be employed for the final cleaning phase of the project. Provide and use an air source that produces sufficient pressure and contains no oil that may foul the surface prior to sealing. Some compressors have in-line sources for the constant lubrication of air tools. Remove these devices along with the oil-coated pressure hoses. Install in-line oil and water traps to provide clean air for the air-blasting operation.

2-5.2.8 Sandblasting Equipment.

Sandblasting equipment is used to remove residue left by a saw, loosened aggregate left by a router, vegetation, and other debris. If debris is left in the crack, the sealant will not bond adequately to the asphalt, causing premature failure. Equipment for sandblasting consists of an air compressor, hoses, and a venturi-type nozzle with an opening not to exceed 0.25 inch (6 millimeters). Equip the air compressor with traps that keep the compressed air free of oil and moisture. Use a compressor capable of supplying air at 150 cubic feet per second (4 cubic meters per second) and maintaining a line pressure of 90 psi (620 kilopascals). Exercise caution to prevent over-blasting the crack. It is important to remove all debris from the crack but over-blasting could cause the pavement to ravel or create voids in the crack face. One disadvantage of sandblasting is the requirement to clean the debris after blasting. This cleaning can be difficult and time-consuming.

2-5.2.9 Hot-applied Sealant Applicator (Melter).

Use equipment to heat and install the hot-applied sealant that consists of a double-boiler, agitator-type kettle. The heat transfer medium in the outer space is an oil with a high flash point. The double-boiler helps eliminate hot spots in the heating kettle and the agitator provides mixing for uniform heating of the sealant. Do not allow use of a direct-heating kettle. Transfer the sealant from the kettle to the crack by means of a direct-connected pressure-type extruding device (hose) with a nozzle that will insert into the crack. Heat the hose or the sealant recirculated. Design equipment to allow the sealant to be circulated back into the inner kettle when sealing is not being performed. Positive temperature devices are used to control the temperature of the oil bath and measure the temperature of the sealant. Recording-type thermometers are useful for monitoring the temperature of the sealant in the kettle as work progresses. Recording-type thermometers are not normally installed on the equipment at the manufacturer but can be installed by the contractor. Position thermometers so they are easy to read.

2-5.2.10 Cold-applied Sealant Applicator.

The necessary equipment for application of cold-applied sealants depends on whether the sealant is a single-component or a two-component mix and whether the material is hand-mixed or machine-mixed. Two-component machine mixers, recommended for larger crack-sealing projects, consist of an extrusion pump, air compressor, and the associated hoses to dispense the components through separate nozzles and mixed in a 50:50 ratio with less than ±5 percent error just prior to discharge from the nozzle. Hand-mixing equipment for two-component sealants is generally a slow-speed electric drill with a paddle mixer or an air-powered mixer. Mix single-component sealants to overcome any segregation before they are applied to the pavement. Small hand-held caulking guns can also be employed for small jobs.

2-5.2.11 Wire Brushes.

Wire brushes are helpful in removing debris and vegetation from shallow cracks, but they do not easily remove debris, such as saw residue, from the walls of the cracks. Debris on the crack faces will cause the sealant to lose adhesion with the pavement and prematurely fail. Do not use worn brushes to clean the cracks because they will not effectively remove residual debris. Take care when wire brushes are used to clean cracks that have been previously sealed; the brushes will have a tendency to smear the old sealant residue on the crack wall instead of removing it.

2-5.2.12 Power Brooms.

To remove debris from the pavement surface and reduce the potential for FOD, use a vacuum-type power broom.

2-5.2.13 Jackhammers.

For large patching operations where full-depth repairs are needed, use a 30-pound (13.6-kilogram) jackhammer model. For smaller jobs, use a 10- to 15-pound (4.6- to 6.8-kilogram) model. Equip the jackhammer with a chipping hammer and work at an angle of between 45 and 90 degrees relative to the pavement surface. Take special care not to damage the layer of concrete under the spall repair area or cause microcracking around the crack. For partial-depth repairs, do not use a jackhammer that is larger than 30 pounds (13.6 kilograms).

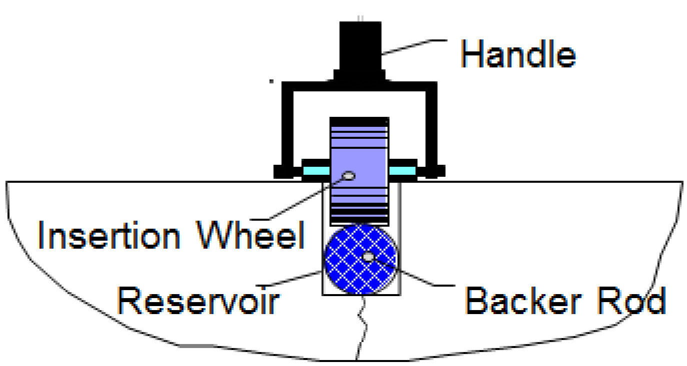
2-5.2.14 Mixers.

Drum or mortar mixers are usually employed for most patching operations. Use a bucket with a hand-held, electric drill-powered (or pneumatic), paddle-wheel mixer for smaller operations.

2-5.2.15 Backer Rod Installation Equipment.

Backer rod may be placed by hand (not recommended, except for short length placement) and many contractors have constructed their own hand-held equipment for this operation. Devices are also available that place the backer rod at a consistent depth without undue stretching or tearing of the backer materials (Figure 2-1).

Figure 2-1 Installation of Backer Rod



2-5.2.16 Sealant Applicators Not Recommended.

Pouring pots or gravity-fed sealant applicators are not recommended for sealing cracks. These applicators have a tendency to trap air in the sealant as it is applied into the crack, creating voids in the sealant. When spot repairs are made to cracks that have been sealed, it may not be feasible to use the hot-applied sealant applicator as described above and pour pots may be used. Equip the pour pot with a nozzle that will fit inside the crack in the same manner as the nozzle of the hot-applied sealant applicator.

2-5.2.17 Hand Tools.

Due to the meandering nature of cracks, hand tools are required to insert the backer rod materials in cracks deeper than 0.75 inch (19 millimeters). Do not twist, cut, or damage the backer rod material with these tools. Ensure the tool is capable of placing the material to the proper depth. When approved by the contracting officer, use hand tools used for repairing or cleaning cracks or removing old crack sealant. Examine the tools to ensure they will not damage the pavement in any manner when properly used.

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CHAPTER 3 FULL-DEPTH ASPHALT PATCHES

3-1 INTRODUCTION.

A full-depth patch repairs distresses of medium to high severity, such as alligator cracking, corrugation, depression, oil spillage, rutting, swelling, edge cracking, bumps and sags, and existing patches. A partial-depth patch is used to maintain/repair distresses of low and medium severity, such as corrugations, depressions, rutting, shoving, slippage cracking, swelling, and existing patches.

Full-depth repairs involve removal of the complete pavement down to the subgrade or to an intermediate base or subbase layer that is intact. Partial-depth repairs usually involve removing the failed asphalt surface, excluding the base course, and replacing the surface layer with hot asphalt plant mix.

Procedural steps for partial-depth patches are in Chapter 4.

3-2 PROCEDURAL STEPS (FULL-DEPTH PATCH).

Place full-depth patches using the following steps:

3-2.1 Mark Repair Area.

Use a string line or straightedge to mark straight lines around the repair area. Clearly mark the lines so they are easily visible when sawing the pavement. Mark repair areas to form a square or rectangle with at least 12 inches (300 millimeters) beyond the distressed area.

3-2.2 Make Saw Cut Through Pavement.

Use a concrete saw equipped with a diamond-tip or abrasive blade (Figures 3-1 and 3-2, respectively) to saw the pavement. Saw the perimeter of the patch since milling tends to leave a rough edge. Overlap saw cuts so that a vertical and square corner is formed (Figure 3-3). Since diamond-tip blades usually require water, completely dry the repair area before placing the prime or tack coat. However, there are some types of diamond-tip blades designed to dry-cut asphalt pavements. The abrasive saw blade is less costly and does not require water when sawing, but they tend to wear quickly. Always confirm the saw blade is the correct diameter to allow cutting to the full pavement depth. Make sure the saw blade is rated for the revolutions per minute (rpm) of the saw; otherwise, the blade could shatter during sawing due to the mismatch.

Figure 3-1 Diamond Tip Saw Blade

Figure 3-2 Abrasive Blade

Figure 3-3 Damaged Pavement Removed by Sawing

3-2.3 Removal of Defective Material.

Remove the defective material by milling, backhoe, or with a jackhammer. Small areas are sometimes removed with a backhoe, small milling head, or jackhammer, while large areas are usually removed with a milling machine or milling head attachment (Figure 3-4). Saw-cut the perimeter of the patch as vertical as possible, regardless of the method used to remove material.

Use an asphalt bit in the jackhammer. Start the jackhammer from the middle of the repair area and work outward toward the edges. Making an additional saw cut a few inches from the border will allow the cut edges to remain square when removing the asphalt mixture. (Do not rock the hammer near the edge—this will damage the vertical face.) After completing the removal of material, remove and discard the loose material.

Figure 3-4 Small Milling Head Attachment

3-2.4 Remove, Replace, and Compact the Base.

When performing a full-depth patch, inspect the base to ensure adequate material conditions. Remove all unacceptable base, subbase, or subgrade and replace the poor-quality material with acceptable material that can be satisfactorily compacted. If subgrade material is removed, crushed stone or other suitable base material may be used to backfill to the top of the subgrade. Place new materials in 2- to 3-inch (50- to 75-millimeter) lifts, with each lift compacted to the required density. When removing the entire thickness of asphalt pavement, the base material is always disturbed; therefore, reshape and recompact the base material prior to performing the next step. After removal of material, make provision to remove any water that enters the resulting hole.

3-2.5 Apply Tack Coat (and Prime Coat, If Used).

Apply a thin tack coat to the edges and bottom of the patch. This coating provides an improved bond between the old and new materials. Ensure the patch area edges are clean, dry, and free of any dust so the tack coat will bond to the edges. Use tack coat materials that are cutback grades RC-70 or RC-250, or emulsion grades RS-1, MS-1, SS-1, SS-1h, CSS-1, or CSS-1h. The same grade of asphalt binder used in the asphalt mix can also be used as a tack coat, but this is difficult in small areas. If used, apply it hot and apply the patch material hot enough to soften the asphalt cement to obtain the required bond.

Use a prime coat can by spraying the sides and bottom of the hole to be patched with hot-asphalt plant mix if a tack coat is not used. Prime coat materials cutback grades RC-70, MC-30, MC-70, or SC-70, or emulsion grades SS-1, SS-1h, CSS-1, or CSS-1h. Applying too much material can cause bleeding. Allow prime coats time to penetrate the base material. They are usually absorbed into the underlying material within two to three hours and fully cured in less than 48 hours. Use a prime coat application rate of 0.05 to 0.2 gallon per square yard (0.23 to 0.90 liter per square meter), depending on the porosity of the material treated. Use a tack coat application rate of 0.05 to 0.10 gallon per square yard (0.23 to 0.45 liter per square meter). Use a hand-spray wand to apply the tack coat at the bottom and sides of the patch (Figure 3-5) if the area is large enough. If a wand is not available or if the area is too small, use a stiff brush. To prevent bleeding, do not apply excess tack to the patch areas.

Figure 3-5 Hand-spraying Edge of Cut

3-2.6 Place the Patch Material.

Use good-quality HMA to fill the patch. Place and compact the material in 2- to 3-inch (50- to 75-millimeter) lifts. In order for the patch to be level with the surrounding pavement, overfill the patch area to allow for compaction (Figure 3-6). When placing by hand, a good rule of thumb is to overfill by 40 percent thicker than the desired compacted thickness, depending on the mix; e.g., 3 inches (76 millimeters) compacted = 4.25 inches (108 millimeters) uncompacted. Do not overwork patch material with a lute, shovel, or rake since this tends to segregate materials and creates additional mixture cooling. When placing with an asphalt paver, a good rule of thumb is to place the asphalt mixture about 20 to 25 percent thicker to allow for compaction.

Figure 3-6 Overfill Prior to Compaction

3-2.7 Compact the Patch Area.

Compact the mix to the proper level using methods described in UFC 3-250-03, *Standard Practice Manual for Flexible Pavements*. It is important to ensure that sufficient material was provided to the patch so adequate density is obtained. The size of the patch determines which type of compactor to use. For a very small patch area or areas, a hand tamper can be used. Larger areas require a vibratory plate tamper (Figure 3-7), a steel-wheel roller (Figure 3-8), or similar compactor. To ensure the required compaction, use the proper equipment as dictated by the patch size. Always compact the edges of the patch first, followed by compaction of the remaining patch area in the direction of traffic. Overlap previous compaction lanes by approximately 6 inches (150 millimeters) across the patch area (Figure 3-8). When the patch is completely compacted, ensure its level is no higher or lower than 0.125 inch (3 millimeters) above or below the surrounding surface (Figure 3-9). Good oversight and density and smoothness testing are required to achieve a good patch.

Figure 3-7 Vibratory Plate Compactor

Figure 3-8 Steel Wheel Roller

Figure 3-9 Check Level of Patch Surface

3-2.8 Ensure Surface of Patch is Watertight.

If performed satisfactorily, the tack coat material applied to the side of the prepared hole is a good sealer between the existing edge and the patch. However, if the surface appears open at the edge of the patch or the surface of the patch is open then additional sealing may be needed on the surface. If the edge is open, seal it with a sand emulsion mix to give it the texture of a slurry seal (Figure 3-10). Refer to the International Slurry Surfacing Association guidelines (https://slurry.org/guidelines) for additional information. Ensure the edge seal is no more than 2 inches (50 millimeters) wide. If the entire surface is open then seal the entire surface with the slurry seal. Apply this material with a small brush for small sections or with a broom or small squeegee for larger sections.

Figure 3-10 Seal the Edges

3-2.9 Problem Areas.

Adequate compaction and obtaining satisfactory smoothness are major challenges when constructing patches. Use care in removing material to ensure the edges and bottom of the repair are square. Remove all unsatisfactory material when patching. It is critical that the underlying material is compacted before applying the patch. Compaction lifts less than 3 inches (75 millimeters) work best. If a spray wand is used to apply tack coat, perform a test on an adjacent area to ensure the correct application rate. Use care when applying tack coat to the edges. For best results, follow recommended best practices for spray nozzles, equipment settings, and other operations.

Note: If using cutback asphalts as a tack coat, comply with local environmental regulations.

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CHAPTER 4 PROCEDURAL STEPS (PARTIAL-DEPTH PATCH).

4-1 INTRODUCTION.

Partial-depth patch procedural steps are identical to full-depth patch (Chapter 3). The one exception is that when saw cutting the pavement, control the patch depth to only allow cutting to the depth required for the repair. Furthermore, removal of the material in the area is usually performed with a cold milling or cold planing device. If the material has delaminated from the layer below, a light-weight jackhammer (10 to 17 pounds [4.5 to 7.7 kilograms]) and/or a shovel or equipment bucket may be used to remove the material from the repair area.

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CHAPTER 5 SPRAYED ASPHALT SURFACE TREATMENTS

5-1 INTRODUCTION.

Use a sprayed asphalt surface treatment at an appropriate time to provide beneficial preventive maintenance. Placing a surface treatment too soon can prevent the surface of the asphalt mix from becoming sufficiently stiff to resist deformations under traffic. Delaying treatments too long will limit the treatment's ability to provide preventive maintenance. Severely weathered or cracked pavements are candidates for maintenance by replacement and will not significantly benefit from surface treatments. Do not place surface treatments on runway pavements unless approved by the Pavements Discipline Working Group (DWG) or their designated representative since they can cause FOD and reduce friction.

5-2 PRIME COAT.

A prime coat is a spray application of bituminous material applied to the surface of a base course that is to be covered with an asphalt pavement layer. The primary purpose of the prime coat is to waterproof the unbound material until it can be covered with asphalt mixture. The prime coat can also help prevent damage to the base during construction. Materials that can be used for prime coats are described in paragraph 3-2.5.

5-2.1 Procedural Steps (Prime Coat).

Conduct the following steps to apply a prime coat:

5-2.1.1 Prepare the Surface.

Ensure the surface is free of all loose material such as dirt, clay, dust, or any other undesirable material. Use a light brooming to remove these undesirable materials. If the base is excessively dry, lightly sprinkle with water prior to application of the prime coat to improve penetration of the material into the underlying layer.

5-2.1.2 Apply the Prime.

Use a distributor if the area to be primed is large. Use a hand spray wand to apply prime coat applications on smaller areas. Prime coat application rates are 0.05 to 0.2 gallon per square yard (0.23 to 0.9 liter per square meter). Coat the entire area. Since the primary purpose of a prime coat is to protect the underlying layer from rain until it is covered, the prime coat is sometimes omitted in patched areas when the surface can be covered with HMA prior to rainfall.

5-2.1.3 Allow Prime to Cure.

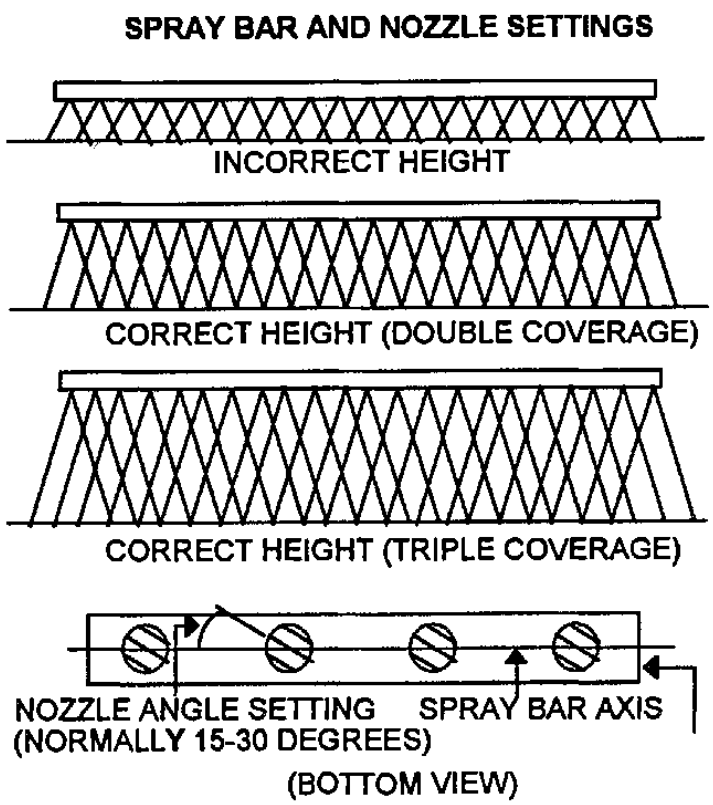
Cure prime coats for as long as necessary. Required curing time is typically 48 hours but satisfactory curing will likely occur in less time, especially in hot, windy conditions.

Blot with find sand or mineral dust if there is excess prime on the surface after penetration into the underlying materials is complete.

5-2.2 Problem Areas (Prime Coat).

A major potential problem is applying too much prime coat material so there is excess on the surface. Test application rates prior to priming. Determine application rates in accordance with ASTM D2995, *Practice for Determining Application Rate for Bituminous Distributors*. Check proper nozzles and settings on the distributor spray bar or hand-wand. Use nozzles with openings that are the same size. Check nozzles to ensure they are not plugged and are set at the proper angle and height (Figure 5-1). Comply with local environmental regulations when using RC-70 or other cutbacks as a prime coat.

Figure 5-1 Spray Bar and Nozzle Settings



5-3 TACK COAT.

The tack coat is applied to an existing pavement surface before it is overlaid with a new asphalt overlay. The tack coat provides a bond between the old and new pavement. Guidance for materials is provided in paragraph 2-2.

5-3.1 Procedural Steps (Tack Coat).

Conduct the following steps to apply a tack coat:

5-3.1.1 Prepare the Surface.

Clean and dry the surface and ensure it is free of dust, loose dirt, and other debris. Clean the surface around and inside the patch with brooms, air, and water.

5-3.1.2 Apply the Tack.

Use a distributor to apply tack coats over large areas. Use a hand-wand for small patches and hard-to-apply areas. If a wand is not available, apply the tack coat to patch edges with a stiff brush. Apply the tack coat at a proper application rate in an even and uniform coat over the entire area. Apply no more tack material than can be covered by the end of a working day. Application rates for tack coats range from 0.05 to 0.1 gallon per square yard (0.23 to 0.45 liter per square meter).

5-3.1.3 Allow Tack to Cure.

Allow the tack coat to cure before placing the overlay or patch material. Cure times will vary according to the type of tack material used and climatic conditions but typically it is a few minutes up to one or two hours. When asphalt cement is used as a tack coat, no cure time is required.

5-3.2 Problem Areas (Tack Coat).

An excessive application of tack will cause bleeding and slippage; therefore, apply at the proper application rate. Test application rates in accordance with ASTM D2995 prior to spraying the tack material. Check nozzles and settings on the distributor spray bar or hand-wand to ensure they are proper. Check nozzles to ensure they are not plugged and adjust nozzles to the proper angle and height. Clean and dry areas prior to tack coating. Comply with local environmental regulations when using RC-70 or other cutbacks as a tack coat. Overlay material that is tacked on the same day; however, as long as traffic is kept off of the surface and it remains clean, the tack may be effective for several days. It may be necessary to slightly increase the tack coat application if it has been in place for too long.

5-4 FOG SEALS AND REJUVENATORS.

Consider surface treatments for use when non-load-associated surface distresses such as non-structural cracking or raveling first begin. The recommended sealer process, once non-structural cracking and/or raveling is first observed, is a fog seal (except for runways). Continue application of the fog seal on an approximately three-year cycle, depending on pavement condition, as long as surface friction is maintained and texture depth is at least 0.03 inch (0.8 millimeter) when tested according to the grease smear test (FAA AC 150/5320-12C, *Measurement, Construction, and Maintenance of Skid-Resistant Airport Surfaces*).

A fog seal is a spray application of a diluted asphalt or tar emulsion. Emulsions used for fog seals are SS-1, SS-1h, CSS-1, or CSS-1h.

Rejuvenators are commercially available products used to restore oxidized pavement surfaces. Rejuvenators do not solve raveling issues (unless raveling is very minor) or reduce cracking problems (unless cracking is very minor hairline cracking). Often, rejuvenators can cause pavement surfaces to be slippery for up to a year; therefore, choose areas and application rates with extreme care. Since there are numerous commercially available products, a list of rejuvenators is not presented in this UFC. Fog seals and rejuvenators are normally used as preventive maintenance procedures on roads and only on airfield shoulders and overruns. Do not apply over airfield pavements without approval of the Pavements DWG or their designated representative.

5-4.1 Procedural Steps (Fog Seals and Rejuvenators).

Apply fog seals and rejuvenators using the following steps:

5-4.1.1 Prepare the Surface.

Thoroughly clean the surface prior to application of fog seals or rejuvenators. Repair distresses before application of fog seal or rejuvenator.

5-4.1.2 Determine Proper Application Rate.

The application rate will vary according to the quantity of material the pavement absorbs and the texture of the surface; therefore, spray small field test sections with different application rates to determine the best rate to apply. Adjust the rate so the treated surface has good friction, is not unstable, and does not contain excess material remaining on the surface after 12 to 24 hours of curing.

5-4.1.3 Dilute the Material.

The material can be used undiluted but is usually diluted. Dilution rates can be as high as 1 part emulsion to 10 parts water, with an average rate of 1 part emulsion to 4 parts water. Follow the manufacturer’s dilution directions. Diluting the rejuvenator with water requires a higher application rate.

5-4.1.4 Apply the Material.

Apply the material with a calibrated asphalt distributor (Figure 5-2). The calibration of the distributor is critical. Important procedures are discussed in paragraph 5-2. To avoid excessive reduction in friction, apply the asphalt material in multiple applications over the entire area so each small increase in application rate can be evaluated for its effectiveness prior to adding another application.

Figure 5-2 Asphalt Distributor

5-4.1.5 Cure Time.

Fully cure the fog seal before allowing traffic on the treated pavement. Cure time is usually 12 to 24 hours.

5-4.2 Problem Areas (Fog Seals and Rejuvenators).

Calibrate, adjust, and clean the distributor as discussed in paragraph 5-2.2 to avoid problems with coverage. Do not apply rejuvenator on airfields without prior approval from the AFCEC Pavements subject matter expert (SME), USACE Pavements SME, NAVFAC Pavements SME, or USACE/TSMCX pavement engineer. Follow proper application and dilution rates to avoid potential problems with excessive material application. Conduct preliminary tests on small test sections to determine the proper application and dilution rates.

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CHAPTER 6 BITUMINOUS SURFACE TREATMENT

6-1 INTRODUCTION.

Single and double bituminous surface treatments (SBST and DBST, respectively) consist of sprayed asphalt applications followed immediately by one or more layers of aggregate. These treatments are used to retard deterioration of raveling, improve skid resistance, seal small cracks, and waterproof the surface. Do not use SBST or DBST on airfield pavements except for overruns and not within 200 feet (61 meters) of the threshold, but SBST or DBST can be used on light-traffic roads, parking lots, and overruns. Another type of bituminous surface treatment, sandseal, is presented in Chapter 7. A variation of SBST to repair bleeding is presented and consists of applying hot sand followed by rolling.

6-2 SINGLE BITUMINOUS SURFACE TREATMENT (SBST).

Use the following bituminous materials for SBST: cutback (RC-250, RC-800, or RC-3000) or emulsion (RS-1, RS-2, CRS-1, or CRS-2). MS and SS asphalt emulsions and medium-curing (MC) cutback asphalt can be used in some cases; however, these materials are not typically recommended because the time for cure is extended and this may result in the treatment being tender for an extended period of time. Use of any other material is prohibited without the approval of the Pavements DWG or their designated representative.

6-2.1 Procedural Steps (SBST).

Place SBST using the following steps:

6-2.1.1 Prepare the Area (SBST).

Repair all failed areas prior to applying an SBST and thoroughly clean all surfaces prior to treatment. Apply prime and/or tack coats in accordance with the procedures in Chapter 5.

6-2.1.2 Apply the Binder Material (SBST).

Apply the binder (asphalt material) with an asphalt distributor. Calibrate the distributor prior to each use. Use the same precautions as discussed for sprayed asphalt treatments in Chapter 5. An asphalt emulsion changes in color from brown to black as it breaks and cures. Apply the aggregate before the binder material has broken and turned black. Provide materials meeting one of the gradations in Table 6-1. Apply the binder and aggregates using the application rates shown in Table 6-2. Do not use Gradation 1, which is a coarse grading for SBST.

6-2.1.3 Apply the Aggregate (SBST).

Apply the aggregate immediately after binder material is applied. Apply the aggregate with tailgate spreaders on dump trucks or by self-propelled hopper-type spreaders (Figures 6-1 and 6-2, respectively). Calibrate spreaders to ensure uniformity of the aggregate at the required rate. Use only aggregate that is clean, dry, and free of dust or other undesirable material. A slightly damp aggregate can be used and works best with emulsions since this small amount of moisture will ensure better coating of the aggregate. Use aggregates that are hard, angular, and abrasion-resistant. Lightweight aggregates are sometimes used to improve friction properties. Construct a test section to ensure the resulting surface is satisfactory prior to large scale or production applications. Construct a test section when making adjustments to the treatment as necessary to provide a satisfactory surface.

Table 6-1 Aggregate Gradations for SBST

% Passing by Weight, Gradation Designation			
Sieve Size	**No. 1 SBST**	**No. 2 SBST**	**No. 3 SBST**
1 in. (25.4 mm)	100	—	—
0.75 in. (19.1 mm)	90 - 100	100	—
0.5 in. (12.7 mm)	20 - 55	90 - 100	100
0.375 in. (9.5 mm)	0 - 15	40 - 70	85 - 100
No. 4 (4.8 mm)	0 - 5	0 - 15	10 - 30
No. 8 (2.4 mm)	—	0 - 5	0 - 10
No. 16 (1.2 mm)	—	—	0 - 5

Table 6-2 SBST Binder and Aggregate Application Rates

Gradation No.	Binder Application Rates gal/yd^2 (l/m^2)	Aggregate Application Rates lb/yd^2 (kg/m^2)
1 SBST	0.40–0.50 (1.81–2.26)	40–50 (22–27)
2 SBST	0.30–0.45 (1.36–2.04)	25–30 (14–16)
3 SBST	0.20–0.35 (0.91–1.58)	20–25 (11–14)

Figure 6-1 Applying Aggregate with Tailgate Spreader on Dump Truck

Figure 6-2 Applying Aggregate with Self- Propelled Hopper-type Spreader

6-2.1.4 Roll the Aggregate (SBST).

Roll the aggregate immediately after application. Use a pneumatic-tire roller with tire pressures of 60 to 80 psi (414 to 552 kilopascals) and tire loads (weights) equal to the largest tire load that will operate on the surface. Use a pneumatic-tire roller to avoid crushing the aggregate. If approved by the contracting officer, a steel-wheel roller can be used; however, use a weight that is heavy enough to seat the aggregate but not so heavy as to crush the aggregate. The steel wheel will bridge over low spots and may not properly seat the aggregate. Continue to roll the treatment area until all aggregate particles are properly seated.

6-2.1.5 Sweep the Area (SBST).

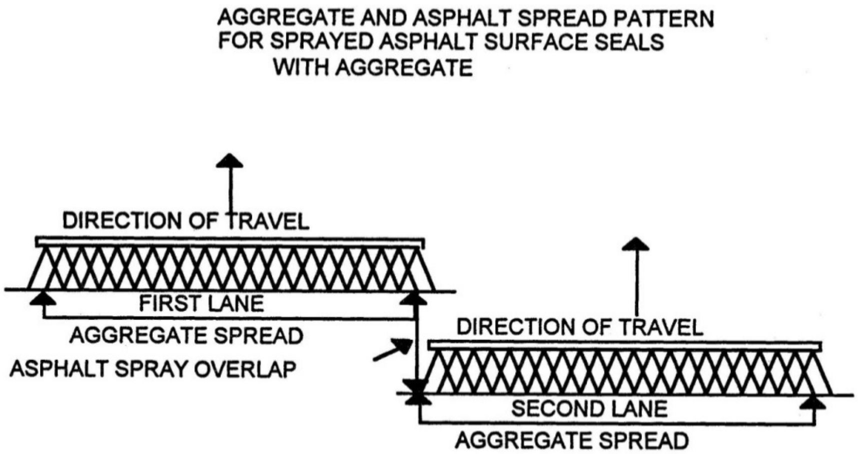
Allow the treated area to cure for at least 24 hours before brooming to remove loose particles. Broom during the coolest portion of the day to prevent dislodging aggregate. Use only enough pressure on the broom to remove the loose particles and not dislodge seated aggregate.

6-2.2 Problem Areas (SBST).

Calibrate all equipment before material placement. Use a test section to ensure all equipment is calibrated and working properly. Use building paper where the spreading of the binder and aggregate begins and ends to make clean and straight transverse joints (Figure 6-3). Remove the paper after application to form a straight edge. Do not spread the aggregate beyond the area of full binder thickness to prevent a buildup of aggregate along the longitudinal joint (Figure 6-4). This distance varies according to the spray width of the nozzle, but it is usually about 6 to 8 inches (150 to 200 millimeters) from the edge of the spray. On the adjacent pass, apply aggregate from the edge of the aggregate on the first pass to about 6 to 8 inches (150 to 200 millimeters) from the edge of the asphalt spray on the opposite side. After completing the work and opening the treated area to traffic, post for 3 days speed limits of no more than 20 miles per hour (32 kilometers per hour). This will ensure that the asphalt is fully cured, help to ensure better seating of the aggregate, and minimize dislodging of additional aggregate.

Figure 6-3 Use Paper for Straight Edge

Figure 6-4 Aggregate and Sprayed Asphalt Spread Pattern



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CHAPTER 7 DOUBLE BITUMINOUS SURFACE TREATMENT.

7-1 INTRODUCTION.

This treatment is essentially the same as the SBST, except that more than one application of binder and aggregate is used. The most common treatment is the DBST. The same bituminous materials used for SBST can also be used for DBST. Aggregate gradations and application rates to be used are shown in Tables 7-1 and 7-2.

7-1.1 Procedural Steps (DBST).

Place DBST using the following steps:

7-1.1.1 Prepare the Area.

Follow the SBST procedures (Chapter 6).

7-1.1.2 Apply the Binder Material.

Follow the SBST procedures (Chapter 6), except two applications of binder and aggregate are placed using rates shown in Tables 7-1 and 7-2.

Table 7-1 Aggregate Gradations for DBST

Sieve Size	% Passing by Weight, Gradation Designation			
	No. 1 DBST	No. 2 DBST	No.3 DBST	No. 4 DBST
1 in. (25.4mm)	100	—-	—-	—-
0.75 in. (19.1 mm)	90 - 100	100		—-
0.5 in. (12.7 mm)	20 - 55	90 - 100	100	—-
0.375 in. (9.5 mm)	0 - 15	40 - 70	85 - 100	100
No. 4 (4.8 mm)	0 - 5	0 - 15	10 - 30	85 - 100
No. 8 2.4 mm)	—-	0 - 5	0 - 10	10 - 40
No. 16 (1.2 mm)	—-	—-	0 - 5	0 - 10
No. 50 (300 µm)	—-	—-	—-	0 - 5

Table 7-2 DBST Binder & Aggregate Application Rates

First Application		
Gradation No.	**Bituminous Material* gal/yd^2 (l/m^2)**	**Aggregate lb/yd^2 (kg/m^2)**
1 DBST	0.20–0.30 (0.91–1.36)	40–50 (22–27)
2 DBST	0.15–0.20 (0.68–0.91)	25–30 (14–16)
Second Application		
Gradation No.	**Bituminous Material** gal/yd^2 (l/m^2)**	**Aggregate lb/yd^2 (kg/m^2)**
3 DBST	0.30–0.45 (1.36–2.04)	20–25 (11–14)
4 DBST	0.20–0.30 (0.91–1.36)	15–20 (8–11)

* If an emulsion is used, increase the application rate by 10 percent.
** Ensure the second application is approximately 50 percent greater than first application.
Note: Use gradations in pairs. If gradation 1 is used for the first application then use gradation 2 for the second application and the same for gradations 3 and 4.

7-1.1.3 Apply the Aggregate.

Use the SBST procedures (paragraph 6-2.1.3).

7-1.1.4 Roll the Aggregate.

Use the SBST procedures (paragraph 6-2.1.4).

7-1.1.5 Sweep the Area.

Use the SBST procedures (paragraph 6-2.1.5).

7-1.1.6 Apply Second Application.

To apply the second application of binder and aggregate, the same steps are followed as for the first application.

7-1.2 Problem Areas (DBST).

DBST applications suffer from the same problems as SBST (paragraph 6-2.2). Remedy or mitigate these problems using the same procedures.

7-1.3 Sandseal (DBST).

Sand seal can be used to address a bleeding pavement surface or provide a thin sealer. When used to address bleeding, do not apply asphalt binder before the sand seal is placed since the primary purpose is to blot up the excess binder on the surface. Use sand with the gradations in Table 7-3. Use gradation 2 for a thinner application of sand. Potential problems include difficulty in getting an even application of sand and difficulty in treating a non-uniform surface underneath. Hence, it is possible that excessive sand will be placed in some areas and not enough in others. When binder is used, select the binder similar to that for SBST (Chapter 6).

Table 7-3 Aggregate Gradations for Sandseal (SS)

Sieve Size	% Passing by Weight, Gradation Designation	
	No. 1 SS	No. 2 SS
0.5 in. (12.7 mm)	—	—
0.375 in. (9.5 mm)	100	—
No. 4 (4.8 mm)	85 - 100	100
No. 8 (2.4 mm)	10 - 40	10 - 40
No. 16 (1.2 mm)	0 - 10	0 - 10
No. 50 (300 µm)	0 - 5	0 - 5

7-1.4 Sand Application and Rolling.

Use the following steps when treating a pavement with bleeding problems:

7-1.4.1 Apply Hot Sand.

Heat the sand to above 275 degrees F (135 degrees C) and spread the sand with a tailgate or box spreader, or by hand. Apply at a rate of 10 to 15 pounds per square yard (5 to 8 kilograms per square meter).

7-1.4.2 Roll the Sand.

Immediately roll the sand with a pneumatic roller after spreading.

7-1.5 Sweep Excess Material.

Sweep the area with a vacuum sweeper after the treated area has sufficiently cooled to remove excess sand.

7-1.5.1 Aggregates.

Use clean, angular, and durable aggregate in a slurry seal or microsurfacing. The minimum sand equivalent value for aggregate used in a slurry seal is 45 (ASTM D2419, *Standard Test Method for Sand Equivalent Value of Soils and Fine Aggregate*, AASHTO T176, *Standard Method of Test for Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test*) and a maximum Los Angeles abrasion test value of 35 in the parent rock (ASTM C131, *Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine*, AASHTO T96, *Standard Method of Test for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine*).

Ensure the aggregate used in microsurfacing has a minimum sand equivalent value of 65 and a maximum Los Angeles abrasion test value of 30 in the parent rock. In addition, limit the maximum soundness value of aggregates for slurry seals and microsurfacing to 15 percent in the parent rock using Na_2SO_4 (sodium sulfate) or 25 percent using $MgSO_4$ (magnesium sulfate) testing (ASTM C88, *Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate*, AASHTO T104, *Standard Method of Test for Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate*).

7-1.6 Problem Areas.

Table 7-4 lists the impacts for each type of surface treatment. Many problems associated with surface treatments occur after its service life has passed. Actual service life depends on the product, application method, application rate, and pavement surface preparation. Some surface treatments are only intended to last a few years while others remain effective in excess of eight years.

Table 7-4 Potential Negative Impacts of Surface Treatments to Airfields

Surface Distress	Liquid Spray Seal	Liquid and Sand Spray Seal	Slurry Seal	Microsurfacing
Decreased friction	H	H	P	N
Debonding	N	P	H	P
Raveling	N	P	P	P

N - Not a significant concern

P - Potential for minor impact

H - High potential for impact

CHAPTER 8 ASPHALT SLURRY SEALS AND MICROSURFACING

8-1 INTRODUCTION.

A slurry seal is a mixture of asphalt emulsion, aggregate, water, and mineral filler. Slurry seals are used to seal and protect worn, weathered, and cracked pavement from the effects of further weather and traffic. Another use is to improve friction properties. A special form of slurry seal has been used in high-traffic areas up to and including interstate highways. Microsurfacing is a heavy-duty slurry seal and includes the use of a polymer-modified asphalt binder. This product has been used to fill ruts on high-volume roadways. In traffic areas, use microsurfacing or slurry seals a maximum of two times between overlays and consider on five- to seven-year cycles. Do not use a slurry seal or microsurfacing on airfield pavements or other high-traffic areas without approval from the contracting officer or Pavements DWG or their designated representative.

8-2 MIXTURE MATERIALS.

8-2.1 Emulsions.

Use one of the following emulsions in a slurry seal: SS-1, SS-1h, CSS-1, or CSS-1h. Use a polymer-modified asphalt binder for microsurfacing. Some microsurfacing mixtures are proprietary products.

8-2.2 Aggregate.

Use clean, angular, and durable aggregates in slurry seals or microsurfaces. Slurry seals and microsurfacing use well-graded aggregates and are classified according to the gradation of the aggregate used. Use aggregates with a minimum sand equivalent value of 45 (ASTM D2419, AASHTO T176) and a maximum Los Angeles abrasion test value of 35 in the parent rock (ASTM C131, AASHTO T96) in slurry seals. Use aggregates with a minimum sand equivalent value of 65 and a maximum Los Angeles abrasion test value of 30 in the parent rock in microsurfaces. In addition, limit the maximum soundness value of aggregates for slurry seals and microsurfacing to 15 percent in the parent rock using Na_2SO_4 (sodium sulfate) or 25 percent using $MgSO_4$ (magnesium sulfate) testing (ASTM C88, AASHTO T104).

Use the aggregate gradations in Table 6-1 and application rates in Table 6-2 when slurry sealing or microsurfacing. The gradations typically include 0.5 to 3.0 percent mineral filler. Use only Type II and Type III gradations for airfield applications. Aggregate gradations to be used are shown in Table 8-1.

8-2.3 Filler.

Use portland cement or hydrated lime if a filler is needed in the slurry. The filler tends to improve the stability of the mixture. If stability or segregation problems occur, use mineral filler at 0.4 to 0.5 percent of the total mixture. Water is the primary control for workability of the mixture; therefore, use only potable water.

Table 8-1 Aggregate Gradations for Microsurfacing and Slurry Seals

Sieve Size	% Passing by Weight, Gradation Designation		
	Type 1	Type 2	Type 3
3/8 in. (9.5 mm)	100	100	100
No. 4 (4.8 mm)	100	90 - 100	70 - 90
No. 8 (2.4 mm)	90 - 100	65 - 90	45 - 70
No. 16 (1.2 mm)	65 - 90	45 - 70	28 - 50
No. 30 (600 µm)	40 - 65	30 - 50	19 - 34
No. 50 (300 µm)	25 - 42	18 - 30	12 - 25
No. 100 (150 µm)	15 - 30	10 - 21	7 - 18
No. 200 (75 µm)	10 - 20	5 - 15	5 - 15
Application Rate (lb/yd^2 dry aggregate)	8 - 12	12 - 20	18 - 30

8-3 SLURRY SEAL PROCEDURAL STEPS.

Place a slurry seal using the following steps:

8-3.1 Prepare the Surface.

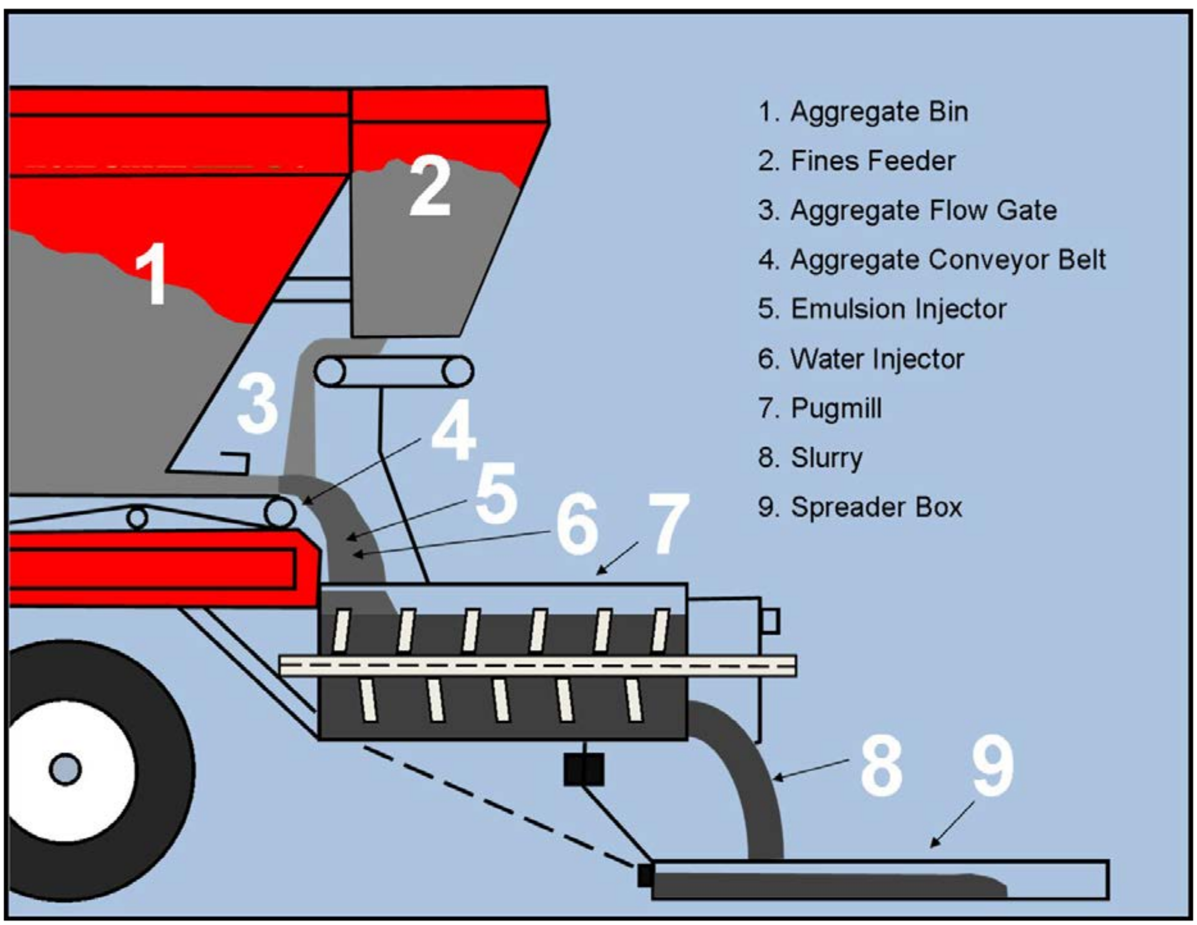
Remove all loose material (including any loose or flaking paint), dirt, and vegetation from the surface. Seal cracks greater than 0.125 inch (3 millimeters) wide. Place the sealant 0.125 to 0.25 inch (3 to 6 millimeters) below the surface during crack sealing. After sealing all cracks and cleaning the surface, spray a very light tack coat at a rate of 0.05 to 0.10 gallon per square yard (0.23 to 0.45 liter per square meter) and allow to fully cure.

8-3.2 Apply the Slurry.

Apply a fog spray of water to the surface with the spray bar on the slurry machine immediately before applying the slurry. Ensure there is no standing water after the spray. Adjust the spray to compensate for temperature, surface texture, humidity, and dryness of the surface. Apply the slurry with a slurry machine (Figure 8-1). The slurry machine is a self-propelled, continuous-flow mixing unit. Provide and use a device that is capable of delivering the proper amount of aggregate, water, mineral filler, and emulsion to the mixing unit. The mixing unit is either a single or double pugmill mixer. The mixing unit discharges the material into the spreader box that is equipped with flexible squeegees and width adjustment. Other parts of the machine include the spray bar for wetting the pavement and an aggregate prewetting device.

Use a burlap drag behind the spreader box to improve the joints and improve the texture and appearance of the mixture. Apply the slurry from 0.125 inch (3 millimeters) up to but no more than 0.25 inch (6 millimeters) thick in one pass. If more than one pass is applied, fully cure the previous layer before applying the second application.

Figure 8-1 Slurry Seal Spreader Machine



8-3.3 Rolling the Slurry.

A slurry seal is not always rolled but rolling does provide improved performance. Roll the slurry to reduce voids, limit surface imperfections, and increase the slurry's resistance to water. Roll the slurry after it has cured enough to support the roller without removing any of the slurry mixture. Use a 5-ton (4,540-kilogram) pneumatic-tire roller with tire pressures of 50 pounds per square inch (345 kilopascals) to roll the slurry.

Cure the Slurry.

The time to allow for curing will vary according to the application rate of the emulsion and aggregate and weather conditions. The slurry cures by evaporation of water from the surface, by deposition of asphalt on the aggregate which frees the water, or by a combination of these. The material at the top will typically cure faster than the material at the bottom. Fully cure the slurry seal before opening the treated area to traffic.

8-3.4 Problem Areas.

Construct a test strip to ensure proper slurry machine calibration and correct mixture. Do not overwork the slurry when hand-applying the slurry; overworking causes the emulsion to break prematurely. Apply the second lane while the edge of the previous lane is still fluid and workable, if possible. If the previous lane's edge is not workable then allow the slurry material to cure enough for the spreader box to not damage the previous lane. Keep the burlap drag clean and replace when necessary. Material buildup on the burlap drag causes streaking and gouging. Inspect the flexible lining of the spreader box for wear or accumulation of cured slurry. Replace the lining when worn. Remove any cured slurry from the lining.

8-3.4.1 General Rule.

Do not place surface treatments on asphalt concrete pavements during the first year of service without approval of the Pavements DWG or their designated representative.

8-3.4.2 Fog Seal Consideration.

Do not apply a fog seal over a slurry seal or microsurface without approval of the Pavements DWG or their designated representative.

8-3.4.3 Slurry Seal Consideration.

Do not use slurry seals on airfield pavements where frequent ice/snow removal occurs without approval of the Pavements DWG or their designated representative. Ice/snow removal equipment can potentially tear the slurry from the underlying pavement.

8-3.4.4 Surface Treatments and Fuel Spillage.

Do not use these surface treatments in areas prone to fuel spillage without approval of the Pavements DWG or their designated representative. Alternative fuel-resistant sealers are appropriate for these areas.

8-3.4.5 Surface Treatments and Crack Sealing.

The use of surface treatments does not negate the need for routine crack sealing. Crack sealing is an additional maintenance procedure required to extend the life of asphalt concrete pavements. Using a slurry seal or microsurfacing results in smaller cracks being sealed but larger cracks will continue to need sealing.

8-3.5 Negative Impacts.

Table 7-4 lists the potential negative impacts for each type of surface treatment. Many problems associated with surface treatments occur after its service life is passed. Actual service life depends on the product, application method, application rate, and pavement surface preparation. Some surface treatments are only intended to last a few years, while others remain effective in excess of eight years.

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CHAPTER 9 ASPHALT CRACK SEALING

9-1 INTRODUCTION.

The purpose of sealing cracks in asphalt pavements is to protect the pavement structure from premature failure. The use of proper crack preparation and sealing techniques can extend the effective life of the sealant, thereby increasing the life of the pavement and reducing maintenance costs. Unsealed cracks allow water intrusion and debris retention in the crack opening. Water intrusion in the cracks penetrates into the base and subbase materials, creating the potential for a loss of strength in these materials. The weakened pavement structure can result in load-related failures such as alligator cracking (Figure 9-1). The debris retention can cause the pavement to “push up” at the edges of the crack when the pavement expands due to thermal changes. This decreases the rideability of the pavement surface. These failures and deficiencies increase the lifecycle cost of the pavements by requiring increased maintenance.

Figure 9-1 Alligator Cracking

9-2 WHEN TO SEAL.

9-2.1 Field Evaluations.

Conduct field evaluations at least twice a year, once during the summer months and once during the winter months. Seasonal evaluations will enable a determination of the number and size of cracks and allow performance evaluations of any existing sealant when the cracks are at their smallest and largest width. Consider sealing when cracks have become approximately 0.25 inch (6 millimeters) wide. Do not seal cracks less than 0.25 inch (6 millimeters) wide unless they cover a large percentage of the pavement.

Use a surface treatment such as seal coating or overlay on pavements that have many cracks less than 0.25 inch (6 millimeters) wide or smaller.

9-2.2 Schedule.

Plan and schedule crack sealing in accordance with field evaluations. Make spot repairs to sealed cracks where the sealant material has failed. Figures 9-2 and 9-3 show typical areas in need of sealing. Consider a major resealing project when a large percentage of the area has failed sealant or cracks with no sealant at all.

Figure 9-2 Reflective Cracking

Figure 9-3 Longitudinal Cracking

9-2.3 Climatic Conditions.

Schedule crack sealing projects during the normal construction season. A normally low rainfall period in the spring or fall is preferred. Do not seal crack(s) until the temperature of the pavement is 50 degrees F (10 degrees C) and rising. Do not seal crack(s) until the crack is free of moisture and debris.

9-2.4 Porous Friction Surfaces.

The guidelines for sealing cracks in a porous friction surface (PFS) are different from a normal asphalt surface. Use the procedures in Chapter 10 for sealing cracks in a PFS.

9-3 SPECIFICATIONS.

9-3.1 ASTM.

Use crack sealant conforming to ASTM D6690, *Joint and Crack Sealants, Hot Applied, for Concrete and Asphalt Pavements*. When selecting a sealant, consider climatic regional temperature performance. Also consider sealant characteristics in high-volume pedestrian traffic where some materials have a tendency to track onto the pavement and stick to the soles of shoes.

9-3.2 Other Specifications.

Rubberized asphalt sealants that are not covered by the above specifications can be used only on roads and only when an appropriate state department of transportation (DOT) or local municipality material specification is available and after the sealant has been approved by the AFCEC Pavements SME, NAVFAC Pavements SME, or USACE Transportation Systems Center (TSMCX) pavement engineer. The DOT and local specifications will often be modified to account for the temperature variations of the region. Asphalt cements that contain synthetic fibers have been used successfully on a limited basis as a crack sealant. Use state or municipality specifications for these materials but only after the sealant has been approved by the Pavements DWG or their designated representative.

9-3.3 Testing.

Test the crack sealant material by a government-approved independent laboratory for specification conformance before it is used on a project. If the quantity of sealant for the project is less than 500 pounds (227 kilograms) then the manufacturer’s certificate of compliance may be accepted in place of testing. Evaluate local field performance data from past sealing projects, if available, to determine which type of sealant to seal the cracks.

9-4 CRACK SEALING PROCEDURAL STEPS.

9-4.1 Crack Size Guidelines.

Procedures for sealing will vary depending upon the size of the crack. Use the following steps as a guide:

9-4.1.1 Hairline Cracks (Less Than 0.25 Inch [6 Millimeters]).

See Figure 9-4. It is very difficult to successfully insert sealant material into a crack that is less than 0.25 inch (6 millimeters). Typically, these cracks are not sealed unless they cover 80 percent or more of the pavement area. If the cracks do require sealing, a surface treatment could be the most effective method. The surface treatment used will depend upon the area being treated and the predicted future traffic. A SBST or DBST could be satisfactory for a roadway or parking lot but not for an airfield. Surface treatments and slurry seals are not recommended for airfields that will encounter jet and high-tire-pressure aircraft because the surface treatment or slurry seal will normally deteriorate quickly. Consider options such as an asphalt overlay or pavement recycling for airfield pavements. For additional information on various types of surface treatments, see UFGS 32 12 36.13, *Asphaltic Seal and Fog Coats,* UFGS 32 12 11, *Bituminous Surface Treatment,* and UFC 3-250-03.

9-4.1.2 Small and Medium Cracks (0.25 to 2 Inches [6 to 50 Millimeters]).

See Figures 9-5 and 9-6. Widen small cracks to a nominal width of 0.125 inch (3 millimeters) greater than the existing nominal or average width. Widening the cracks 0.125 inch (3 millimeters) will help eliminate the potential for raveling of the pavement along the edges of the crack and will provide a sealant reservoir with vertical faces. After the crack has been cleaned and inspected, it is ready for sealing. The depth of the cracks to be sealed is determined and, if the depth is greater than 0.75 inch (19 millimeters), a backer rod material is inserted. If the depth of the crack is not deep enough to accommodate the backer rod and maintain a sealant depth of 0.5 to 0.75 inch (13 to 19 millimeters) then the crack can be routed or the backer rod material omitted.

9-4.1.3 Large Cracks (Greater Than 2 Inches [50 Millimeters]).

See Figure 9-7. Fill cracks that are 2 inches (50 millimeters) and larger with a sand asphalt or fine-graded asphalt mix and compacted. The procedures and equipment used are identical to those used to repair potholes. Cut or route the edges vertical and clean the cracks to obtain a patch that meets the specified requirement. The asphalt material could prematurely fail if the proper cleaning and patching procedures are not followed. Square by sawing, fill with asphalt mix, and compact the cracks. Refer to TM 5-624/NAVFAC MO-102/AFJMAN 32-1040, *Maintenance and Repair of Surface Areas*, for additional information.

9-4.1.4 Cracks in Pavements to be Overlaid.

Small and medium cracks in pavements to be overlaid are usually not filled prior to overlay. Also, if milling occurs, it is very difficult to locate these small cracks so sealing will be very difficult. However, many designers require these cracks to be filled with an emulsion, a sand emulsion mixture (Figure 9-9), or one of the types of sealants previously mentioned. Recess the material in the crack a minimum of 0.25 inch (6 millimeters) to prevent the material from “bleeding” through the overlay. Bleeding occurs when the asphalt cement in the crack sealant material is drawn to the surface of the overlay. Bleeding causes the pavement above the crack to become soft and a crack or bump in the overlay is usually the end result.

9-4.2 Crack Widening.

Use a router to widen meandering cracks. Use a saw with a small-diameter blade to widen straight cracks. When a saw is used, clean the crack with a high-pressure water stream or a sandblaster to remove debris created by the saw. The recommended procedure is to use a router since water would not be required. When resealing, remove all of the old sealant from the crack. After the crack has been widened or the existing sealant has been removed, clean the crack to prevent any debris from contaminating the crack.

9-4.3 Initial Crack Cleaning.

Use the sandblasting equipment, water-blasting equipment, HCA heat lance, or wire brushes to clean cracks. Information about this equipment follows:

9-4.3.1 Sandblasting.

When sandblasting equipment is used, establish a technique that enables both faces of the crack to be sandblasted. Use a multiple-pass technique consisting of positioning the sandblaster nozzle approximately 1 inch (25 millimeters) above the pavement surface, sandblasting the entire length of one crack face then sandblasting the entire length of the opposite crack face. Sandblast approximately 1 inch (25 millimeters) of the pavement surface on both sides of the crack to remove debris. Do not over-blast the cracks. Over-blasting can damage the pavement, causing raveling and premature bond failure of the sealant. Demonstrate the cleaning technique on 5 feet (1.5 meters) of cracks in an area not subject to direct wheel traffic to ensure proper techniques are used.

9-4.3.2 Water Blasting.

Water-blast the crack faces and pavement surfaces extending a minimum of 0.5 inch (13 millimeters) from the crack edges. Use a multiple-pass technique until the surfaces are free of dust, dirt, old sealant residue, or foreign debris that might prevent the sealant material from bonding to the asphalt pavement. After final cleaning and immediately prior to sealing, blow out the cracks with compressed air and leave them completely free of debris and water. Excessive water pressure can cause damage to the asphalt adjacent to the crack and result in loss of material. If the pressure is too low then the joint will not be properly cleaned. Demonstrate the cleaning technique on 5 feet (1.5 meters) of cracks in an area not subject to direct wheel traffic to ensure proper techniques are used.

9-4.3.3 HCA Heat Lance.

Use the HCA heat lance when the pavement is wet and/or cold (pavement temperature below 50 degrees F [10 degrees C]). Use extreme care to ensure the crack faces do not become overheated or burned. Overheating the crack faces will greatly reduce the life expectancy of the seal and adjacent pavement. Adhesion failure of the sealant or additional cracking of the pavement between the area that was overheated and the remainder of the pavement is expected.

9-4.3.4 Wire Brushes.

Wire brushes are sometimes used during sealing projects; however, wire brushes are not always capable of removing debris from the crack faces and this debris can cause adhesion failures. Inspect the wire brushes to ensure they are not worn. Inspect the cleaned crack to ensure all debris and dust have been removed.

9-4.4 Debris Removal.

Remove debris from the crack after water-blasting or sandblasting. This method normally removes the debris more effectively with less chance of pavement damage.

9-4.5 Final Crack Cleaning.

Once the old sealant and debris have been removed from the crack, clean the crack with compressed air. The compressed air is blown into the crack to remove sand or any debris that was loosened during the initial cleaning. The compressed air also helps remove moisture.

9-4.6 Inspection.

Inspection is the final phase of crack preparation. Inspect the crack for cleanliness and dryness. It is essential for the crack to be clean and dry so the sealant will adhere to the pavement. One method to check for cleanliness is to rub one’s finger along the crack face. If a dusty residue is left on the finger, re-clean the crack. If there is no residue, the crack is ready for sealing.

9-4.7 Crack Cleaning Summary.

The cleanliness of the crack is one of the most important factors in crack preparation that affects the life of the sealant. It is not the only important factor, but it is one that can be controlled. After the crack has been inspected and approved for cleanliness, the crack is ready to be sealed (Figure 9-8).

Figure 9-4 Hairline Crack

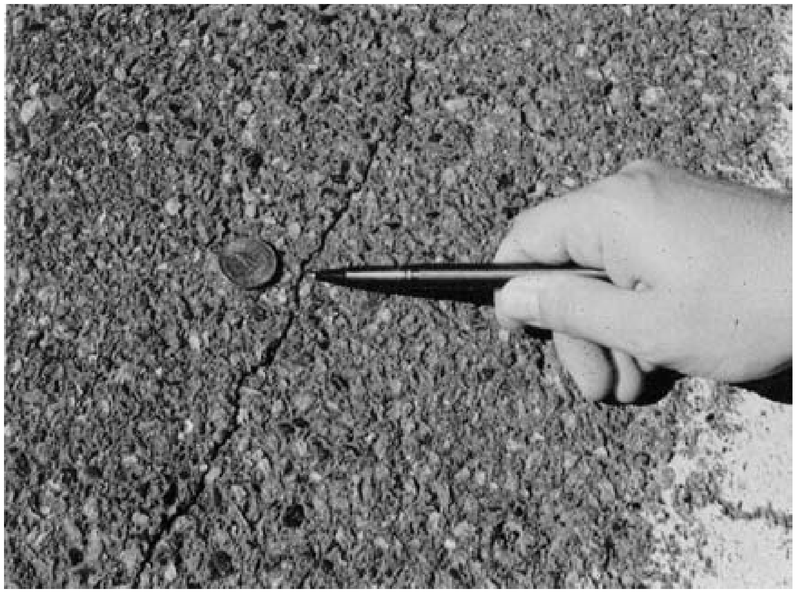

Figure 9-5 Small Crack

Figure 9-6 Medium Crack

Figure 9-7 Large Crack

Figure 9-8 Crack After Cleaning

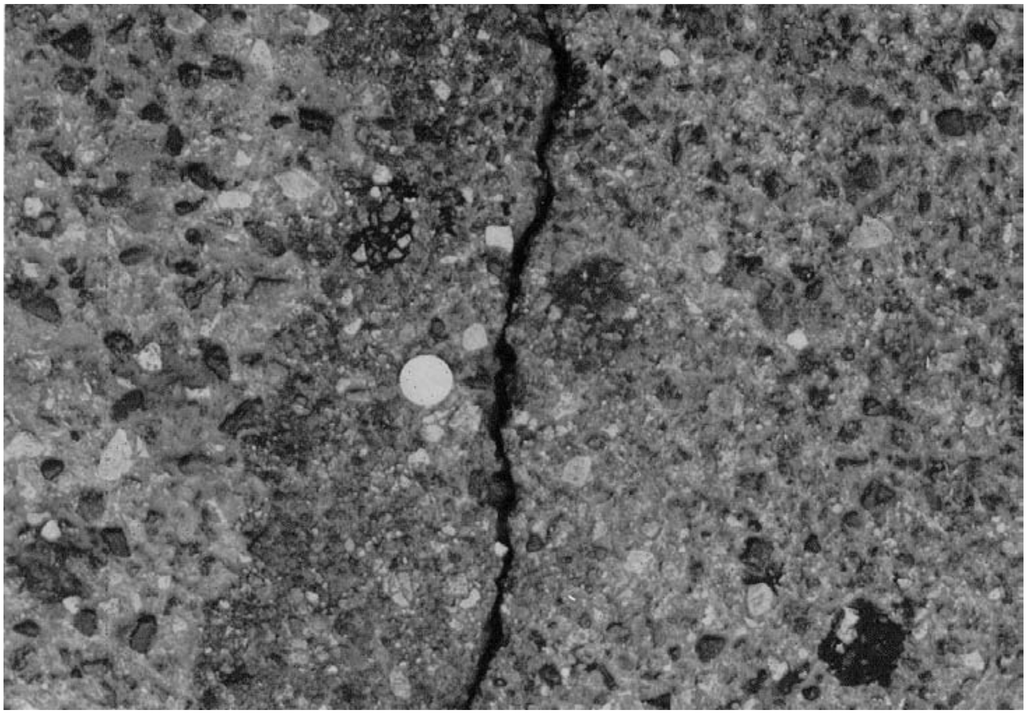

Figure 9-9 Filling Crack with Sand Emulsion Mixture

9-4.8 Backer Rod Material.

The backer rod (Figure 9-10) is a compressible, non-shrinking, non-absorptive material. Provide and use backer rods whose melting point is higher than the pouring temperature of the sealant. Provide and use backer rod that is approximately 25 percent wider in diameter than the nominal width of the crack. The larger size will enable the sealant to be inserted without dislodging the backer rod. Place the backer rod to a depth that will provide a shape factor (depth-to-width ratio) of approximately 1 for petroleum-based sealants. However, do not place the top of the backer rod deeper than 0.75 inch

(19 millimeters). This will provide a reservoir for the sealant that will minimize the internal stresses in the sealant. High internal stresses can create cohesion failure, split the material, or dislodge loose aggregate from the pavement, damaging the effectiveness of the seal. However, if the shape factor is too small, adhesion failure can occur; therefore, it is important to maintain the proper shape factor.

Figure 9-10 Examples of Backer Rod Materials

9-4.9 Inspection Prior to Sealing.

Inspect the cracks immediately prior to sealing. Ensure the backer rod is at the specified depth and that debris has not been blown into the crack. Clean cracks are essential in obtaining adhesion between the sealant and the crack face.

9-4.10 Sealant Temperature and Application.

Check the temperature of the sealant to ensure it is at the manufacturer's recommended application temperature. Insert the nozzle of the application equipment into the crack and seal the crack from the bottom to the top (Figure 9-11). Sealing in this manner minimizes bubbling of the sealant due to entrapped air. Recess the sealant approximately 0.125 to 0.25 inch (3 to 6 millimeters) below the pavement surface to prevent tracking. Remove excess sealant with a squeegee or similar equipment.

Figure 9-11 Sealing the Crack

9-4.11 Crack Sealing Delays.

Blow out with compressed air before sealing any cracks that are not sealed the same day they are prepared. Clean and dry cracks again if rain delays the sealing operation to remove any debris that may have been washed into the crack by rain. Use the sandblaster, wire brushes, or HCA heat lance, but not by using only compressed-air cleaning to remove debris washed in by the rain.

9-4.12 Inspection After Sealing.

Inspect the sealant to ensure the sealant is bonding to the pavement and that the cracks were not overfilled after the cracks have been sealed (Figure 9-12). Overfilled material can track onto the pavement surface and/or stick to pedestrians' shoes. Inspect the sealant to ensure the proper sealant recess has been obtained. Sealants that are not properly recessed will be pushed above the pavement surface as the pavement expands and become damaged by traffic. Cracks that have been under-filled can have additional crack sealant applied.

Figure 9-12 Crack After Sealing

9-5 PROBLEM AREAS.

9-5.1 Categories of Problems.

Many problems that arise during a sealing project can be divided into three categories: crack sealant materials, crack preparation, and crack sealant application. The following information is presented for these three sealing problems:

9-5.1.1 Materials.

One of the main problems associated with sealant materials is nonconformance to the required specification. Test the sealant through an independent laboratory to minimize this problem. Another problem is a combination between materials and application that involves the sealant not setting up or curing after it has been applied to the crack. This problem is often caused by overheating the sealant before it is applied to the crack. The overheating can be caused by heating the sealant at too high a temperature or heating it at the recommended pouring temperature for a longer period of time than recommended by the manufacturer.

Most sealants used to seal cracks in asphalt concrete pavements are asphalt cement-based materials and overheating causes the light volatiles to “cook off” or evaporate. This causes the sealant to become brittle, resulting in premature failure of the sealant. Monitor the temperature of the sealant in the application equipment and discard any material that is overheated or heated for longer than four hours to eliminate this problem. Discard the sealant remaining in the equipment and thoroughly clean the equipment after each day’s work has been completed.

9-5.1.2 Preparation.

The main problem associated with crack preparation is the cleanliness of the crack. The crack sealant will not adequately bond to the pavement if there is oil, dust, debris, or loose aggregate remaining in the crack. Damaging the pavement during the routing process can also be a problem. Prevent jamming in the crack by following each crack and controlling the speed of the equipment. Dry the crack prior to placing sealant to prevent the moisture from vaporizing when the sealant is placed, which will result in loss of bond to the crack wall.

9-5.1.2.1 Dust and Debris.

Checking for dust and debris in the crack is a relatively simple procedure: rub a finger along the crack; if the finger gets dusty, the crack is dirty. Checking for moisture is more of a judgment decision. There is no test for checking the moisture of a crack except by observation or feeling with one’s hand. It is important that the crack is dry at the time of sealant application so the sealant will bond to the pavement.

9-5.1.2.2 Crack Preparation Methods.

An additional problem dealing with crack preparation is deciding which method to use. This is a problem because most cracks are not uniform in size and the surrounding pavement will have varying degrees of deterioration. Make adjustments as work progresses. The main consideration for crack preparation is that the crack be cleaned without damaging the surrounding pavement.

9-5.1.3 Application.

There are two major problems associated with crack sealant application. The first problem is brittleness of the sealant material due to overheating or prolonged heating. Brittleness is a materials problem because some sealant materials are more susceptible to overheating than others, but it is also an application problem because it can be corrected by implementing a good quality control program. Monitor the temperature of the sealant and discard any material that is overheated or heated for longer than four hours to eliminate this problem. Discard the sealant remaining in the equipment and clean the equipment thoroughly after each day’s work has been completed.

The second problem is overfilling the crack. The sealant can be tracked onto the pavement and abraded if the crack is overfilled. Reduce, if not eliminate, overfilling the crack by vigilant quality control measures and inspection. Remove excess sealant with a squeegee or similar object before the sealant cools. Fill from the bottom up to prevent entrapped air.

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CHAPTER 10 POROUS FRICTION SURFACES.

10-1 INTRODUCTION.

A porous friction surface (PFS) is an open-graded asphaltic concrete wearing surface containing a large amount of air voids that allow water to drain vertically and laterally through the pavement structure (Figure 10-1). These surfaces are usually 0.75 to 1 inch (19 to 25 millimeters) thick and the large void content provides a means to prevent hydroplaning at high speeds. The surface texture of the PFC provides excellent skid resistance and decreases tire spray under wet conditions. Several procedures to repair a PFS are presented in the following paragraphs.

Figure 10-1 View of a Porous Friction Surface (PFS)

10-2 SEALING CRACKS.

The guidelines for sealing cracks in a PFS are different from a normal asphalt surface. The materials used for sealing cracks on a PFS are the same as for a normal asphalt pavement. Use the following steps for sealing cracks on a PFS:

10-2.1 Prepare the Crack.

To prepare the crack, remove all loose material and ensure the crack is free of dust and dirt.

10-2.2 Seal the Crack.

Follow the same sealant placement procedures as for an asphalt surface (Chapter 9). Do not seal cracks 0.25 inch (6 millimeters) wide or less unless loose debris is causing a FOD problem. Seal cracks from 0.25 to 0.75 inch (6 to 19 millimeters) if they are raveling and causing a FOD problem. Fill cracks greater than 0.75 inch (19 millimeters) wide with a PFS asphalt mixture and rolled with a steel-wheel roller. Only seal longitudinal cracks when regular sweeping methods no longer remove all loose aggregate from the surface. The loose aggregate can block internal drainage. Seal transverse cracks except those perpendicular to the water flow. In any case, do not seal the joint if it will interfere with water drainage.

10-2.3 Patching PFS.

If correctly performed, a PFS patch is indistinguishable from the remainder of the surface. Patch PFS using the following steps:

10-2.3.1 Remove Defective PFS.

Do not saw PFS when patching. Only use a milling machine to remove any defective PFS. Mill the full depth and extent of PFS damage.

10-2.3.2 Clean and Tack Repair Area.

Remove the defective material and, if necessary, repair the underlying pavement. Thoroughly clean the repair area before placing the tack coat. Apply a light tack coat to the bottom of the repair area. Do not apply tack coat to the edges of the repair areas as this will clog or interfere with the flow of water through the PFS.

10-2.3.3 Place Patch Material.

Provide and use repair material that conforms to the existing PFS. Roll the repair material using the same method as the original construction after material is placed. A cold-mix asphalt can be used for a temporary repair.

10-2.4 Raveling Control.

Apply a very light spray of asphalt emulsion to help control raveling of the PFS until replacement of the area can be completed. If this procedure is performed, do not apply so much as to hinder drainage of the PFS.

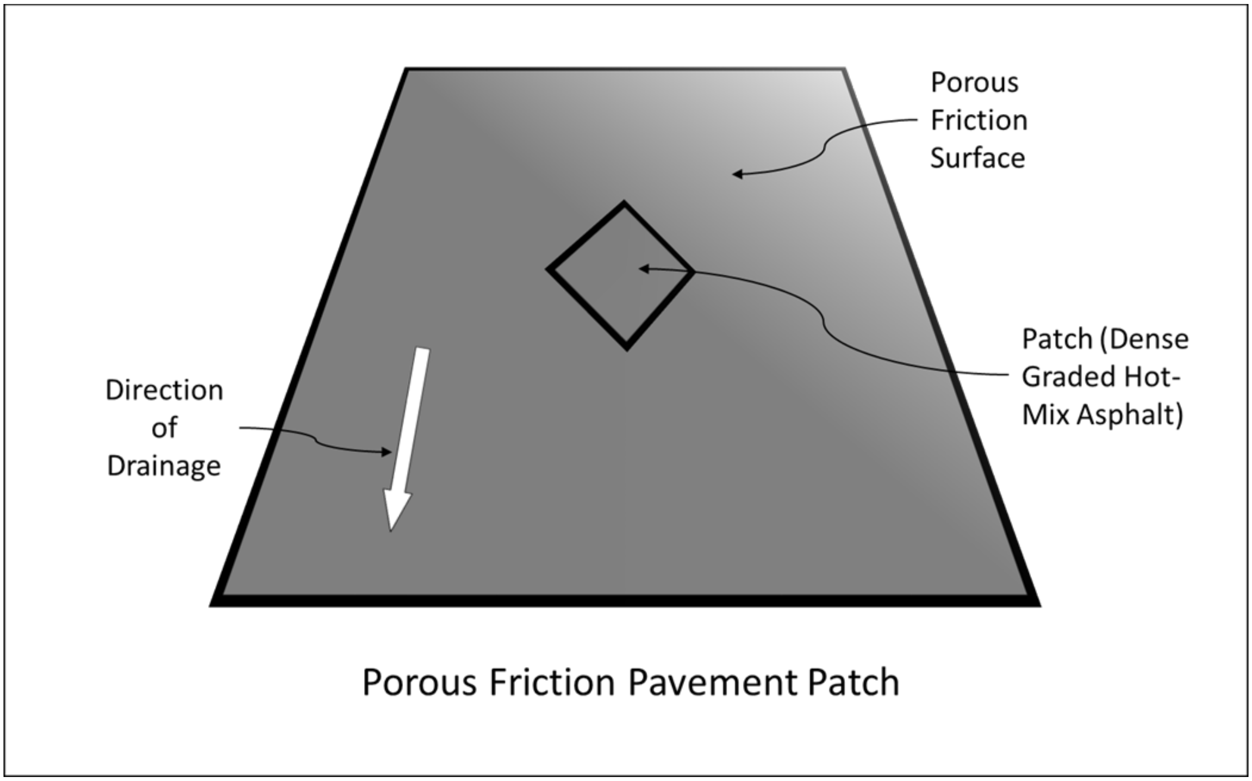
10-2.5 Patching Using Standard Hot Asphalt Plant Mix.

If a standard hot asphalt plant mix is used to repair a PFS, employ the following steps:

10-2.5.1 Mark the Repair Area.

Lay out and mark the boundaries of the repair for saw cutting. Shape the patch as a diamond with a point of the diamond at the highest elevation (Figure 10-2). This will allow water to flow around the patch area.

Figure 10.2. Porous Friction Pavement Using Hot-Asphalt Plant Mix



10-2.5.2 Remove Defective PFS.

Saw the area to the thickness of the porous friction surface. Remove defective material. Do not damage the edges of the patch.

10-2.5.3 Place Patch Material.

Apply tack coat to the sides and bottom of the patch area. Do not over-apply the tack coat. After the tack coat has cured, place and compact a well-graded hot asphalt plant mix.

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CHAPTER 11 DIAMOND-GRINDING ASPHALT CONCRETE PAVEMENTS

11-1 INTRODUCTION.

Diamond grinding, using closely spaced diamond saw blades mounted on a rotating shaft, removes a thin layer of the concrete surface to correct for faults at joints and crack locations and correct for surface defects, such as wheel path rutting. As such, diamond grinding results in re-profiling the pavement and improves the pavement's ride quality.

Diamond grinding removes bumps, re-profiles pavements, removes surface defects, and restores the pavement to a smooth surface. Because the hardness of the aggregate will influence the grinding operation, identify the type of aggregate in the asphalt pavement when the work is to be contracted. Limit grinding to small, localized areas. Do not grind more than 10 percent of the surface area without prior approval of the Pavements DWG or their designated representative.

11-2 NEED FOR GRINDING.

Consider diamond grinding when a pavement has bumps in excess of 0.125 inch (3 millimeters), roughness in excess of 0.125 inch (3 millimeters) in a 10-foot (3-meter) length, or rutting up to 0.375 inch (10 millimeters). If skid resistance is to be examined, examine skid resistance on the areas not scheduled for grinding for any of the previously mentioned defects. **[caution missing as in Ch. 17]**

11-3 GRINDING PROCESS.

The diamond-grinding process results in less impact than milling. The pavement grinder is similar to a wood plane. The front wheels are designed to pass over a fault or bump, the cutting head shaves it off, and the rear wheels ride in a smooth path left by the cutting head. Diamond grinding requires heavy, specially designed equipment (Figure 11-1) that uses diamond saw blades gang-mounted on a cutting head. Spacers are placed between the saw blades to reduce the amount of cutting to be done. This combination of saw blades and spacers gives the pavement the characteristic corduroy texture that improves skid resistance.

Figure 11-1 Diamond Grinding Equipment

11-4 TEST SECTION.

Before work begins, use the equipment in a test section to ensure that proper blade spacing is being used for the specific aggregate on the project. The width of the spacers between the saw blades varies depending on the hardness of the aggregates. The harder the aggregate, the thinner the spacing between the blades. When grinding aggregate susceptible to polishing, use a wider spacing.

11-5 GRINDING PROCEDURE.

When areas have been identified as being too rough, set a level of restoration and grind sections having excess roughness. Test the roughness again following the grinding. Test using a California profilograph (Figure 11-2), Mays Ride Meter, or 12-foot (3.7-meter] straightedge. Establish the grade prior to grinding. Do not use the old pavement surface as the reference unless a long beam or skid is used. Grinding a sag will not remove roughness.

Skid resistance can be improved by grinding. Only grind those lanes needing improved friction. Feather the edges of the ground areas into the adjoining pavement to eliminate a sharp drop-off. Grind the pavement in the longitudinal direction. Produce a uniform finished surface and provide positive lateral surface drainage. Continuously remove the slurry residue resulting from the grinding operation. Do not permit the grinding slurry to flow across adjacent lanes into gutters or flow into other drainage facilities.

Figure 11-2 California Profilograph

11-6 ACCEPTANCE TESTING.

Test the pavement for smoothness after completing the grinding and texturing. Accept only those pavement surfaces that meet the surface tolerance for a new pavement as required by the specifying agency. Use the same test equipment and procedure used in the initial evaluation for the acceptance testing. Do not reduce the nominal load-carrying capacity of the pavement through grinding without prior approval of the Pavements DWG or their designated representative.

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CHAPTER 12 CONCRETE PAVEMENT CRACK SEALING

12-1 INTRODUCTION.

Concrete pavement cracking is a result of tensile stress in the concrete slab exceeding the tensile strength of the concrete at the time of cracking. The cracking may develop soon after concrete placement or develop after some time. The cracking may be due to a number of factors such as marginal pavement design, poor construction practices, environmental conditions, and repeated traffic loading (fatigue related). The cracking may include the following types of cracks: transverse cracking, longitudinal cracking, corner cracking, or randomly oriented cracking.

Crack sealing, together with joint resealing, is the most commonly performed pavement maintenance activity. It reduces the amount of moisture that can infiltrate a pavement structure, thus reducing moisture-related distresses such as pumping, crack faulting, base and subbase erosion, and corner breaks at crack locations. It also prevents the intrusion of incompressible materials so compression-related distresses such as crack spalling, blowups, and slab shattering are minimized. The compression-related damage typically occurs at or along cracks oriented in the transverse direction; however, joint spalling can be of concern for cracks oriented in other directions.

Crack sealing is most effective when performed on concrete pavements that exhibit low-severity structural deterioration and when the cracks are full-depth but relatively narrow, with minimal spalling. Crack sealing may be used on cracks of low or medium severity where the crack width is 0.5 inch (13 millimeters) or less. If load transfer restoration (LTR) or partial-depth patching at the crack location is to be applied, seal cracks after these activities have been completed. If the cracks have deteriorated and exhibit a high degree of spalling, consider full-depth patching.

12-2 KEY STEPS.

The key steps in performing effective crack sealing include the following:

- Old sealant removal, if any
- Crack sawing/routing to specified depth and width
- Crack reservoir cleaning by sandblasting, water-blasting, and air-blasting
- Backer rod installation to control depth of sealant
- New sealant installation, typically hot-poured or cold-poured

12-3 GENERAL PRACTICE.

The general practice is to make only small sections of repair at a time to prevent the sawed or routed crack faces from being exposed to weather for more than 24 hours. If the cracks are wet, dry them with a high-pressure air compressor before placing the sealant and backer rod.

12-4 TEST SECTION.

Saw or route a test section of approximately 200 linear feet (60 meters) of cracks. Do not begin the full crack-sealing project until the contracting officer has approved a successful test section. Re-accomplish the test section until it meets requirements and is approved. Use the same procedures and materials in the full project that were used and approved in the approved test section. Demonstrate that crack sawing or routing does not cause spalling exceeding 0.25 inch (6 millimeters) in width or depth. Demonstrate cleaning of the crack faces before placement of any sealant. For two-component sealants, demonstrate and verify the mixing ratio is within a specified tolerance according to the manufacturer’s specifications for that particular sealant. If using hot-applied sealants, use calibrated thermometers to verify correct application temperatures. Demonstrate that all equipment is in good working condition.

Use sealant that conforms to UFGS 32 01 19, *Field Molded Sealants for Sealing Joints in Rigid Pavements,* or the applicable ASTM specifications and is approved for use at a particular facility by the base engineer.

12-5 CRACK SEALANTS.

Concrete crack repair sealants are essentially the same as joint sealants. Crack sealants mitigate two problem areas: moisture intrusion into the pavement base and debris retention in the crack opening. Crack sealants are either hot-applied thermoplastic materials or cold-applied thermosetting materials.

12-5.1 Hot-Applied Sealants.

Hot-applied thermoplastic sealant materials are bitumen-based materials that typically soften upon heating and harden upon cooling, usually without a change in chemical composition. These sealants vary in their elastic and thermal properties and are affected by weathering to some degree. Thermoplastic sealants are typically applied in a heated form and include the following:

- Rubberized asphalt: Self-leveling (most commonly used)
- Polymeric materials: Self-leveling
- Elastic materials: Jet fuel-resistant
- Elastomeric polyvinyl chloride (PVC) coal tar: Jet fuel-resistant

12-5.2 Cold-Applied Sealants.

Cold-applied thermosetting sealant materials are typically one- or two-component materials that either set by the release of solvents or cure through a chemical reaction. These sealants cost more than the commonly used rubberized asphalt sealants. Liquid oxygen (LOX) is a one-component cold-applied thermosetting compatible sealant. Thermosetting sealants include the following:

- Silicone (most widely used):
    - Non-sag, toolable, low modulus
    - Self-leveling, low modulus
    - Self-leveling, ultra-low modulus
- Polysulfide and polyurethane: Self-leveling, low modulus
- Two-component elastomeric polymer: Jet fuel-resistant
- W.R. Meadows Poly-Jet LOX

<u>Caution:</u> The performance of sealant material is sensitive to crack reservoir moisture and cleanliness. Do not use expensive sealant materials unless good sealant installation practices can be assured at the job site.

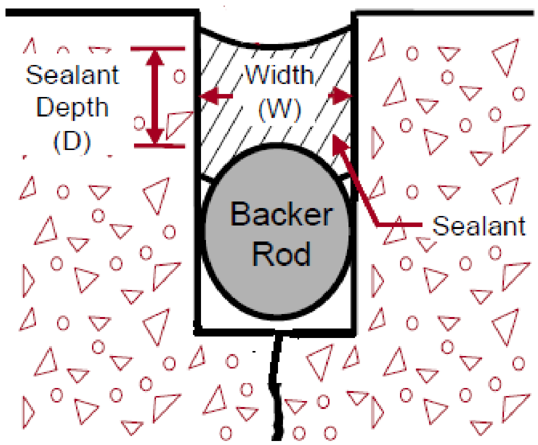
12-5.3 Fuel- and Blast-Resistant Sealants.

Additional considerations for crack repair material are jet fuel and jet blast resistance. The crack to be repaired may be located in an area where fuel or lubricating or hydraulic fluid spillage may occur or in an area subjected to high temperature from jet blast or exhaust from auxiliary power units (APU). Use repair materials that conform to UFGS 32 01 19 or ASTM specifications designated for joint and crack sealants for use in these areas.

12-6 SEALANT SHAPE FACTOR.

For crack sealing to be effective over the long term, route or saw the crack to the designated width and depth for the particular type of sealant employed in the crack repair. The dimensions of a typical crack reservoir (Figure 12-1) are defined by a shape factor, S, that is the ratio of the depth of the sealant (D) to its width (W). Shape factors generally range from 0.5 to 2.0, with 1.0 being most common; however, these dimensions may be specific to the type of sealant employed in the repair operation and a recommended value will be supplied by the sealant manufacturer. The depth of the sealant is controlled by use of a backer rod, as shown in Figure 12-1.

Figure 12-1 Crack Sealant Reservoir Shape Factor



Silicone sealants require a shape factor of approximately 0.5. For example, if the width (W) of the sawed crack is 0.5 inch (13 millimeters), saw the crack to a minimum depth of 1.25 inches (30 millimeters) to accommodate a backer rod of 0.625 inch (16 millimeters). The top of the backer rod will be 0.5 inch (13 millimeters) below the pavement surface. This allows for a depth (D) of 0.25 to 0.375 inch (6 to 9 millimeters) of silicone sealant on top of the crown of the backer rod to keep the sealant at 0.125 to 0.25 inch (3 to 6 millimeters) below the pavement surface.

12-7 BACKER ROD AND SEPARATING MATERIALS.

12-7.1 Backer Rod Materials.

The backer rod is placed in the sawed or routed crack to minimize excess stress on the sealant material from an improper shape factor and to prevent three-sided adhesion that would inhibit the ability of the sealant to expand and compress under thermal stress. Use a backer rod material that is chemically inert to prevent reaction with the sealant, flexible to conform to the shape of the crack path, non-absorptive to prevent water retention, non-shrinkable, and compressible to allow for easy installation.

Typical backer rod materials are polychloroprene, polystyrene, polyurethane, and polyethylene closed-cell forms. Do not use paper, rope, or cord. Use a backer rod material with a melting temperature that is at least 25 degrees F (14 degrees C) higher than the sealant application temperature to prevent damage during sealant placement.

Provide and use a backer rod with an uncompressed diameter at least 25 percent larger than the sealant reservoir width to ensure it remains in position during the sealing operation. Use a backer rod when repairing cracks by sealing.

12-7.2 Separating Materials.

A separating tape may be used when the sealant reservoir dimensions correspond to that for the proper shape factor for the sealant material to be used and the use of a backer rod would lead to an incorrect shape factor for that sealant material. The separating material is usually a thin adhesive tape or a flexible plastic strip employed to prevent three-sided adhesion of the sealant. Use materials that are flexible enough to deform with the sealant as the concrete expands and contracts. However, only use this repair method when the crack has been sawed to provide a reservoir of the proper depth and width.

12-8 CRACK PREPARATION.

12-8.1 Introduction.

One essential element of the crack-sealing operation is proper preparation of the crack and the crack face. If the prepared crack faces are dirty or wet, the sealant will not adhere to the concrete surface and eventually will separate from the crack wall. Schedule the crack-sealing operation such that the prepared cracks are sealed as soon as possible to prevent contamination of the crack faces before sealant application. If vegetation is growing in the cracks, remove it and use a hot lance or a water-based herbicide to kill the weeds within the cracks. Oil-based herbicides can leave a residue that may prevent adhesion of the sealant to the crack face.

Route or saw the cracks to the proper depth and width according to the shape factor previously discussed or designated by the manufacturer's recommendations for the particular sealant being used. The random orientation of most concrete pavement cracks makes it difficult to create a uniform sealant reservoir directly over the crack.

After completing the sawing or routing operation, clean the crack face to remove laitance, sawing debris, and other foreign material. Perform cleaning with a multiple-pass technique in which one side of the sawed crack face is cleaned, followed by the other face. Sand or water-blast the pavement surface directly adjacent to the sawed crack to remove any debris or material that may cause problems during crack sealing.

12-8.2 Cleaning.

The importance of proper cleaning of the crack faces cannot be over-emphasized. Surface dust, debris, and laitance remaining in the sawed crack can prevent adhesion of the crack sealant to the prepared crack face. Follow the initial cleaning operation with final cleaning using high-pressure air to remove material remaining in the sawed cracks. Do not use water blasting for final cleaning as it will require additional time to dry out the crack faces. Repeat this cleaning process immediately prior to placing the sealant in the sawed reservoir if the sealant is not placed within three hours of the cleaning. Use a vacuum sweeper, shop vacuum, power broom, or hand broom to remove sand and dust adjacent to the crack to prevent the sand and dust from reentering the crack.

12-9 CRACK SEALING PROCEDURES.

12-9.1 Introduction.

Only seal cracks when the air and the pavement temperatures are above 50 degrees F (10 degrees C) and rising. Constantly monitor application temperatures for hot-applied crack sealants to ensure they are in the correct range.

12-9.2 Process.

Ensure the crack faces are clean and free of moisture. If moisture is present, use compressed air to dry the crack face before sealing. Seal the crack using the following steps:

1. Fill the crack from the bottom up to prevent air from becoming trapped under the sealant and bubbling.
2. Fill the crack from beginning to end in one smooth operation whenever practical.
3. Fill the crack to a depth of 0.25 inch (6 millimeters) below the surface of the pavement
4. Do not open the sealed pavement to traffic until the sealant has adequately cooled or cured so as not to be picked up by vehicle tires.
5. Remove all excess sealant application or spills and any other debris from the sealant application work and properly dispose of it.
6. For hot-applied sealants, remove and discard sealant remaining in the pot at the end of a day’s work. Do not reheat and use the sealant unless the sealant supplier allows reheating and use.

12-9.3 Cautions.

Comply with the following precautions:

- For crack resealing, completely remove the old sealant.
- Do not start sealing cracks if rain is imminent or within 10 miles and moving toward the worksite.
- Do not begin, continue, or apply sealant if there is any sign of moisture on the surface adjacent to the crack or along the prepared crack faces.
- Follow the sealant manufacturer’s installation instructions.
- Avoid getting voids or bubbles in the applied sealant.
- Do not apply sealant that rises above a point that is 0.25 inch (6 millimeters) below the pavement surface or rises over the pavement surface as it will be picked up by traffic or it will be pushed above the

pavement surface during hot weather and make the sealing process ineffective.

- Provide and use equipment with all safety mechanisms and guards in place and functioning properly during the crack sawing or routing and cleaning operations. Do not permit operators to use equipment without the proper use of required personal protective gear.

12-10 TEMPORARY CRACK/JOINT SEALING PROCEDURES FOR PCC.

12-10.1 Introduction.

Short-term performance (less than two years) of pavement joint and crack repairs is acceptable in circumstances identified by the contracting officer or engineer in charge. Example: The pavement is scheduled to be abandoned in two years but is maintained due to FOD potential from spalling. This guidance provides standard procedures and details for temporarily sealing joints and cracks in rigid pavements.

12-10.2 Repair Procedures Neoprene Compression Seal (NCS) Joints.

12-10.2.1 Compression Seal Removal Procedures.

See Figures 12-2 and 12-3. Perform the following key steps when removing seals:

1. Remove compression seal.
2. Remove all loose and poorly bonded concrete from the joint and joint walls.
3. Sandblast joint walls and bottom.
4. Air blow reservoir to remove debris and dry joint.
5. Install separating tape along joint bottom.
6. Prime joint reservoir walls if recommended by sealant manufacturer's published installation procedures.
7. Fill reservoir to within 0.375 inch (9 millimeters), ± 0.125 inch (3 millimeters) of slab surface.

Figure 12-2 Existing Spalled NCS Joint

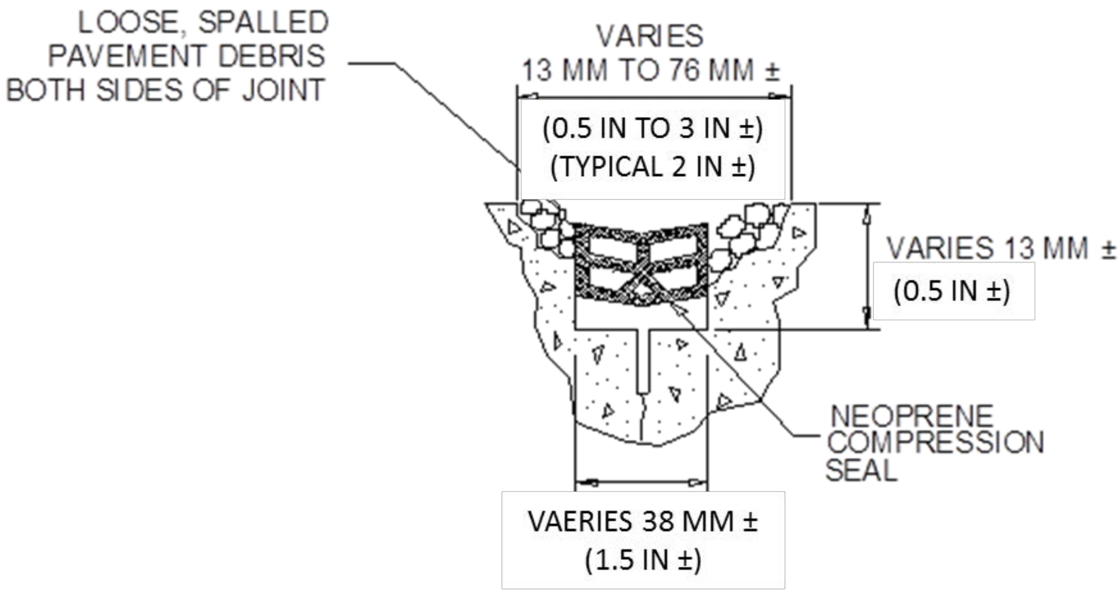
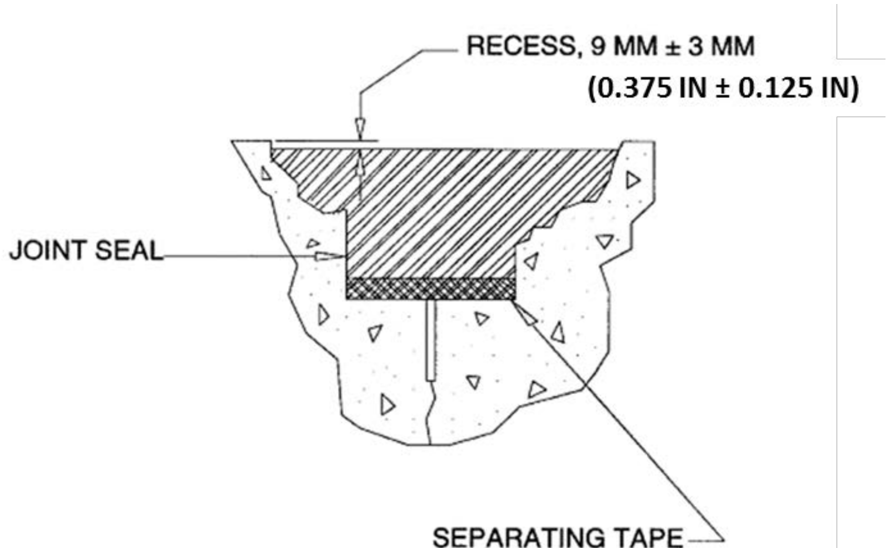


Figure 12-3 Repaired NCS Joint, Compression Seal Removed



12-10.2.2 Compression Seal in Place Procedures.

See Figures 12-4 and 12-5. The key steps in performing effective seal in place include the following:

1. Remove loose or delaminated concrete by hand, chisel, or other tool as required.
2. Air-blast to a clean condition.
3. Fill with sealant to top of existing compression seal.

Figure 12-4 Existing NCS Random Spall Area

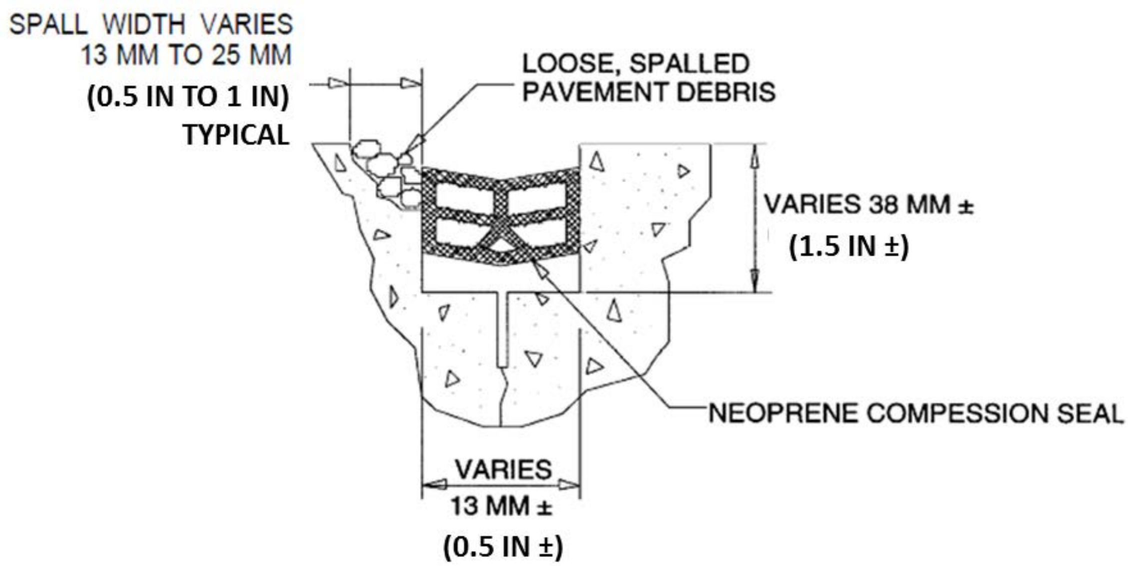
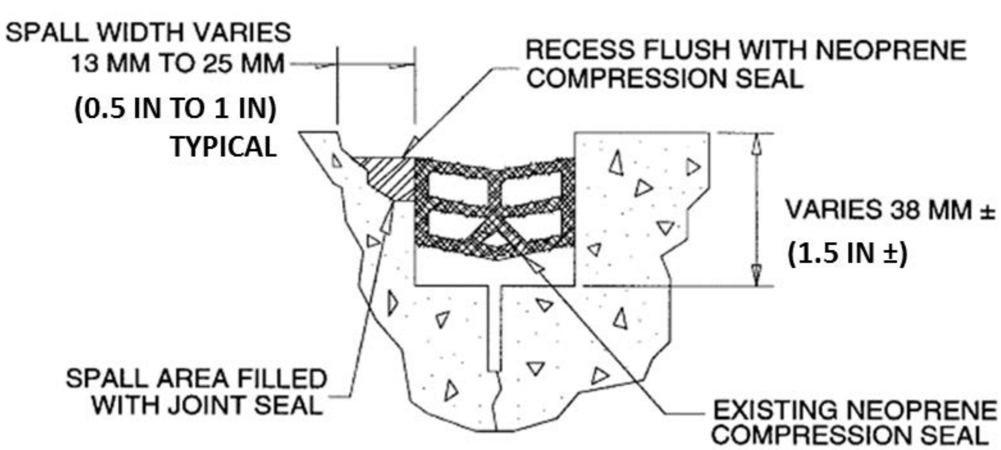


Figure 12-5 Repaired NCS Random Spall Area, Compression Seal in Place

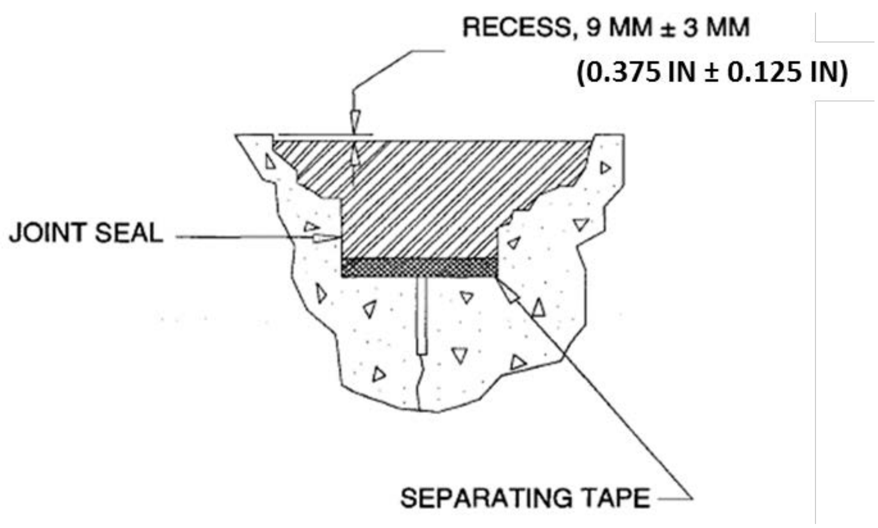


12-10.2.3 Section of Compression Seal Removed.

See Figures 12-6. The key steps in performing effective seal removal include the following:

1. Cut and remove neoprene compression seal.
2. Remove all loose, poorly bonded, and delaminated concrete from joint and joint walls.
3. Sandblast joint walls and bottom.
4. Air-blow reservoir to remove debris and dry joint.
5. Install separating tape along joint bottom.
6. Prime joint reservoir walls if recommended by sealant manufacturer's published installation procedures.
7. Fill reservoir to within 0.375 inch (9 millimeters), ± 0.125 inch (3 millimeters) of slab surface.

Figure 12-6 Repaired NCS Random Spall Area, Section of NCS Removed



12-10.3 Random Cracks.

See Figures 12-7 and 12-8. The key steps in performing effective random crack sealing include the following:

1. Rout crack with vertical spindle router or crack chasing saw. Width of cut: 0.5 inch (13 millimeters), minimum; depth of cut: 0.625 inch (17 millimeters), minimum. Use a vertical spindle router where crack chasing saw kerf (0.5-inch [13 millimeters] width) will not remain over cracks.

2. Flush crack seal reservoir with high-pressure water only if wet sawing of crack reservoir is used.
3. Remove all loose, poorly bonded, and delaminated concrete debris from crack seal reservoir (walls and bottom) by chipping with hammer or chisel.
4. Sandblast both walls and bottom of crack seal reservoir.
5. Air-blow reservoir to remove debris and dry joint.
6. Install separating tape in bottom of crack seal reservoir.
7. Prime joint reservoir walls if recommended by sealant manufacturer's published installation procedures.
8. Fill reservoir to within 0.125 to 0.25 inch (3 to 6 millimeters) of slab surface.

Figure 12-7 Existing Random Crack

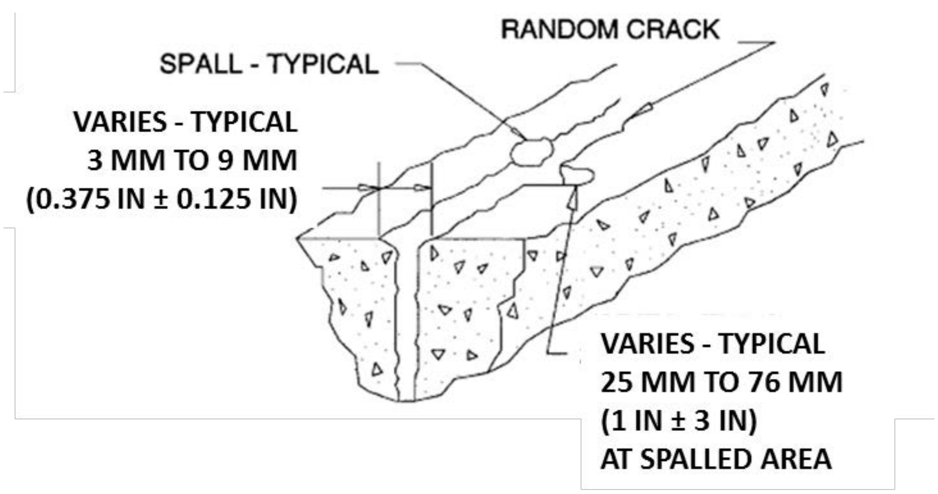
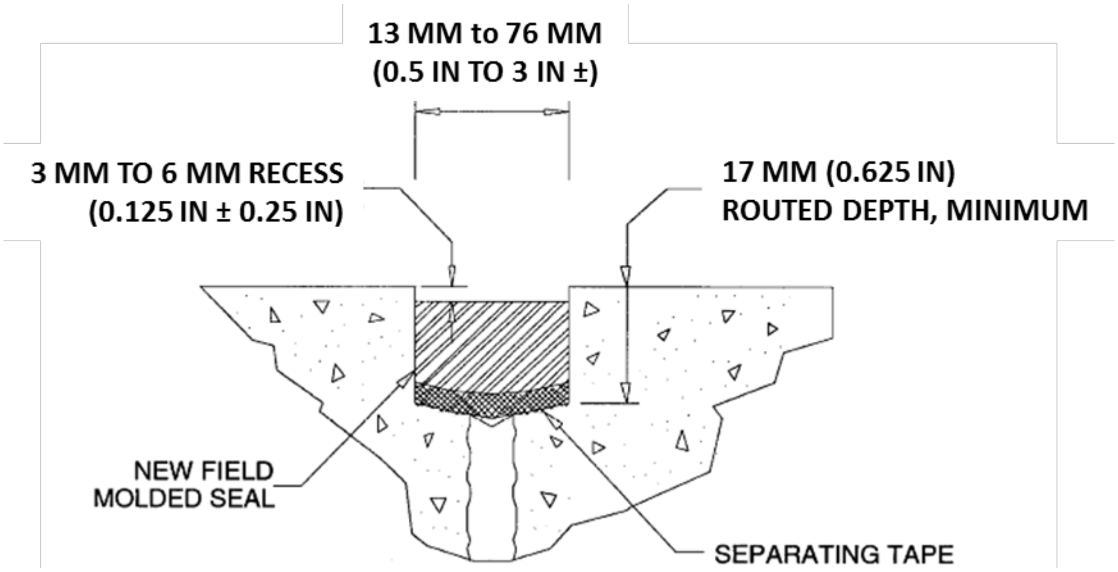


Figure 12-8 Repaired Random Crack



12-10.4 Field Molded Joints.

See Figures 12-9, 12-10, and 12-11. The key steps in performing effective field molded crack sealing include the following:

1. Remove existing seal by saw-cutting with gang of saw blades. Width of cut: one saw blade width greater than existing joint width (excluding spalls); depth of cut: 0.625 inch (17 millimeters), minimum. For joints with backer rod, remove to bottom of backer rod. Existing joint seal or expansion board below saw-cut may remain in bottom of joint. Where spalling has widened the joint reservoir, saw-cut width need not be expanded beyond width required for unspalled condition.

2. Flush joint seal reservoir with high-pressure water only if it was wet sawed.

3. Remove all loose, poorly bonded, and delaminated concrete debris from joint seal reservoir (walls and bottom) by chipping with a hammer or chisel.

4. Sandblast both walls and bottom of joint seal reservoir.

5. Air-blow reservoir to remove debris and dry joint.

6. Install separating tape or backer rod in bottom of joint seal reservoir. See details for proposed repair of joints.

7. Prime joint reservoir walls if recommended by sealant manufacturer's published installation procedures.

8. Fill reservoir to within 0.125 to 0.25 inch (3 to 6 millimeters) of slab surface.

Figure 12-9 Existing Spalled Field Molded Joint

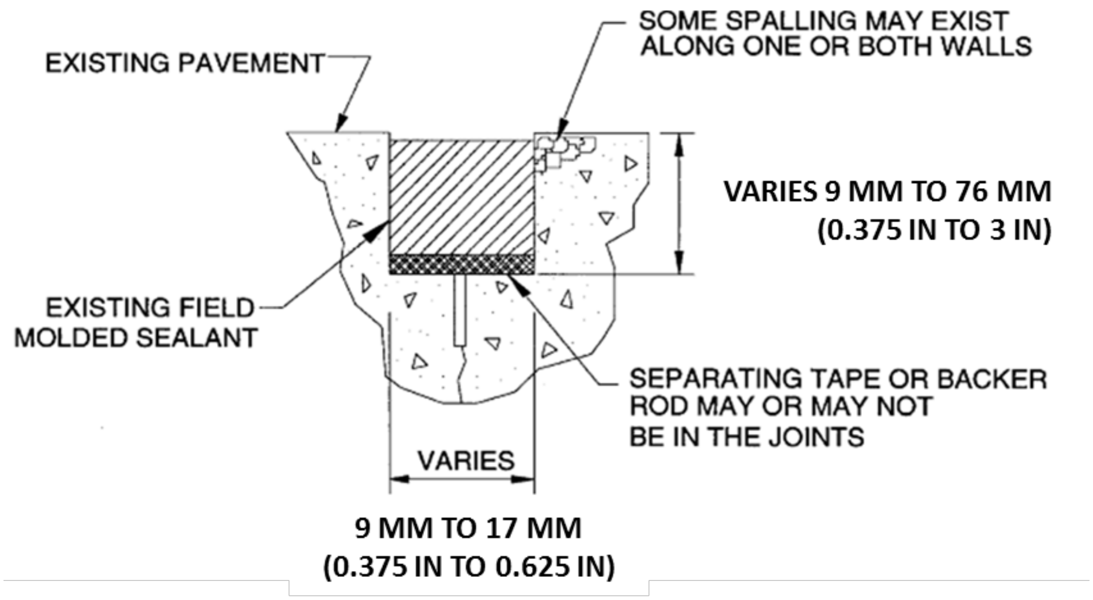


Figure 12-10 Resealed Field Molded Joint with Separating Tape

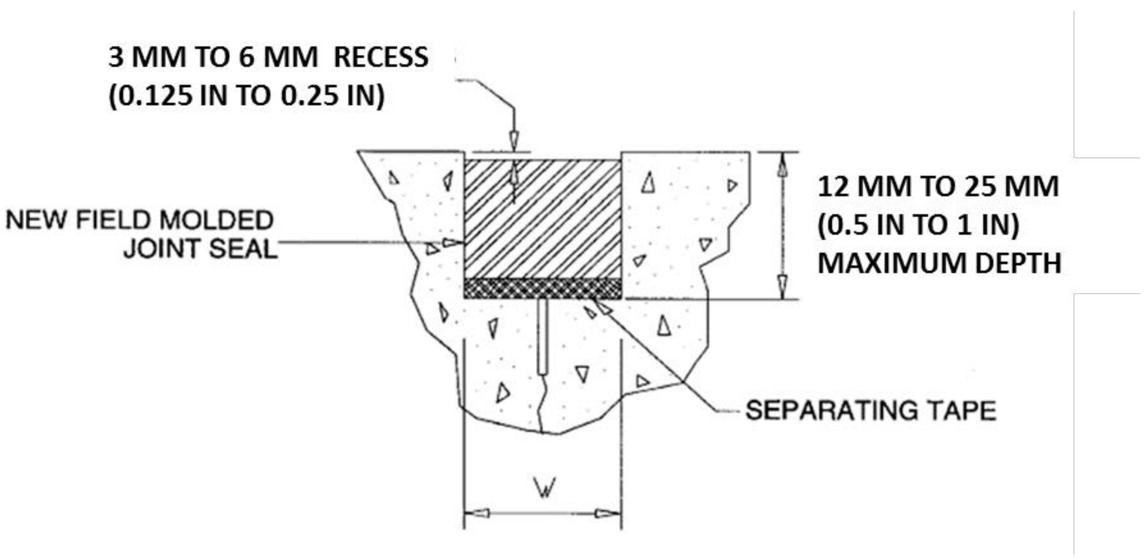
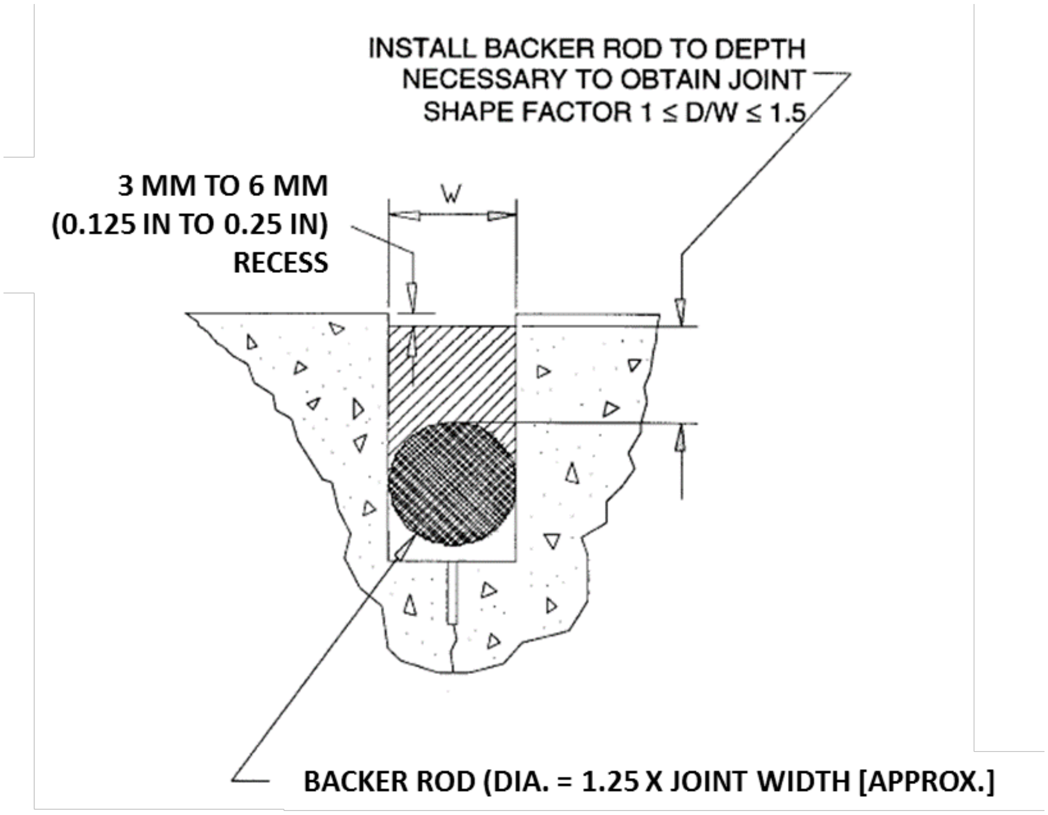


Figure 12-11 Resealed Field Molded Joint with Backer Rod



12-10.5 Partial-depth Joints.

See Figures 12-12 and 12-13. The key steps in performing effective partial-depth crack sealing include the following:

1. Make vertical saw-cut 2 inches (51 millimeters) deep, approximately 3 inches (76 millimeters) from distressed area. Overlap corner saw-cuts by 1 inch (25 millimeters), minimum.
2. Remove all concrete and loose material within the sawed area to sound concrete (3 inches [76 millimeters] minimum depth).
3. Use a separating medium to maintain and protect joints.
4. Use bonding agent to insure good contact between the pavement and patch as recommended by manufacturer's instructions.
5. Apply patch.
6. Apply curing compound to the patch surface if recommended by manufacturer's instructions.
7. After patch has cured, clean joint and apply joint sealant.

Figure 12-12 Existing Partial-depth Spalled Joint

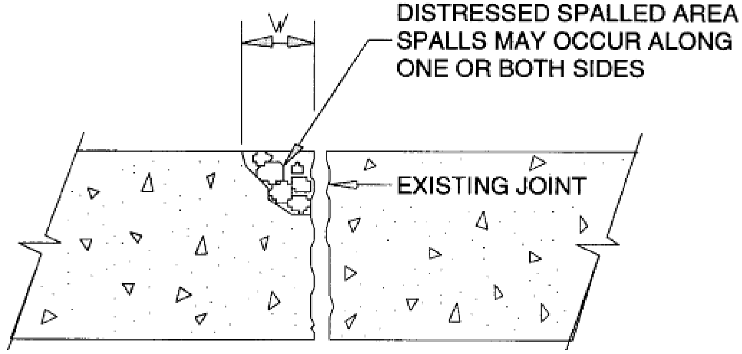
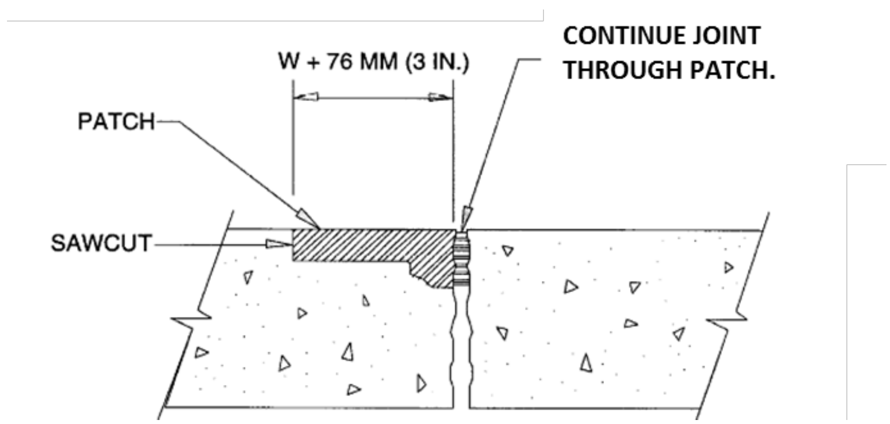


Figure 12-13 Repaired Partial-depth Joint with Backer Rod



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CHAPTER 13 PARTIAL-DEPTH REPAIR OF CONCRETE PAVEMENTS

13-1 INTRODUCTION.

The purpose of partial-depth repairs is to correct localized areas of concrete pavement distress. Repair of this type restores rideability, deters further deterioration, reduces FOD potential, and provides proper edges so joints can be effectively resealed. Spalling can be a significant distress for airfield pavements because spalling leads to loose material, which results in FOD. Timely spall repairs can extend the service life of the pavement. Partial-depth repairs of spalled joint areas also restore a well-defined uniform joint sealant reservoir prior to joint resealing.

Partial-depth repairs perform well when installed correctly; however, partial-depth repair can exhibit premature failures due to improper installation techniques.

13-2 NEED FOR PARTIAL-DEPTH REPAIR.

Partial-depth repair is typically used to repair spalling either at pavement joints and cracks (Figure 13-1) or at mid-slab locations. In this chapter, reference is made to joint spalling repair only; however, the discussion is also applicable to crack spalling repair. Spalling is typically a localized distress and therefore warrants a localized repair.

If several severe spalls are present along one joint, it may be more economical to place a full-depth repair along the entire joint than to repair individual spalls. Also, if the spall depth is greater than one-third of the slab thickness, use full-depth patching.

13-2.1 Joint Spalling.

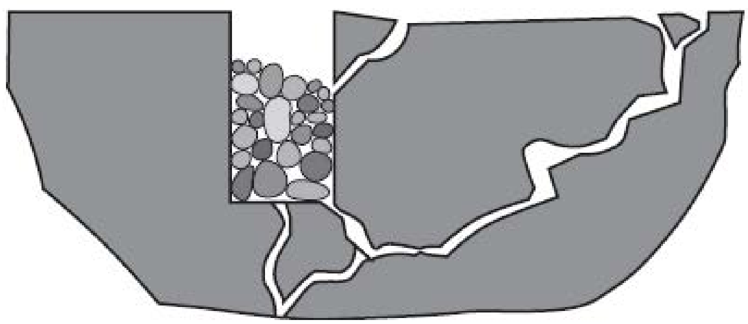
Spalling along a joint can occur when unsealed joints are filled with incompressible materials that prevent expansion of the slab in hot weather and result in breakage of the concrete (Figure 13-2). Other causes of spalling at joints include keyway failures (of oversized, poorly designed keyways), poor construction, poor repairs, dowel bar lockup, improperly located dowels, and dowels in reamed-out sockets. Minor spall at joints may also be caused by snowplows.

13-2.2 Mid-slab Spalling.

Spalling at mid-slab is generally caused by reinforcement that is too close to the surface and foreign matter or poor surface finish in the original PCC. Spalls create a rough ride and can accelerate deterioration.

Figure 13-1 Pavement Joint Spall

Figure 13-2 Incompressible Causing Spalling at a Joint or Crack



13-2.3 Partial-depth Repair Key Steps.

The key steps in performing a partial-depth spall repair include the following:

1. Selection of repair boundaries
2. Removal of existing unsound concrete
3. Cleaning the repair area
4. Joint preparation for joint spall repair
5. Selection of the patch (repair) material
6. Placement of the patch material
7. Finishing activities

8. Treatment of saw-cut runouts and patch/slab vertical interface
9. Patch curing
10. Joint resealing

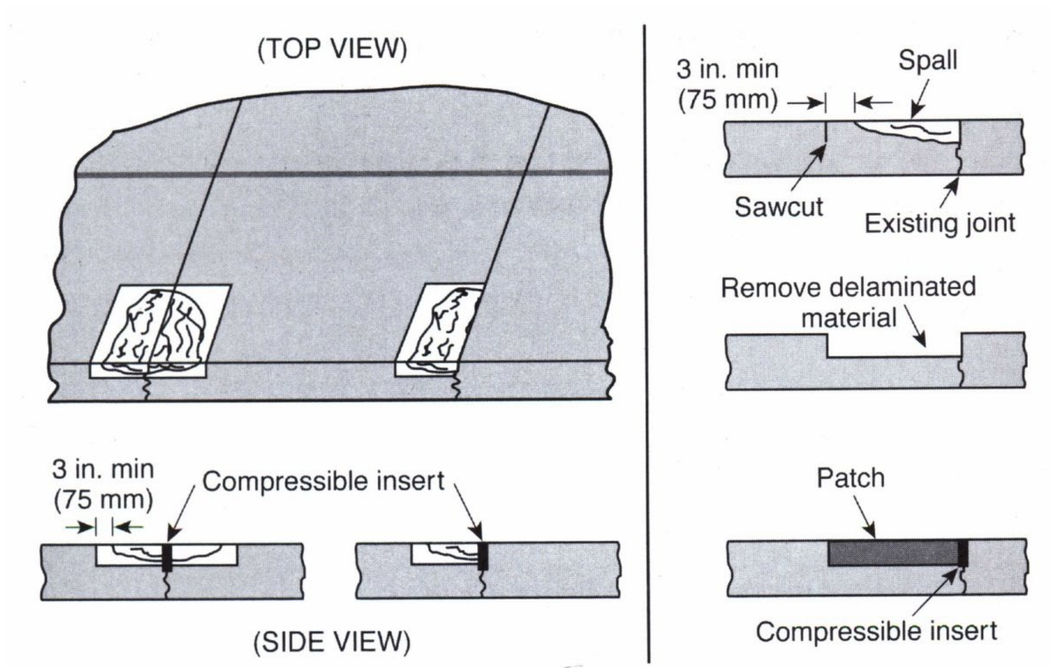
13-3 SELECTION OF REPAIR BOUNDARIES.

Prior to commencing work, survey the pavement to determine areas of unsound or delaminated concrete to establish the repair boundaries. During the survey, use a sounding technique to identify all areas of unsound concrete or delamination. Sounding the pavement to find delamination and spall removal areas is accomplished by striking the existing concrete surface with a steel rod or carpenter's hammer (Figure 13-3). Delaminated or unsound concrete will produce a dull or hollow thud, while sound concrete will produce a sharp metallic ring. Locate and remove all weak and deteriorated concrete to ensure the repair is effective.

Extend the repair boundaries beyond the detected delaminated or spalled area by 3 inches (75 millimeters) to assure removal of all unsound concrete (Figure 13-4). Keep the repair boundaries square or rectangular in line with the jointing pattern to avoid irregular shapes; irregular shapes may cause cracks to develop in the repair material. Consider combining repair areas along a joint if they are closer than 24 inches (600 millimeters) apart. This will help reduce costs and eliminate numerous small patches.

Figure 13-3 Sounding with a Hammer

Figure 13-4 Typical Spall Repair Boundaries



It is good practice to use rectangular-shaped repairs for all partial-depth spall repairs. The minimum length and width of the rectangular saw-cut boundary around a joint spall is 6 inches (150 millimeters). For corner spalls, do not make the rectangular saw-cut boundaries closer than 6 inches (150 millimeters) from the joint corner.

13-4 REMOVAL OF EXISTING CONCRETE.

13-4.1 Sawing and Chipping.

To remove concrete by sawing and chipping, make a minimum 2-inch (50-millimeter) -deep saw cut (in a rectangular pattern at least 3 inches [76 millimeters] outside all visible deterioration) around the perimeter of the repair area. This will provide a vertical face of sufficient depth to provide stability to the patch (Figure 13-4). Additional saw-cuts may be made within the repair area to speed chipping. A saw cut 2 inches (50 millimeters) away from joints might reduce the possibility of damaging the opposite joint face. A saw cut along the opposite joint face made by skimming the blade along the joint face will remove sealant residue and leave a clean vertical joint face. Remove concrete within the repair area to the bottom of the saw cuts or to 0.5 inch (13 millimeters) into visually sound and clean concrete, whichever is deeper, with light pneumatic tools (Figure 13-5). It is important that the proper tools are used. The recommended maximum size of the chipping hammer for partial-depth repairs is 30 pounds (13.6 kilograms).

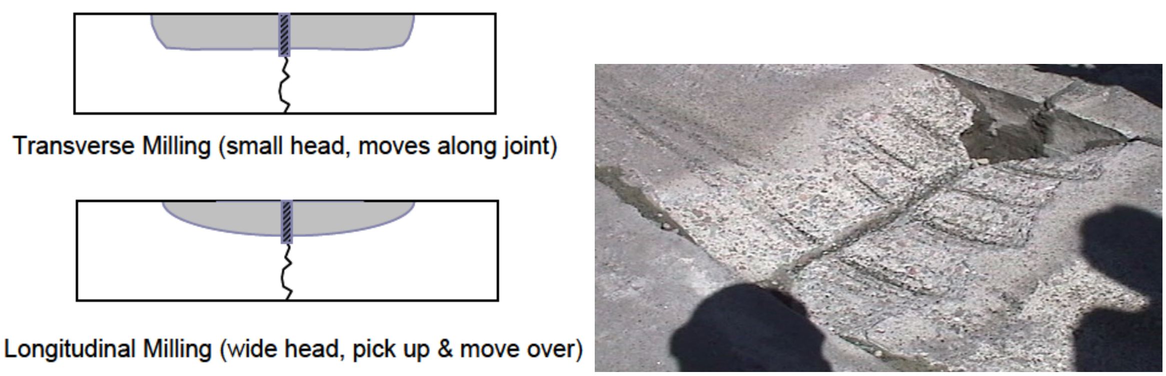
Figure 13-5 Repair Boundary Sawing and Use of Chipping Hammer

13-4.2 Milling Process.

Concrete within the repair area can also be removed by carbide-tipped cold milling equipment. Cold milling is especially effective where the repair area extends over the majority of the slab width (Figure 13-6) or along a long length of a longitudinal joint. Equip milling machines with a device for stopping at a preset depth to prevent excessive removal or damage to existing dowel bars or reinforcement.

After removal of the concrete in the repair area, survey by sounding the pavement again to ensure all unsound or delaminated concrete has been removed.

Figure 13-6 Milling Techniques



13-4.3 Partial Versus Full-depth Repair.

Occasionally, surface spalling will actually extend through the full slab depth or for more than one-third the slab depth. Do not attempt partial-depth repair at such locations. Mark the area and perform a full-depth repair. Make full-depth repairs if the concrete below one-third the slab depth is damaged during chipping or if dowel bars or reinforcing are encountered during removal.

Caution: Do not, under any circumstances, rest/place partial-depth repair material directly upon dowel bars or reinforcement. Typically, if a dowel bar is exposed within the repair area, it would indicate that the depth of repair is not acceptable. Completely expose steel reinforcement that is encountered in spall areas by removing at least 0.5 inch (13 millimeters) of concrete around the steel bars and the bars cleaned and covered with the patch material.

13-5 CLEANING.

Prior to patching, clean the exposed faces, bottom of the patch area, and any exposed steel to remove all loose particles, oil, dirt, dust, asphaltic concrete, rust, and other contaminants. As a minimum, air-blow with compressed air, wash with high-pressure water, and air-blow again (Figure 13-7). Check the prepared surface prior to placing the new patch material. Thoroughly clean the area with a power broom, vacuum sweeper, or hand broom to prevent debris from reentering the repair zone. Any contamination of the surface will reduce the bond between the patch material and the existing concrete.

Figure 13-7 Cleaning Repair Area (Sandblasting/Water Blasting, and Air Blowing)

13-6 JOINT PREPARATION.

When placing a partial-depth patch along a joint, do not allow the repair patch to bond to the joint face of the adjacent concrete and do not allow the repair material to penetrate into the joint. The most frequent cause of failure of partial-depth repairs at joints is excessive compressive stresses on the repair material abutting the adjacent concrete joint face. Partial-depth repairs placed directly against transverse joints will be crushed by the compressive forces created when the slabs expand and insufficient room is provided for the thermal expansion. Failure may also occur when the repair material is allowed to infiltrate the joint opening along the sides of the repair area and below the bottom of the repair, resisting slab movement and thereby preventing the joint from functioning.

13-6.1 Joint Bond-Breaking.

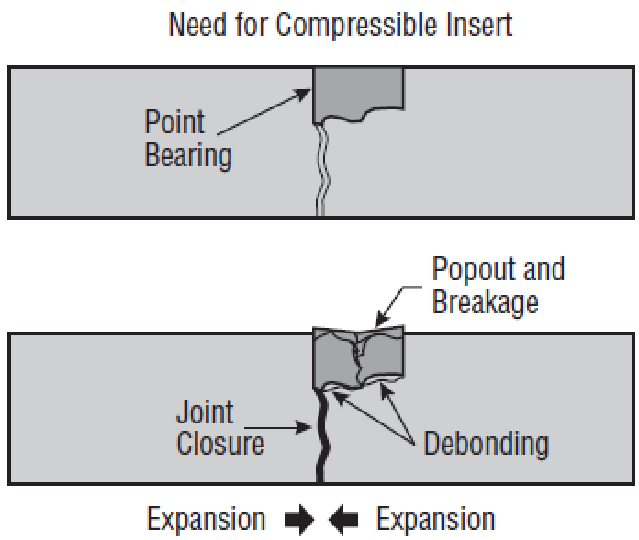
Elimination of bond between the patch and the adjacent concrete face can be accomplished by using a compressible insert. Styrofoam, asphalt-impregnated fiberboard (Figure 13-8), and plastic joint inserts are commonly used along the joint prior to placing the patch material. Patches that abut working joints or cracks that penetrate the full depth of the slab require a compressible insert or other bond-breaking medium to reform the joint or crack and prevent the repair material from flowing into the side and bottom of the joint areas undergoing repair. Use of an insert will form a uniform face against which the joint or crack can be properly sealed and will separate the patch from the adjacent slab.

Figure 13-8 Compressible Insert

13-6.2 New Joint/Crack Width.

Ensure the new joint or crack width adjacent to the repair is equal to or more than the width of the existing joint or crack. Failure to reform the joint or crack as described can result in point bearing stress at the repair area and failure by blowup, delamination, or new shear planes, sometimes in the adjacent slab (Figure 13-9).

Figure 13-9 Failure Due to Non-use of Compressible Insert



13-6.3 Shoulder Joints.

When placing a partial-depth patch along a shoulder joint, place a piece of joint material along the slab edge even with the surface to prevent the patch material from penetrating the open shoulder interface. A wooden form may also be used for this purpose. Otherwise, the material may restrict longitudinal movement of the slab in response to thermal changes and result in damage to the repair or the shoulder.

13-7 PLACEMENT OF PATCH MATERIALS.

The volume of material required for a partial-depth repair is usually less than 2 cubic feet (0.056 cubic meter); therefore, mix cement-based patching material onsite in a small mobile drum or paddle mixer. Transit mix trucks and other large equipment cannot efficiently produce such small quantities since maximum mixing times for a given temperature may be exceeded, decrease the quality, and result in waste of material. Slightly overfill the repair area to compensate for consolidation. Tamp the repair to consolidate the repair material. The patch material also may be consolidated by small spud vibrators to eliminate voids at the interface of the patch and the existing concrete. Vibrators greater than 1 inch (25 millimeters) in diameter are not recommended for this work. On very small repairs, hand tools are sufficient to work the repair and attain adequate consolidation.

When using premixed or proprietary materials, follow the vendor’s instructions related to patch material placement. If the patch material packaging is damaged, do not use the patch material.

13-8 FINISHING.

Finish the patch area flush to the cross-section of the existing pavement without leaving excess material on the adjacent pavement surface (Figure 13-10). The recommended finishing procedure is to screed from the center of the patch area to the patch boundaries. By moving the screed toward the patch boundaries, the material is pushed toward the vertical interface to increase the potential for high bond strength. After finishing, give the patch a burlap drag or broom finish to approximately match the surface finish of the existing adjacent concrete pavement unless a grinding operation is to follow.

Figure 13-10 Finished Patches

13-9 TREATMENT OF SAW-CUT RUNOUTS AND PATCH/SLAB INTERFACE.

Use the paste portion of the repair material to fill any saw-cut runouts that extend beyond the patch perimeter at patch corners. This will prevent any spalling at these locations.

If the repair material is properly placed in the patch area there will not be any need to place any sealer type material along the perimeter of the patch surface. However, if within a few days or few weeks, the patch material appears to be pulling away from the existing concrete, seal the patch/slab interface with a cement grout or an epoxy material. Use of a joint sealant for this purpose is not recommended.

13-10 CURING.

Proper curing of cement-based partial-depth repairs is very important due to the large surface of small patches compared to the volume of patch material, as well as the fact that concrete gains bond strength much slower than it gains compressive strength. Proper curing requires the application of curing compound at the time bleed water, if any, has evaporated from the surface of the patch. Because curing is critical for cement-based patches, for the first 24 hours wet-cure with burlap or a similar material and apply a curing compound after that period. In hot or dry climates, cure the patches for three days with a double mat of saturated burlap covered with polyethylene sheeting over which plywood or lumber is placed. Remove the covering and re-saturate the burlap as often as is necessary, but at a minimum of once a day, and the covering re-placed.

For premixed and proprietary repair materials, follow the manufacturer's directions regarding curing. Some rapid strength material may not require curing application and can be opened to traffic within four hours.

13-11 JOINT/CRACK RESEALING.

Resealing the repaired joint is extremely important because it will help prevent moisture and incompressible materials from entering the joint or crack and causing further damage. It is important that the new transverse and longitudinal joints constructed within the patch area be formed or sawed to provide the proper joint seal reservoir and match surrounding joints. Ensure the joint faces are clean and dry for good sealant performance.

CHAPTER 14 FULL-DEPTH REPAIR OF CONCRETE PAVEMENTS

14-1 INTRODUCTION.

When normal maintenance procedures can no longer correct the deteriorated concrete pavements, full-depth repair may become necessary to restore damaged areas to their original condition and extend the service life of the pavement. Full-depth repairs are generally necessary when slabs have been shattered (Figure 14-1) or have deteriorated to such an extent that the safe support of the required load is no longer possible. Full-depth repairs are an effective means of restoring the rideability and structural integrity of deteriorated concrete pavements and, therefore, extending their service life.

14-2 NEED FOR FULL-DEPTH REPAIR.

There are several types of distress that occur at or near transverse joints that may require full-depth repair when classified as medium- or high-severity level distress. Comprehensive distress manuals (ASTM D6433, *Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys,* and ASTM D5340, *Standard Test Method for Airport Pavement Condition Index Surveys*) are available that define distress types and severity levels.

14-2.1 Rigid Pavement Distress Types.

Types of distress that occur in rigid pavements that may justify full-depth repair when classified as medium- or high-severity distresses include:

- Blowup
- Corner break
- Durability (“D”) cracking
- Patch deterioration
- Shattered slab (a slab broken into four or five pieces with some or all cracks of high severity or a slab broken into six or more pieces with over 15 percent of the cracks of medium or high severity) (Figure 14-1)
- Spalling (if spalling extends to greater than one-third the slab thickness)
- Punchout
- Railroad crossing distress

Figure 14-1 Shattered Slabs

14-2.2 Other Rigid Pavement Concerns.

Concrete pavements may also exhibit spalling and faulting at intermediate cracks. This deterioration may be caused by repeated heavy traffic loads, failure of doweled joints to function properly, and/or the intrusion of incompressible materials in the open cracks. If the spalling extends to greater than one-third the slab thickness or if the faulting is in excess of 0.5 inch (12 millimeters), full-depth repair at the crack locations may be considered.

14-2.3 Full-Depth Repair Key Steps.

The key steps in performing a full-depth repair include the following:

1. Selection of repair boundaries
2. Sawing of repair boundaries
3. Removal of existing concrete
4. Restoring the repair area support (subgrade and base preparation)
5. Dowel bar and tie-bar placement
6. Replacing reinforcement, if any
7. Restoring expansion joints, if any
8. Use of filler material at joints
9. Dowel bar placement
10. Concrete placement
11. Concrete finishing and texturing
12. Curing

13. Joint sealing
14. Opening to traffic.

<u>Caution:</u> Successful performance of full-depth repairs requires proper restoration of the base and subgrade and provision of effective load transfer across trafficked joints, other than thickened edge slip joints. Also, full-depth repairs are not effective over the long-term if the existing pavement exhibits materials-related distress, such as D-cracking or ASR.

14-2.4 Selection of Repair Boundaries.

First, conduct a detailed survey to accurately identify the required repair areas so all significant underlying distresses are identified and corrected. Quite often, and particularly in freeze-thaw climates, the deterioration near joints and cracks is greater at the bottom of the slab than is apparent from the top of the slab.

In both plain jointed and reinforced jointed concrete pavement, partial-slab replacement is acceptable where the distresses are within one-half of the slab length. Full-width slab patching is required if the original slab width is less than 20 feet (6 meters) or full-depth cracks are located within the interior area of the slab. A minimum slab length is required to avoid rocking and pumping of the repair. General experience indicates that 10 feet (3 meters) is a minimum length for airfield applications. For roadways with 11- to 14-foot (3.4- to 4.3-meter) -wide lanes, the repair area needs to be full lane width with a minimum length of 6 feet (1.8 meters). If the repair extends over half the length of the panel, consider full panel replacement.

14-2.4.1 Saw Cut.

Saw cut will be a minimum of 3 feet (900 millimeters) from a joint and the minimum patch length will be 6 feet (1.8 meters). Saw cut in lines forming rectangles parallel with or perpendicular to the jointing pattern.

14-2.4.2 Patch Boundary.

Extend the patch boundary to the joint(s) if the length of the patch is greater than half the length of the panel.

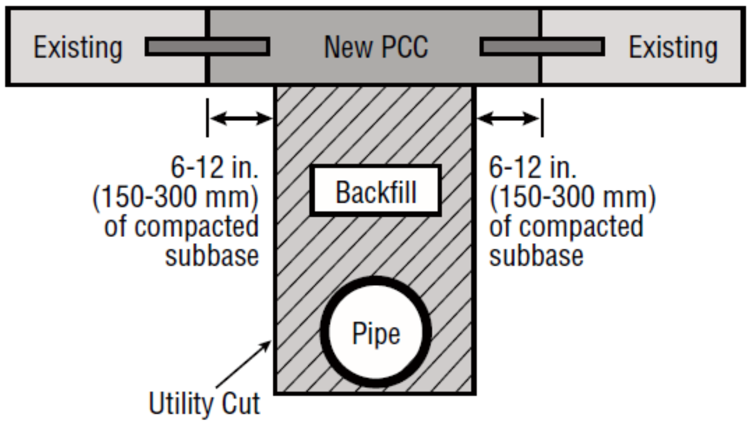
14-2.4.3 Utility Cut.

If the patch is a utility cut, make cut about 12 inches (300 millimeters) beyond limits of the excavation and any sloughing of the trench. This saw cut limit of the excavation area allows the repair concrete to extend beyond the excavation. (Figure 14-2)

14-2.4.4 Continuously Reinforced Concrete.

For continuously reinforced concrete, position the patch area so the distressed portion is in the middle of the patch area. Patch at least 6 feet (1.8 meters) in length if reinforcing steel is to be tied, and at least 4 feet (1.2 meters) long if welded or if mechanical splices are used to connect reinforcing steel.

Figure 14-2 Utility Cut



14-2.5 Sawing Cutting Repair Boundaries.

The repair boundaries of mesh-reinforced, plain doweled, and plain undoweled jointed concrete pavement are typically cut full-depth using diamond blade sawing (Figure 14-3). Sawing is the recommended method.

14-2.5.1 Hammer Use.

Do not use hammers to outline the area. The rough joint formed by hammers typically spalls in service and it is difficult to lift out the concrete within the repair boundaries or break it up with large pavement breakers.

14-2.5.2 Partial-Depth Cuts.

The use of the partial-depth saw cut is not recommended. The partial-depth saw cut does provide some aggregate interlock due to a rough face but micro-cracking will develop at the bottom of the repair area and the bottom of the slab may spall when using a large pavement breaker to shatter the concrete within the repair boundaries.

14-2.5.3 Full-Depth Cuts.

Full-depth saw cuts will completely separate the concrete that is to be removed, leaving undamaged vertical faces, and eliminate damage at the bottom of the remaining slab.

14-2.5.4 Warm Weather.

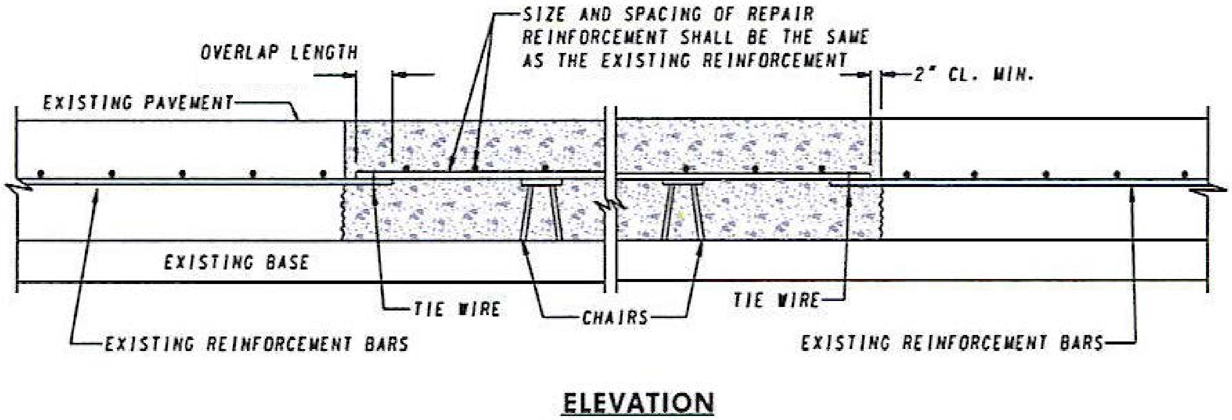
On warm days, a double saw cut method may be necessary to prevent binding of the sawing blade.

Figure 14-3 Diamond Blade Sawing

14-2.5.5 Continuously Reinforced Concrete (CRC).

The repair boundaries of CRC pavement are provided by sawing full depth at the repair boundaries. Partial-depth saw cuts above the reinforcing steel are then provided at a distance (typically about 20 inches [500 millimeters]) required by the lap length of the reinforcement) from the repair boundaries (Figure 14-4). Locate the partial-depth saw cuts at least 18 inches (450 millimeters) from the nearest tight crack and do not saw across an existing crack. If any of the reinforcing steel is cut during partial-sawing, extend the repair area by the required lap length of the reinforcement.

Figure 14-4 CRC Pavement Full-depth Repair Layout



14-2.5.6 Matching Joints.

Matching joints in adjacent lanes (typically for roadways) is not necessary as long as a debonding material (e.g., fiberboard) has been placed along the longitudinal joint to separate the lanes. However, if the distressed areas in both lanes are similar and both lanes are to be repaired at the same time, it is a good practice to align repair boundaries to avoid small offsets and maintain continuity.

14-2.6 Removal of Existing Concrete.

Do not use procedures for removal that spall or crack adjacent concrete or significantly disturb the base or subgrade. There are two basic methods to remove concrete pavement, as discussed below.

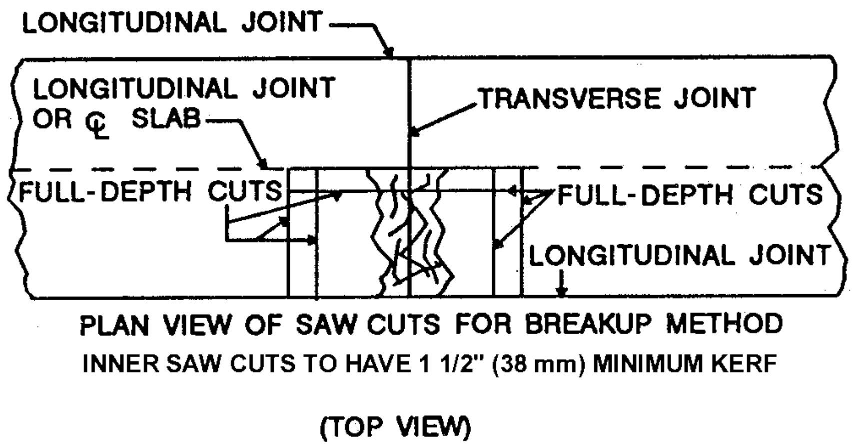
14-2.6.1 Breakup and Cleanout Method.

Concrete breakup is accomplished using a pavement breaker with removal by a backhoe (Figure 14-5). This method disturbs the base and requires base replacement or filling with concrete. It also has the potential to damage the adjacent slab if proper sawing procedures are not followed. This is not a preferred method for concrete removal.

After the repair is isolated by full-depth saw cuts, additional saw cuts using a wheel saw with at least 1.5-inch (38-millimeter) kerf, are made within the repair area, parallel and approximately 1.5 feet (450 millimeters) from each perimeter saw cut or joint (Figure 14-6). Begin breakup in the center of the removal area within the inner saw cuts. After breakup of the inner area, a backhoe can be used to gently pull the outer region free of the adjacent slab, or this strip can be broken up with light hand-held jackhammers.

Figure 14-5 Concrete Removal Using Backhoe

Figure 14-6 Additional Saw Cuts (Breakup Method)



14-2.6.2 Lift-out Method.

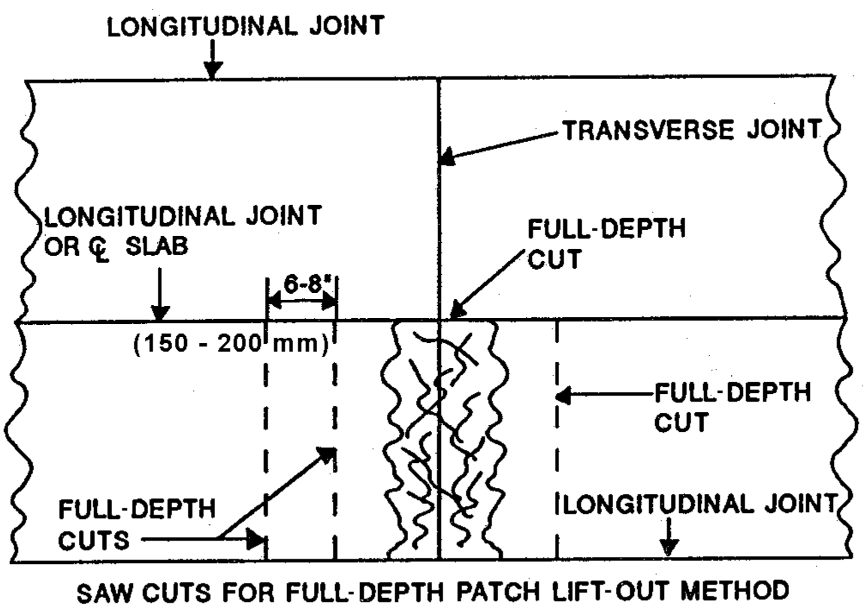
This is a recommended practice as it results in little damage to the base and the subgrade. This procedure is accomplished using a crane or front-end loader to lift the deteriorated concrete from its in-place position (Figure 14-7). Closely control lift-out operations to prevent accidents. After the repair area is isolated by full-depth saw cuts, holes are drilled through the slab and fitted with lift pins and the slab is then lifted in one or more pieces. If it is necessary to decrease the load, the slab may be saw cut into smaller pieces.

Figure 14-7 Lift-out Method

During hot weather, the sawing equipment may bind during initial transverse sawing procedures. It may be necessary to perform sawing at night when the temperatures are lower and the slabs are contracting. Another solution is to use a carbide-tipped wheel saw to provide a pressure relief cut within the patch area prior to the perimeter sawing (Figure 14-8). It is strongly recommended that the carbide-tipped wheel saw cut be made no closer than 6 to 8 inches (150 to 200 millimeters) from the proposed patch boundary due to the possibility of damage and micro-cracking in adjacent concrete. The same procedures may be used for the removal of CRC. Carefully remove concrete in the two reinforcing lap areas by jackhammering so as not to damage the reinforcing.

For CRC pavements, after the concrete between the two full-depth saw cuts is removed, remove the concrete between the full-depth saw cuts and the partial-depth saw cuts by jack-hammering to expose the steel reinforcement.

Figure 14-8 Pressure Relief Cuts for Lift-out Method



(TOP VIEW)

14-2.7 Subgrade and Base Preparation.

After the deteriorated and loose concrete has been removed, examine the base course. Remove all excess disturbed material. Compact the patch area using a plate compactor (Figure 14-9). If excessive moisture exists in the repair area, remove it or dry the repair area before re-grading and compacting the base. It is difficult to adequately compact granular material along the perimeter and the corner areas of the patch, which may result in settlement of the patch under future traffic loading. Replacing some or all disturbed base material with lean concrete or flowable fill is a very good alternative for critical operational areas.

Figure 14-9 Patch Area Compaction

14-2.8 Dowel and Tie-Bar Placement.

In full-depth repair of jointed concrete pavements, good load transfer across the transverse repair joints is a critical factor affecting the performance of the full-depth repairs. Load transfer is best achieved by properly installed dowel bars of sufficient size and number. For dowel bar size and spacing, follow the recommendations provided in Table 18-1.

Deformed tie-bars along longitudinal joints in new construction are used to restrict movement at these joints. These bars are typically #5 or #6 in size and spaced at about 30 inches (750 millimeters). For roadway full-depth repairs, tie-bars along interior joints (e.g., centerline joint) are necessary for repair lengths exceeding 40 feet (12 meters) to prevent drifting of the full-depth patch.

For full-depth repair of airfield pavements, incorporate dowel bars along longitudinal joints within the patch and dowel all edges to the existing pavement (longitudinal and transverse).

14-2.8.1 Smooth Dowel Bars.

Use of smooth dowel bars at the joints provide load transfer across these joints while allowing the joint to open and close as the surrounding pavement expands and contracts in response to temperature and moisture changes.

14-2.8.2 Deformed Dowel Bars.

In contrast to smooth dowel bars, deformed dowel bars are used along certain repair joints to provide both load transfer and prevent movement at the specific joints. Since in repair both smooth and deformed dowel bars have a load transfer role, select their dimensions and spacing based on the design loading for that facility.

14-2.9 Drilling Dowel and Tie-Bar Holes.

Installation of smooth or deformed dowel bars and deformed tie-bars requires drilling holes at specified locations into the exposed (saw cut) face of the existing slab. Gang drills are available to drill multiple holes simultaneously (Figure 14-10). The gang drill maintains the drills in a rigid frame to prevent the drill bits from wandering and holds them in a horizontal position at the correct height (typically, one-half the slab thickness). Make the depth of the holes approximately one-half the length of the dowel or tie-bar. Do not use hand-held drills to drill holes for dowel bars as the required dowel alignment cannot be easily achieved.

Figure 14-10 Drilling Multiple Holes at Mid-depth for Dowel Bars

Hole diameters exceeding the bar diameter by 0.125 inch (3 millimeters) or less are recommended when using epoxy materials. Clean the drilled holes using air blasting before injecting the epoxy grout into the hole. Take care during the drilling to ensure that spalling around the drilled hole at the joint face is kept to a minimum. Ensure spalling does not exceed the diameter of the retainer ring used to keep the epoxy from flowing out of the drilled hole. In case of such minor spalling, the epoxy is used to patch the spalls. For larger spalls around the drilled holes, the spalled area needs to be repaired before installing the dowel bars.

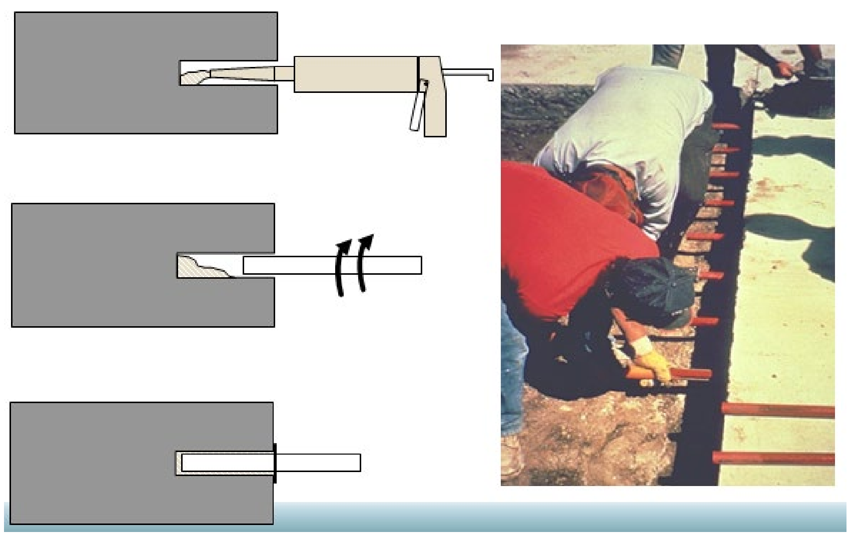
14-2.10 Dowel and Tie-Bar Installation.

Use dowels, tie-bars, or reinforcement that are clean and free of flaking rust. Specify appropriate sizes of dowels (at least matching the size of dowel bars used in the existing pavement) for different thicknesses of pavements (refer to UFC 3-260-02, *Pavement Design for Airfields,* for required sizes). Exercise care in epoxy grouting dowels or tie-bars to ensure complete coverage and support of the bars. Use grout retention devices that fit tightly over the dowel or tie-bar and seal the hole to prevent loss of epoxy. The steps for correctly installing dowel bars after air-blasting the holes are illustrated in Figure 14-11.

The proper installation of the smooth dowel bars is very important. Misaligned dowels can lead to early joint failure (spalling around the dowel bars) or cracking in the slab panel adjacent to the joint. The smooth dowels allow movement of the adjoining slabs. Oil or treat with a debonding material the portion of the bars that extend into the repair when using dowels to prevent bonding of the bars with the repair concrete. Cap one end of dowels used at expansion joints, in addition to oiling or treating with a debonding material, to permit further penetration of the dowels into the concrete when these joints close during warm weather.

Deformed tie-bars with surface ridges provide a locking anchorage with surrounding concrete. These tie-bars are placed in joints that are not intended to have movement.

Figure 14-11 Dowel Bar Installation



A. Injecting the epoxy into the back of the hole in sufficient amount to ensure full coverage around the inserted dowel bars

B. Inserting dowel bars into the hole with a slight twisting motion

C. Using a retainer ring to stop the epoxy from flowing out of the hole

14-2.11 Continuous Reinforced Concrete (CRC) Pavement Repair.

Successful performance of CRC pavements requires good load transfer across all transverse cracks and repair joints. Failure to provide adequate load transfer will cause the repair and the surrounding pavement to fail due to excessive deflection at the joints.

For conventional full-depth repair of CRC pavements, the longitudinal reinforcing is generally carried through the repairs by carefully removing the old concrete to allow the appropriate length of steel (lap length) from the existing pavement to extend into the repair area. This steel is then tied, welded, or mechanically connected to new reinforcing steel that extends through the repair area. When replacing reinforcing steel in the patch area, match the original rebar in size (diameter), grade, and number. Place the new bars on bar supports to ensure proper position and cover. Do not extend bars closer than 2 inches (51 millimeters) to the patch/slab interface.

14-2.11.1 Tied Splices.

Lap tied splices the proper length that provides full bar strength. The recommended lap length for tying longitudinal steel is a minimum of 25 times the diameter of the steel bars.

14-2.11.2 Welded Splices.

Use the proper length for the welding procedure chosen when using welded splices. Lap bars at the center of the repair area to avoid the potential buckling of bars on hot days.

14-2.11.3 Mechanical Splices.

Use mechanical splices in accordance with the supplier’s instructions.

14-2.12 Expansion Joints.

Expansion joints are placed in concrete pavements to provide relief for expansion of the concrete pavement due to temperature changes. Generally, expansion joints are installed at all intersections of pavements with structures or when a pavement ends near a structure but are rarely required within pavement features.

Expansion joints may be required if longer-length full-depth repairs are made during cool weather when adjacent concrete is in a contracted state or crushing and spalling of concrete at the joints may occur during subsequent hot weather when the concrete expands. Keep expansion joints in pavements to the minimum necessary to minimize future maintenance issues. The types of expansion joints commonly used by the military are the thickened-edge expansion joint (Figure 14-12) and the doweled type expansion joint (Figure 14-13).

Figure 14-12 Thickened-edge Expansion Joint

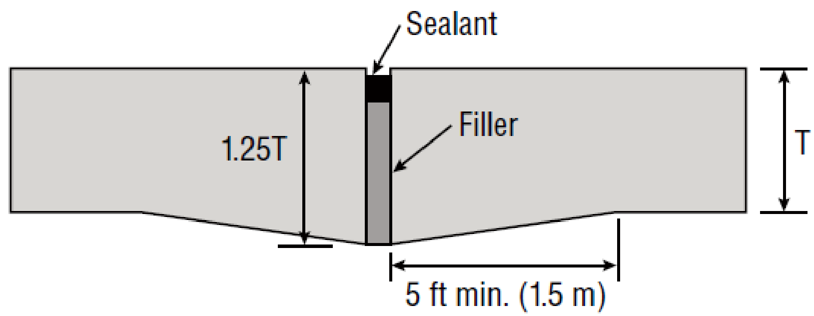
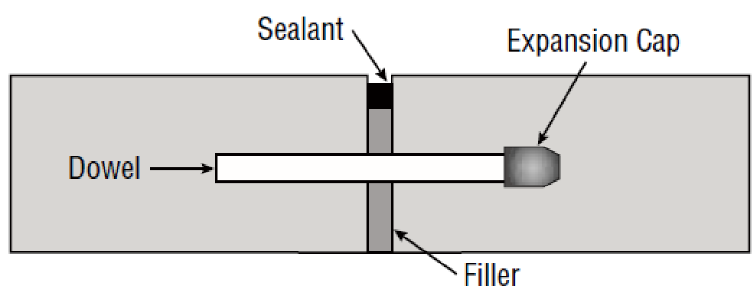


Figure 14-13 Doweled Expansion Joint



14-2.12.1 Thickened-edge Longitudinal Expansion Joint (Without Dowels).

The thickened-edge type is suggested for longitudinal expansion joints (slip joints) within airfield pavements. Dowels are not used in thickened edge longitudinal expansion joints because differential expansion and contraction parallel with the joints may develop undesirable localized stresses and possibly failure of the existing concrete or the full-depth patch, especially near the corners of existing slabs at transverse joints.

14-2.12.2 Thickened-edge Isolation Joint (Without Dowels).

The thickened-edge isolation joint (without dowels) is the expansion joint best suited to surround or separate any structure that projects through, into, or against the pavement (approaches to buildings, drainage inlets, roadway bridges, and hydrant refueling outlets).

14-2.12.3 Doweled Transverse Expansion Joints.

Use doweled transverse expansion joints within roadway pavements. However, at the angular intersection of pavements, it might be desirable to allow some slippage in the transverse joint to prevent the expansion of one pavement from distorting the other. In such instances, design the transverse expansion joint as a thickened-edge expansion joint.

14-2.13 Filler Material.

Use non-extruding type material for filler material for the thickened-edge and doweled-type expansion joint. The type and thickness of the filler material will depend upon the particular project. Usually, a preformed material of 0.75-inch (20-millimeter) thickness will be adequate, but in some instances a greater thickness may be required, depending on the geometric design of the facility and temperature at the time of full-depth repair. Use a heavy coating of bituminous material not less than 0.25 inch (6 millimeters) in thickness or a standard non-extruding type material not less than 0.25 inch (6 millimeters) in thickness for filler material for thickened-edge slip joints.

Filler material at expansion joints where dowels are used require that the dowels be securely placed and properly aligned. Drill or punch the non-extruding filler material to the exact diameter at the location of the dowels. Furnish it in lengths equal to the width of the placement. When more than one length of the filler board is used along a joint, hold the abutting ends of the filler in alignment. Hold the filler boards firmly in place and extend downward completely to the bottom of the slab and hold the top edge about 0.5 inch (13 millimeters) below the surface of the pavement. Protect the top edge of the filler material while the concrete is being placed. Use a zip strip to accomplish this, where available.

14-2.14 Concrete Placement.

Conventional concrete is typically used for full-depth repairs. The concrete mixture selection depends on the curing time available to reach required strength before the repair area is opened to traffic. If it is acceptable for the concrete to cure for several days (similar to new construction), regular concrete mixtures using Type I or Type II cement can be used. If an earlier opening time (12 hours to 3 days) is needed, a high early-strength concrete, incorporating a higher volume of Type I or Type II cement or using Type III cement, can be used. However, carefully consider the use of a higher volume of cement in areas subject to ASR in concrete. Follow standard concrete placement procedures, including concrete consolidation procedures.

Place the concrete when the ambient temperature is between 40 and 90 degrees F (4 and 32 degrees C).

14-2.14.1 Vibration Adjacent to Edge.

Give extra attention to ensure that the concrete is vibrated well around the edges and beneath the reinforcement.

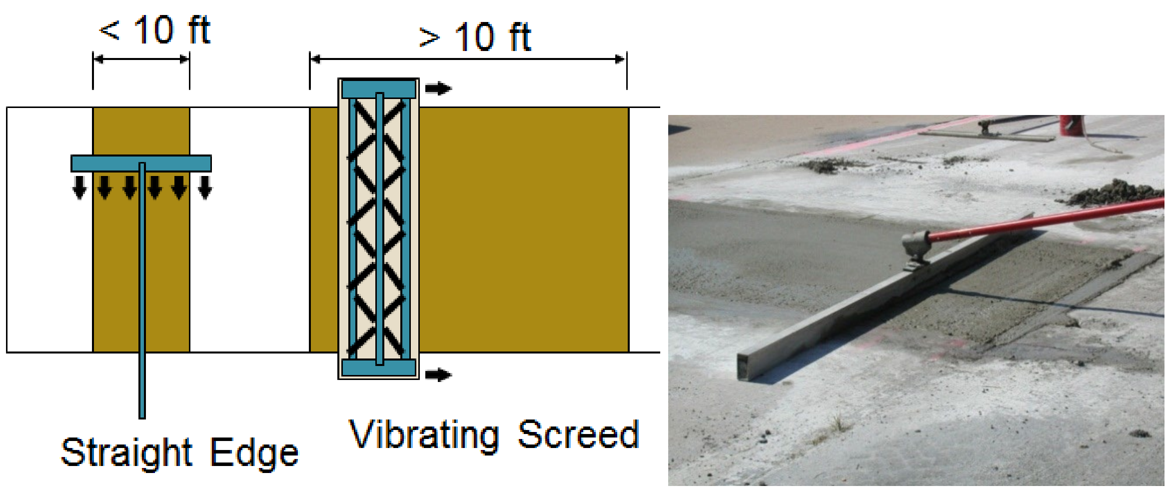
14-2.14.2 Rapid-set Proprietary Cementitious Materials.

Rapid-set proprietary cementitious materials that attain sufficient strength for opening to traffic in as little as four hours are available. Use rapid-set proprietary materials in compliance with the manufacturer’s recommendations. These recommendations typically include mixture proportioning, placing, consolidation, curing, time required before opening to traffic, and allowable placement temperature ranges.

14-2.15 Concrete Finishing and Texturing.

Follow standard procedures when finishing. For repairs less than 10 feet (3.048 meters) in length, strike off the surface of the concrete with the screed parallel to the centerline of the pavement. For repairs more than 10 feet (3 meters) in length, strike off the surface with the screed perpendicular to the centerline of the pavement. Give extra attention to ensure the concrete is not over-finished. Before the concrete becomes non-plastic, give the surface a burlap drag or broom finish to approximately match the surface finish of the existing adjacent concrete pavement unless a grinding operation is to follow the repair work. Typical finishing techniques are illustrated in Figure 14-14.

Figure 14-14 Typical Finishing Techniques for Full-depth Repairs



14-2.16 Curing.

There are many ways to cure concrete. Wet burlap (with or without sand) or white pigmented curing membranes are commonly used for full-depth repairs. Although ponding and constant spraying are the best curing methods, it is generally not practical to do so. Use of white pigmented curing membrane is better for indication of proper coverage and minimizes heating from solar radiation on warm, sunny days. Start curing as soon as the concrete has set sufficiently and the bleed water, if any, has evaporated, but typically no later than 45 minutes after concrete finishing. In hot weather conditions, curing may need to be initiated earlier to minimize the risk of plastic-shrinkage cracking. Proper concrete curing is crucial to achieving a good repair.

14-2.17 Joint Sealing.

Seal any longitudinal or transverse joints around the perimeter of the repair area and any intermediate joints within the repair area. This reduces the entry of water, which may cause pumping and faulting, and reduces the incidence and severity of spalling along the joints. Saw, do not form, the transverse and longitudinal joint sealant reservoirs at the repair area.

14-2.17.1 Inspection of Saw Cuts.

After joint sawing for sealing purposes, inspect the saw cuts for spalling. Repair spalls that extend more than 0.25 inch (6 millimeters) horizontally from the sidewall of the saw cuts. Patch void areas caused by honeycombing of the concrete to provide a solid joint sidewall for the sealant to bond.

14-2.17.2 Cleaning Joints.

Following the sawing operation, clean the joint by sandblasting to remove laitance, sawing dust, and other foreign debris from the joint sidewalls and from the pavement surface adjacent to the joint to a width of approximately 1 to 2 inches (25 to 50 millimeters). A multiple-pass technique has proven very successful in removing foreign debris. When using the multiple-pass technique, the nozzle is directed at one of the joint faces and that face is sandblasted the entire length of the slab. After one face has been completed, the nozzle is directed at the other joint face and it is sandblasted for the entire length of the slab. The pavement surface adjacent to the joint is then sandblasted to remove all surface debris. If water-blasting is used instead of sandblasting, employ a multiple-pass technique and dry the joints before starting the sealing operation. Cleaning the joint is one of the most important steps in obtaining high-quality sealed joints. If the joints are not clean and dry before the sealant is installed, the sealant will usually prematurely fail.

After the joint has been cleaned by sandblasting, clean it again with compressed air to remove any remaining sand or dust. However, complete the final air cleaning of the joint immediately before sealing to prevent sand and dust from blowing back into the joint. A vacuum sweeper can be used to clean around the joints, which will help reduce the amount of debris that blows back into the joints.

14-2.17.3 Installing Backer Rod.

After the joint is cleaned, install the backer rod or separating material. Do not leave the backer materials in the joint for an extended period of time before sealing. These materials may work loose and move up or down in the joint or may even come completely out. Do not twist, stretch, or otherwise damage these materials when they are installed in the joint. Damaging the backer material can cause sealant failure or a poor-quality finished product. Inspect the backer rod or separating material after installation to ensure it has been placed at the proper depth and has not been damaged. After installation of the backer or separating material, the joint is ready for the sealant material. However, seal the joint only if all steps have been properly performed.

14-2.17.4 Sealant Specifications.

Special considerations for the sealant material are jet fuel and jet blast resistance. The full-depth repair may be located in an area where fuel or lubricating or hydraulic fluid spillage may occur or in an area subjected to high temperature from jet blast or exhaust from APUs. Provide and use sealant material that conforms to UFGS 32 01 19 or to ASTM specifications designated for joint and crack sealants for use in these areas.

14-3 PRECAUTIONS.

Comply with the following precautions when performing full-depth repairs:

- Avoid undercutting spalled areas at bottom of remaining existing slab; saw back into adjacent slab until sound concrete is encountered.
- Avoid damaging remaining concrete when lifting out damaged concrete pieces.
- Keep repair areas dry before concrete application.
- Ensure dowel bars are properly aligned.

Although not a common practice for roadway full-depth repairs, consider reinforcement (about 0.2 percent of the cross-sectional area) along the long direction of the full-depth patch at the mid-width location for airfield applications. The reinforcement will keep any crack that may develop tight.

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CHAPTER 15 CONCRETE PAVEMENT SLAB JACKING

15-1 INTRODUCTION.

The purpose of slab jacking is to raise one or several adjacent slabs in place permanently as a result of settlement of the support under the pavement. Concrete pavement settlements sometimes occur in areas of poor foundation support. Such settlements not only provide riding discomfort, they also can create large stresses in the slab that can lead to cracking and shattered slabs.

<u>Caution:</u> **Slab jacking involves injection of a grout or polyurethane foam under the settled slab and raising the slabs slowly under pressure to the desired elevation. Use only experienced contractors to perform the slab jacking work due to the complexity and specialized equipment required for the work. The risk of over-stressing the slab being raised is high if the work is not performed with care. Slab jacking is not recommended for repairing faulted joints. Correct faulted joints using a combination of subsealing and diamond grinding of the faulting. Subsealing is also called slab sealing, slabsealing, slab subsealing, slab stabilization, undersealing, and pavement grouting.**

15-2 NEED FOR SLAB JACKING.

Consider slab jacking for any condition that has resulted in slab settlement, such as embankment settlement, settlement of approach slabs, settlement over culverts or utility cuts, voids under the pavements, differences in elevation of adjacent pavements, and pavement slabs that rock under traffic.

The effectiveness of slab jacking is highly dependent on closely monitoring the amount of lift being performed at any one location. It is very important that the slab not be lifted more than 0.25 inch (6 millimeters) at a time to prevent the development of excessive stresses in the slab. Care is required to get the slab to initially move as the grout applied under pressure can cause the slab to move unexpectedly and more than intended. Where careful monitoring during the uplift has been conducted, slab jacking has been effective at leveling out isolated depressed areas

15-3 SLAB JACKING GROUT MATERIALS.

A variety of grout materials have been successfully used for slab jacking and subsealing (Chapter 16). These materials include the following:

15-3.1 Cement-Fly Ash Grout.

The grout typically consists of one-part portland cement (typically Type I or Type II cement) three parts Class F or Class C fly ash, three to seven parts fine aggregates, water in sufficient amount to produce the desired consistency, and wetting agents or other additives may also be used to increase the flowability. The use of a wetting agent lubricates the grout, permitting runs of up to 6 feet (1.8 meters). It also tends to reduce "pyramiding." (A stiff grout may form a pyramid under the slab, leaving unfilled cavities.)

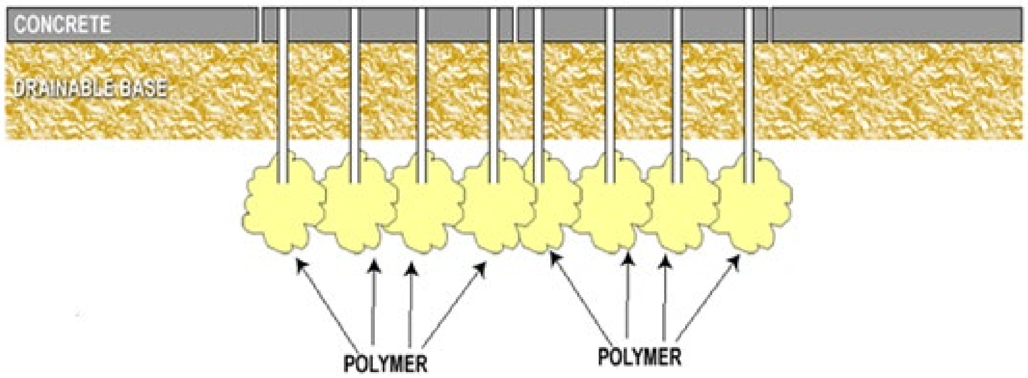
Use a repeated and consistent method of proportioning the grout mixture to ensure uniform consistency. The proper consistency to be used for any given condition is best determined by experience. Generally, a mix of stiff consistency is used to raise the pavement slabs. Check the consistency by a flow cone (CRD-C-611, *Test Method for Flow of Grout Mixtures (Flow-Cone Method)*, ASTM C939, *Standard Test Method for Flow of Grout for Preplaced-Aggregate Concrete (Flow Cone Method)*) at least twice each day. Typical flow-cone times vary between 16 to 30 seconds, depending on the type of materials used in the grout mix. Specify strength requirements of the grout mixture consistent with the location of the grout and the design loads on the pavement. A common requirement is 600 psi (4,134 kilopascals) at seven days as determined by ASTM C39, *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*. The grout mixing equipment is shown in Figure 15-1.

Figure 15-1 Grout Mixing Equipment

15-3.2 High-density Polyurethane Polymer Deep Injection.

High-density polyurethane polymer materials are made of two specially formulated liquid chemicals that combine to form a strong, light-weight, foam-like substance. After being injected beneath the pavement into the soil mass, the low-viscosity polymer flows into the voids and weak zones in the soil mass. As the polymeric reaction occurs, the expanding polymer compacts the surrounding soils (Figure 15-2). As more polymer material is injected, the compacted soil mass lifts upwards and raises the profile of the settled slab. The polymer injection process is controlled to ensure the desired uplift of the slab. Because of the complexity of the operation, only use a qualified contractor to perform this process. When using this process, store, proportion, and blend all material within a self-contained pumping unit. Handle and use these materials in accordance with the material manufacturer's instructions and specifications.

Figure 15-2 The Polymer Deep Injection Process



In this chapter, only the generic process using the cement-fly ash grout is presented. Information on the polymer injection process is not presented here because of the proprietary nature of the process. Information can be obtained from contractors on a project-by-project basis.

15-4 INJECTION HOLE LOCATIONS.

Identify the location of injection holes in the field. The slab jacking crew superintendent normally locates the holes, taking into consideration the size or length of the pavement area to be raised, the elevation differences, subgrade and drainage conditions, location of joints or cracks, and the manner in which the slabs will be tilted or raised.

As a general rule, do not place holes less than 12 inches (300 millimeters) or more than 18 inches (450 millimeters) from a transverse joint or slab edge. Do not place the holes more than 6 feet (1.8 meters) center to center so that not more than approximately 25 to 30 square feet (2.33 to 2.79 square meters) of slab is raised by pumping any one hole. Additional holes may be required if the slab is cracked. Where the pavement has settled and the slabs are in contact with the subbase, a single hole located in the middle of the panel may be sufficient.

15-5 DRILLING INJECTION HOLES.

Holes that are 1.25 to 2 inches (32 to 50 millimeters) in diameter are drilled by pneumatic drills, core drills, or other devices capable of drilling grout injection holes through the concrete pavement and base material. Provide and use equipment that is in good condition and operated in such a manner that the holes are vertical and round. Do not exceed 200 psi (1,379 kilopascals) of down-feed pressure. Where the concrete pavement is tight against the base material, the use of an airline or blow pipe may be necessary to form a cavity under the pavement slab for the grout pressure to take effect.

Where the pavement is placed and bonded to a cement-treated or other stabilized base material, drill grout holes completely through the base material. Inject the grout below the base material rather than between the pavement and base material. Do not leave grout holes ungrouted overnight and grout holes within four hours.

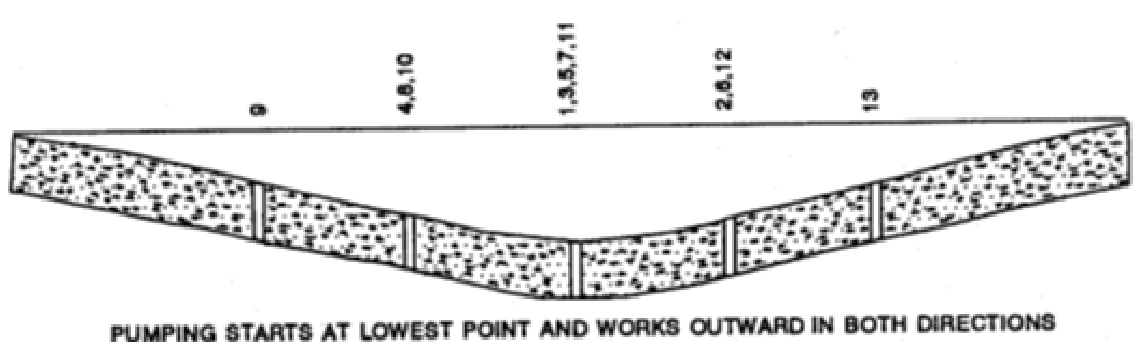
15-6 GROUT PUMPING.

Start pumping and jacking operations at the lowest point in a depressed area and work outward in both directions (Figure 15-3). Pumping progresses by lowering into successive holes an injection pipe connected to the discharge hose of the grout pump. An expanding rubber packer is used to seal the open space between the pipe and the drill hole. Do not extend the injection pipe below the bottom of the pavement. Provide and use an injection pipe equipped with a return line to circulate the grout while no grout is being placed. Lift in increments of about 0.25 inch (6 millimeters), with frequent changes in injection locations to minimize slab stresses and avoid cracking.

Use a rate of grout injection that is uniform and as slow as possible, usually a minimum of 0.5 cubic foot (0.014 cubic meter) per minute to a maximum of 2 cubic feet (0.056 cubic meter) per minute. Initial pumping is normally at the lower rate and is increased as lifting progresses. As the desired elevation is approached, reduce the lifting rate. When grout is extruded from joints, cracks, or from the pavement edge before the target elevation is reached, regrouting in new drill holes and additional slab jacking will be necessary. Applied pressures for slab jacking are normally in the range of 75 to 200 psi (517 to 1,379 kilopascals), with short pressure surges up to 600 psi (4,134 kilopascals) to initiate lifting of bonded slabs.

Constant observation and monitoring of the applied pressure is the most important single factor affecting the successful application of slab jacking. A rapid increase in the applied pressure can signal a stoppage of flow that could be followed by excessive lifting of the slab and slab cracking if pumping continues. A sudden reduction of pressure could indicate a loss of lift due to subsurface leakage of the grout.

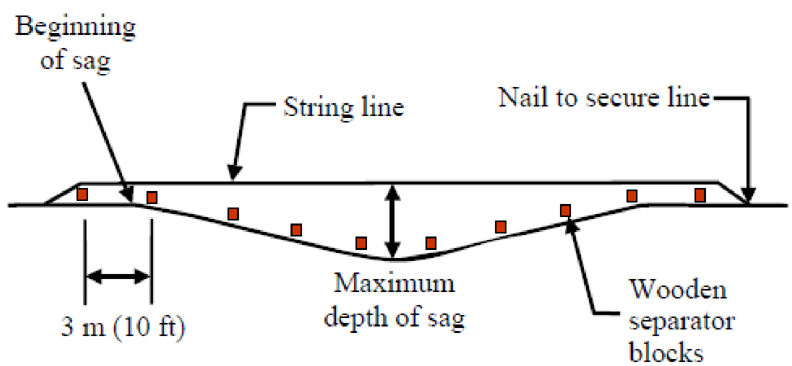
Figure 15-3 Grout Pumping



15-7 ELEVATION CONTROL DURING SLAB JACKING.

Before slab jacking operations are started, **e**stablish a method of controlling the amount the slab is to be raised and establish the finished elevation of the pavement. For short dips up to approximately 50 feet (18.3 meters) in length, a tight string line is adequate, provided the joints are true and plane with those of the adjacent pavement (Figure 15-4). For dips in excess of 50 feet (18.3 meters) in length, use an engineer's level and rod or a laser-based elevation control system to check the profile well beyond the dip; this will avoid building a localized bulge into the pavement.

Figure 15-4 Elevation Control

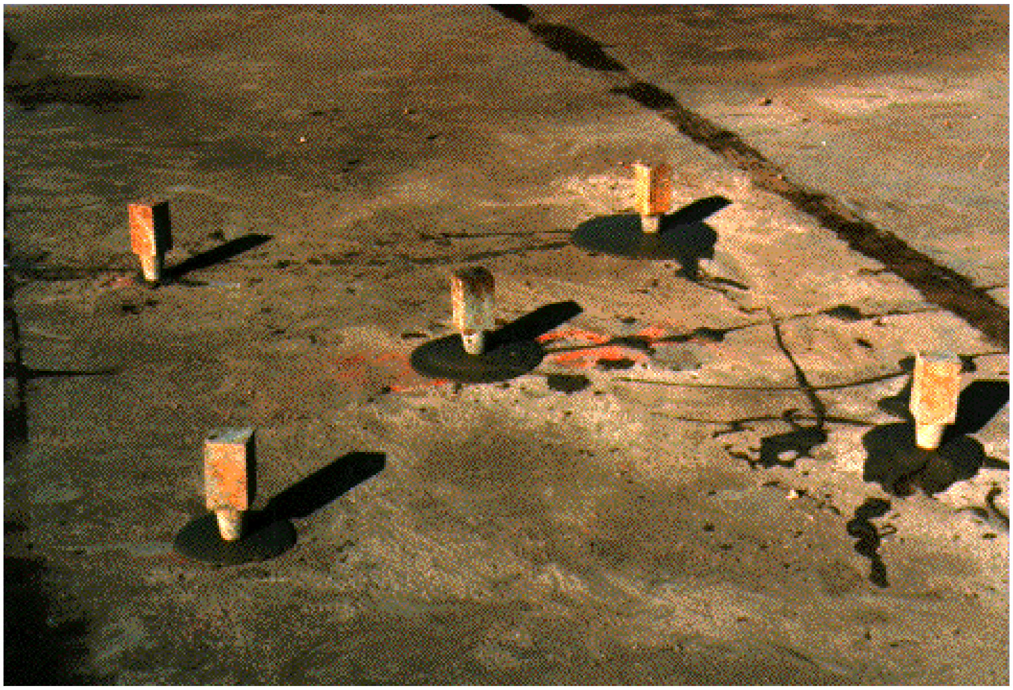


15-8 PLUGGING AND CLEANUP.

After completing slab jacking at a hole and the discharge pipe is removed, plug the hole immediately. Place temporary tapered wooden plugs into the injection hole to retain the grout pressure and stop any mixture return flow (Figure 15-5). Once the slab is jacked to the desired elevation, the temporary plugs are removed and the injection holes are filled with a stiff one-part-water, three-part-cement grout, or an approved concrete mixture, or a proprietary patching product. These areas are then finished flush with the existing pavement surface. Keep surfaces adjacent to the grouting operation clean of excess grout and other materials. Broom and wash off grout on the pavement to avoid unsightly discoloration and to remove the grout before it bonds to the concrete surface.

Caution: **The primary concern with slab jacking is excessive raising of the slab, which can induce stress concentrations in the slab and produce cracking. Therefore, it is critical to raise the slab slowly and no more than 0.25 inch (6 millimeters) at a time when pumping grout at each hole.**

Figure 15-5 Temporary Plugs



CHAPTER 16 SUBSEALING JOINTED CONCRETE PAVEMENTS

16-1 INTRODUCTION.

The purpose of subsealing is to stabilize the pavement slab by restoring support under the slab, typically at joint and crack locations. Subsealing is also called slab sealing, slabsealing, slab subsealing, slab undersealing, slab stabilization, undersealing, and pavement grouting. Pumping at joints and cracks with subsequent loss of support under the slab can occur beneath concrete pavements due to the presence of an erodible base or subbase, presence of moisture under the pavement, or significant slab deflections due to heavy traffic loadings.

Poor support conditions can lead to joint or crack faulting and corner breaks. Loss of support (voids) is indicated by signs of pumping at joints or by means of nondestructive deflection testing at joints. Subsealing involves the injection of a cementitious grout through holes drilled in the slab. The cementitious grout will, without raising the slab, fill the voids under it, displace water from the voids, and reduce the damaging pumping action caused by excessive pavement deflections. Subsealing reduces deflections at joints and cracks and retards the development of additional pavement deterioration.

16-2 NEED FOR SUBSEALING.

For jointed concrete pavement, accomplish subsealing as soon as significant loss of support is detected at slab corners. Symptoms of loss of support include increased deflections under vehicular loading, transverse joint faulting, corner breaks, and the accumulation of fines in or near joints or cracks on traffic lanes or shoulders. Consider subsealing at all existing repairs that show evidence of pumping or settlement. To be effective, perform subsealing before the voids become so large that they cause pavement failure.

<u>Caution:</u> To be most effective, it is important that slab undersealing be performed prior to the onset of pavement damage due to loss of support. Also, before considering undersealing of the slabs exhibiting loss of support, it is important that the cause(s) of the condition that led to the slab loss of support be addressed. This may require improving subsurface drainage conditions and/or restoration of load transfer at joints and cracks. Undersealing slabs where loss of support does not exist may be detrimental to pavement performance.

16-3 PAVEMENT SUBSEALING KEY STEPS.

The key steps for effective undersealing include the following:

1. Void (loss of support) detection
2. Selecting the grout material

3. Establishing the grout hole pattern
4. Drilling holes
5. Grout injection
6. Testing effectiveness of grouting
7. Grinding, if necessary, to restore profile at affected joint and crack location

16-4 SUBSEALING GROUT MATERIALS.

A variety of grout materials have been successfully used for slab jacking and subsealing. These materials are described in paragraph 15-3. The difference between slab jacking and subsealing is that when subsealing, the cementitious or polymer injection process is stopped at the point where all voids are filled to ensure there is no raising of the slab.

16-4.1 Polyurethane Polymer Subsealing.

The application of high-density polyurethane polymer material is similar to the application using cementitious grout. The polymer is injected directly into the void under the slab so as to fill the void with the high-density polymer foam (Figure 16-1).

Figure 16-1 Polymer Subsealing Process

In this chapter, only the generic processes using the cement-fly ash grout and polymer foam to directly fill the voids are presented. Information on the polymer deep injection process is not presented here because of the proprietary nature of the process. Information can be obtained from contractors on a project-by-project basis. Also note that in the past, asphaltic materials were used to underseal concrete pavements. This practice is no longer widely used and therefore not discussed.

16-5 VOID DETECTION.

Conduct a comprehensive survey to determine void locations beneath concrete pavement. Take void detection measurements during the preliminary evaluation and the repair process. Void detection can be a complicated process as natural wetting and drying cycles and thermal variations can cause slab curling. Interpretation of field conditions by experienced personnel is always desirable. Suggested methods follow.

16-5.1 Visual Inspection.

The simplest method is a visual inspection of the pavement to locate areas of distress. The presence of ejected subgrade or base material, staining of pavement surfaces adjacent to joints, excessive vertical movement at joints or cracks under traffic, and faulting of joints are evidence of possible voids under the slab.

16-5.2 Proof Rolling.

A common method of determining the presence of voids is called “proof rolling.” In this procedure a heavily loaded vehicle (minimum 18,000-pound [80-kilonewton] axle load) drives slowly over a transverse joint while observing deflection of the slabs. If deflection is visually observed, under-seal the joint. Deflections during proof rolling can be measured by devices equipped with sensitive dial gauges that contact the pavement. Gauges are attached to a firm base located off the pavement or at a sufficient distance from the test locations. The dial gauges are read visually or recorded electronically. Under-seal any slab showing deflection in excess of 0.015 inch (0.38 millimeter).

16-5.3 Nondestructive Deflection Testing.

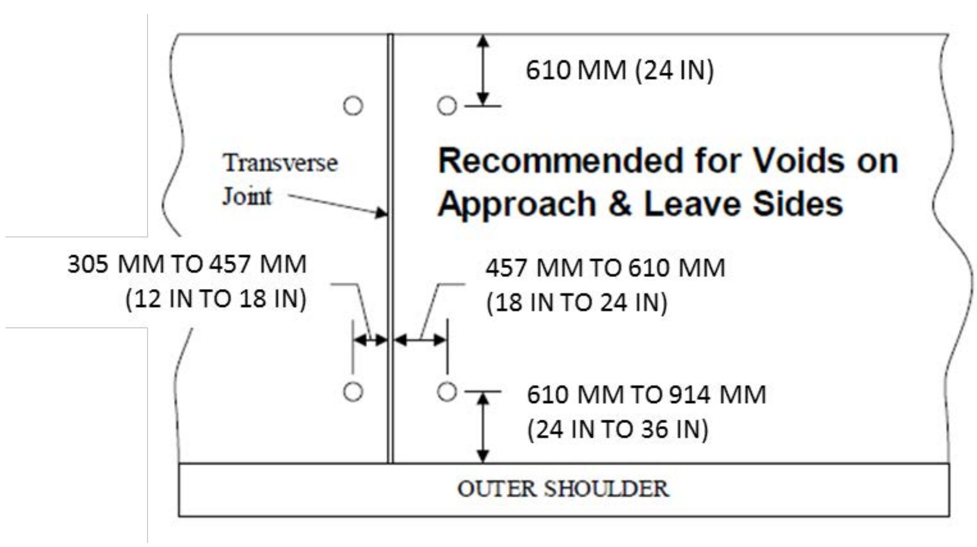
On large critical projects, the most effective method to locate voids under the pavement slab is the falling-weight deflectometer (FWD). The device measures deflections at a joint under several load levels and the deflection data is analyzed to determine the extent of void at the test location (Figure 16-2).

Figure 16-2 Falling Weight Deflectometer

16-6 INJECTION HOLE LOCATIONS.

Subsealing injection hole locations are similar to slab jacking (paragraph 15-4), the exception being to locate subsealing at pavement joints where the most common hole pattern is a four-hole pattern with two holes on each side of a transverse joint. The holes are located in the wheel tracks, with the approach slab holes nearer the joint than the leave slab holes. Typical distances from the joint are 12 to 18 inches (305 to 457 millimeters) for the approach slab and 18 to 24 inches (457 to 610 millimeters) for the leave slab (Figure 16-3). It is noted that in some cases the slab undersealing may be needed only on the leave (exhibiting void) side of the joint. Also, additional holes may be required for voids under the longitudinal joints or along the shoulder edge.

Figure 16-3 Four-hole Pattern at Joint for Grout Injection



16-7 DRILLING HOLES.

Drilling holes is identical to paragraph 15-5.

16-8 GROUT INJECTION.

Grout injection proceeds by lowering into successive holes a pipe connected to the discharge hose of the grout pump. The grout hole is sealed by a device called a packer. Two types are commonly used, as described below. The drive packer consists of a tapered pipe tapped into and out of the grout hole. Drive packers are used with 1-inch (25-millimeter) -diameter holes, and the expanding rubber packer consists of a threaded inner pipe, a thin-walled steel outer sleeve, and a short rubber sleeve at the bottom. This type of packer is used with 1.5-inch (33-millimeter) -diameter and larger holes.

Monitor movement (uplift) of the slabs during the grouting operation. To properly monitor movement of the slabs, gauges capable of reading movement of 0.001 inch (0.025 millimeter) must be used. Place the base for the gauge 3 to 4 feet (0.91 to 1.22 meters) off the slab being monitored. The gauges are set up at the joint corner locations and are not moved until grouting of the joint is completed. Typical pumping pressure are in the range of 40 to 60 psi (275 to 413 kilopascals) range. Always start grout injection with a low pumping rate and pressure. Stop pumping if the slab begins to rise or when no material is being injected at the maximum allowable pressure of 100 psi (689 kilopascals). Pumping of short surges up to 200 psi (1,378 kilopascals) are allowable for the grout to penetrate the void structure. If grout returns through an adjacent hole, stop pumping and insert the packer into another hole. If water or diluted grout is observed flowing from joints or cracks in the pavement, continue pumping until undiluted grout is observed.

Generally, when pumping the four-hole pattern at a joint, begin pumping first at the centerline and then continue with the holes closest to the shoulder. This sequence will drive any trapped water to the outside of the slab and through the transverse and shoulder joints. Where there is also void along the shoulder and extra holes are required, the sequence of grout injection becomes more complicated. Usually, the shoulder joint locations are pumped last.

<u>Caution:</u> To ensure that the slab is not raised, place straightedges with gauges attached over the slab to measure any upward movement of the slab. At the first indication of movement, stop the grout-injecting procedure. If the slab is raised, high slab stresses may develop, leading to slab cracking.

16-9 RETESTING SLAB CORNERS.

After a minimum of 24 hours has elapsed following completion of subsealing, test the grouted slabs for stability at the same points as previously tested. Conduct this testing using the same procedure used for the pre-grouting test. Include other joints that were not grouted in this test for use as a control. If loss of support still exists after grouting, re-grout the slab. In each regrouting, new holes will be needed. It is recommended that if voids are still present after three attempts to stabilize the slab, do not attempt any further regrouting and consider other repair methods such as full-depth repair in lieu of regrouting.

16-10 PLUGGING AND CLEANUP.

Plugging and cleanup is identical to paragraph 15-8.

CHAPTER 17 PCC PAVEMENT DIAMOND GRINDING

17-1 INTRODUCTION.

Diamond grinding, using closely spaced diamond saw blades mounted on a rotating shaft, removes a thin layer of the concrete surface to correct for faults at joints and crack locations and correct for surface defects, such as wheel path rutting. Diamond grinding results in re-profiling the pavement and improves the pavement's ride quality.

Note that diamond grinding is a different process than diamond grooving. Diamond grooving is a process in which parallel grooves in the transverse direction are cut into new airfield runway pavements using diamond saw blades with a typical center-to-center blade spacing of 0.75 inch (19 millimeters). The principal objective of grooving is to provide escape channels for surface water, thereby reducing the incidence of hydroplaning that can cause wet weather crashes. Diamond grooving is typically not used for roadway pavements except at sharp curves.

17-2 NEED FOR GRINDING.

Consider diamond grinding when a pavement survey reveals surface defects such as faulted joints and cracks in excess of 0.125 inch (3 millimeters), roughness in excess of 0.125 inch (3 millimeters) in a 10-foot (3-meter) length, or rutting up to 0.375 inch (10 millimeters). If skid resistance is to be examined, examine it on the areas not scheduled for grinding for any of the previously mentioned defects. If a large area requires grinding to improve skid resistance, economics may favor grinding the entire pavement surface.

<u>Caution:</u> Note that diamond grinding primarily improves the pavement's ride quality and does not directly improve the structural condition of the pavement. Diamond grinding is frequently used in combination with other concrete pavement repair techniques that improve the structural condition of the pavement. Diamond grinding may not be effective over the long term if the pavement exhibits significant deterioration or if causes of faulting are not addressed. Do not consider diamond grinding for pavements exhibiting concrete materials-related distress, such as D-cracking and ASR. Perform any partial-depth and full-depth patching before grinding.

17-3 GRINDING PROCESS.

The diamond grinding process is free of impact and does not damage joints. The pavement grinder is similar to a wood plane. The front wheels are designed to pass over a fault or bump, the cutting head shaves off the fault or bump, and the rear wheels ride in a smooth path left by the cutting head.

Diamond grinding requires heavy, specially designed equipment (Figure 17-1) that uses diamond saw blades gang-mounted on a cutting head (Figure 17-2). Spacers are placed between the saw blades to reduce the amount of cutting to be done. This combination of saw blades and spacers gives the pavement the characteristic corduroy texture that also improves skid resistance (Figure 17-3).

Because the hardness of the aggregate will influence the grinding operation, identify the type of aggregate in the PCC pavement when contracting the work. Grinding a pavement with extremely hard aggregate (such as trap rock, river gravel, or quartzite) takes more time and effort than grinding a pavement with a softer aggregate (such as limestone) and will cost more.

Figure 17-1 Grinding Equipment

Figure 17-2 Gang-mounted Diamond Saw Blades

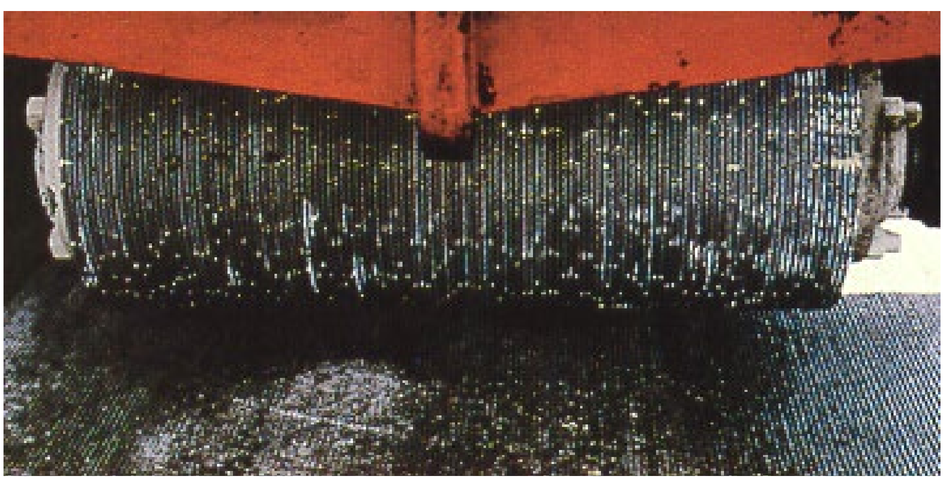


Figure 17-3 Diamond-ground Surface

17-4 TEST SECTION.

Before work begins, test the equipment on a small section of the pavement to ensure that proper blade spacing is being used for the specific aggregate on the project. The width of the spacers between the saw blades is varied depending on the hardness of the aggregates. Use a thinner (smaller) spacing between the blades with harder aggregate. As the diamond grinding head cuts the surface of the pavement, thin fins of concrete are left between the cutting blades. These fins typically break off during the grinding process. If these fins do not break off, use a grinding head with thinner spacers. When grinding aggregate susceptible to polishing, provide more area between the blades.

Use a fin depth (land area thickness) measured at the thickest point of 0.08-inch (2-millimeter) minimum and have an average thickness of 0.1 inch (2.5 millimeters). For harder aggregates not subject to polishing, use a minimum fin depth of 0.065 inch (1.7 millimeters) and an average thickness of 0.08 inch (2 millimeters).

17-5 GRINDING PROCEDURE.

Grinding equipment uses diamond blades mounted in series on a cutting head. The cutting head typically has a width ranging from 48 to 50 inches (1.22 to 1.27 meter). The desired corduroy texture is produced using a spacing of 50 to 60 blades per foot (164 to 197 blades per meter). New, improved grinding machines and grinding blades have greatly increased the capability to provide extremely smooth profiles. Always start and end grinding perpendicular to the pavement centerline and consistently maintain the grinding parallel to the centerline.

The grinding and grooving operation produces slurry consisting of ground concrete and the water used to cool the blades. This slurry is picked up by onboard wet-vacuums. Continuously remove the slurry residue. Do not permit grinding slurry to flow across adjacent lanes into gutters or other drainage facilities. Dispose of grinding slurry in accordance with local environmental regulations.

The following grinding procedures are for roughness and fault removal.

17-5.1 Roughness Removal.

For areas identified as being too rough, establish a level of restoration and grind the nominated sections. Following grinding, test the roughness again. Testing is typically accomplished using equipment such as the California profilograph (Figure 17-4). Prior to grinding, establish the grade. Do not use the old pavement surface as the reference unless using a long beam or skid. Where sags in the pavement are encountered, first remove the sags by slabjacking. Grinding at a sag point will not remove roughness. Reinvestigate the pavement following slabjacking to revise the grinding requirements, if necessary.

Figure 17-4 California Profilograph

17-5.2 Fault Removal.

Prior to grinding the faulted joints (and cracks), underseal the slabs to prevent the fault from recurring. Cut in to the faulted joint during grinding to produce smoother joints and a more efficient operating surface. Feather the fault back some distance into the slab. The distance required depends on the allowable roughness. The American Concrete Pavement Association has a general guideline of 1 foot (300 millimeters) for every 0.1 inch (2.5 millimeters) of faulting. This is slightly rougher than 0.125 inch (3 millimeters) in 10 feet (3 meters). Feathering distances necessary to meet straight-edge requirements of 0.125 inch (3 millimeters) in 10 feet (3 meters) are shown in Table 17-1. If the entire slab is to be ground, feather out the depth of the cut to the next joint to remove the fault.

Table 17-1 Feathering Distances

Fault Height Inches (Millimeters)	Feathering Distance Feet (Meters)
0.125 (3)	2.5 (0.76)
0.25 (6)	5.0 (1.52)
0.375 (10)	7.5 (2.29)
0.5 (13)	10.0 (3.04)
0.625 (16)	12.5 (3.81)
0.75 (19)	14.0 (4.27)

17-5.3 Skid Resistance.

Grinding can improve skid resistance. Grind only those lanes needing treatment. Feather the edges of the ground areas into the adjoining areas to eliminate a sharp drop-off. Grind the pavement in a longitudinal direction that begins and ends at a line marked perpendicular to the pavement centerline. A successful grinding operation produces a uniformly finished surface that is free of joint or crack faults and provides positive lateral surface drainage.

17-6 ACCEPTANCE TESTING.

After completing grinding and texturing, test the pavement for smoothness. Accept only pavement which meets the surface tolerance for a new pavement as required by the specifying agency. Specify use of the same test equipment in the acceptance testing as used in the initial evaluation along with the procedures to be followed in acceptance testing. Do not reduce the thickness of the pavement through grinding by an amount that reduces the nominal load-carrying capability of the pavement without prior approval of the Pavements DWG or their designated representative.

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CHAPTER 18 CONCRETE PAVEMENT LOAD TRANSFER RESTORATION

18-1 INTRODUCTION.

New pavement joints typically exhibit good load transfer, particularly if the joints are doweled. However, repeated heavy loads over time can cause an elongation of the dowel sockets and result in dowel looseness and a reduction of load transfer efficiency. As the load transfer efficiency decreases, the load-related deflections along the joints, especially at corner locations, increase. This can accelerate the development of joint-related distresses, such as pumping, spalling, faulting, and slab corner cracking. For non-doweled concrete pavements, aggregate interlock at joints is relied upon to provide load transfer across a joint. However, under traffic loading and due to concrete drying shrinkage over time, aggregate interlock becomes less effective. If the non-doweled pavement continues to carry heavy traffic, the non-doweled joints may be good candidates for load transfer restoration (LTR).

For many years, the typical way to transfer shear at a construction joint was with a keyed joint. Many steel bulkhead forms are available with a keyed profile. However, most experts no longer recommend keyed joints since they seldom stay tight enough to provide positive shear transfer. In accordance with ACI 360R-10, *Guide to Design of Slabs-on-Ground*, the male and female components lose contact when the joint opens due to drying shrinkage, which can lead to breakdown of the joint edges and failure of the top side portion of the key.

Restoration of load transfer is used to retard further deterioration of the concrete pavement by reducing the potential for joint-related distresses. Restoration of load transfer can improve pavement performance by reducing pumping, faulting, and corner breaks, and also by retarding the deterioration of transverse cracks. In most instances, the pumping and faulting distresses can be corrected by installing joint load transfer devices. Diamond-grinding the pavement surface is often done in conjunction with LTR to restore rideability.

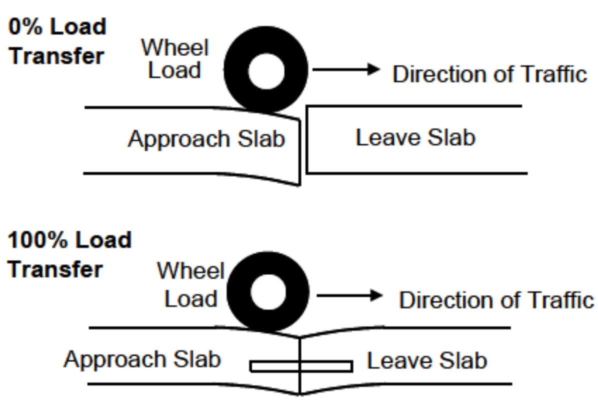
<u>Caution:</u> LTR is not used for heavily trafficked airfield concrete pavements. The shear stresses caused by the heavy loading may be greater than the bond strength between the slot patch material and the existing concrete. This can cause dowel bars in the slots to break out of the slots under repeated aircraft loadings.

18-2 NEED FOR LOAD TRANSFER RESTORATION.

Transverse joints or cracks that would benefit from improved load transfer can be identified by measuring the existing load transfer efficiency using a nondestructive deflection testing device such as the FWD. Conduct these tests during periods of cooler temperatures (less than about 80 degrees F [27 degrees C]) when the slab joints and cracks are not tightly closed. Consider LTR for joints or cracks having a measured load transfer efficiency (ratio of the deflection on the unloaded side of a joint or crack divided by the deflection of the loaded side) of less than 50 percent.

For thicker airfield pavements being considered for LTR, use the heavier version of the FWD, commonly called the heavy weight deflectometer (HWD). The HWD can apply loading up to 50,000 pounds-force (222 kilonewtons) that better simulates the loading of the heavier aircraft. For concrete pavements 12 inches (300 millimeters) or less in thickness, a standard FWD meets the testing needs and test loads of up to 20,000 pounds-force (89 kilonewtons) can be applied. The concept of load transfer at a joint is illustrated in Figure 18-1. Take deflection measurements as near as possible to the joint or crack. Take deflection measurements in the center of the load plate, positioned tangentially along the joint, and at 12 inches (300 millimeters) across the joint (from the center of the load plate).

Figure 18-1 Load Transfer at a Joint



18-3 LOAD TRANSFER RESTORATION (LTR) KEY STEPS.

The key steps in performing LTR include the following:

1. Correct causes of poor load transfer
2. Create slots at the joints being treated by saw-cutting and chipping concrete
3. Place load transfer devices, typically dowel bars, into the slots and properly align the bars
4. Use compressible inserts
5. Place repair material into the slots, ensuring good coverage under the dowel bars
6. Restore the joint at the slot locations and seal the joints
7. Grind at joint locations or over the full pavement width and length to improve ride quality

18-4 CORRECTION OF DEFICIENCIES.

Before load transfer devices are installed, it is necessary to determine the cause of the joint or crack distress. Attempt to correct the cause(s) of these deficiencies prior to LTR. Slabs exhibiting extensive distress along a joint may require portions of or the entire slab to be replaced. Also, successful installation of load transfer devices requires sound concrete adjacent to the joint or crack. If the concrete near the joint or crack is significantly deteriorated, perform full-depth repair (with provisions for load transfer) in lieu of LTR. Perform the following additional work if required prior to LTR. Subsealing (essential if loss of support exists) to fill voids in the pavement structure and to restore support to the pavement slabs, and full-depth and spall repairs to replace highly distressed joints and slabs with corner breaks, "D" cracking, etc.

18-5 DOWEL LOAD TRANSFER RESTORATION (LTR) PROCESS.

Installing round dowel bars is the primary method of restoring load transfer at existing joints or cracks. In the past, use of proprietary devices was attempted but has fallen out of favor because of cost and uneven performance in the field. Field experience indicates that round dowel bars can effectively transfer loads across joints and cracks.

18-5.1 Dowel Size Requirement.

Specify different size dowels for different thicknesses of pavements. Dowel size and spacing for construction, contraction, and expansion joints are shown in Table 18-1.

Table 18-1 Dowel Size Requirements

Pavement Thickness, inches (millimeters)	Dowel Length, inches (millimeters)	Dowel Spacing, inches (millimeters)	Dowel Bar Diameter, inches (millimeters)
8 to 11.5 (200 - 290)	16 (400)	12 (300)	1 (25)
12 to 15.5 (300 -395)	18 (450)	15 (380)	1.25 (32)
16 to 20.5 (400 - 520)	20 (500)	18 (450)	1.5 (38)
21 to 21.5 (530 - 550)	24 (600)	18 (450)	2 (50)
>26 (660)	30 (762)	18 (450)	3 (75)

For roadway pavements, four dowel bars are typically used for each wheel path. The bars are typically spaced at 12 inches (300 millimeters).

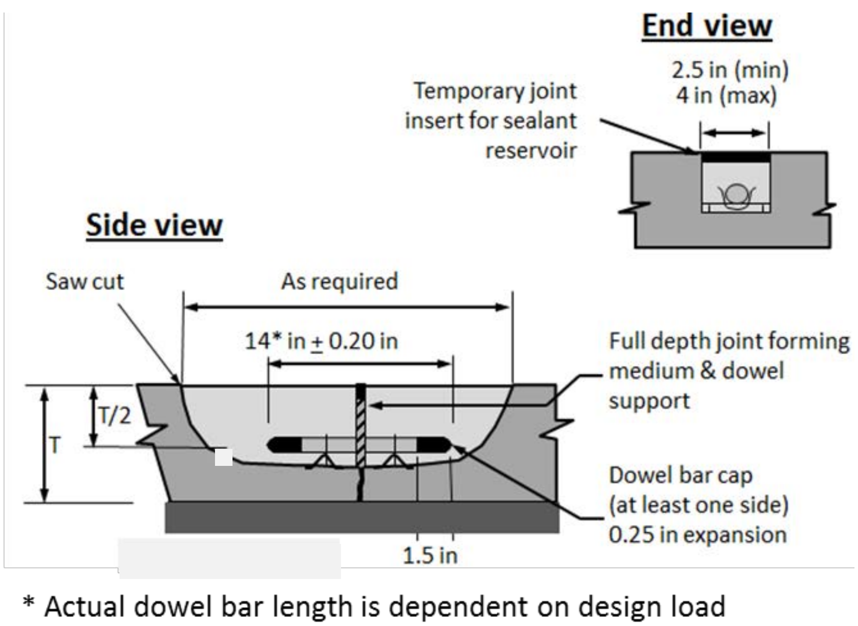
18-5.2 Cutting Slots for Dowel Installation.

Slots for installing dowels are cut using diamond-blade saws. Gang-mounted multiple blade saws are recommended to speed operations (Figure 18-2). Cut the slots so the dowels can be placed horizontally parallel to the pavement surface, perpendicular to the joint, and at mid-depth of the slab (Figure 18-3).

Figure 18-2 Gang-Mounted Multiple Saw Blades for Slot Cuts

Where slab movement at the crack/joint location is required, cut slots to allow dowel placement parallel to the pavement surface at mid-depth and perpendicular to the orientation of the crack/joint.

Figure 18-3 Dowel Placement in Slot

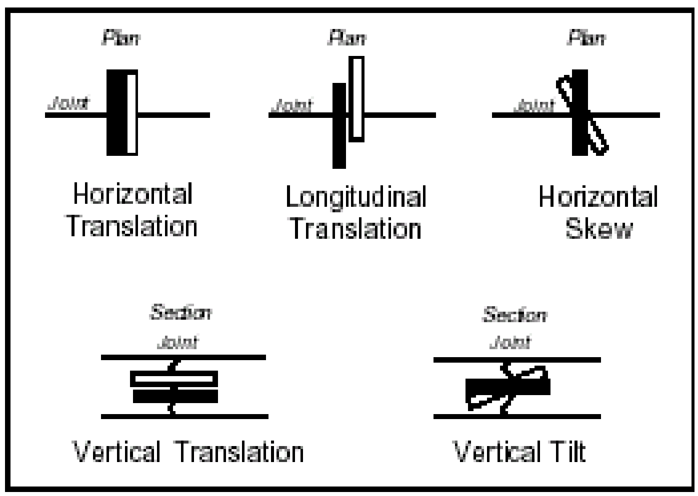


Take care to ensure the dowel bars are correctly aligned in the slots. Poor dowel alignment, as shown in Figure 18-4, can cause joint locking (or a working crack), spalling in the patch material, and poor load transfer efficiency.

Figure 18-4 Types of Dowel Bar Misalignment and Effect on Performance

Type of Misalignment	Effect on Spalling	Cracking	Load Transfer
Horizontal Translation	—	—	yes
Longitudinal Translation	—	—	yes
Vertical Translation	yes	—	yes
Horizontal Skew	yes	yes	yes
Vertical Tilt	yes	yes	yes

Categories of dowel misalignment are illustrated below.



Misalignment categories.

18-5.3 Concrete Removal & Dowel Installation.

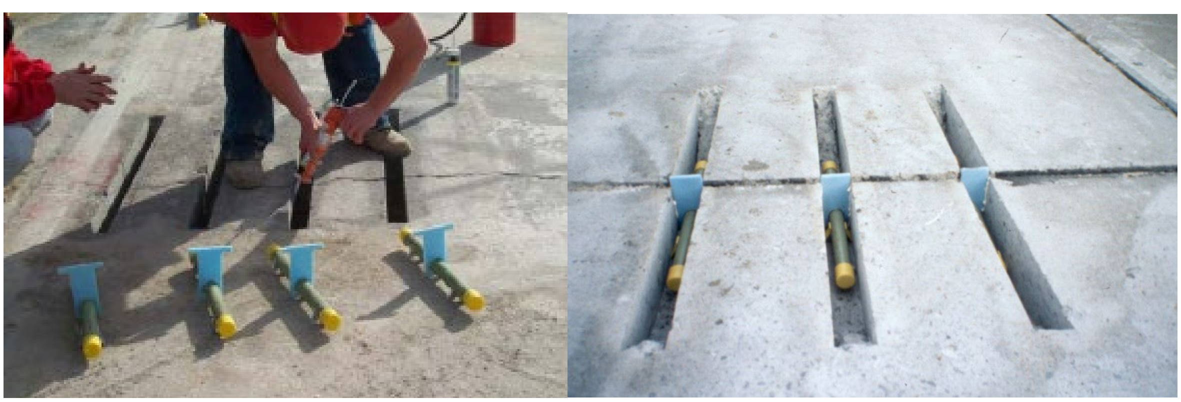
Light-weight (10 to17 pounds [4.5 to 7.7 kilograms]) chipping hammers are used to remove the concrete within the saw cuts (Figure 18-5). Take care not to punch through the slot bottom. The slot is then cleaned by sandblasting or any method that will ensure removal of all sawing residue, dirt, or oil that may prevent bonding of the patch material to the slot faces.

Figure 18-5 Use of Chipping Hammers to Remove Concrete

Each dowel is placed upon a support chair to allow the patch material to surround the dowel. One end of the dowel is oiled and painted and an expansion cap placed at the end of the dowel bars (Figure 18-6). Provide and use the dowels with a filler board or Styrofoam material at mid-length to prevent intrusion of the patch material into the joint or crack (causing point bearing and compression failure during warm weather) and to form the joint in the slot (Figure 18-6).

Before installing the dowel bar, caulk the perimeter of the joint within each slot to prevent the intrusion of the patch material into the joint (Figure 18-6).

Figure 18-6 Use of Compressible Insert



18-5.4 Patching Material.

High early-strength concrete or proprietary cementitious materials extended with small-sized aggregate have been used to fill the slot at most installations to date. The patch material used with load transfer devices is a critical factor in performing this technique. It is necessary to ensure there is thermal compatibility between the patch material and the existing concrete; therefore, use aggregates in the patch material that have a coefficient of thermal expansion (CTE) property similar to that of the aggregates used in the existing concrete.

It is important that a laboratory evaluation be made of any patch material utilized for patching the slots. Evaluate the following key factors: working time, rapid early-strength gain, thermal compatibility with existing concrete, and shrinkage property.

18-5.5 Placing Patch Material.

After properly cleaning the patch area, apply a bonding agent if required by the patching material manufacturer. The type of bonding agent depends on the bond development requirements for opening to traffic and type of patching material used. Follow the manufacturer's recommendations with all patching materials. Use bonding agents recommended by the manufacturer for the placement conditions. Bonding agents or grouts may not be needed when using high-early-strength concrete.

Place and consolidate the patch material to eliminate all voids at the interface of the patch and the existing concrete and at the load transfer device and the patch material (Figure 18-7). Each slot requires two to four short, vertical penetrations of a small-diameter spud vibrator. Place the patch material flush with the adjacent concrete and take care to prevent intrusion of the patch material into the adjacent joint areas. However, the patch material is finished slightly "humped" (no more than 0.125 inch [3.175 millimeters]) if diamond grinding is to be employed.

Figure 18-7 Placing and Consolidating Patch Material

After consolidation and finishing, place a curing compound on the patching material to minimize rapid patch material shrinkage. Depending upon the type of repair material, the pavement may be opened to traffic in as little as a few hours. The minimum compressive strength required to open a repair to traffic is about 2,000 psi (13.7 megapascals) for slabs 8 inches (200 millimeters) or thicker.

18-5.6 Finishing Activities.

LTR may result in increased roughness at joint locations if the patch materials are not properly finished. This is typically due to differences in elevation between the finished repair area and the existing pavement, or perhaps due to shrinkage or settlement of the repair material. Consequently, the joint locations or the entire pavement project being rehabilitated is often diamond-ground to provide a smooth-riding surface. Complete grinding as soon as is feasible after the patch material has attained the specified strength, typically 4,000 psi (27.4 megapascals) compressive strength.

After the patch material has cured and the surface diamond-ground, re-establish the transverse joint at the affected joints by sawing over the length of the joints and through the filler board then prepare and seal the joint.

18-6 KEYED JOINTS LOAD TRANSFER RESTORATION PROCESS.

Although not recommended for new construction, keyed construction joints (Figure 18-8) are still found in existing airfield pavements. In addition to the loss of load transfer due to shrinkage, the female keyed flanges are prone to spalling. For this reason, keyed joints are recommended to be removed and replaced with a doweled joint.

Figure 18-8 Keyed Joint

18-6.1 Keyed Joint Key Steps.

Restoration of keyed joints is identical to full-depth repair of concrete pavements (Chapter 14), with the following exceptions.

18-6.1.1 Keyed Joint Concrete Removal.

Depending on the joint stress severity, remove the complete keyed joint for the entire edge of the slab. The male end of the keyed joint needs to be removed with a concrete saw, leaving the joint flush, vertical, and ready to accept new dowels. The female end needs to be cut far enough back to allow the use of a dowel drill. This can be as much as 4 feet (1.2 meters) for the typical gang-operated concrete dowel drill (Figure 18-9).

Figure 18-9 Gang-operated Dowel Drill

18-6.1.2 Dowel Bar Placement and Installation.

Install dowels along the face where the keyed joint male end has been removed. Place and install the dowel bars in accordance with paragraph 18-5.

18-6.1.3 Tie Bar Placement and Installation.

Secure the newly cut joints other than the existing keyed joint with tie bars. Install tie bars in the same manner as the dowel bars (paragraph 14-2.10), but both ends are permanently secured.

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CHAPTER 19 CONCRETE PAVEMENT RETROFITTED EDGE DRAINAGE

19-1 INTRODUCTION.

The presence of moisture under pavement, if not removed quickly, leads to poorly performing pavement or failure. One of the most critical considerations for pavement design is how to control water entering the pavement. The primary source of water under the pavement is rainwater that infiltrates into the pavement due to poorly sealed transverse and longitudinal joints and cracks. Many older concrete pavements have non-drainable bases and subbases with no provision to quickly remove water from the pavement system. The infiltration of water through the pavement causes saturation of the base and subbase. Without drainable layers, traffic loads cause pumping at joints and crack locations. Over time, repeated traffic loading leads to a loss of support along joints and cracks, resulting in high deflections and slab cracking.

19-2 NEED FOR PAVEMENT-EDGE DRAINAGE.

- The following conditions may warrant the addition of pavement-edge drainage:
- Inadequate surface drainage facilities (shallow ditches or absence of ditches)
- Water table may rise within the pavement system
- Surface water entering the pavement system at joints or cracks, surface edges, or percolating through the shoulders
- Water in the subgrade rising vertically via capillary action

19-3 DRAINAGE SYSTEM CLASSIFICATIONS.

Pavement drainage is grouped into two major classifications: surface and subsurface. When both types are required for efficient maintenance and protection of the pavement, it is generally a good practice for each system to function independently.

19-3.1 Surface Drainage.

Surface drainage keeps surface water (rain) out of the pavement system, typically by incorporating adequate cross-slopes and longitudinal grades and properly designed and maintained ditches.

19-3.2 Subsurface Drainage.

Subsurface drainage quickly removes water that has entered the pavement system. These systems are designed so the outflow capacity is greater than the long-term maximum inflow into the pavement system. These systems may consist of drainage layers discharging to daylight or in conjunction with built-in edge drains. One way to provide for subsurface drainage for an existing system without an effective subsurface drainage system is to retrofit edge drainage along the shoulder.

19-4 EDGE DRAINAGE REQUIREMENTS.

Edge drainage in an existing pavement is required where seasonal fluctuations of ground water are expected to rise in the subgrade water table to less than 1 foot (0.305 meter) below the bottom of the base course or seeping water in a pervious stratum will raise the ground water table to a depth of less than 1 foot (0.305 meter) below the bottom of the base course.

19-5 EDGE DRAINAGE CANDIDATES.

A good candidate project for retrofitted edge drainage is a pavement showing early signs of moisture-related damage. Additionally, projects with acceptable surface geometrics (longitudinal grades and transverse cross-slopes) and adequate depth and condition of roadside ditches are good candidates for retrofitted edge drainage.

Retrofitted edge drainage is not effective at extending the service life of concrete pavements already experiencing significant moisture-related deterioration. Concrete pavements in which the following conditions are present are poor candidates for retrofitted edge drainage:

- More than 15 percent of the slabs exhibit full-depth cracking, all of which require extensive corrective work to return the pavement to an adequate level of service
- A high number of transverse joints are spalled
- Pumping has occurred
- A cement-treated base exists that is no longer intact
- The existing base contains greater than 15 percent fines (material passing the 0.075-millimeter [No. 200] sieve). Base materials with these characteristics may be too impermeable for effective use of a retrofitted edge drainage system.

19-5.1 Edge Drainage Key Steps.

The key steps in providing retrofitted edge drainage include the following:

1. Select edge drainage system and materials
2. Locate the edge drainage
3. Dig a trench

4. Place edge drainage material (e.g., filter fabric [geotextile], perforated flexible drainage pipe [or fin drain], backfill filler material, outlet pipes)
5. Finish the surface of the edge drainage system

Note: Consider retrofitting edge drainage by itself or in combination with other repair techniques, such as full-depth repairs and dowel bar retrofit.

19-6 EDGE DRAINAGE MATERIALS.

While this chapter discusses edge drainage systems using perforated pipes, most of the steps discussed are also applicable to fin drain systems. Edge drainage systems require the following materials:

19-6.1 Drainage Pipe.

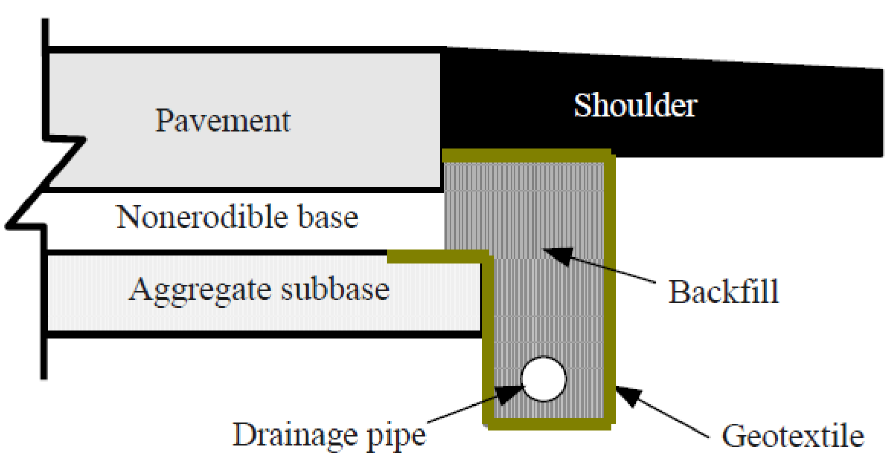
Although in the past several different types of pipe of various materials, lengths and diameters have been used in edge drainage systems, the pipe that is currently widely used is the perforated corrugated plastic pipe. These pipes are flexible. Select the type of pipe based on local requirements, such as the condition of the soil, loading and amount of cover, cost, and availability of pipe. Most highway agencies use flexible, corrugated polyethylene (CPE) adhering to AASHTO M252, *Standard Specification for Corrugated Polyethylene Drainage Pipe*.

19-6.2 Perforated Drainage Pipe.

A typical retrofitted edge drainage system is illustrated in Figure 19-1. Such an edge drainage system incorporates a perforated drainage pipe.

Aggregate trench drains (drainable aggregate material) constructed along pavement edges are not generally recommended because they have poor stability, a relatively low hydraulic capacity, and are difficult to maintain.

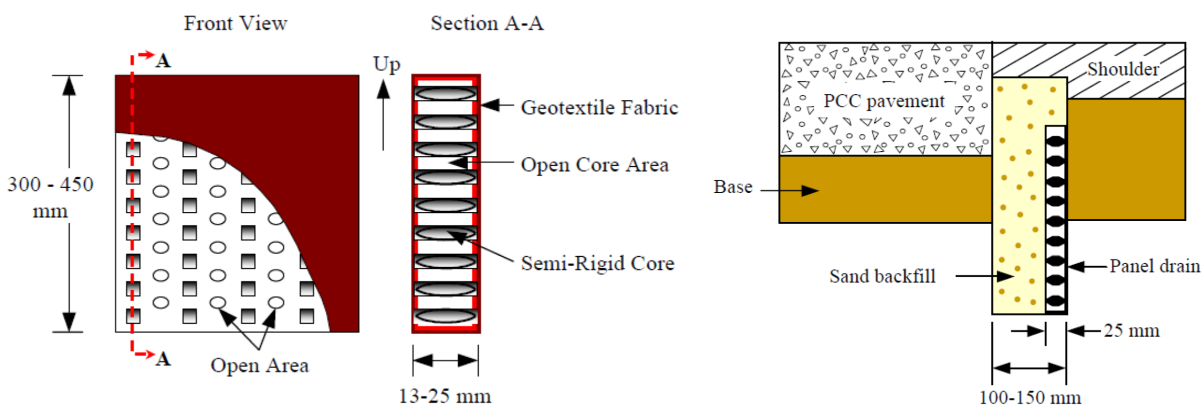
Figure 19-1 Typical Retrofitted Edge Drainage System



19-6.3 Fin Drains.

Fin (geocomposite) drains are another acceptable type of edge drainage system. This system comprises an extruded plastic drainage core wrapped with a geotextile filter. Figure 19-2 shows details of a typical geocomposite edge drain and recommended installation details. Geocomposite edge drains are typically 0.5 to 1 inch (13 to 25 millimeters) thick and manufactured in long strips coiled into rolls.

Figure 19-2 Geocomposite Edge Drain Features & Installation Details



19-6.4 Filter Material.

19-6.4.1 When possible, for economic reasons, use locally available processed sands and gravels. Use filter material that is more permeable than the material being drained. Provide and use only filter materials with a grain size curve that is smooth (no gap grading) and parallel to or flatter than that of the protected material. Standard concrete aggregates can be used as a filter, but provide and use aggregates that meet the filter criteria. Provide and use filter material fine enough to prevent infiltration of the material from which drainage is occurring. To avoid contamination of the filter by fines by the material in the layer being drained, the required ratio of d15 percent passing size of filter material / d85 percent passing size of material being drained is < 5, where d15 is the equivalent grain diameter (millimeters) at which 15 percent of the material is finer by weight and d85 is the equivalent grain diameter (millimeters) at which 85 percent of the material is finer by weight. The required ratio of d50 percent passing size of filter material / d50 percent passing size of material being drained is < 25, where d50 is the equivalent grain diameter (millimeters) at which 50 percent of the material is finer by weight. Use these criteria when protecting all soils, except for nondispersive lean clay (CL) or fat clay (CH) soils without sand or silt particles, whereupon disregard the d50 percent size relationship.

19-6.4.2 It is essential to use well-graded filter material. The required coefficient of uniformity equates to d60 percent passing size of filter material / d10 percent passing size of filter material having a value less than or equal to 20, where d60 is the equivalent grain diameter (millimeters) at which 60 percent of the material is finer by weight and d10 is the equivalent grain diameter (millimeters) at which 10 percent of the material is finer by weight.

19-6.4.3 To prevent clogging of perforated pipe or screens, the required ratio of d85 percent passing size of filter material / slot width or hole diameter slot or hole diameter is > 1.2.

19-6.4.4 To prevent clogging of the openings in porous pipe the ratio of d15 percent passing size of aggregate in porous pipe / d85 percent passing size of filter material is < 5.

19-6.5 Dispersive Clays.

If dispersive clays are encountered, obtain the services of a geotechnical expert having experience detecting and determining the best way to handle these clays. Dispersive clays normally deflocculate when exposed to water with a low salt content. This behavior is the opposite of aggregated clays that remain flocculated in the same soil-water systems. Generally, dispersive clays are highly erosive, are subject to high shrink-swell potential, and have lower permeability rates than aggregated clays.

19-6.6 Filter Fabrics.

The use of woven or nonwoven geotextile materials meeting the requirements of AASHTO M288, *Standard Specification for Geotextile Specification for Highway Applications*, are widely accepted as filters in pavement edge drainage systems. In some instances, these materials may replace one or more components of a graded filter. Filter fabrics may be used to wrap the collector pipe, thus permitting use of a relatively fine backfill material; or line the trench (most common), allowing use of a relatively coarse backfill material. Filter fabrics are rarely used without the entire granular backfill. The only instance where a geotextile can completely replace a granular system is when the subgrade soil is a clean, granular material.

19-6.6.1 Filter Fabric-wrapped Collector Pipe.

When a geotextile is used to wrap the collector pipe, the required ratio of d85 percent passing size of granular filter material (millimeters) / apparent opening size (AOS) of geotextile (millimeters) is > 1.0, where apparent opening size is a property that indicates the approximate largest particle that will effectively pass through the geotextile. This is for a gradient ratio < 3, where gradient ratio is the ratio of the hydraulic gradient through a soil-geotextile system to the hydraulic gradient through the soil alone. For woven geotextiles, do not use a cloth with an open area that is less than 4 percent or greater than 36 percent of the total area. Where these criteria are met, the criteria given for perforated pipe or screens are no longer applicable.

19-6.6.2 Filter Fabric-lined Drainage Trench.

Where geotextiles are used to line a drainage trench and the geotextile adjacent to granular materials containing 50 percent or less by weight of fines (minus No. 200 materials) the required ratio of d85 percent size of the material (millimeters) / apparent opening size (AOS) (millimeters) is > 1 and a gradient ratio < 3. For woven geotextiles, do not use cloth with an open area that is less than 4 percent or greater than 36 percent.

19-6.6.3 Filter Fabric and All Other Soil Types.

For geotextiles adjacent to all other types of soil and an AOS no larger than the opening in U.S. Standard Sieve No. 70 and gradient ratio < 3, do not use cloth with an open area that is less than 4 percent or greater than 10 percent. Where these criteria are met, the criteria for stability and permeability are no longer applicable and the backfill may be selected based on the criteria for perforated pipe or screens.

19-6.6.4 Filter Fabric Clogging.

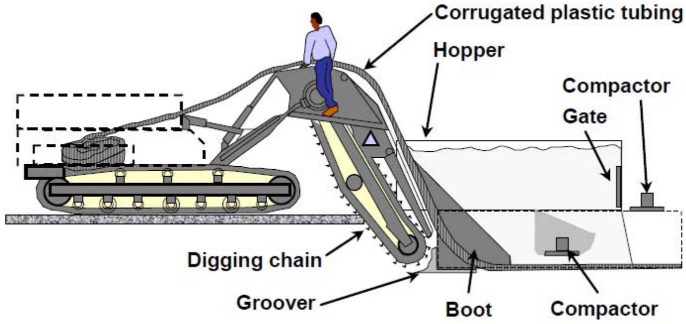
To reduce the possibility of clogging, specify no geotextile with an AOS smaller than the openings of U.S. Standard Sieve No. 100. When possible, it is preferable to specify a geotextile with openings as large as allowed by the above criteria. Do not use geotextiles for soils with 85 percent or more passing the No. 200 sieve.

Methods for determining the AOS and gradient ratio of geotextiles are given in ASTM D4751, *Test Method for Determining Apparent Opening Size of a Geotextile,* and ASTM D5101, *Standard Test Method for Measuring the Filtration Compatibility of Soil-Geotextile Systems*, respectively. Percent open area is defined as the summation of the open areas divided by the total area of the geotextile (refers to woven geotextiles only).

19-7 SUBSURFACE DRAIN INSTALLATION.

Subsurface drains are typically installed using trenchers or other suitable equipment (Figure 19-3). Grade control and elevations are normally obtained from the pavement surface. A minimal slope of 0.15 foot (0.04 meter) in 100 feet (30.4 meters) is recommended for subsurface drains. Cap or plug the upstream end of drainage pipes not terminating in a structure.

Figure 19-3 Trenching Equipment for Installing Pipe Edge Drains



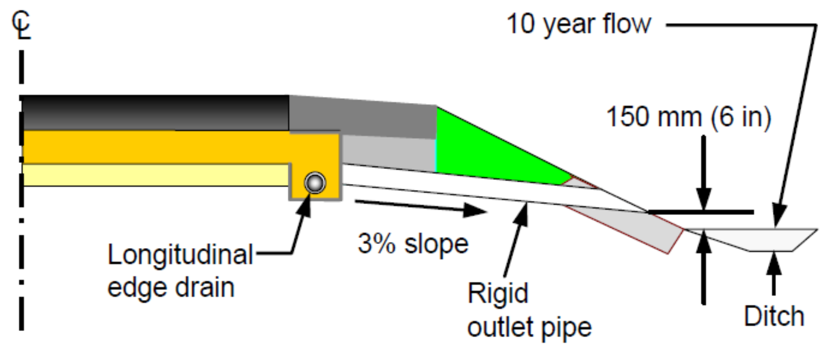
19-7.1 Filter Material Placement.

Place a minimum thickness of 6 inches (152 millimeters) of filter material around all types of subsurface drains. Place the backfill material using chutes or other means to avoid dumping the material onto the pipe from the top of the trench. To prevent displacement of drainage pipes during compaction, do not compact the filter material until the trench is backfilled above the level of the top of the pipes. Do not allow the filter material to become segregated or contaminated prior to, during, or after installation. Segregation results in zones of material too fine to meet the permeability requirements and other zones too coarse to meet the stability requirements. Contamination can clog voids in the material and render the drainage system useless. Nominally compact filter material in trenches and cover up with an appropriate material.

19-7.2 Drainage Pipe Outlets.

Where practicable, feed outlets from drainage pipes into existing storm drainage manholes. Protect outlets 12 inches (304 millimeters) in diameter and smaller, not terminating in a manhole with rodent screens, and locate them to prevent surface water from entering the system. The outlet pipe is typically a 4-inch (100-millimeter) -diameter stiff, non-perforated, smooth-walled PVC or high-density polyethylene (HDPE) pipe, installed with minimum slope of about 3 feet in 100 feet (0.03 meter/meter) (Figure 19-4). Good compaction control of the backfill below, around, and above the outlet pipe is required to avoid transverse shoulder sags. Place the outlet end at least 6 inches (150 millimeters) above the 10-year ditch flow line and protect with a headwall and splash block that is blended into the slope. Mark the outlet end (headwall) to prevent damage by mowers or other equipment.

Figure 19-4 Outlet Pipe Design



19-7.3 Drainage Pipe Access.

Provide manholes or other access points for inspection and cleaning approximately every 250 to 500 linear feet (75 to 150 linear meters), depending on grades, and at the upper ends of runs. If elbows are used instead of manholes, provide and use pipes with a radius and diameter of the pipe of sufficient size to allow cleaning and inspection equipment to pass.

19-7.4 Caution.

<u>Caution:</u> Take care to ensure that construction equipment does not track over the completed edge drainage system as it can damage the drain pipe. Also, monitor the drainage system regularly by checking the functioning of the drains at outlet ends or by using a video-based pipe inspection system. A damaged edge drainage system that retains water within the trench is more damaging to pavement performance than having no edge drainage system.

CHAPTER 20 MAINTENANCE OF HEAT-RESISTANT CONCRETE

20-1 INTRODUCTION.

Concrete pavement damage resulting from high temperatures of jet blast includes spalling, delamination, aggregate popouts, scaling, cracking, and loss of joint sealant (Figure 20-1). Such damage can result in FOD that can damage aircraft engines.

Figure 20-1 Heat-damaged Concrete

Spalling and Scaling **Delamination and Blistering**

Conventional PCC rapidly loses free moisture around 212 degrees F (100 degrees C) and starts to lose its chemically combined water at around 250 degrees F (121 degrees C). The highest rate of dehydration occurs around 350 degrees F (177 degrees C). At temperatures above 350 degrees F (177 degrees C), pavement damage increases exponentially. In accordance with this UFC and UFGS 32 13 13.43, *High Temperature Concrete for Airfields with Applied Pavement Temperatures of 482 Degrees C (900 Degrees F) or Higher Using Lightweight and Traprock Aggregates*, use of high-temperature concrete is mandatory where operations apply temperatures at the surface of the concrete from 900 degrees F to 1700 degrees F (482 degrees C to 926 degrees C), even for durations of a fraction of a second. Operations that apply temperatures at the surface of the concrete from 300 degrees F to 900 degrees F (148 degrees C to 482 degrees C) for longer durations may use this UFC and UFGS 32 13 11. If using UFGS 32 13 11, modify the specification to require only traprock for the coarse aggregate for durations greater than 1 minute.

High-temperature concrete (HTC) has been used in vertical landing zones (VLZ), aprons, forward arming and refueling pads (FARP), taxiway hold points, trim pads, and engine warm-up or run-up pads. The pads are usually associated with the operations of \1\ V-22 /1/, F-35B, and AV-8 aircraft but have also been used in parking areas affected by APUs on B-1 and F-18 aircraft.

20-2 MAINTENANCE AND REPAIR.

Material and construction requirements are intended to provide the longest performance available. Periodic maintenance is required at installations subject to high heat scenarios as described below.

20-2.1 Pavement Markings.

Commonly available pavement marking paints are not expected to maintain a bond or survive repeated heat applications from vertical landing (VL) operations from aircraft on the high-temperature range. Markings are on the perimeter of the VL pad so they will experience damage only when aircraft land near the safety zone. Paint may not adhere to pavement surfaces coated with sodium silicate. Avoid over spraying areas treated with surface sealers.

20-2.2 VL Pad Surface Grinding.

Tests indicate the HTC used for the VL pad may need 0.125 to 0.25 inch (3.2 to 6.4 millimeters) ground off the surface after about 500 landings in the same location. The time required for 500 landings in the exact same location is a function of the operational tempo of the VL pad and landing accuracy. It is reasonable to expect that grinding will be required every three to seven years to reduce spalling and potential FOD. Grinding removes damaged HTC and maintains the slope for required surface drainage. Add an additional 0.5 inch (12.7 millimeters) to the VL pad design thickness to allow future grinding.

20-2.3 Frequency and Depth.

Visually determine frequency and depth of grinding by examining the VL pad pavement surface. Do not exceed 2 inches (50 millimeters) total depth of grinding during the lifetime of the VL pad pavement. Beyond this depth, the concrete cover over the continuous reinforcement is too thin for proper performance. Distresses (e.g., additional cracking or spalling) may begin to develop. The surface area to be ground includes the VL pad plus a limited portion of the adjacent safety zone. Grinding of the remainder of the safety zone or the shoulder areas is not required. Pavement markings and the isolation joint sealant will need to be replaced in areas affected by grinding.

20-2.4 Diamond Grinding Procedures.

20-2.4.1 Pre-Planning.

Prior to grinding, consult the as-built drawings to determine the surface grades and better plan the grinding depth and area to maintain drainage. In the absence of as-built drawings, field-survey the pad using conventional survey equipment. A survey grid of 10 feet by 10 feet (3 meters by 3 meters) is adequate; however, use a grid that matches the width of the grinding machine cutting head for enhanced control of final surface elevations.

20-2.4.2 Diamond Grinding Equipment.

Use concrete grinding machines, not milling machines with hardened teeth. Provide and use grinding machine saw blades impregnated with an industrial diamond abrasive. Assemble saw blades in a cutting head mounted on a machine designed specifically for diamond grinding, which will produce the required texture and smoothness level without damage to the concrete pavement or joint faces.

Provide and use saw blades 0.125 inch (3 millimeters) wide, with a minimum of 60 blades per 12 inches (300 millimeters) of cutting head width, depending on the hardness of the aggregate. Provide and use machines capable of cutting a path 3 feet to 4 feet (0.9 meter to 1.2 meters) wide. Grinding equipment that causes ravels, aggregate fractures, spalls, or disturbance to the joints is prohibited. Ensure finished surfaces are free of raised slivers (commonly referred to as “fins”).

20-2.5 Water Cutting.

It may be possible to remove the recommended 0.125 to 0.25 inch (3 to 6 millimeters) using special high-pressure water-cutting machines fitted to pavement surface scrubbers. These are substantially more advanced machines than a conventional pressure washer, and are typically trailer-mounted with a pressure rating of approximately 10,000 psi (68.9 megapascals). This procedure requires validation by USACE (CEMP-ET), the AFCEC pavements SME, or NAVFAC EXWC for up-to-date guidance.

20-2.6 Surface Sealing.

Re-apply sodium silicate solution after grinding. Prior to application, clean the VLZ concrete areas (including the VL pad and safety zone, at a minimum) using a rotary power washer/scrubber. To remove tire rubber and, to the extent possible, fuel and oil spills, use a rotary power washer/scrubber. Apply the sealer as described for a new installation. Ensure all joint seals are in good condition prior to any application of surface sealers. Replace any damaged, cracked, debonded, or missing joint seals in accordance with UFC 3-250-08FA, *Standard Practice for Sealing Joints and Cracks in Rigid and Flexible Pavements,* before applying any surface sealer.

20-2.7 HTC Patching and Materials.

Do not design or construct partial-depth patches on areas subject to vertical take-off or landing or short take-off operations of the F-35B or located on a VLZ without prior approval of the Pavements DWG. Partial-depth patches are allowed on pavement that is continuously reinforced in both directions provided the partial-depth patching uses hydro-demolition to remove material within 2 inches (50 millimeters) of the rebar and the bottom of the repair is at least 2 inches (50 millimeters) below the bottom of the rebar. If the remaining concrete is cracked or less than 2 inches (50 millimeters), continue to remove all the concrete and treat as a full-depth repair. Patches of areas not subject to vertical take-off or landing or short take-off operations of the F-35B and not located on VLZs can be design and constructed as a partial-depth repair when full-depth cracks are not present in the repair area. Otherwise, a full-depth patch must be designed and constructed in these areas.

Design and construct partial-depth patches with a minimum 3 inches (75 millimeters) deep, ± 0.25 inch (± 6 millimeters), instead of the standard 2-inch (50-millimeter) minimum used for conventional concrete pavements. Shallower repairs separate from the rest of the pavement due to thermal expansion cycles. Partial-depth patches deeper than 3 inches (75 millimeters) in reinforced areas are not recommended, as the depth of cover of the longitudinal reinforcement is 4 inches (100 millimeters) unless hydro-demolition is used to excavate the patch area at least 2 inches (50 millimeters) below the bottom of the rebar.

Provide and use materials for patching HTC surfaces that match the materials used to originally construct the pad. If the original HTC materials are not available, specify and use only materials that will survive high-temperature applications and are approved by the contracting officer or for in-house work by the Pavements DWG. Some prepackaged rapid-repair materials that will survive high-temperature applications are available on the GSA schedule at the time of the publication of this UFC.

20-2.8 PCC Patching.

Applying high temperatures to a PCC safety area may generate spalling. The surface sealer may allow the PCC to survive a few landings per location. Landing on PCC may also result in very thin delamination, which can be corrected by brooming and resealing with sodium silicate. Repeated landings at the same PCC location or over-exposure to high temperatures generates more severe spalling. Repair the PCC with HTC patching materials or conventional PCC. Do not use rapid spall repair materials (e.g., epoxy-based or activated fly-ash products) if sited near the VL pad due to the risk of future high-temperature exposures.

20-3 SUMMARY OF MITIGATION TIPS.

20-3.1 Water/Cement Ratio.

Use concrete with a low water/cement ratio (below 0.42). Properly cure the concrete. Leaner concrete mixes (low cement to aggregate ratio) perform better than richer mixes.

20-3.2 PCC Mix.

Use of hydrated portland cement that has lower calcium hydroxide content is preferable to those with higher calcium hydroxide content for high-temperature applications. For temperatures of 1,500 degrees F (816 degrees C) or more, high alumina cement provides superior performance.

20-3.3 Construction Quality.

Proper consolidation of concrete and proper finishing is critical. Minimize the amount of paste on the surface to minimize scaling.

20-3.4 Proper Material.

Aggregate selection is the most important single material-related factor; however, there is no standard specification for heat-resistant aggregate. Aggregates with low coefficients of thermal expansion (CTE) are desirable. The optimal aggregate is formed at a temperature higher than the expected exposure temperature, such as igneous trap rock. Lightweight aggregates, such as expanded shale and expanded slate, tend to perform better than conventional natural concrete aggregates subject to high temperature. Air-cooled slag aggregates also provide good results.

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CHAPTER 21 REPAIR OF PCC DAMAGED BY POL

21-1 INTRODUCTION.

Engine exhaust combined with petroleum, oil, and lubricant (POL) contamination can damage ordinary PCC pavements. Damage occurs in the form of scaling or spalling of the top 1 to 2 inches (25 to 50 millimeters) of the pavement. Pavement fragments from these surface scales can cause FOD to aircraft engines. High exhaust temperatures, coupled with spilled fluids (POL), damage ordinary PCC airfield pavements. Damage occurs progressively to the pavement surface under repeated thermal cycling and chemical reaction of the spilled aircraft fluids with the cement paste.

PCC surface treatments reduce or eliminate spalling, scaling, and other surface damage caused by heat and POL. These treatments are suitable for repairing PCC damaged by POL and heat from B-1, F-18, F-35, \1\ V-22 /1/ operations. Apply these treatments prior to POL contamination, where possible. When in doubt as to the length or number of operations, treat the affected area.

Do not use this UFC to deny or restrict operations of any aircraft, including \1\ V-22s /1/. Use it to identify and establish projects and protocols to effectively support air operations.

\1\ When selecting a pavement surface treatment, consider the pavement condition, duration and frequency of operations, and any scheduled maintenance/repair work.

Most concrete coatings only work on clean, uncontaminated concrete. On pavement with petroleum, oil and lubricant (POL) stains, coatings slow, but do not eliminate, degradation. Contaminated concrete slabs fail below the coating and the coating delaminates.

For newly replaced or pavement in otherwise good condition free of POL contamination, supporting daily operations that require long-term performance, use Epoxy Coatings per Paragraph 21-3.6 and High Temperature Aggregates per Paragraph 21-4.6. /1/

21-2 PRIMARY DAMAGE MECHANISMS.

Testing has revealed three primary damage mechanisms: thermal fatigue, vapor pressure, and chemical degradation. Thermal fatigue has produced failures without the presence of POL. Vapor pressure damage has been observed when the water vapor pressure cannot be relieved fast enough during the heating phase. Chemical degradation results in a significant loss of strength—up to 50 percent in some cases—which accelerates failure. Chemical degradation by itself can result in raveling of the concrete, which has been observed under APUs for the B-1 and F-18; it does not produce scaling, but accelerates scaling.

21-3 REPAIR TECHNIQUES/MATERIALS.

The following techniques can reduce damage from combined exhaust heat and POL.

\1\ Repair and treat effected area larger than the area subject to damage directly under each Nacelle. Repair and treat the surface all concrete slabs (the entire slab) which have any portion of the slab within 20 feet from the vertical nacelle of the parked aircraft or asphalt within 20 feet of the nacelle.

Repair and treat areas where aircraft are likely to release POL and expose the contaminated pavement to heat from the nacelles for more than two to five minutes in the same location.

Repair and treat any locations used as a FARP. If a FARP is asphalt instead of PCC, use a fuel resistant asphalt inlay per UFGS 32 12 17.19 Fuel Resistant Asphalt Paving For Airfields - Surface Course or protect with a fuel resistant micro surface such as Grip-flex. /1/

21-3.1 Sodium Silicate Application.

\1\ Recommend limiting sodium silicate application to use as a surface hardener. Sodium silicate solutions are ineffective as waterproofing sealers since they have a limited depth of penetration and are unable to stop or reduce hydrostatic pressure.

Sodium silicate treatments do not eliminate the degradation under the V-22 Nacelles. The sodium silicate slows, but does not stop POL penetration and may suffice for transient aircraft, but not for permanently assigned aircraft. Apply surface treatment prior to any POL contamination. Allow a minimum of 70 days prior to applying sodium silicate coating to a surface after the PCC curing compound removal. /1/

21-3.2 Multifilament Fibers.

Multifilament polypropylene fibers at a dosage of 3 pounds per cubic yard (1.8 kilograms per cubic meter) of concrete further improves concrete durability when subjected to exhaust heat.

21-3.3 Polymer Coatings.

The US Army Corps of Engineers, Engineering Research and Development Center Geotechnical and Structures Laboratory performed laboratory test and field demonstrations with two polymer coats which, when combined with a sealer, provided results equal to or greater than coal tar emulsions. If polymer coatings are used on the airfield pavements, specify or use materials and methods recommended in ERDC/GSL Technical Report TR 03-24. Do not specify or use any materials or methods other than those included in this report without prior approval of the Pavements DWG. Do not specify or use polymer coating on any areas used for landing or take-off of jet, turbo-prop, \1\ or V-22 /1/ aircraft. These products have been used on parking aprons and FARPs.

21-3.4 Surface-Applied Penetrating Chemically Reactive Silicates.

Surface-applied penetrating water-soluble, chemically reactive silicates migrate through micropores and chemically bond with calcium hydroxide and calcium chlorides in cements to form calcium silicates which inhibit hydrolysis with POL esters. They also fill micropores, reducing the permeability of concrete. If surface-applied penetrating water-soluble, chemically reactive silicates are used on the airfield pavements, specify or use materials and methods that do not leave a surface film or coating and cannot be scraped or removed from the surface using mechanical means. Specify and use only those products and methods that reduce the chloride ion penetration in PCC by at least 60 percent, as determined by ASTM C1202, AASHTO T277, or AASHTO T259, and that penetrate at least 0.75 inch (19 millimeters) into the surface of the concrete. Materials and methods proven effective on airfield pavements are documented in “Auxiliary Power Unit (APU) Resistant Concrete: State-Of-The-Art,” by Anderson, John R., et al, 1 March 2000. Do not specify or use any materials or methods other than those included in this report without prior approval of the Pavements DWG.

21-3.5 Magnesium Phosphate Cement (MPC)

MPC is a different cement formulation than conventional PCC. MPC is less sensitive to reaction with acids than PCC. It can be extended with any normal aggregate; however, for applications under B-1 aircraft, using aggregate that is not reactive with acids (limestone is reactive) is necessary. MPC is a fast-setting cement that reaches high strength (above 5000 psi [34.5 megapascals]) in less than one hour, with an ultimate strength after several hours of approximately 8000 psi (55.1 megapascals). It is more resistant to the types of aviation fluids that have caused damage to pavement under Navy F/A-18 Hornet fighter aircraft (TDS NAVFAC EXWC-CI-1403, *Mitigating Concrete Damage Caused by Engine Exhaust Surface Temperature Below 500 °F]*).

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21-3.6 Epoxy Coatings

The US Army Corps of Engineers, Engineering Research and Development Center Geotechnical and Structures Laboratory performed laboratory testing on and field demonstrations with multiple coatings. Two epoxy coatings identified as suitable for protecting clean concrete surfaces from POL penetration that support aircraft traffic are Epoxy-A Addagrip 1000 System, and Mod Epoxy-1 PolySpec Thiokol FEC 2234. If using epoxy coatings on newly placed airfield concrete pavement, specify or use materials and methods recommended in Transportation Research Record TRR 20-07019, Full Scale Evaluation of Surface Treatments for Airfield Concrete Pavement Repair, 26 April 2021, https://journals.sagepub.com/doi/full/10.1177/03611981211008882. Using any materials or methods other than those included in this technical report requires prior Pavements DWG approval. Do not specify or use epoxy coating on any area used by jet, turboprop, or V-22 aircraft for landings or take-offs. Only use these products on parking aprons free from POL contamination.

THIOKOL Primer and Polysulfide Sealant are elastomeric joint sealants and are not suitable for V-22 Parking Aprons. Do not use; Transpo T-70 (HMWMMA) or TK Products epoxy (TK-2110) as they do not adequately adhere.

21-3.7 Joint Sealant

Engine exhaust from the V-22 deteriorates standard joint seal material in concrete pavements. During ground operations with inoperative exhaust deflectors, applying moderately high power settings or ground power assurance checks can cause surface spalling.

Use Silicones joint seals in accordance with ASTM D5893 for general applications where the V-22 does not take-off vertically or perform ground runs. Use Chloroprene (Neoprene) or fluorocarbon adhesive joint seals in accordance with ASTM D2628 for locations where the V-22 takes-off vertically or performs ground runs for operations or training. Neoprene shows good chemical resistance and heat resistance up to 550ºF. Fluorocarbon adhesive shows excellent chemical and heat resistance up to 750ºF.

Plan to reapply join sealant every five to 10 years. Preventing POL contamination of PCC is the key to long-term performance. This requires cleaning and resealing the joints when there is any joint seal failure. Plan to reseal the joints when re-sealing the surface even if not failed. For damaged surface coatings (i.e. chipped or cracked), or if the underlying PCC cracks along with the surface seal, decontaminate the area and reseal before re-contamination with POL. /1/

21-4 REQUIREMENTS.

21-4.1 Cleaning.

Before applying surface sealants, remove all contaminants such as POL, dust, curing compound, and moisture. If water is used to clean the pavement, dry the pavement and keep it dry for at least 24 hours prior to any surface application.

21-4.2 When to Seal.

Initiate steps to protect the pavement within six months of commencing operations; however, apply surface sealants, such as sodium silicate, no earlier than 70 days after placing pavement.

For locations subject to less than two operations per week, this time may be extended to 12 months. Surface treatments are most effective when placed prior to the application of heat loads and prior to any contamination by POL. Damage to PCC has been observed as early as six months and as late as 60 months after operations commence.

21-4.3 Distress Repairs.

When possible, repair the following distresses within the treatment area prior to the placement of surface treatments: damaged joint and crack seals, spalls, and medium- and high-severity patches as defined by ASTM D5340. Surface treatments can be applied before completing these repairs; however, retreatment of the surface within 6 inches (150 millimeters) of the repair area is recommended after completing the repairs. If the repair includes the placement of concrete or magnesium phosphate-based cements, do not reseal the surface of the repair during the first 70 days after placement.

21-4.4 Existing Distress Effects.

There are some distresses that, if present, reduce the effectiveness of the surface treatment; therefore, if you have shattered slabs, medium- or high-level durability cracking (D cracking), medium- or high-severity scaling, or medium- or high-level ASR as defined in ASTM D5340, the surface treatment can be omitted because they are not effective. In rare cases where older pavements have had their entire surfaces scaled and additional scaling or surface cracking has ceased, surface treatments can increase the life span of the pavement and can be effectively applied. Parking/operating the \1\ V-22 /1/ on pavements with these types and levels of distresses increases the rate of deterioration under the nacelles. Applying surface treatments to pavements with low-severity distresses of these types increases the service life of the pavement.

21-4.5 Where to Seal.

Seal those areas most susceptible to POL and direct exhaust, a circular area with a minimum 15-foot (4.5-meter) radius, centered where the engine exhaust is directed at parking, maintenance, and preflight check areas, including parking/maintenance ramps, forward area refueling points (FARP), and hot refuel/re-arm pads.

21-4.6 High-Temperature Aggregates.

If constructing new or replacing existing pavement to support \1\ V-22 /1/, or F-35A/B parking, maintenance, FARP, or hot refuel/re-arm operations, a high-temperature aggregate such as an igneous trap rock, expanded shale, or expanded slate may be used as the coarse aggregate in the concrete mix design. Unlike a concrete mix for a vertical landing pad, the fine aggregate can be a natural sand. If the cost of the pavement using high-temperature aggregates is more than twice the cost of standard \1\ airfield /1/ PCC then construct/repair the pavement using standard \1\ airfield /1/ PCC. Apply sodium silicate. However, do not apply the sealant any earlier than 70 days after placement of the concrete repair material. Where practical, include multifilament polypropylene fibers at a dosage of 3 pounds per cubic yard (1.8 kilograms per cubic meter) of concrete in any PCC or PCC with high-temperature aggregates.

21-5 PCC SODIUM SILICATE SURFACE SEALING.

The sodium silicate surface sealer is absorbed into the top 0.125 inch (3 millimeters) of the concrete, providing resistance to high exhaust temperatures and POL stains. Sodium silicate requires reapplication if surface wear occurs. Do not apply sodium silicate surface sealers to asphalt pavement.

21-5.1 Sodium Silicate Solution.

Provide and use a sodium silicate surface sealer that is a colorless, water-based solution containing 9 percent sodium silicate. While many manufacturers provide a product with this concentration, it often comes in 40 percent solutions. Higher-concentration products can be diluted to 9 percent sodium silicate. The 9 percent sodium silicate provides optimum concrete penetration with three applications. In order to dilute a 40 percent solution of sodium silicate to 9 percent, add 3.5 parts of water to 1 part of the 40 percent solution, i.e., for every gallon of 40 percent solution add 3.5 gallons of water. The sodium silicate sealer is applied to PCC subject to heat and POL, such as from F-35B, \1\ V-22 /1/ engines. Use of concentrations higher than 9 percent results in an excess buildup that will bubble and discolor under the heat load of the nacelles. If this occurs, remove the excess material by washing the area with warm water. Use a scrub brush and/or a high-pressure pump to speed removal. In extreme cases, use ultra-high-pressure rubber removal equipment. The portion of the sodium silicate that has combined with the concrete surface remains in place.

21-5.2 Surface Cleaning.

Before application, clean the concrete with a rotary power washer/scrubber to remove tire rubber, curing compound, and POL. If heavy POL contamination is present or if the sodium silicate will not penetrate the surface, follow the procedures in paragraph 21-6 before applying the pavement sealant.

21-5.3 When to Seal.

Do not apply the sodium silicate earlier than 70 days after the pavement has been placed. Testing has determined that sodium silicate applications prior to 70 days result in surface flaking of the PCC. Ensure all curing compound has been removed prior to sealing the PCC.

21-5.4 Joint Sealing.

Properly seal the pavement joints before applying the sodium silicate. If the joint seals are not in good condition then repair or replace them before applying the sodium silicate.

21-5.5 Paint Markings.

Ensure all paint markings (including shadow markings) are in place, in good condition, and contain no cracks or chips before applying the sodium silicate. Repair or replace damaged markings before applying the sodium silicate.

21-5.6 Environmental Conditions.

Do not apply the sodium silicate until the concrete surface has been dry for at least 24 hours and the pavement markings have been applied. Do not apply the sodium silicate until the air temperature is 40 degrees F (4.4 degrees C) or higher and relative humidity is 80 percent or less, both during application and for 48 hours after application. It is acceptable to apply the sodium silicate over pavement markings and glass beads.

21-5.7 Surface Seal Application.

Apply three coats of the sodium silicate solution with low-pressure airless spraying equipment to ensure uniform application or use a roller with a 0.25-inch to 0.5-inch (6-millimeter to 13-millimeter) nap. Start applying the solution at the highest point in the pavement and continue downgrade. Each coat will cover no more than 200 square feet per gallon (4.9 square meters per liter). Avoid excessive application, as it may cause efflorescence and reduce friction. Allow the sodium silicate to penetrate for two hours then wash off any visible excess (ponded) solution. Allow the area to dry for at least 24 hours between each coat.

21-5.8 Final Evaluation.

After allowing the last coat to dry for 24 hours, evaluate the surface for any excess silica or dusting. Wash off any excess silica or dusting as needed. Protect the application from any pedestrian or vehicular traffic until the last coat has dried.

21-6 CLEANING POL CONTAMINATION FROM PCC AND PCC JOINTS.

21-6.1 Stains.

If POL stains are present, treat the entire stain before sealing the pavement. Several methods to remove POL stains and, in the case of POL stains on joints, improve the bond to the joint surface are described below. Most stains require several applications and may require the use of more than one treatment method. By implementing all of these steps maximum removal will be achieved; however, one or more of the steps can be omitted to achieve acceptable results. Steam may be used; however, steam alone will provide some cleansing of the immediate surface but not penetrate deep enough to provide a long-term result. Properly collect and dispose of any POL-contaminated water, paste, or solids.

21-6.2 Dawn (or Simple Green) Dishwashing Detergent and Hot Water.

Apply to the stained area and scrub to develop a thick lather. Let set for five minutes then rinse with warm/hot water. Use of steam to pretreat the area and rinse may aid removal.

21-6.3 Tri-Sodium Phosphate (TSP).

TSP (also called sodium orthophosphate) is available in hardware stores.

Note: Some states have banned this product because phosphate can cause problems with waterways. Check with the environmental office before using.

Mix one measure of TSP with six measures of water. Apply over the stain with a paintbrush and allow to dry completely before scraping off the dried paste. Rinse the surface and scrub with a stiff brush and clean water.

Caution: DO NOT MIX TSP WITH ANY ACID! A violent reaction can occur and release noxious gas. You can use both products but use them separately, with a thorough rinsing with water between applications.

Alternate application method: Dissolve 1 pound, 6 ounces of TSP in a gallon of water. Add enough finely ground calcium carbonate (also called whiting or agricultural lime) to make a thick paste. Agricultural lime is available at garden supply stores. Spread the paste over the stain and allow it to dry for a day, if possible. Brush off the dry paste with a stiff brush and scrub the concrete with water. Provide and use PPE and keep the paste away from aircraft due to the high pH of the paste. If it is windy, protect the treated area until the area is cleaned and rinsed to keep the caustic material from blowing around the apron.

21-6.4 Sodium Hydroxide.

If TSP is not available or not allowed, use sodium hydroxide. Prepare and use a solution of 5 percent sodium hydroxide (caustic soda: $NaOH$). Apply it over the stain with a paintbrush and allow to dry for at least 24 hours. Rinse and scrub with clean water then repeat as required. Provide and use PPE and keep the solution away from aircraft due to the high pH of the solution. If it is windy, protect the treated area until the area is cleaned and rinsed to keep the caustic material from blowing around the apron.

21-6.5 Super Washing Soda.

Washing Soda or Super Washing Soda, sodium carbonate, can be used as a substitute for TSP or sodium hydroxide; however, it does not work as well and may take more applications to remove the POL. Apply in accordance with manufacturer directions. Rinse well with water. This is an organic salt. If it is windy, protect the treated area until the area is cleaned and rinsed to keep the salt from blowing around the apron.

21-6.6 Phosphoric Acid Cleaner.

Apply phosphoric acid cleaner in accordance with manufacturer directions. Rinse well with water and sodium carbonate (washing soda or soda ash) to neutralize the pH then rinse with clear water. This product will etch the concrete so do not leave it on too long and ensure the area is rinsed well to ensure no acid is left on the concrete. Acid deteriorates ordinary Portland cement.

21-6.7 Bacteria and Enzymes that Remove Oil Stains in Concrete.

Biological materials (bacteria and enzymes) that consume POL can also help to remove stains. Use a biologic product as a final treatment prior to sealing. The bacteria stay in the concrete and help eliminate any remaining POL over time. Follow the product directions.

21-6.8 Replacement.

If the contamination is too extensive, consider removal/repair.

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CHAPTER 22 F-35B AND C CRITICAL AREAS

22-1 BACKGROUND.

This chapter provides guidance concerning maintenance and repair of rigid and flexible pavements with regard to F-35 variant critical areas. Critical areas include, but are not limited to, areas designated for short take-off, flight carrier landing practice, and vertical landing and take-off operations which are further defined in 22-6 Definition of Critical Areas. Because of the asymmetrical external pressures of the F-35 variants, it is necessary to maintain an elevated maintenance policy for pavement within the critical areas the F-35 perform their operations.

22-2 ASPHALT CONCRETE PAVEMENT.

22-2.1 Distresses in Asphalt Concrete Pavement.

Certain asphalt pavement distresses, as described in UFC 3-260-16 *O&M Manual: Standard Practice for Airfield Pavement Condition Surveys*, are especially susceptible to asymmetrical applications of the F-35 variant exhaust pressures. Asphalt pavements that exhibit the distresses of; block cracking, corrugation, swelling, and slippage of all severities, joint reflection cracking, and longitudinal and/or transverse cracking, of medium and high severities and shoving of all severities are all distresses that put asphalt pavements in critical areas at risk of partial or full depth delamination or “erosion”. Many of the distresses listed are found in concrete to asphalt transitional areas.

22-2.2 Maintenance of Asphalt Concrete Pavement.

Maintenance of asphalt pavement in critical areas must be considered as stop-gap maintenance only until reconstruction with concrete can be contracted. For the purposes of stop-gap maintenance, the distresses of block cracking, corrugation, swelling, and slippage of all severities require full depth asphalt concrete patching in the critical areas. The distresses of joint reflection cracking, and longitudinal and transverse cracking of medium and high severities require shallow depth asphalt concrete patching in the critical areas. Lastly, the distress of shoving of all severities require shallow depth asphalt concrete patching in the critical areas. The definitions of pavement distresses and severity levels and stop-gap maintenance recommendations are described in reference UFC 3-260-16 *O&M Manual: Standard Practice for Airfield Pavement Condition Surveys*. The critical areas are defined in 22-6 *Definition of Critical Areas*. Perform all repairs in accordance with UFC 3-270-01 O&M Manual: Asphalt and Concrete Pavement Maintenance and Repair, Chapter 3 *Full-Depth Asphalt Patches* and Chapter 4 *Procedural Steps (Partial-Depth Patch).* The required asphalt pavement stop-gap maintenance in the critical areas is cost prohibitive over time; therefore, consideration must be made to either limit the mission or convert these pavements to plain jointed concrete pavements.

22-3 PLAIN JOINTED CONCRETE PAVEMENT.

22-3.1 Distresses in Plain Jointed Concrete Pavement.

Concrete pavement distresses, as described in UFC 3-260-16 *O&M Manual: Standard Practice for Airfield Pavement Condition Surveys*, are also susceptible to asymmetrical impacts of the F-35 variant exhaust pressures. Concrete pavements that exhibit full depth corner breaks, full depth linear cracking, joint sealant damage, joint and corner spalls, and partial depth repairs in critical areas, as described in 22-6 *Definition of Critical Areas*, can result in failure by separation or "erosion". Distresses that diminish mechanical restraint (aggregate interlock or bond) are especially susceptible to failure and include joint and corner spalls, and debonded partial depth concrete repairs.

22-3.2 Maintenance of Plain Jointed Concrete Pavement.

The following are distress repairs required within critical areas as defined in 22-6 *Definition of Critical Areas*: Existing partial depth repairs (small and large patches) of all severities require full depth concrete repairs. Joint and Corner spalls of medium and high severity require full depth concrete repairs. Joint Sealant damage of medium and high severity requires localized joint sealant replacement. Full depth concrete repairs must include dowels to ensure repairs are mechanically fixed in place. Any linear cracking or corner breaks that exhibit lack of aggregate interlock require full depth repairs. If linear cracking and corner breaks are mechanically fixed by dowels and aggregate interlock, then only crack sealing per UFC 3-270-01 *O&M Manual: Asphalt and Concrete Pavement Maintenance and Repair*, *Chapter 12 Concrete Pavement Crack Sealing* is necessary. Due to the requirement of full depth repairs, if slabs have multiple distresses it may be more economical to replace the entire slab. The definitions of pavement distresses and severity levels can be found in UFC 3-260-16 *O&M Manual: Standard Practice of Airfield Pavement Condition Surveys*. Perform all repairs in accordance with UFC 3-270-01 O&M Manual: Asphalt and Concrete Pavement Maintenance and Repair, Chapter 14 Full-Depth Repair of Concrete Pavements.

22-4 MAINTENANCE OF CONTINUOUSLY REINFORCED CONCRETE PAVEMENT

Refer to UFC 3-270-01 *O&M Manual: Asphalt and Concrete Pavement Maintenance and Repair*, Chapter 20 *Maintenance of Heat-resistant Concrete* for maintenance of continuously reinforced concrete pavements. The partial depth repair methods described for heat resistant concrete can be applied for use in conventional concrete.

22-5 REQUIRED MATERIAL FOR MAINTENANCE AND REPAIR

Cementitious material used for full depth patches must be like parent concrete material to be repaired. Conventional concrete must be used in non-heat resistant concrete critical areas. Heat-resistant concrete is required in heat resistant concrete critical areas. Due to the temperatures of the F-35 variant exhaust only use ASTM D5893/D5893M silicone joint sealant.

22-6 DEFINITION OF CRITICAL AREAS

22-6.1 Short Take-off (STO) Areas

The critical area boundaries for STO operations is defined as the full width of the runway, and 457 meters (1,500 feet) in length (122 meters (400 feet) behind and 355 meters (1,100 feet) in-front of the F-35B engine). It is necessary that field operations designate a starting position for this operational maneuver. Refer to Figure 22-1 *STO Critical Area Scenario 1* and Figure 22-2 *STO Critical Area Scenario 2*.

22-6.2 Flight Carrier Landing Practice (FCLP) Critical Areas

The critical area boundaries for FCLP operations is defined as to the runway edge left of the centerline and 50 feet right of the centerline, and 396 meters (1,300 feet) in length (91.5 meters (300 feet) from runway threshold to 488 meters (1,600 feet) from runway threshold). Refer to Figure 22-3 *FCLP Critical Areas*.

22-6.3 Vertical Landing Pad (VLP) Critical Areas

The critical area boundaries for a VLP is defined as the Vertical Landing Pad and the 61 meter by 61 meter (200 foot by 200 foot) Safety Zone UFC 3-260-01 *Airfield and Heliport Planning and Design*, Figure 8-23 *Vertical Landing (VL) Pad Facility Outline with Safety Zones*.

22-6.4 LHD STOVL Critical Areas

The critical area boundaries for a LHD STOVL Facilities is defined as Area A and Area D per UFC 3-260-01 *Airfield and Heliport Planning and Design*, Figure 8-21 *LHD Pavement Surface Types* and Figure 8-22 *LHD Pavement Surface Types Detail*.

22-7 FIGURES

FIGURE 22-1 STO CRITICAL AREA SCENARIO 1

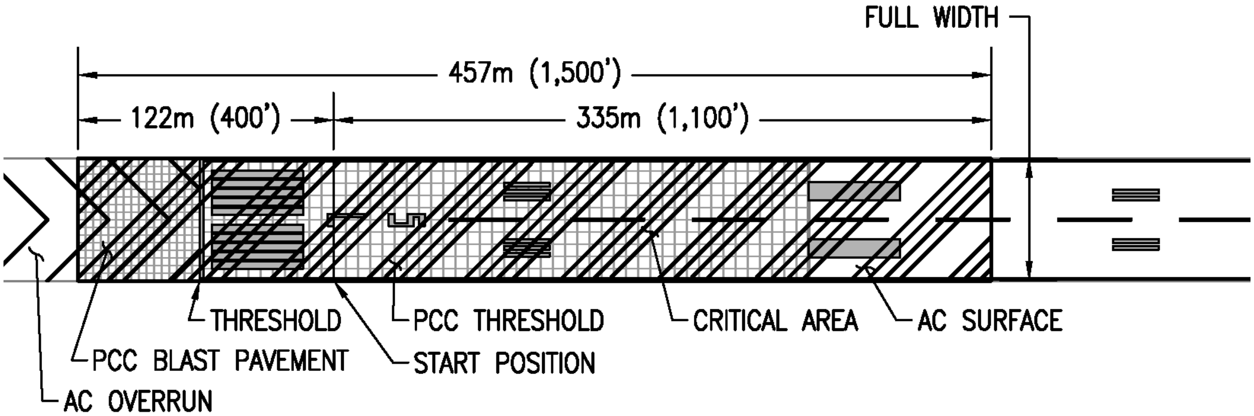


FIGURE 22-2 STO CRITICAL AREA SCENARIO 2

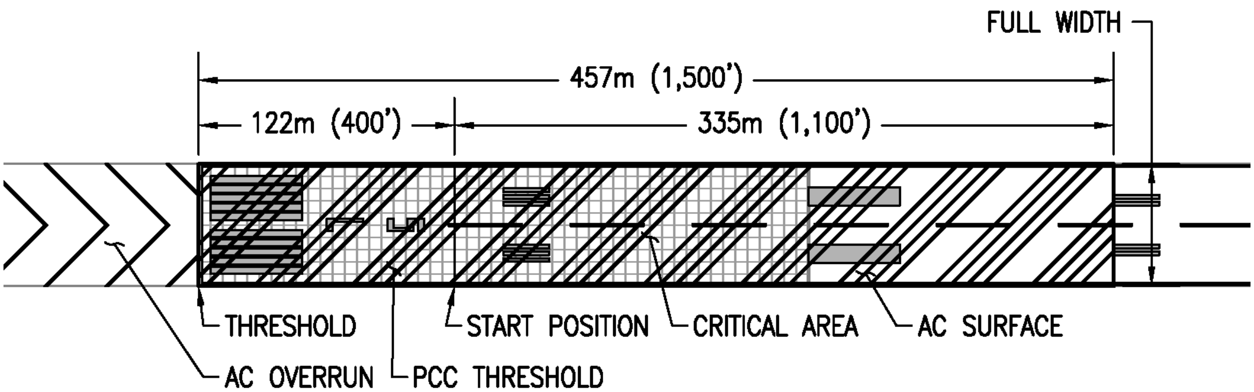
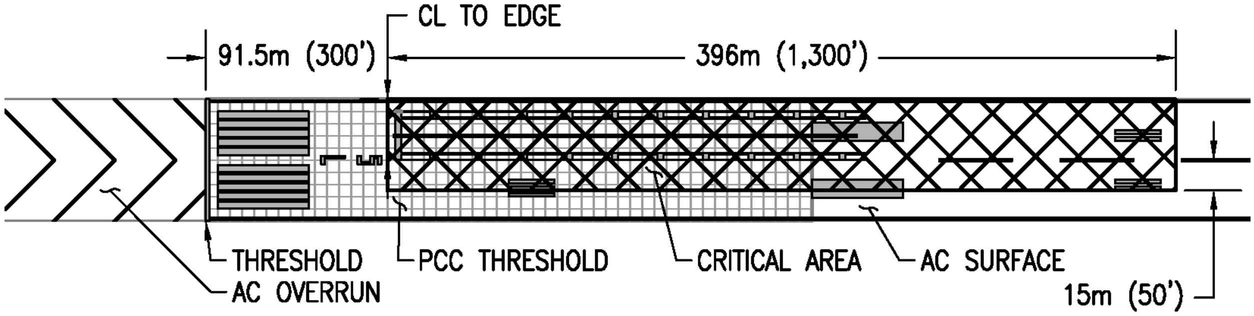


FIGURE 22-3 FCLP CRITICAL AREA



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APPENDIX B BEST PRACTICES

RESERVED

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APPENDIX C GLOSSARY

C	degrees Celsius
F	degrees Fahrenheit
AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
AFCEC	Air Force Civil Engineer Center
AFJMAN	Air Force joint manual
AOS	apparent opening size
APU	auxiliary power unit
ASR	alkali-silica reaction
ASTM	American Society for Testing and Materials
CRC	continuously reinforced concrete
CTE	coefficient of thermal expansion
DBST	double bituminous surface treatment
DOD	Department of Defense
DWG	Discipline Working Group
ETL	Engineering Technical Letter
FAA AC	Federal Aviation Administration Advisory Circular
FARP	forward area refueling point
FOD	foreign object damage
FWD	falling-weight deflectometer
gal/yd2	gallon per square yard
HCA	hot compressed air
HMA	hot-mix asphalt

HMAC	hot-mix asphalt concrete
HTC	high-temperature concrete
in.	inch
JPCP	Jointed Plan Concrete Pavement
kg/m2	kilogram per square meter
kPa	kilopascal
l/m2	liter per square meter
lb/yd2	pound per square yard
LTR	load transfer restoration
M&R	maintenance and repair
mm	millimeter
MMA	methyl methacrylate
MPC	magnesium phosphate cement
MS	medium-setting emulsion
NAVFAC EXWC	Naval Facilities Engineering Command Engineering and Expeditionary Warfare Center
NCS	neoprene compression seal
PFC	porous friction course
PFS	porous friction surface
OSHA	Occupational Safety and Health Administration
PCC	Portland cement concrete
pH	numeric scale to specify the acidity or alkalinity of an aqueous solution
PM	preventive maintenance
POL	petroleum, oil, lubricants

PPE	personal protective equipment
psi	pounds per square inch
PVC	polyvinyl chloride
QA	quality assurance
QC	quality control
QS	quick-setting emulsion
RPM	revolutions per minute
RS	rapid-setting emulsion
SBST	single bituminous surface treatment
SMA	stone mastic asphalt
SME	subject matter expert
SS	slow-setting emulsion
TDS-NAVFAC EXWC	TechData - Sheet Naval Facilities Engineering Command Engineering and Expeditionary Warfare Center
TM	Army technical manual
TSMCX	Transportation Systems Center
TSP	trisodium phosphate
TSPWG	Tri-Service Pavements Working Group
UFC	Unified Facilities Criteria
UFGS	Unified Facilities Guide Specifications
USACE (CEMP-ET)	United States Army Corps of Engineers, Directorate of Military Programs
VL	vertical landing
VLZ	vertical landing zone comprising the imaginary airspace, VL pad, safety zone, shoulders, and connecting taxiway
WMA	warm mix asphalt

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UFC 3-270-08
19 January 2024

UNIFIED FACILITIES CRITERIA (UFC)

PAVEMENT MANAGEMENT

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UNIFIED FACILITIES CRITERIA (UFC)

PAVEMENT MANAGEMENT

Indicate the Military Department Preparing Activity responsible for the document.

U.S. ARMY CORPS OF ENGINEERS (Preparing Activity)

NAVAL FACILITIES ENGINEERING SYSTEMS COMMAND

AIR FORCE CIVIL ENGINEER CENTER

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

Change No.	**Date**	**Location**

This UFC supersedes UFC 3-270-08, *Pavement Maintenance Management*, dated 16 January 2004.

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FOREWORD

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

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

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

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

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

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CHAPTER 1 INTRODUCTION

1-1 BACKGROUND.

Pavement management involves determining the quantity of pavement assets on each installation, organizing information on these assets in a well-defined structure known as a pavement inventory, evaluating the condition of these assets, then analyzing the data to predict future condition, determine maintenance and repair (M&R) requirements, and develop a pavement management plan (PMP).

1-2 PURPOSE AND SCOPE.

This UFC provides guidance on pavement management concepts, processes, and standards.

It addresses requirements for both paved and unpaved airfield, heliport, road, and parking pavements. It defines standards for using automated tools, including the PAVER pavement management application and the Pavement Computer Assisted Structural Engineering (PCASE) application, with a focus on standards for collecting, analyzing, and reporting pavement management data as well as how to use products from these applications to prioritize maintenance and/or repair requirements and develop PMPs.

1-3 REISSUES AND CANCELS.

This UFC reissues and cancels UFC 3-270-08, *Pavement Maintenance Management*, dated 16 January 2004.

1-4 APPLICABILITY.

This UFC applies to all Service elements and contractors responsible for managing pavements. This includes Service evaluation teams or contractors performing pavement evaluations as well as personnel at installations responsible for using pavement evaluation data to develop and execute PMPs.

1-5 GENERAL BUILDING REQUIREMENTS.

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

1-6 GLOSSARY.

Appendix B contains acronyms, abbreviations, and terms.

1-7 REFERENCES.

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

1-8 NATO AIRFIELD AND OPERATIONS STANDARDS.

Comply with NATO STANAG 7131, *Aircraft Classification Number (ACN)/Pavement Classification Number (PCN)*, and NATO Standard AEP-46, *ACN/PCN*, when evaluating/reporting the PCN of airfields used by NATO forces or NATO campaigns. Comply with NATO STANAG 3634, *Runway Friction and Braking Conditions*, and NATO Standard AATMP-13, *Runway Friction and Braking Conditions*, when assessing/reporting the friction characteristic of the airfields used by NATO forces or NATO campaigns. Comply with NATO STANAG 7181, *Standard Method for Airfield Pavement Condition Index (PCI) Surveys*, and NATO Standard AEP-56, *Standard Method for Airfield Pavement Condition Index (PCI) Surveys*, when surveying/reporting the condition of airfields used by NATO forces or NATO campaigns. Comply with TSPWG Manual 3-260-00.NS7210, *Standards for NATO Deployed Air Operations*.

CHAPTER 2 PAVEMENT MANAGEMENT

2-1 DESCRIPTION.

Pavement management is a systematic process used to determine M&R requirements, maintain the safety of operations, and optimize the life cycle cost of paved and unpaved airfield, road, and parking pavement. The overarching concept is to manage pavements to extend life and optimize life cycle cost rather than just repairing or reconstructing pavement when it fails, also known as "worst first."

The pavement management process uses the Pavement Condition Index (PCI) to define the surface condition of the pavement. While the PCI is a key index in pavement management, other indexes developed for other types of evaluations are also used to get a more holistic assessment of the pavement condition, capability, and performance, which is key to developing a PMP and a rational determination of feasible M&R alternatives. Pavement management is implemented at either the network level or project level. The distinctions between the two are the factors considered in the analysis as well as the sampling process/rate used when conducting a PCI survey. This chapter outlines basic concepts and the overall process.

2-1.1 Pavement Condition Index (PCI).

The PCI is a numerical rating based on the type, severity, and quantity of distresses identified during a pavement condition survey. UFC 3-260-16, *O&M Manual: Standard Practice for Airfield Pavement Condition Surveys*, provides instructions for conducting PCI surveys, distress definitions, and PCI computation details. The PCI captures data on the surface condition of the pavement and is used in conjunction with other indexes and considerations to manage pavements.

2-1.2 PAVER Pavement Management Application.

a. Executive Order (EO) 13327, *Federal Real Property Asset Management*, directs efficient and economical use of the federal government's real property assets. The 2013 Under Secretary of Defense (Acquisition, Technology, & Logistics) policy letter mandated a standardized process for facility condition assessments. It also established the Sustainment Management System (SMS) suite of software tools (including PAVER) as the facility and infrastructure condition assessment methodology for DoD to implement EO 13327.

b. PAVER was in use well before OSD mandated its use. It was created to automate the PCI computation process and provide tools used to organize, collect, and analyze pavement management data. PAVER has two versions—a distributed (PC-based) version intended for individual users and a server-based version to provide multiple users access to a central pavement database. Both provide the same engineering functionality but each Service determines whether they use the PC-based, the server-based, or a combination of both versions of PAVER.

c. DoD personnel can download PAVER with a common access card (CAC) from the Tri-Service Pavement Site, https://transportation.erdc.dren.mil/triservice. Installation and activation instructions are also available at this site. Consultants may get PAVER from the Colorado State distribution center, http://www.paver.colostate.edu/, or the American Public Works Association, https://www.apwa.net/store/.

d. Governmental and commercial entities around the world use PAVER. The user can select a language from a list under the **Preferences** drop-down. This capability is useful when dealing with overseas installations or working with NATO partners. Any PAVER database developed for any of the Services will be delivered with preferences set to the English language. Details for using the language option are outlined in the PAVER user manual.

2-1.3 Network-Level Pavement Management.

Fewer samples are inspected for Network-Level Pavement Management, but the samples inspected are representative of the entire section. UFC 3-260-16 defines the required minimum number of inspected samples. In the Network-Level approach, the confidence level in the measured condition is lower. This approach is used when a higher degree of risk is acceptable. Each Service defines when to use Network-Level Pavement Management based on mission requirements.

2-1.4 Project-Level Pavement Management.

Project-Level Pavement Management requires inspecting more samples. UFC 3-260-16 defines the procedure to determine the required number of and the location of the samples based on the systematic random sampling process. The Project-Level approach results in a 95 percent probability that the reported pavement condition index (PCI) is within ±5 points of the true mean PCI (the PCI obtained if all the sample units were inspected), given a defined standard deviation. Use this approach when a higher degree of risk is not acceptable. Each Service determines when to use Project-Level Pavement Management based on mission requirements.

2-2 PAVEMENT INVENTORY ORGANIZATION.

Whether using the Network-Level or Project-Level Pavement Management approach, organize the pavement inventory following the guidance in this UFC to facilitate data collection and analysis for both the PCI survey and other types of evaluations.

The pavement inventory is simply all pavements grouped by their function. Create a separate PAVER database for each pavement inventory at an installation. For example, include all airfield pavements in one database and all road and parking pavements in a separate database.

2-2.1 Inventory Mapping.

Whether doing a PCI survey or structural evaluation and either creating a new inventory or updating an existing inventory, the first step in organizing the inventory is creating a geospatially correct map using a Geographic Information System (GIS) application such as Esri ArcMap or AutoCAD Map 3D. This map defines the geospatial extent of the pavement inventory. It is subdivided into polygons for the networks, branches, sections, and sample units that make up the inventory. Inventory mapping is covered in detail in paragraph 3-2.

2-2.2 Pavement Inventory.

The pavement inventory map imported into PAVER can have inventory attributes included. When it does not, the inventory associated with the map is defined in PAVER. In this case, use the PAVER **Inventory** form to input network, branch, section, and sample unit data, then link the data to the inventory map polygons using the **GIS Assignment** tool. Next, populate the work history for each section and the real property asset information to complete the inventory.

When the GIS is used to create some or all of the inventory as part of the mapping process, the inventory is already linked to the polygon when the map is imported to PAVER.

2-3 PAVEMENT EVALUATION.

Pavement evaluation encompasses activities involving data collection, analysis, and report generation for various aspects of pavement condition, performance, or capability. In addition, two other publications, UFC 3-260-16, *Standard Practice for Pavement Condition Surveys* and UFC 3-260-03, *Airfield Pavement Evaluation*, provide pavement evaluation guidance.

The results of the various types of evaluations provide data on pavement structural capability, surface friction characteristics, roughness, the presence of voids, and the potential for foreign object damage (FOD). While much of this UFC focuses on the PCI and PAVER processes used to define M&R requirements, these other pavement evaluation factors play a significant role in prioritizing requirements, determining courses of action to repair pavement, and developing PMPs.

2-4 DEVELOPING PAVEMENT DETERIORATION MODELS.

PAVER's **PCI Deterioration Families** tool uses PCI and work history data to determine pavement performance. The user groups pavements with similar uses and characteristics into families to develop a deterioration model for each family. This past pavement performance defines the deterioration rate of each family and is used in the PAVER **Condition Performance Analysis** tool and in **Work Planning** to predict the future condition of the pavement in the inventory.

PAVER also uses the family model to generate a **Current Predicted PCI** that provides a real-time estimate of the PCI today. Both the PCI at last inspection and the **Current Predicted PCI** are available in multiple reports and in the **Project Planning** module.

2-5 DEFINE WORK PLANNING PARAMETERS.

PAVER's **M&R Family Model** tools define the parameters used to develop work plans. These parameters are defined for each M&R category: localized operational (aka safety or stopgap), localized preventive, global, and major M&R.

The parameters defined include work types, cost by work type, distress maintenance polices, consequence of maintenance policy, consequent surface, minimum condition, and cost by condition. M&R family models are created for each M&R category then sections are assigned to the appropriate M&R family models.

2-6 DETERMINE WORK REQUIREMENTS.

PAVER's **M&R Work Planning** tool is used to develop work plans based on the PCI deterioration models, M&R family models, and other parameters defined in the **M&R Work Planning** tool based on specific scenarios.

These M&R work plans define near-term and long-term work requirements for each M&R category for each budget scenario. The near-term requirements include specific work types and estimated quantities and costs identified in the year following the latest inspection. The long-term requirements define costs for each M&R category but do not include specific work type or quantity requirements.

2-7 DEVELOP PAVEMENT MANAGEMENT PLANS (PMP).

Work plans generated by PAVER provide a list of repair requirements to develop PMPs. This part of the process involves a person with knowledge of pavement management, design, and construction who uses the PAVER products to prioritize and group requirements into executable tasks and projects.

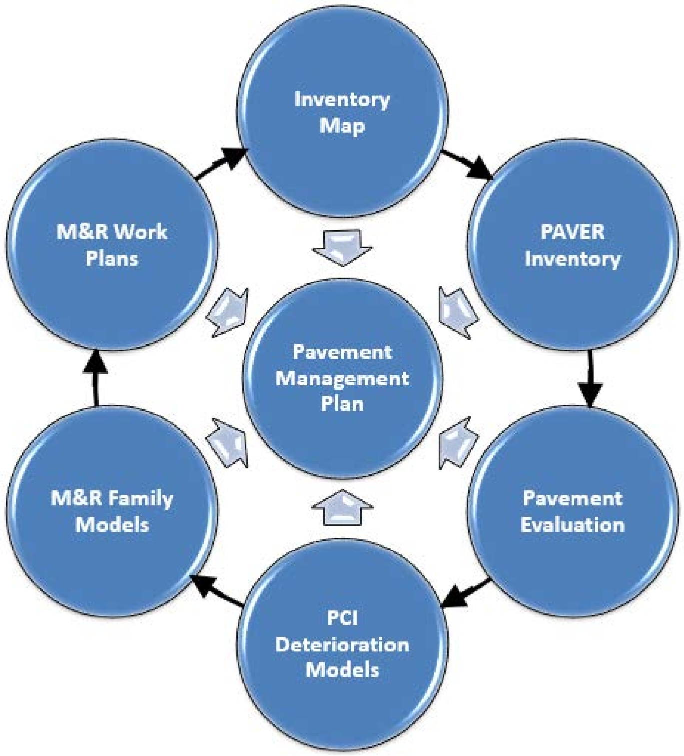
2-7.1 Other Pavement Management Plan (PMP) Considerations.

In addition to the PCI, other important factors such as pavement load-carrying capacity, FOD risk, surface friction characteristics, existing waivers, and operational considerations are used to prioritize and group requirements into executable tasks and projects.

2-7.2 Required Work and Project Planning Tool.

Once requirements are grouped into an executable task for in-house execution or a project for contract execution, they are entered into PAVER using the **Required Project** tool or the **Project Formulation Wizard**. Then rerun the M&R work plan with the required work included to develop a revised work plan. This process may go through several iterations until the entire PMP is defined. The overall process defined above is shown in Figure 2-1.

Figure 2-1 PAVER Pavement Management Process



2-8 STRATEGIC PAVEMENT MANAGEMENT.

Another important aspect of pavement management is the ability to do strategic pavement management analysis. By combining the databases for each installation into a single database, the Services can analyze and generate reports on condition, performance, and M&R requirements at the enterprise level.

This combined database is also known as a “rollup database.” A rollup database is created for airfield pavements and a separate rollup database is created for road and parking pavement. To facilitate enterprise analysis, each PAVER database that is combined in a rollup database must adhere to the standards outlined in this UFC. Services may supplement these standards based on mission-specific requirements.

2-9 SERVICE PAVEMENT EVALUATION PROGRAMS.

Each Service has a centrally managed pavement evaluation program for performing some or all the following evaluation types on a regular cycle: structural pavement evaluations, pavement condition index surveys, friction characteristics evaluations, and void detection surveys.

2-9.1 Airfields.

The types of evaluations performed and the evaluation cycle are determined by Service mission requirements.

2-9.2 Roads and Parking

Road and parking evaluations are typically constrained to PCI surveys but are also performed on a regular cycle as defined by each Service. The organizations listed in paragraph 2-9.3 are responsible for their respective evaluation programs and may be contacted for more information. These organizations are referred to as Service pavement POCs in this UFC.

2-9.3 Points of Contact (POC).

2-9.3.1 U.S. Army.

- Installation Management Command (IMCOM), Army Dams & Transportation Infrastructure in San Antonio, Texas has overall program responsibility.

- Engineer Research and Development Center (ERDC) Geotechnical and Structures Laboratory in Vicksburg, Mississippi performs airfield evaluations.

2-9.3.2 U.S. Navy.

- Naval Facilities Engineering Systems Command (NAVFAC) Atlantic in Norfolk, Virginia has overall program responsibility. NAVFAC/EXWC in Port Hueneme, California provides support to the overall program.

- NAVFAC Airfield Pavement Evaluation Teams perform airfield evaluations.

2-9.3.3 U.S. Air Force.

- The Air Force Civil Engineer Center (AFCEC) at Tyndall AFB, Florida has overall program responsibility.

- The AFCEC Airfield Pavement Evaluation Team performs airfield evaluations.

CHAPTER 3 PAVEMENT INVENTORY

3-1 INTRODUCTION.

Pavement inventory organization is the foundation for pavement management data collection and analysis. When performing a pavement evaluation for airfield or road and parking pavement, use the inventory structure from the previous evaluation as a starting point. Update the inventory to ensure it meets the standards outlined in this UFC but maintain the same inventory structure to the maximum extent possible. The intent of this guidance is to maintain continuity and facilitate analysis between successive evaluations. The following pavement inventory components are used to properly manage pavement assets.

3-2 INVENTORY MAP.

An accurate map showing the location and geospatial extents of pavement on an installation is critical when evaluating and managing pavement assets. These maps must be geospatially correct and are typically created using a geographic information system (GIS) such as Esri's ArcMap or AutoCAD Map 3D.

3-2.1 Mapping Guidelines.

PAVER uses the inventory map to navigate between segments in the inventory and to generate map-based PAVER reports.

a. Pavement mapping for DoD installations uses each installation's GIS data, called the Common Installation Picture (CIP). The CIP must comply with the Spatial Data Standards for Facilities, Infrastructure, and Environment (SDSFIE). Each Service has an approved SDSFIE adaptation and each has a Pavement Feature Class with "entities" and "attributes" that align with the required PAVER data structure standards as outlined in the PAVER user manual. Information on the SDSFIE is available at http://www.sdsfieonline.org.

b. At a minimum, the map must subdivide the inventory into polygons for the networks, branches, sections, and sample units. The map may also have attributes associated with these network, branch, section, and sample unit polygons, but if populated with the map data in the GIS, the attributes must align with the PAVER data structure standards as described above.

c. The pavement inventory map is exported from the GIS to a shapefile or table imported into PAVER. If the map is imported into PAVER with just the inventory geometry and without the inventory attributes, these attributes are populated in PAVER and are assigned to the inventory polygons using the **GIS Assignment** tool in PAVER.

3-2.2 Mapping Metadata.

When performing an evaluation, check the CIP metadata to determine if it was developed from surveyed geometry or digitized geometry. If it is the latter, determine the accuracy of the imagery; this dictates the accuracy of the map. Do not use a lower accuracy to change the network, branch, or section polygons.

3-2.3 Coordinate Systems.

Optimally, maps are created using the World Geodetic System (WGS) 84 datum, but the State Plane Coordinate System (SPCS) for bases within the United States or the Universal Transverse Mercator (UTM) Coordinate System for bases outside the United States may be used if that is the datum used to create the CIP.

3-2.4 Use of Imagery.

Imagery can be used to check maps for accuracy and update the map if the imagery is at the same or a higher accuracy than was used to create the original map (the CIP). Environmental Systems Research Institute (Esri) has world imagery on which you can overlay a shapefile to check geometry. Imagery may be imported into PAVER in a Tagged Image File Format (TIFF) as a context map. This imagery is useful when performing pavement evaluations, but when the database is combined into a rollup database, the imagery is removed to reduce file size.

3-2.5 Topology Validation.

Always validate a shapefile using the GIS application or in PAVER using the **GIS Manager** tool. The most important things to check for are that polygons have no gaps and are not overlapping.

> Once topology is validated, **delete** the validation information before exporting a new shapefile. If the topology is not deleted, PAVER will import it and the shapefile is rendered “unassignable.”

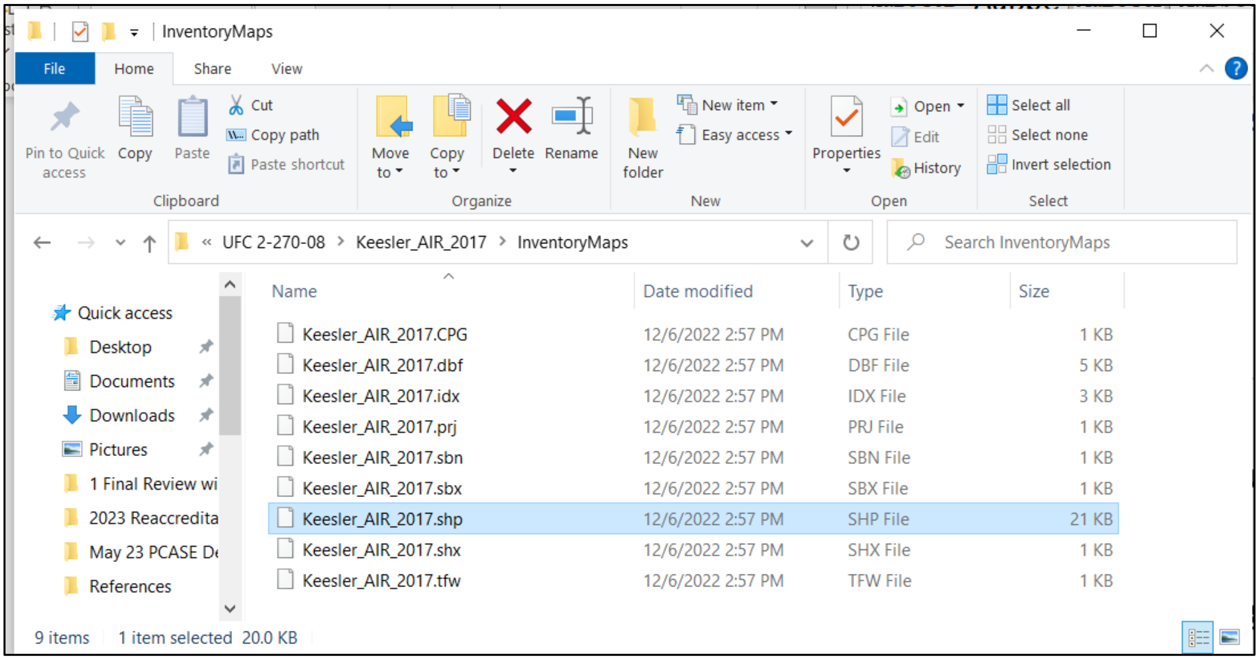
3-2.6 Importing Inventory Maps.

PAVER does have a section split wizard for altering the polygons on a map, but map changes are typically done in a GIS. PAVER uses the **GIS Tabular Import and Update** tools to bring maps into the database. PAVER stores the map data in a folder named **Inventory Maps** within the folder containing all the files associated with the database.

The main files needed in the **Inventory Maps** folder are the *.shp, *.prj, *.dbf, and *.shx files. If any of these files is missing, you will likely get an "unassignable" shapefile error message. There will be other files in this folder if you imported attributes in addition to the polygons. The file name used for each of these files must be the same, with the exception of the extension, and must clearly identify the network so it can be distinguished from other network maps in a rollup database (see Figure 3-1).

- Use **Site Name_Air_Year** for the name of airfield inventory map files.
- Use **Site Name_Road_Year** for the name of roads and parking inventory map files.

Figure 3-1 Inventory Maps



3-2.7 Exporting SDSFIE Data.

Once the attributes associated with the polygons in a database are updated, export the map to a shapefile or other compatible file format outlined in the PAVER User Manual for import into the installation's GIS. When using a shapefile, the field names have a limited length and some PAVER field names must be translated to SDSFIE-compliant field names.

3-3 INVENTORY DATA.

The pavement inventory is simply all pavements grouped by their function. An airfield database has the inventory for all airfield pavements at an installation and a separate database with inventory of all road and parking pavements at an installation. The terms "inventory" and "database" are often used interchangeably; however, the database includes the inventory, condition data, performance data, system tables with M&R policies, and work plans.

3-3.1 Database File Names.

a. Each Service maintains a repository for pavement evaluation databases. Database naming standards facilitate database management in these repositories. The site name/location, inventory type (airfield or road), type of evaluation, and date of the evaluation are required. Services may supplement the requirement with standard conventions for airfield type or type of evaluation to improve clarity.

b. Use **Installation Name_Air_Comp_Year** for the name of an airfield database when the most recent evaluation has both PCASE and PAVER data.

c. Use **Installation Name_Air_Str_Year** for the name of an airfield database when the most recent evaluation just has PCASE data.

d. Use **Installation Name_Air_PCI_Year** for the name of an airfield database when the most recent evaluation just has PAVER data.

e. Use **Installation Name_Road_PCI_Year** for the name of a road and parking database when the most recent evaluation just has PAVER data. Typically, all road and parking databases are for PCI surveys, but the same approach used for airfields is applied to roads if there are structural evaluation data in the database.

3-3.2 Database Properties.

Many government and commercial organizations around the world use the PCI and PAVER. These organization use both standard and user-defined data fields to meet their needs. The DoD limits the use of user-defined fields and uses specific standard data fields not typically used by other PAVER users. Select **File>>Database Properties** to open the form shown in Figure 3-2 to set the **DoD database properties**.

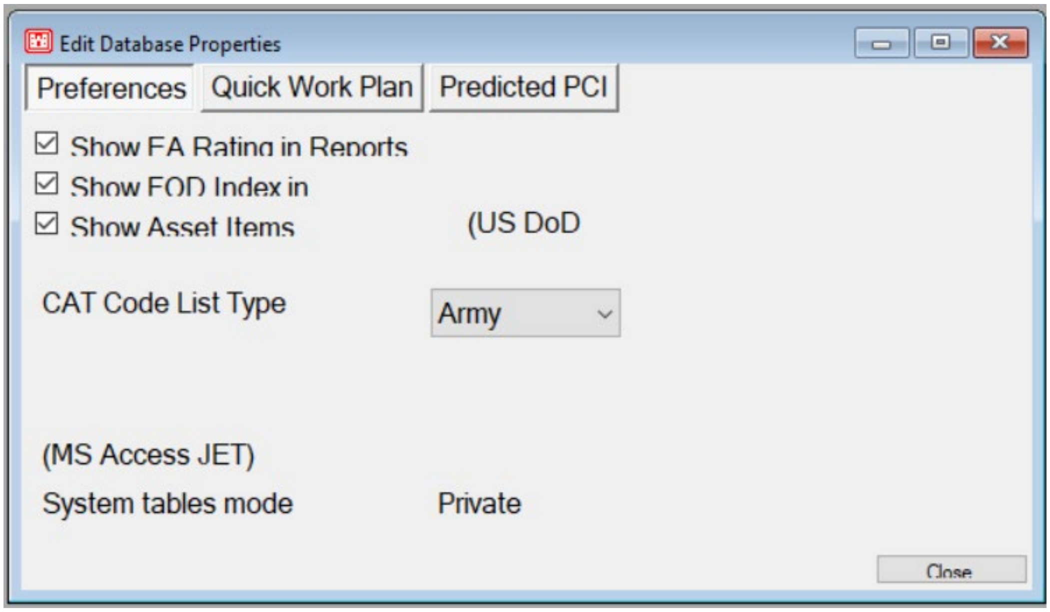
3-3.2.1 Airfield Database Properties.

Once the **Edit Database Properties** form is open, check the boxes for **Show EA Rating in Reports**, **Show FOD Index in Reports**, and **Show Asset Items** Select the appropriate Service from the **Cat Code List Type** drop-down.

3-3.2.2 Road and Parking Database Properties.

For road and parking databases, **Show Asset Items** is checked and both **Show EA Rating in Reports** and **Show FOD Index in Reports** are unchecked. Select the appropriate Service from the **Cat Code List Type** drop-down.

Figure 3-2 Edit Database Properties Form



3-3.3 Network Definition.

An airfield or road and parking pavement inventory will have one or more networks. Following are conventions for creating and naming networks. Note that the same network, branch, and section hierarchy is used for all pavement evaluation types, e.g., a structural evaluation uses the same inventory as a PCI evaluation for a given site.

3-3.3.1 Airfield versus Road and Parking Networks.

Since airfield and road and parking pavements are maintained in separate inventories, there is no need to distinguish between them in the network ID.

3-3.3.2 Multiple Sites on an Installation.

When an installation has multiple sites as indicated by the real property site unique identifier (RPSUID), include sites in the proximity of the main installation in the same inventory but make them separate networks.

If the site is separated from the main installation such that it cannot be legibly shown on the same inventory map, create a separate inventory (database) for the site. For example, create a separate database for an auxiliary airfield or a range complex geographically separated from the main installation.

3-3.3.3 Housing Pavement Networks.

Create a separate network for pavement in housing areas whether the housing is privatized or not. The Services will each establish a standard field in a rollup database to filter housing area pavement for data analysis and reporting purposes. This field may vary based on Service-specific real property regulations and the real property management applications used by each Service. See paragraph A-1 for a recommended procedure.

3-3.3.4 Other Networks Based on Ownership.

Create a separate network for pavements when a different organization has ownership / maintenance responsibility for the pavement. For example, create a separate network for pavements that are maintained by a National Guard or Reserve unit that is collocated on an active duty installation.

3-3.3.5 Paved and Unpaved Surfaces.

Include both paved and unpaved surfaces in an airfield or road and parking network.

3-3.3.6 Network ID Standard.

a. Each network must have a network ID based on the site name. The network ID is the primary field used to navigate between networks in PAVER and must clearly identify the network so it can be distinguished from other networks, particularly those in a rollup database.

b. The network ID field is limited to ten characters, so truncate the site name as required. The recommended approach is to use camel case (capitalize the first letter of each word in the name) when populating network IDs, e.g., ChinaLake or MtHome. If you have multiple networks in a database, truncate the site name and add characters at the end to make the distinction. For example, the landing zone for Little Rock AFB would be LittleRoLZ.

c. Privatized housing will use the truncated site name with a PH suffix (FtRuckerPH) and unprivatized housing will use the truncated site name with a UH suffix (FtRuckerUH).

d. If an asset management system used by a Service, e.g., iNFADS, requires a specific naming convention for network IDs in the future, that requirement will govern for that Service.

3-3.3.7 Network Name Standard.

Each network must have a network name based on the site name. The network name has a 60-character limit, which is more detailed than the network ID and is used to provide more detail about the network. For example, Fort Hood Privatized Family Housing.

3-3.3.8 Other Network-Level Inventory Fields.

A database can have one or more networks in the inventory for a specific installation. The network IDs are used to filter data for analysis and reporting purposes. When working with a rollup database with multiple installations, the network ID has limitations as a filtering tool. The recommended solution is for each Service to create a standard set of network level user-defined fields saved in a system table template. Import this template into each database. This ensures the unique ID for these user-defined fields are the same in every database. This procedure provides a means of filtering networks for analysis and reporting to meet specific mission and pavement management requirements. For example, a user-defined field for a major command provides the ability to generate reports by command and user-defined fields for housing and privatized pavements provides a means of filtering out these networks when running M&R plans.

Once the template is imported, the field remains a part of the database but the value for that field can be modified as required over time. For example, the value of the Major Command field could be updated if it changes, but the “unique ID” for the field will remain the same.

3-3.4 Branch Definition.

A network consists of one or more branches, which are defined by use. For example, a runway, named taxiway, named road, or contiguous parking area would each be a branch. Each branch must have the branch ID, branch name, and branch use fields populated.

3-3.4.1 Branch ID Standard.

The branch ID field is limited to ten characters. It must consist of a prefix indicating the branch use and the short name (truncated) for the branch. For example, RW1028 or RDPerimete. Branch prefixes are related to branch uses which are in turn related to the category codes that define the use of an asset in the real property records.

Each Service has asset types that are similar, whereas others are unique to that Service. Table 3-1 lists the standard branch prefixes for asset types that are similar. Each Service establishes a standard naming convention policy for its unique branch/asset uses consistent with the approach used in Table 3-1. Some Services allow a pavement facility to have multiple category codes. When multiple category codes are allowed, the branch naming convention will use some prefixes as suffixes. For instance, a runway facility consists of the runway, overrun, and shoulder pavement. The branch name for the runway shoulder is RW1028SH and the overrun is RW1028OR. A similar approach would be used with an apron or taxiway shoulder; for example, PAMainSH or TWASH.

Table 3-1 Branch Prefixes

Airfield Branch ID Prefixes	Road and Parking Branch ID Prefixes
RW = Runway	RD = Paved Road
TW = Taxiway	UR = Unpaved Road
PA = Parking Apron	PL = Paved Parking Area
AP = Other Apron	UP = Unpaved Parking Area
OR = Overrun	DW = Paved Driveway
HP = Helipad	UD = Unpaved Driveway
SH = Shoulder	MP = Motor Pool
	SA = Staging Area or Parade Deck

3-3.4.2 Branch Name Standard.

The branch name has a 60-character limit, so it is more detailed than the branch ID and is used to provide more detail about the branch. For example, Runway 10/28 or Perimeter Road.

3-3.4.3 Branch Use.

The branch use field is used to filter data for analysis and reports. It is also used to prioritize M&R work requirements when used in conjunction with the pavement rank. There is also an important relationship between the branch use and the real property category code, which can also be used to filter data and is discussed in more detail in paragraph 3-5.

Table 3-2 has a list of the PAVER default branch use categories used by the DoD. PAVER allows users to create user-defined branch uses, but Services will only use these default categories for DoD pavement evaluations. Services will submit new default branch uses to the PAVER Tri-Service Working Group to add it to the UFC and PAVER.

Table 3-2 Branch Use Categories

Airfield Branch Use		Road and Parking Branch Use	
Use Code	**Description**	**Use Code**	**Description**
APRON	APRON	CLOSED-RD	CLOSED ROADWAY
BLAST PAD	BLAST PAD	DRIVEWAY	DRIVEWAY
CARGO	CARGO	MTRPOOL	MTRPOOL
CLOSED-AF	CLOSED AIRFIELD	OTHER	OTHER
DEICING PAD	DEICING AREA	PARKING	PARKING
HELIPAD	HELIPAD	ROADWAY	ROADWAY
LINE VEHICLE	GROUND EQUIPMENT	ROUND	ROUNDABOUT
OVERRUN	OVERRUN	SHOULDER-RD	ROAD SHOULDER
RUNWAY	RUNWAY	STORAGE	STORAGE
SHOULDER-AF	AIRFIELD SHOULDER		
TAXIWAY	TAXIWAY		

3-3.5 Section Definition.

Each branch consists of one or many sections but the guidance for determining airfield sections varies from guidance for roads.

3-3.5.1 Airfield Sections.

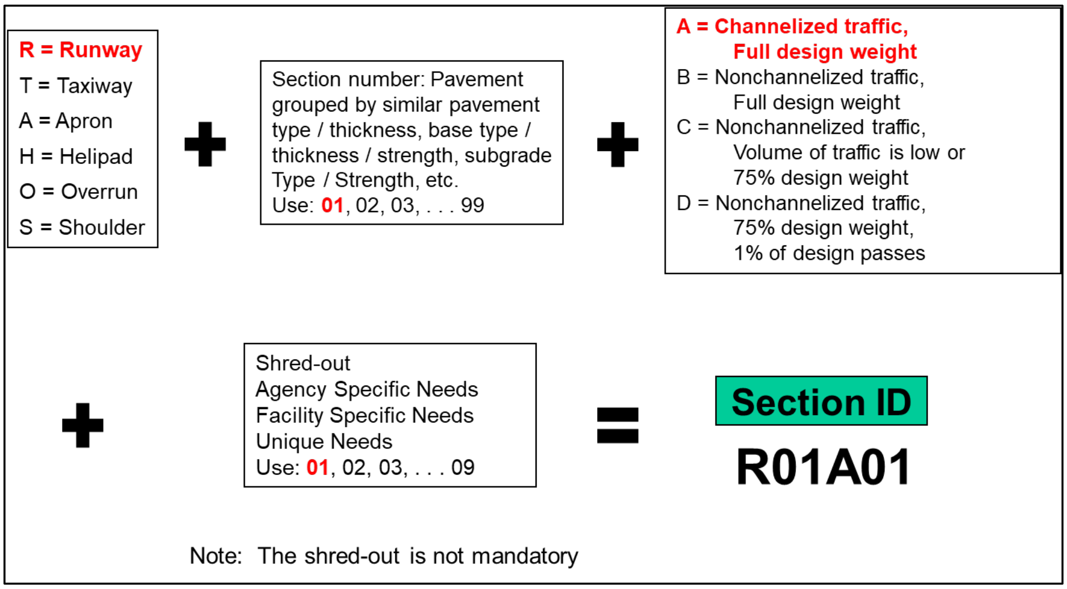
Define airfield sections by physical characteristics such as pavement type or thickness, construction history, or traffic area. Use test data, imagery, UFC standards, pavement design documents, or construction records to determine where to divide sections. Refine the location of section changes or further subdivide sections based on visual changes or structural evaluation. The overall intent is to ensure that all pavement in a section is uniform in terms of surface condition and structural capability.

3-3.5.2 Airfield Section ID Standard.

The airfield section ID consists of a prefix that indicates the use, a number, and a letter that indicates the traffic area. All pavement with a given section ID is structurally the same from an allowable load perspective. See Figure 3-3 for a section ID example.

The section ID may also include an additional number, known as a shred-out. The shred-out is used to distinguish pavements that are structurally similar but need to be segmented further for a specific reason. This may include pavement that is structurally the same but is part of a separate branch or a portion of a section whose surface condition is consistently different from other areas of the section. The prime example of this is the keel section of a runway versus the outer portions of the runway. Note that an airfield section ID for a given installation is unique for that installation.

Figure 3-3 Airfield Section Identification Example



3-3.5.3 Road and Parking Sections.

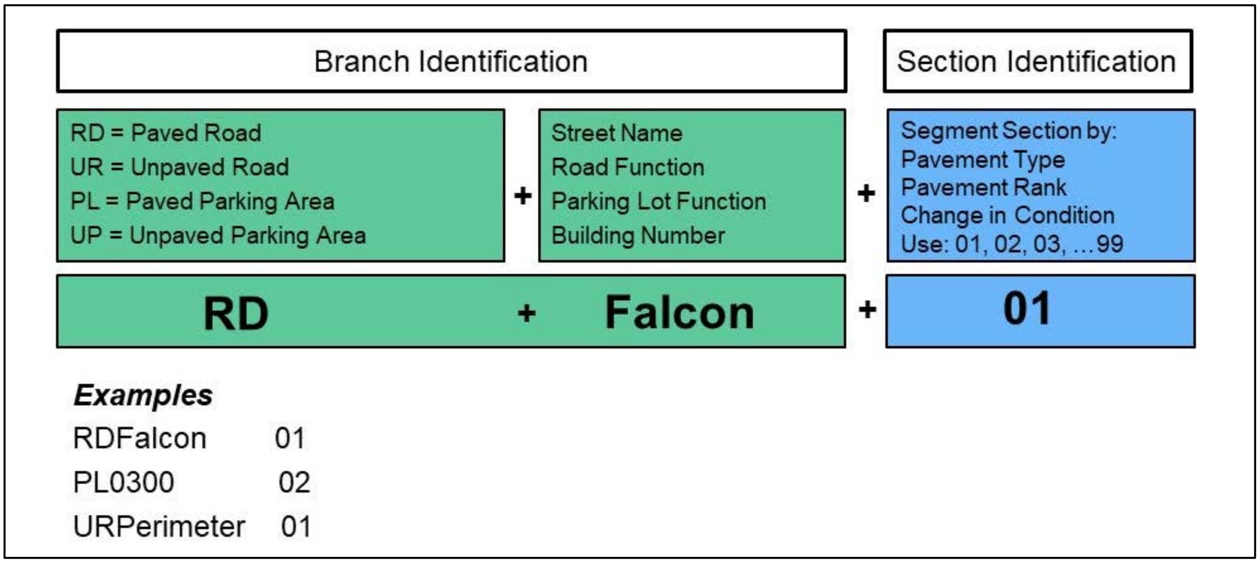
Sections for road and parking pavements must have the same pavement type and are assumed to be structurally similar. Sections for roads can be defined based on other characteristics such as the number of lanes. When the road is consistent along its length, sections are typically defined based on set intervals such as a section break at the edge of each intersection. When intersections are infrequent, sections are defined every 0.25 mile (402 meters) for roads in main installation areas and every 0.5 mile (804 meters) for lower volume roads outside the main installation.

A contiguous parking area (including the pavement to access that parking area) with the same pavement type is considered a section. If other physical characteristics such as thickness, construction history, or subsurface conditions are known, they can be used to better define the section. The overall intent is that all pavement in a section is uniform in surface condition and assumed or known structural capability.

3-3.5.4 Road and Parking Section ID Standard.

Unlike airfield section IDs, road and parking section IDs are not unique for a given installation. They are numbered sequentially for a given branch. To uniquely identify a road and parking section, use the concatenation of the branch ID and the section ID. Table 3-1 gives a complete list of branch prefixes and Figure 3-4 provides an example of how they are used to identify a section.

Figure 3-4 Road and Parking Section Identification Example



3-3.5.5 Mandatory Section Fields.

There are five mandatory section fields for asphalt concrete (AC) pavements and five mandatory section fields for portland cement concrete (PCC) pavements. These fields are mandatory for both airfield and road and parking pavement. PCC pavement has two additional fields required by DoD policy: slab length and slab width. Table 3-3 lists the mandatory fields. When updating a database, change any user-defined fields to default (standard) PAVER fields and delete the user-defined fields from the database.

Table 3-3 Mandatory Section Fields for PCC Pavement

Field	Description
Section ID	Identifies a specific area of pavement within a branch. The entire section must have the same pavement type.
Surface Type	PAVER has a list of default surface types that must be used. User-defined surface types are not allowed. The list of surface types is available in PAVER at **System Tables and Tools**>>**Edit Inventory Picklists**>>**Engineering Fields** and in the PAVER user manual.
Rank	Pavement rank is used to prioritize work requirements. PAVER has a list of default pavement ranks, but the only ones used by DoD are primary (P), secondary (S), tertiary (T) and unused (U). Rank definitions are in paragraph 3-3.5.6.
Last Construction Date	The last construction date is the last date that major M&R was performed that brought the PCI back to 100.
True Area	The section area is measured or determined from the GIS mapping application.
Slab Length	The representative measured longitudinal length of the slabs in the section. This field only applies to PCC pavement.
Slab Width	The representative measured transverse length of the slabs in the section. This field only applies to PCC pavement.

3-3.5.6 Section Rank Definitions.

Pavement ranks are listed on the section rank tab in PAVER at **System Tables and Tools**>>**Edit Inventory Picklists**>>**Engineering Fields**. When developing PMPs, use the section rank in conjunction with the branch use priority to prioritize M&R requirements at the section level.

Following are definitions for airfield and road and parking pavement section ranks. The rank definitions for roads are derived from Army SDDCTEA Pamphlet 55-17, *Better Military Traffic Engineering.*

Table 3-4 Pavement Section Rank

Airfield Section Rank		
Rank	**Code**	**Description**
Primary	P	Primary pavements are mission-essential pavements such as runways, parallel taxiways, main parking aprons, arm-disarm pads, alert aircraft pavements, and overruns (when used as a taxiway or for takeoff). In general, only pavements that have aircraft use on a daily basis or frequently used transient taxiways and parking areas are considered primary.
Secondary	S	Secondary pavements are mission-essential but occasional-use airfield pavements, including ladder taxiways, infrequently used transient taxiway and parking areas, overflow parking areas, and overruns (when there is an aircraft arresting system present). In general, any pavements that do not have daily use by aircraft are secondary.
Tertiary	T	Tertiary pavements include pavements used by towed or light aircraft, such as maintenance hangar access aprons, aero club parking, wash racks, and overruns (when not used as a taxiway or to test aircraft arresting gear). Paved shoulders are classified as tertiary. In general, any pavement that does not support aircraft taxiing under their own power or is used only intermittently is considered a tertiary pavement.
Unused	U	Unused pavements include any pavements that are abandoned (not maintained) or scheduled for demolition.
Road and Parking Section Rank		
Rank	**Code**	**Description**
Primary	P	Primary pavements include installation roads and streets that serve as the main distributing arteries (arterials) for traffic originating outside or within an installation. These pavements have high traffic volumes and speeds of 35 to 55 mph, but may include collector or local streets that service mission-critical facilities. Primary vehicle parking areas are restricted to those areas associated with access to mission-essential facilities, such as alert facilities, munitions facilities, and medical facilities.
Secondary	S	Secondary pavements include collector streets that gather and disperse traffic between arterials and local streets. They will have lower traffic volumes than primary pavements and speeds of 25 to 40 mph. Most parking areas that support daily traffic on a base are considered secondary pavements unless a specific mission dictates otherwise.
Tertiary	T	Tertiary pavements include local streets that provide access from collector roads to individual facilities. Unsurfaced roads are also typically classified as tertiary. Any parking area that is not used on a daily basis or is excess to the standard facilities requirements is considered a tertiary pavement.
Unused	U	Unused pavements include any pavements that are abandoned (not maintained) or scheduled for demolition.

3-3.6 Sample Unit Definition.

Subdivide each section into one or many sample units. A sample unit is a defined portion of a pavement section designated only for the purpose of pavement inspection. The number of samples inspected in a PCI survey is dictated by whether a network- or project-level inspection is called for.

Sample unit size requirements and the number of sample units inspected for both network- and project-level inspections are outlined in UFC 3-260-16. Use PAVER's **Inspection Report/Forms/Setup Wizard** to create a new inspection using the same samples inspected in the previous inspection. Add any new sections to the inspection. Specify the requirements in the contract statement of work if a higher sampling rate or a 100 percent inspection is required to better define the scope of a project.

3-4 WORK (CONSTRUCTION) HISTORY.

The term "work history" is often used interchangeably with the term "construction history." Both mean the same thing: a record of the type of work performed on each section and the date it was performed. Accurate work history dates play a critical role in creating PCI family models and defining the deterioration rate of a pavement. Use Paver's **Work History** tool or **Work Entry Wizard** to populate the work history. When work history is updated in a GIS application, use the PAVER **Add Work History from GIS or Tabular Data** tool. Details on these tools are outlined in the PAVER User Manual.

3-4.1 Last Construction Date.

Update the PAVER work history with the last major M&R date for each section. This is known as the Last Construction Date (LCD) and indicates the last work performed that brought the PCI of the pavement to 100. PAVER uses the LCD to determine the pavement deterioration rate, which in turn is required to predict the future condition of the pavement and generate future M&R requirements.

3-4.2 Unknown Last Construction Date.

When no construction records are available to indicate the last construction date, use the **Last Construction Date Wizard** to backcalculate a construction date based on the current PCI, using either a fixed rate of deterioration or using a deterioration family generated for similar sections at the installation with known LCDs.

3-4.3 Complete Work History Record.

In addition to the LCD, document any other M&R actions in the work history. This includes any localized preventive M&R such as crack sealing or global M&R such as applied surface treatments. An accurate construction history helps users determine the effectiveness of M&R strategies, better understand the development of pavement distresses, and develop better courses of action for future M&R.

3-5 REAL PROPERTY ASSET DATA.

When OSD mandated the use of PAVER, the primary driver was to get accountability of pavement assets from a real property perspective. This mandate created a requirement for PAVER to report pavement inventory in terms of each asset (facility) as outlined in GSA *Guidance for Real Property Inventory Reporting*.

From a pavement management perspective, DoD pavement inventories were historically segmented into networks, branches, sections, and sample units, but not facility. So, while PAVER pavement management inventories for DoD installations provide accurate information on location, area, type, and condition of pavements, the segmentation was historically not related to real property facilities in the Real Property Asset Database (RPAD). Linear segmentation resolves that issue.

3-5.1 Linear Segmentation.

Create a map showing the location and geospatial extents of each pavement asset (facility) on an installation as the first step in aligning pavement management data with the RPAD pavement assets (facilities). **Note:** This is not the same as a map from an earlier pavement evaluation that shows networks, branches, and sections because these maps give no indication of the location or geospatial extent of each real property pavement facility. Creating a pavement facility map requires the participation of real property, engineering, and GIS personnel and can be complicated, depending on the level of detail available in the real property record. Once the pavement facility map is completed, each real property pavement asset can be associated with a branch in the PAVER inventory allowing an installation to meet OSD requirements to account for pavement assets via the regularly scheduled pavement evaluations performed by the Services.

DoD Guide for Segmenting Types of Linear Structures provides guidelines for segmenting pavements. The Services implemented linear segmentation initiatives but gaps still exist in completing the effort to identify the location and geospatial extent of pavement facilities (pavement facility maps) and then linking the facilities to pavement management data; the effort is ongoing. Following are terminology and guidelines for linear segmentation that supplement *DoD Guide for Segmenting Types of Linear Structures* and the PAVER user manual.

3-5.2 Populating Real Property Asset Data in PAVER.

There are several ways to import pavement real property asset data into PAVER. These include manually entering each asset for an installation into PAVER, using the **Inventory**>>**Asset Management**>>**Import/Assign Asset Items Using GIS/Tabular Import** tool or using the **Inventory**>>**Centralized Asset Management**>>**asset file** tool.

Details for each of these procedures are outlined in the PAVER User Manual. The following sections describe required fields. Importing and assigning pavement asset data can be done as a one- or two-step process.

3-5.2.1 One-step Asset Assignment Process.

When the GIS or tabular data file has both inventory (network, branch, and section) fields populated and the required asset data fields populated when it is imported into PAVER, all asset data will appear in the appropriate tables and the assignment is complete.

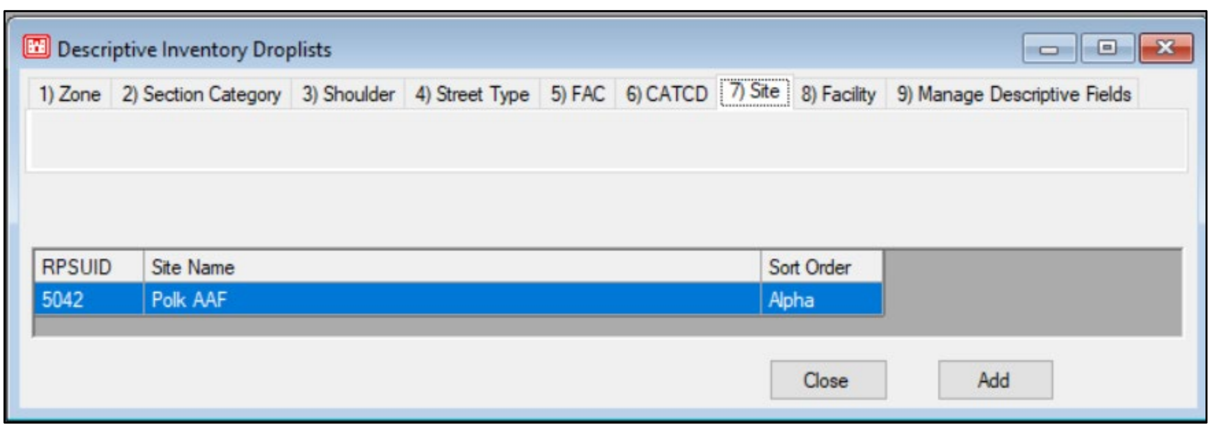
3-5.2.2 Two-step Asset Assignment Process.

When the GIS or tabular data file just has the map or the map with the inventory (network, branch, and section) fields included, but does not have the required asset data fields populated, the asset data must be entered manually or imported into PAVER and the assets must be assigned to the appropriate branch using the **Inventory**>>**Asset Management**>>**Assign/Unassign Asset Items** tool.

3-5.3 Real Property Site Unique ID (RPSUID).

The RPSUID is a code assigned by OSD to define a site permanently and uniquely. An installation can have multiple sites associated with it. Each will have its own RPSUID. If manually entering the field into PAVER, get the correct RPSUID for each site from the RPAD. Enter the RPSUID into PAVER using **System Tables and Tools**>>**Edit Inventory Picklists**>>**Descriptive Fields**>>**7) Site** (see Figure 3-5). If there is preexisting data in the database, add missing RPSUIDs and site names from the RPAD for all sites included in the installation database and delete any RPSUIDs not associated with the installation.

Figure 3-5 Adding a Real Property Site Unique ID (RPSUID)

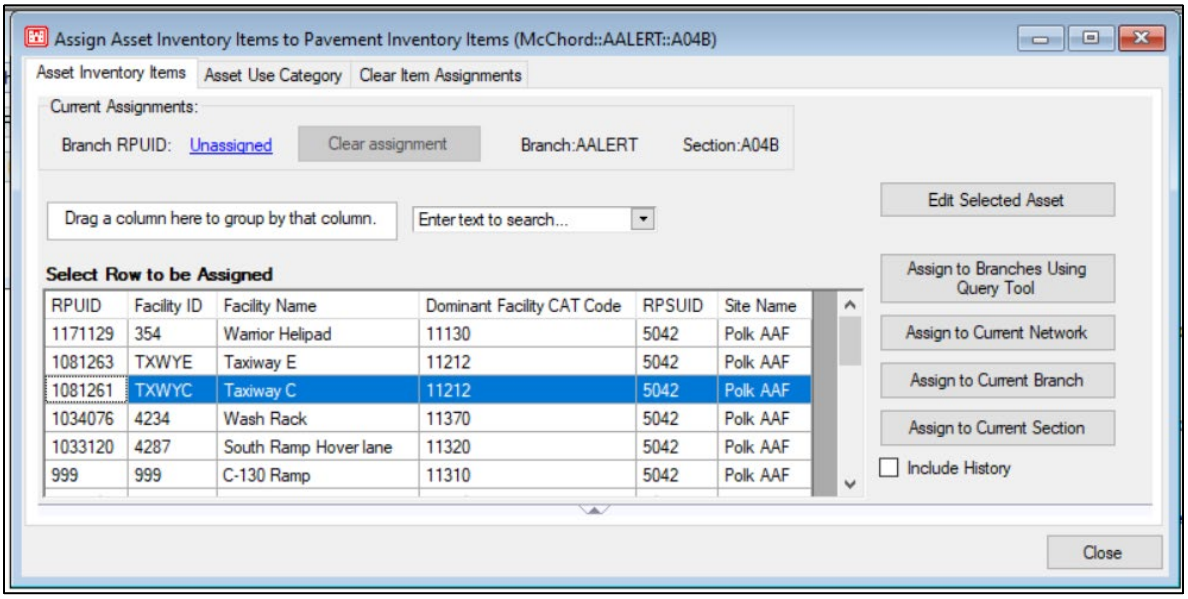


3-5.4 Real Property Unique ID (RPUID).

The RPUID is a code assigned by OSD to define a DoD real property asset (facility) permanently and uniquely. The RPUID is the key field used to link the real property pavement asset (facility) data to pavement management data. While PAVER allows the RPUID to be assigned at the network, branch, or section level in the event of future policy changes, the current policy is to assign the RPUID to the branch.

To assign the RPUID to a branch, navigate to the branch you want to update, then select **Inventory**>>**Define Inventory**. Select the **Assign Asset Items** button on the branch tab to open the assign asset items form. On the **Asset Inventory Items** tab, select the correct RPUID row for the current branch and assign it to the current branch. See Figure 3-6.

Figure 3-6 Assigning a Real Property Unique ID (RPUID)



3-5.5 Facility Number / ID.

The facility number is a code assigned by the installation or Service to define a real property asset. This code may or may not be unique to the enterprise and may change over time. However, this number will correlate to an RPUID and is often used when developing pavement facility maps. It is associated with the RPUID when asset data is imported into PAVER but can also be entered/updated manually at **System Tables and Tools**>>**Edit Inventory Picklists**>>**Descriptive Fields**>>**8) Facility**. When the RPUID is assigned to a branch, the facility number/ID is also assigned as shown in Figure 3-6.

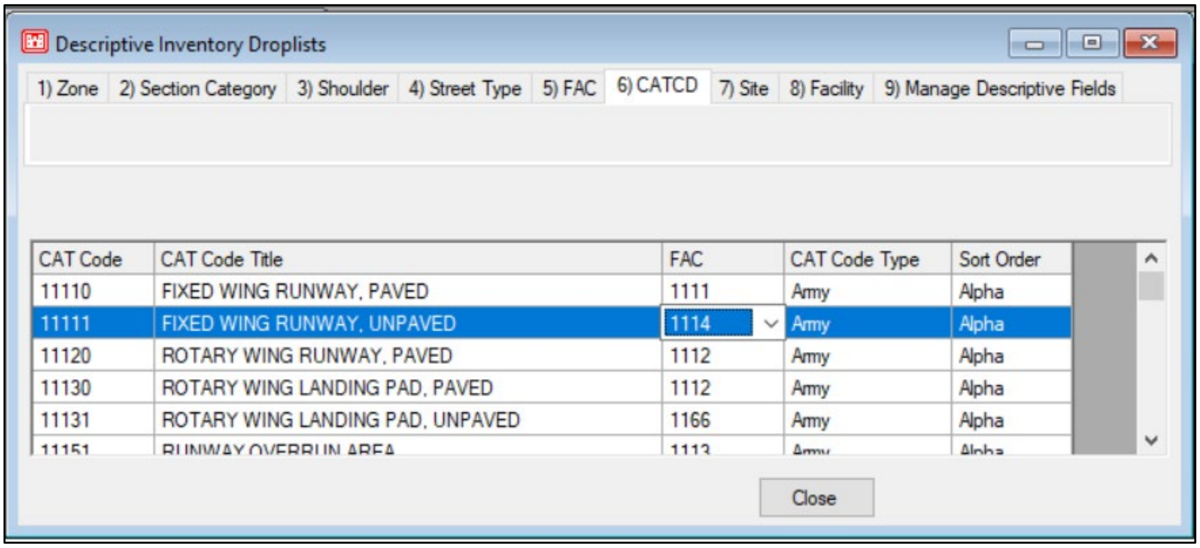
3-5.6 Facility Analysis Code (FAC).

The FAC is a classification of real property types within a "Basic Category," represented by a four-digit code. DoD FACs aggregate Military Department categories into common groupings based upon commonality of function, unit of measure, and unit costs. FACs are used in UFC 3-701-01, *DoD Facilities Pricing Guide*, to define replacement unit costs (RUC) and sustainment unit costs (SUC). RUCs form the basis for calculating plant replacement value (PRV) and SUCs serve as the basis for projecting OSD sustainment budget requirements.

The FAC is populated in PAVER in the **System Tables and Tools**>>**Edit Inventory Picklists**>>**Descriptive Fields**>>**6) CATCD** in association with the Category Code (see

Figure 3-7). It is assigned when the Category Code is assigned at the branch (or section) level.

Figure 3-7 Adding a Facility Analysis Code (FAC)

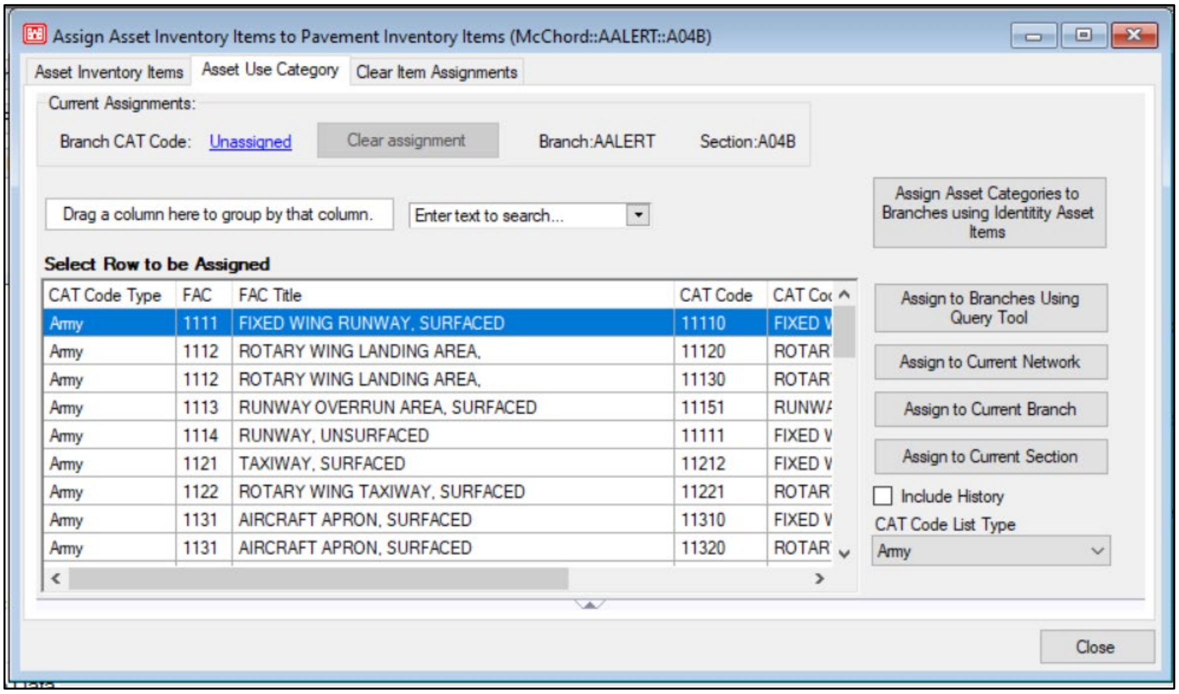


3-5.7 Category Code (CAT Code).

The FAC is further broken into Category Codes (CAT Codes) as shown in Figure 3-7. The CAT Code is the most detailed classification of real property that describes a specific real property type and function. It is represented by a numerical five- (Army and Navy) or six- (Air Force) digit code. CAT Codes are established by the Military Departments, so the CAT Code for a respective asset type may be different for each Service. Standard practice is to assign the CAT Code at the branch level.

From the **Inventory**>>**Define Inventory** form, open the **Assign Asset Items** form. On the **Asset Use Category** tab, select the correct CAT Code row for the current branch and then assign it to the current branch. When Service real property guidance allows for a facility to have more than one CAT Code, the predominant CAT Code for the branch must also be populated. See Figure 3-8.

Figure 3-8 Assigning a Category Code (CAT Code)

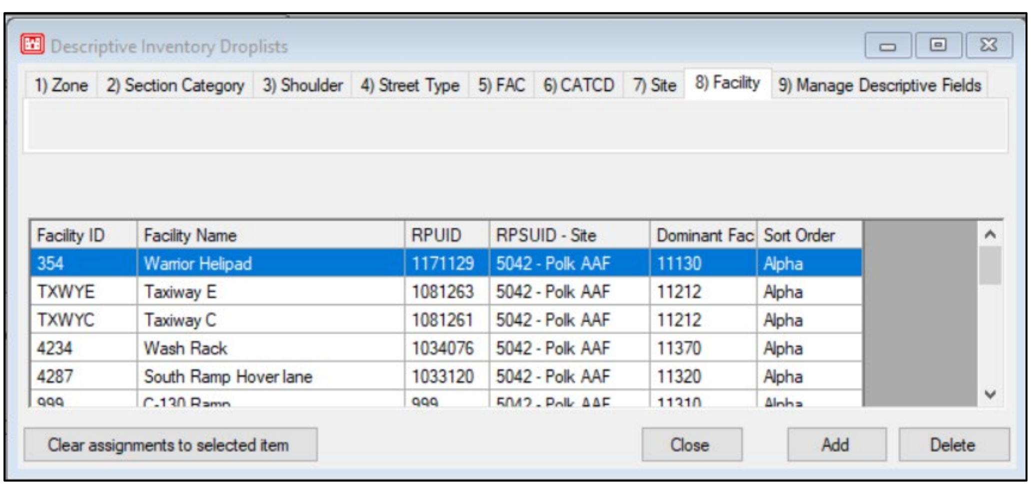


3-5.8 Predominant Facility CAT Code.

"Predominant use" is the term to describe the primary use of a real property asset based upon the largest quantity of usage for a specific activity or function. If there is only one CAT Code for a facility, leave the Dominant Facility CAT Code field in PAVER blank. If a pavement facility has more than one CAT Code, populate the Dominant Facility CAT Code field in PAVER based on the CAT Code with the greatest area.

Use the **System Tables and Tools**>>**Edit Inventory Picklists**>>**Descriptive Fields** form. Select **8) Facility**, then select the dominant facility CAT Code field for a row using the drop-down to select the predominant CAT Code as shown in Figure 3-9.

Figure 3-9 Assigning a Category Code



3-5.9 Facility Condition Index.

The DoD regularly collects data on the condition of every DoD facility to assess the health of its facility infrastructure. GSA *Guidance for Real Property Inventory Reporting* requires a Condition Index (CI) data element for all real property assets. The CI is defined as "a general measure of the constructed asset's condition at a specific point in time."

From the pavement management perspective, DoD uses the weighted area average of all the sections in a facility to define the facility PCI. This is not the same as the real property Facility Condition Index (FCI). The FCI is calculated as the ratio of the M&R requirement cost to the plant replacement value (PRV) cost, expressed in dollars. It is considered a critical metric for real property professionals who require accurate and consistent FCI data. PAVER does not compute the FCI at this time but is used to compute the M&R cost for each section in a facility. The sum of these section costs can be used to define the M&R cost for the facility for the FCI computation. To compute the FCI, these M&R costs are entered in the respective Service asset management programs, e.g., iNFADS for the Navy and Tririga for the Air Force.

CHAPTER 4 PAVEMENT EVALUATION

4-1 INTRODUCTION.

Pavement evaluation encompasses several different assessment types. Each is conducted to gather data on a different aspect of the properties or physical characteristics of the pavement. This data is used to analyze performance, define current capability, and predict future condition. The result of each is typically an index or metric that defines the condition, performance, or capability regarding the focus of the evaluation. Some or all of these evaluation types may be performed and, when results are taken together, they paint a more complete picture of condition, capability, and performance. This is key to developing a PMP and making a rational determination of feasible M&R alternatives.

In addition to the PCI survey, other evaluation types include structural, surface friction characteristics, void detection, and roughness evaluations. Details on these evaluation types are covered in UFC 3-260-03, commercial standards, and other Service-specific criteria. Following is a summary of evaluation types and a discussion of the indexes and products generated.

4-2 PAVEMENT CONDITION INDEX SURVEYS.

4-2.1 PCI Survey Process.

4-2.1.1 PCI Survey Mapping and Inventory.

PCI surveys involve collecting data on the type, quantity, and severity of distresses to determine the surface condition (PCI) for each section. Before conducting a PCI survey, create the mapping and inventory as outlined in Chapter 3. Note that the terms “PCI survey” and “inspection” are used interchangeably.

4-2.1.2 PCI Survey Planning.

After establishing the mapping and inventory, determine whether the inspection is network or project level. This defines the sampling requirements as outlined in UFC 3-260-16. A network-level survey requires the team to identify representative samples in the field. For a project-level survey, the team can plan the specific samples to be inspected before starting the survey. When a project-level PCI Survey has not been previously conducted, use the systematic random process described in UFC 3-260-16 to select the specific samples to be inspected. When a PCI Survey was previously conducted, inspect the same sample units inspected in the previous PCI Survey. Services may define more stringent sampling rates based on mission requirements.

Whether performing an initial inspection or a re-inspection, use PAVER’s **Inspection Report**>>**Forms**>>**Setup Wizard** to plan the inspection. This wizard generates inspection records and inspection forms to collect data and, if previously inspected, generates a re-inspection report for quality checks. The PAVER user manual has details on using this wizard.

4-2.1.3 PCI Survey Field Work.

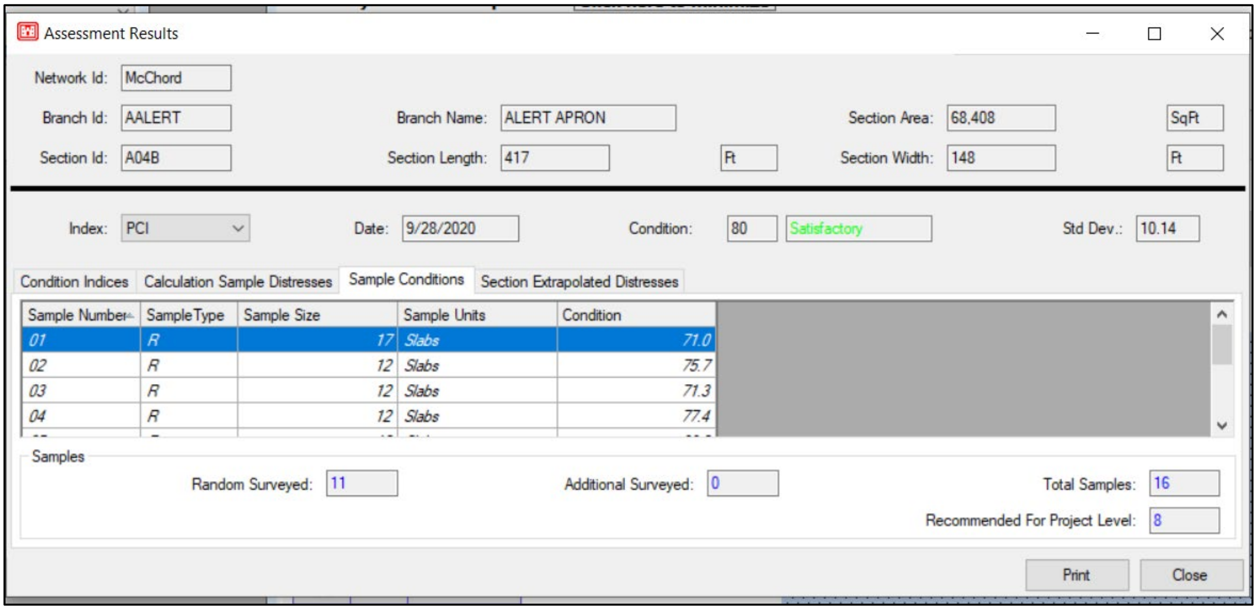
a. PCI surveys involve collecting data on the type, quantity, and severity of distresses to determine the surface condition (PCI) for each section. Before conducting a PCI survey, the mapping and inventory must be created as outlined in Chapter 3. Note that the terms “PCI survey” and “inspection” are used interchangeably.

b. A best practice is to perform the PCI survey with a GPS-enabled tablet, but it can also be performed using paper forms. If using paper forms, a tablet that is not GPS-enabled, or if you have poor GPS coverage, mark the sections and sample unit designations on the ground using paint, chalk, or a lumber crayon before performing the inspection. This allows inspectors and quality control personnel to easily locate them. A best practice is to perform the layout ahead of the inspection team(s).

c. Survey tools include a measuring wheel that measures to 0.1 foot (30 mm), a 10-foot (3 m) straightedge or string line, a scale or tape measure that reads to 1/8 inch (3 mm), a map of the pavements being inspected, and PCI distress handbooks. Handbooks for asphalt and concrete airfield or road and parking pavements are available at https://transportation.erdc.dren.mil/paver/Manuals.htm. The information in the handbooks is also available when entering data in the PAVER **Edit Inspection** tool.

d. Whether performing the survey using a tablet or paper forms, enter the distress data into PAVER using the **Edit Inspection** tool. Once the distress data is entered for each sample unit, PAVER computes the PCI for that sample unit. Once the distress data for all inspected sample units is complete, PAVER computes the section PCI. Record any sample units that are not representative of the section (for a project-level survey) as “Additional” sample units. “Additional” sample units are handled differently in the computation than random samples.

Figure 4-1 PAVER Sample Conditions Tab



e. Select the **Show Conditions** button on the **Edit Inspection** form once the selected sample units have been inspected, then select the **Sample Conditions** tab on the **Assessment Results** form to determine if enough samples were inspected to get a 95 percent confidence level for a project-level inspection as shown in Figure 4-1. If the **Recommended for Project Level** field indicates that more samples are needed, inspect more random samples to achieve the required confidence level.

f. Repeat this inspection process for each section. UFC 3-260-16 outlines PCI inspection and computation details. PAVER also calculates other condition index values based on the PCI Survey.

4-2.2 Structural Condition Index.

Pavement distresses are categorized as load related, climate/durability related, and other. The other category includes distresses caused by material or construction issues or related to repairs. The Structural Condition Index (SCI) is based on the deduct values for only the load-related distresses, as shown in Equation 4-1. So, like the PCI, 100 is a good rating and 0 is a bad rating. The PAVER user manual identifies load-related distresses.

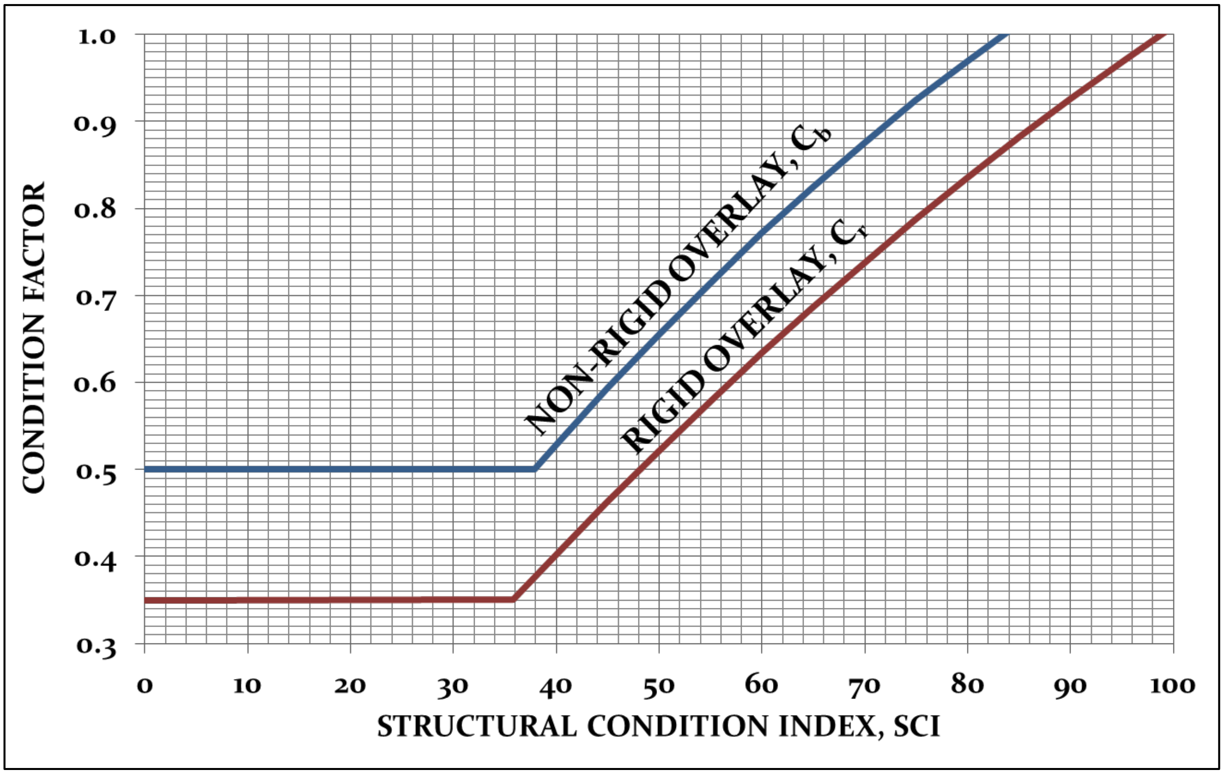
Equation 4-1. Structural Condition Index

$$SCI = 100 - CDV_{LR}$$

Where:
SCI = Structural Condition Index
CDV = Corrected Deduct Value
LR = Load Related

The SCI is used in the layered elastic analysis procedure to define failure in rigid pavements. This prediction is based on a relationship between design factor and stress repetitions as related to crack formation in the PCC slabs due to load. Details are found in UFC 3-260-02, *Pavement Design for Airfields*, and UFC 3-260-03, *Airfield Pavement Evaluation*. The SCI is also used to determine overlay requirements for rigid pavements by relating the SCI to the condition factor for bituminous overlays (C_b) and rigid overlays (C_r), as shown in Figure 4-2. UFC 3-260-02 and UFC 3-260-03 provide guidance for determining an appropriate overlay type based on the condition factor.

Figure 4-2 Using SCI to Determine Condition Factors



4-2.3 Foreign Object Damage (FOD) Index.

The FOD Index is also determined using PCI survey data but is calculated by considering only the distresses/severity levels capable of producing FOD. Table 4-1 lists the FOD-producing distresses and severities for AC pavement and Table 4-2 lists them for PCC pavement.

When calculating the PCI for determining the FOD Index (see Equation 4-2), note that a multiplier, or modification factor, of 0.6 is applied to the deduct value for alligator cracking and a multiplier, or modification factor, of 4.0 is applied to the deduct value for joint seal damage. The computation results in a value from zero to 100, but, unlike the PCI and the SCI, a low FOD Index value is good and a high value is bad. PAVER calculates the FOD index at the same time as the PCI.

Equation 4-2. Foreign Object Damage (FOD) Index

$$FOD\ Index = 100 - PCI_{FOD}$$

Where:
FOD = Foreign object damage
PCI = Pavement Condition Index

Table 4-1 FOD-Producing Distress List for AC Pavements

Distress Type	Severity Levels (L = Low, M = Medium, H = High)
Alligator cracking (modification factor: 0.6)	L, M, H
Block cracking	L, M, H
Jet blast erosion	N/A
Joint reflection cracking	L, M, H
Longitudinal and transverse cracking	L, M, H
Oil spillage	N/A
Patching	M, H
Raveling and weathering	L, M, H
Shoving	M, H
Slippage cracking	N/A

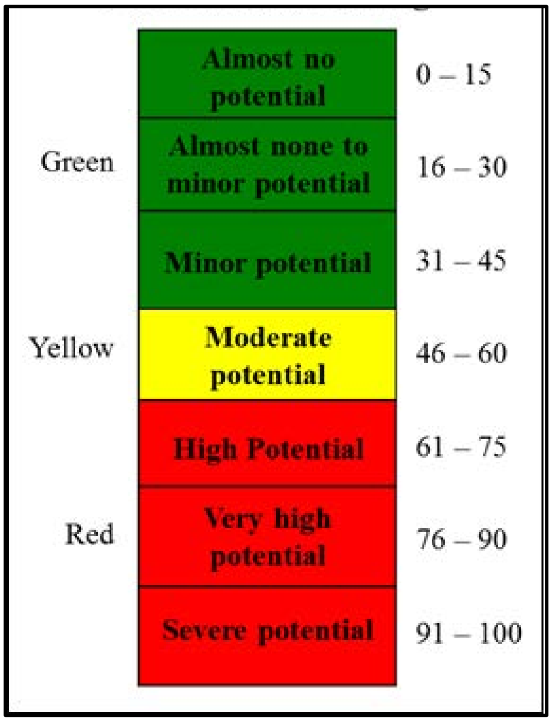
Table 4-2 FOD-Producing Distress List for PCC Pavements

Distress Type	Severity Levels (L = Low, M = Medium, H = High)
Blow-up	L, M, H
Corner break	L, M, H
Durability cracking	M, H
Linear cracking	L, M, H
Joint seal damage (modification factor: 4.0)	L, M, H
Small patching	L, M, H
Large patching	L, M, H
Popouts	N/A
Pumping	N/A
Scaling	L, M, H
Shattered slab	L, M, H
Joint spalling	L, M, H
Corner spalling	L, M, H

4-2.4 FOD Potential.

a. The FOD potential relates the FOD Index to the FOD susceptibility of three aircraft groups. A FOD potential scale ranging from 0 to 100 is used to indicate the potential for FOD problems. Figure 4-3 shows the numerical FOD potential scale and corresponding descriptive categories.

Figure 4-3 FOD Potential Scale



b. The FOD potential depends on the type of aircraft using the pavement, the type of pavement surface (asphalt or concrete), and the FOD Index. The FOD Index and the FOD potential rating are determined from the most current PCI survey.

c. Relationships between FOD indexes and FOD potential were developed for three aircraft groups: F-16, KC-135, and C-17. These three aircraft were selected as a representative cross-section due to engine height above the pavement surface and engine susceptibility to FOD (e.g., engine type, size, air flow, thrust). Table 4-3 provides recommendations on which standard aircraft group curve (F-16, KC-135, or C-17) to use when determining the FOD potential for other aircraft.

Table 4-3 FOD Potential Aircraft Groups

Standard Aircraft	For Aircraft Listed Below, Use FOD Index/FOD Potential Relationship Curve for Standard Aircraft (Left Column)
F-16	A-37, AT-38, F-15, F-22, F-35, T-37, T-38
KC-135	A-300, A-310, A-320, A-321, A-330, A-340, A-380, AN-124, B-1, B-2, B52, B-707, B-720, B-737, B-747, B-757, B-767, B-777, C-21, C-32, C38, C-40, C-135, DC-8, DC-10, E-3, E-4, E-8, EC-18, EC-135, IL-76, KC-10, L-1011, MD-10, MD-11, P-8, T-1A, T-43, VC-25, VC-137
C-17	A-10, B-717, B-727, C-5, C-9, C-12*, C-20, C-22, C-23*, C-27, C-37, C38, C-41, C-130*, C-295, CN 235, CV-22, DC-9, MC-12, MD-81, MD82, MD-87, MD-90, MV-22*, P-3*, RC-26, RQ-4, T-6*
* Denotes turboprop or turboshaft-equipped aircraft	

d. Figures 4-4 and 4-5 show the relationship between the FOD Index and FOD potential for asphalt and concrete pavements, respectively.

Figure 4-4 FOD Index and FOD Potential Relationship for AC

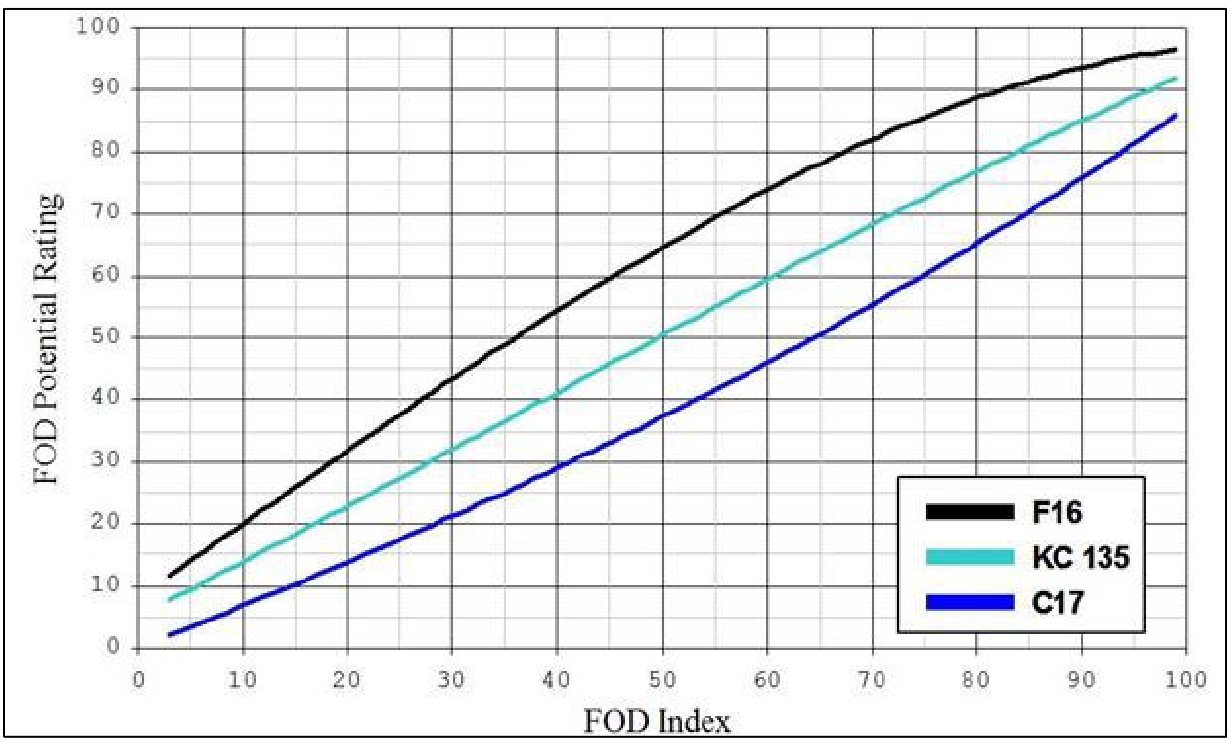
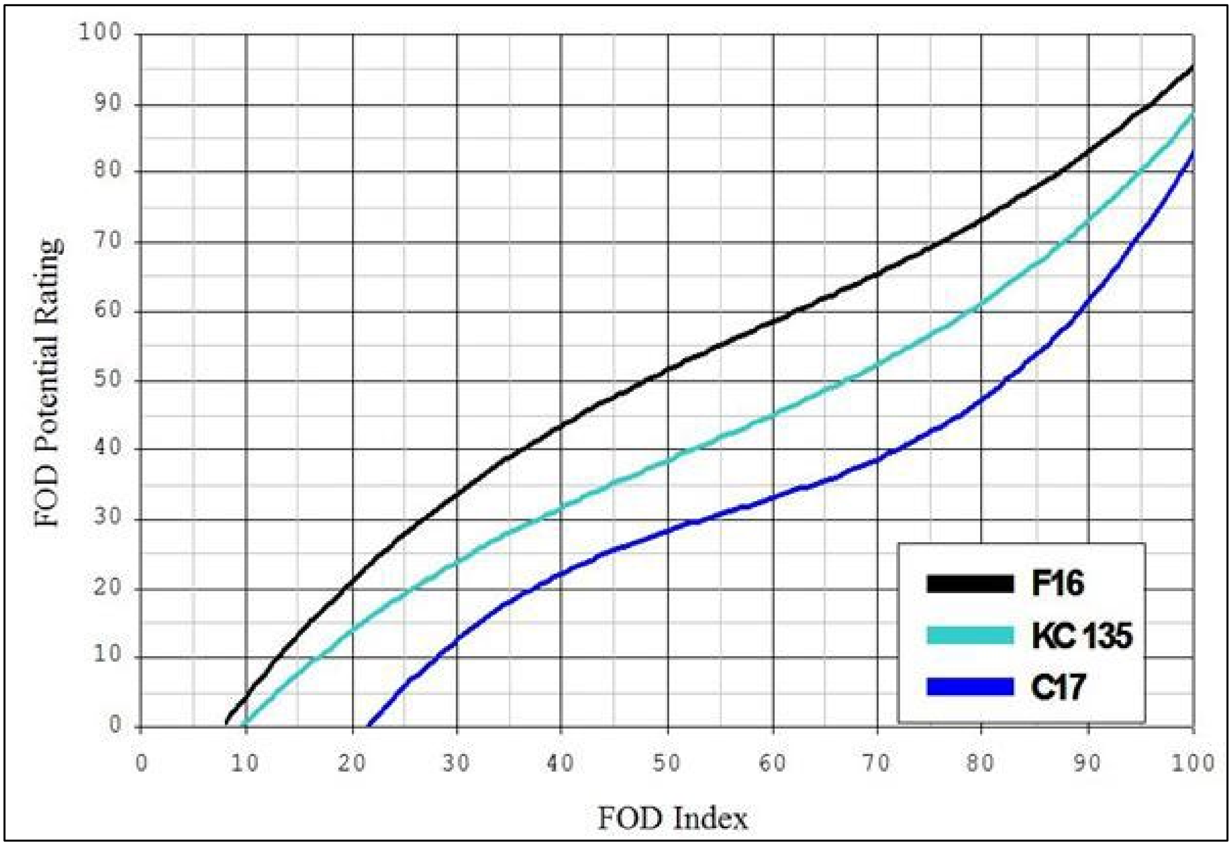


Figure 4-5 FOD Index and FOD Potential Relationship for PCC



e. The aircraft group curves in Figures 4-4 and 4-5 were used to determine the FOD potential risk levels in Table 4-4. The FOD Index and the FOD potential group for a section corresponds to the low, medium, and high FOD potential risk for that section. The FOD potential can be displayed on a color-coded airfield layout map, using green for the corresponding rating of low, yellow for medium, and red for high.

Table 4-4 FOD Potential Risk Level

FOD Potential Risk Level		**FOD Index**					
		F-16		**KC-135**		**C-17**	
		AC	**PCC**	**AC**	**PCC**	**AC**	**PCC**
Low	0–45	0–32	0–41	0–44	0–60	0–59	0–77
Medium	46–60	33–45	42–62	45–60	61–78	60–75	78–89
High	61–100	46–100	63–100	61–100	79–100	76–100	90–100

4-3 STRUCTURAL PAVEMENT EVALUATIONS.

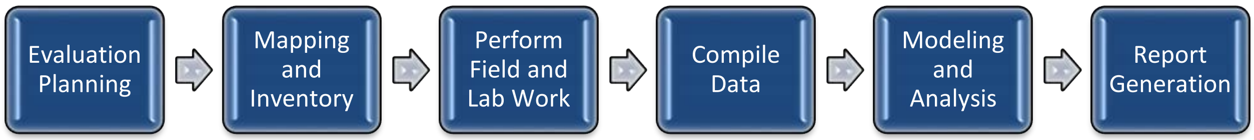
a. The objective of a structural evaluation is to determine the allowable load, allowable passes, and the Pavement Classification Number (PCN) (for airfields only) for a specific mix of traffic. UFC 3-260-03 uses the terms “nondestructive testing” and “direct sampling” to describe the two approaches to structural evaluation testing procedures. Both approaches determine the layer types and thicknesses and characterize the material properties of each layer.

b. Specifically, nondestructive testing uses tools such as the falling weight deflectometer (FWD) to determine modulus of elasticity or ground penetrating radar (GPR) to determine pavement thickness, whereas direct sampling uses test methods such as coring to determine pavement thickness, the dynamic cone penetrometer (DCP) to determine the California Bearing Ratio (CBR) for flexible pavements, or the Modulus of Subgrade Reaction (K) for rigid pavement. Each approach also uses different performance models for analysis.

c. Like PCI surveys, structural evaluations are performed on a section-by-section basis using the same inventory structure used for the PCI survey. Structural pavement evaluation data is often used to delineate pavement sections since each section represents a unit of the pavement network that is uniform in structural composition and subjected to consistent traffic loadings.

d. Service evaluation teams perform regularly scheduled airfield structural evaluations. Consultants may perform structural evaluations or geotechnical investigations in conjunction with specific project designs. Service evaluation teams or consultants may also perform structural evaluations for roads and parking pavement on an as-needed basis. Evaluations follow the general process shown in Figure 4-6. More details are provided in UFC 3-260-03.

Figure 4-6 Structural Evaluation Process



4-3.1 Structural Evaluation Planning.

Planning involves gathering data from the installation and doing a records review of the historical data from previous evaluations and other sources to develop a test plan. The test plan will vary depending on the type of testing and the availability of construction history and previous test data.

4-3.2 Structural Evaluation Mapping and Inventory.

The data gathered in planning is used to create/update maps and inventory as discussed in Chapter 3. The same maps and inventory used for PCI surveys are also used for structural evaluations. Update the maps and inventory to the maximum extent possible before conducting a structural evaluation. Maps and inventory may be adjusted in the field based on testing results. If testing includes coring or DCP testing, the test plan will include a map showing the test locations. The map helps communicate testing requirements and timing to installation personnel and is used to process work clearance requests for the evaluation.

4-3.3 Structural Evaluation Field/Laboratory Data Collection and Testing.

4-3.3.1 Structural Evaluation Field Testing.

Field work involves collecting data regarding traffic, pavement use, temperature, climate, water table, and geology as well as test data to determine layer types, thicknesses, and properties. When doing a nondestructive evaluation, use one or more of the test methods shown in paragraph 4-3.3.2 to determine layer types and thickness. Use the FWD to gather data for the backcalculation procedure to determine the modulus of each layer. The direct sampling evaluation will use one or more test methodologies shown in paragraph 4-3.3.2 to determine layer types and thicknesses as well as CBR (for flexible pavement) or K (for rigid pavement) values. UFC 3-260-03 and Service-specific guidance outline details for the test methods shown in paragraph 4-3.3.2. Any samples collected that cannot be tested in the field are returned to the laboratory for additional testing.

4-3.3.2 Structural Pavement Evaluation Test Methods.

- California Bearing Ratio (CBR)
- Concrete split tensile testing
- Dynamic cone penetrometer (DCP)
- Falling weight deflectometer (FWD)
- Ground-penetrating radar (GPR)
- Pavement coring
- Plate bearing
- Soil laboratory testing
- Ultrasonic testing (MIRA)

4-3.4 Compile Structural Evaluation Data.

Compile the field and laboratory test data in the physical property data (PPD) table. If a previous structural evaluation was done, use the PPD from the previous evaluation as a starting point. The PPD content may vary based on the type of evaluation performed and mission requirements, but, at a minimum, must have the information in Table 4-5.

Table 4-5 Physical Property Data

Physical Property Data Table Requirements	
Section ID	Thickness of each soil layer
Section name	Description of each soil layer
Thickness of each pavement layer	Modulus, CBR, or K for each layer depending on analysis procedure
Description of each pavement layer	
Flexural strength of PCC layers	

4-3.5 Data Modeling and Analysis.

Import the field test data into the PCASE application. Define the section properties for each section in the inventory, including the evaluation type (airfield or road/parking), traffic area (A, B, C, or D), PCI, traffic pattern, and analysis type (layered elastic or CBR/K). The process varies from this point depending on the analysis type: layered elastic analysis using FWD data or a conventional analysis using CBR/K evaluation procedures.

4-3.5.1 Layered Elastic Modeling and Analysis.

a. The first step in Layered Elastic Analysis is reviewing the test data (known as deflection basins). Use the PCASE Nondestructive Test **FWD Data** tool when one file has test data for multiple sections. Parse out the test points and assign them to the appropriate sections. When a file only has test data for a specific section, just assign the test data to the section without any parsing.

b. Next, use the layer structure data compiled in the PPD to create a layer model in PCASE for each section and select basins for backcalculation for each of these sections. This process involves reviewing the basin data to eliminate outliers to achieve a coefficient of variation below 20 for the data set.

c. The PCASE backcalculation procedure determines modulus values for each basin in the test data as well as the convergence error for each basin. PCASE also performs representative basin computations and selects a representative basin for the data set. A low percent error for either the convergence error or the representative basin computation does not necessarily indicate a good result. Review the results to determine whether they are reasonable. If not, re-evaluate the input parameters, adjust the model, and repeat the process until the results are reasonable. The reasonableness of results is typically determined based on published modulus ranges for different material types and the other evaluation test results.

d. After determining a reasonable set of modulus values for the layer model, run the analysis to determine the allowable load, allowable passes, and

Pavement Classification Number (PCN). Based on the results, the user may re-evaluate the model parameters and repeat the process. Details for both the layered elastic backcalculation and analysis procedures are outlined in UFC 3-260-03 and the PCASE User Guide.

4-3.5.2 Conventional Analysis Using CBR/K Analysis Procedures.

While field testing may be less complicated with the CBR/K procedure, the analysis is not as robust as the layered elastic procedure, especially when dealing with non-standard pavement structures. With that said, the CBR/K procedures have served well for many years and are especially useful for contingency evaluations.

Once section properties are defined in the PPD based on the test results, use the data compiled for each section to create a layer model in PCASE. Like the layered elastic procedure, the layer model may combine similar layers to facilitate analysis. Run the analysis to determine the allowable load, allowable passes, and PCN for each section. Based on the results, the user may re-evaluate the model parameters and repeat the process.

4-3.6 Report Generation.

PAVER and PCASE both generate a variety of reports. These reports are typically Excel spreadsheets that the user incorporates in their design analysis or pavement evaluation report.

4-3.7 Aircraft Classification Number (ACN).

The ACN number expresses the relative structural effect of an aircraft in terms of a standard single-wheel load on flexible or rigid pavement types for four specified standard subgrade strengths. UFC 3-260-03 discusses the standard procedures for determining the ACN of an aircraft. The specifics of the computation are given in the International Civil Aviation Organization (ICAO) *Aerodrome Design Manual, Part 3, Pavements*. The rigid pavement ACN algorithm used by the DoD considers all loads (tires) within eight times the radius of stiffness as opposed to three times, which is used in the ICAO *Aerodrome Design Manual*. Aircraft manufacturers publish ACN values for each aircraft using the ICAO procedure. The PCASE application also calculates ACNs using the ICAO procedure but uses a linear relationship between the minimum and maximum load that can vary slightly from the manufacturer’s ACN values.

4-3.8 Pavement Classification Number (PCN).

The PCN number expresses the relative load-carrying capacity of a pavement in terms of a standard single-wheel load on flexible or rigid pavement types for four specified standard subgrade strengths. The numerical PCN value for a pavement is determined from the allowable load for a defined aircraft at a specified number of passes on the pavement. Once the allowable load is established, determine the PCN value by converting that load to a standard single-wheel load and then to a standard relative value. PCNs are discussed in more detail in UFC 3-260-03 and the criteria for converting allowable loads to PCN values are presented in the ICAO *Aerodrome Design Manual, Part 3, Pavements*.

4-3.8.1 Publishing PCNs.

An airfield pavement structural evaluation report publishes a PCN for each section in the inventory and may publish a limiting PCN for each branch (runway, taxiway, and apron). The Air Force Air Mobility Command (AMC) publishes PCNs in their Airfield Site Suitability Reports for installations used by the Services in the U.S. and overseas. The "Giant Report" is a summarized compilation of the information in the Site Suitability Reports and includes the PCN. In addition, the National Geospatial Intelligence Agency publishes the PCNs for runways, taxiways, and aprons generated by these airfield pavement evaluations in Flight Information Publications (FLIP) used by the military and civil aviation community.

4-3.8.2 PCN Based on Standard versus Controlling Aircraft.

The PCN is based on the allowable load of an aircraft at a specified number of passes. There are two alternatives for selecting the aircraft the PCN is based on for a specific airfield. The first uses the controlling aircraft at a specified number of passes based on the traffic mix for that specific installation. The second uses a standard aircraft at a set number of passes established by the Service. The PCN computed using either alternative is used to compute the ACN/PCN ratio. Each Service can use one or both procedures when publishing PCNs in their reports.

The procedure using the specific traffic mix for the installation relies on information from the installation regarding the types of aircraft that use the airfield as well as the number of operations of each. When the information provided is accurate, this approach provides greater fidelity for managing aircraft traffic on pavements at the local level but does not work as well when comparing capability between installations. Note that the controlling aircraft and passes can vary between sections on an installation. While the controlling aircraft and passes used to compute the PCN are published in the pavement evaluation report, just the PCN is published in the Giant Report or FLIP. The standard aircraft procedure can be used to manage traffic on pavements at the local level but has the inherent benefit of knowing the controlling aircraft and number of passes when looking at capability between sections and between installations since the controlling vehicle does not vary. The controlling aircraft and passes are published in the structural evaluation report, the AMC Site Suitability Report, and the Giant Report, but this detail is not published in the FLIP.

4-3.9 ACN/PCN Ratio.

The ACN/PCN is a method for reporting weight-bearing capacity intended to provide planning information for individual flights or multi-flight missions to avoid overloading pavement facilities. While it was not originally intended as an evaluation procedure, it is used this way. The ACN/PCN procedure provides a means to compare the ACNs published by aircraft manufacturers to the PCNs published in evaluation reports and the

FLIP. The system is structured so that a pavement with a PCN value greater than or equal to the aircraft ACN value can support that aircraft without weight restrictions.

4-3.9.1 Structural Index (SI).

The DoD pavement community applies the ACN/PCN ratio as a pavement management metric and uses the term “structural index” (SI) in this context. This metric compares the ACN of the critical aircraft at a specified load for each section to the published PCN for that section. See Equation 4-3.

Equation 4-3. Structural Index (SI)

$$SI = ACN/PCN$$

Where:
ACN =Aircraft Classification Number
PCN = Pavement Classification Number

4-3.9.2 ACN Critical Aircraft.

The critical aircraft used to determine the ACN varies based on the traffic using the pavement. For example, the critical aircraft for the runway at an installation may be the P-8 but aprons or taxiways that the P-8 does not traffic will use a different critical aircraft to determine the ACN.

The critical aircraft used to determine the ACN can be the same as the controlling aircraft used to determine the PCN for a given section, but when using the standard aircraft alternative to determine the PCN, the primary assigned mission aircraft using respective sections at that installation are used as the critical aircraft to determine the ACN. Adjust the aircraft load used to compute the ACN such that the results of SI computation align with the allowable gross loads (AGL) published in the report. For example, you do not want the SI as defined in the next paragraph to indicate load restrictions when the AGL report showed that there were no load restrictions.

4-3.9.3 Structural Index (SI) Ratios.

The SI is used differently in Service-specific pavement management processes based on mission requirements, but in all cases when used for pavement management, the SI is interpreted as outlined in Table 4-6.

Table 4-6 Structural Index (SI) Ratios

Structural Index (SI)	Description
SI ≤ 1.1	The pavement structure for the section is adequate to support the mission traffic for the defined design life.
1.1 < SI ≤ 1.4	The pavement structure for the section will not support the mission traffic for the defined design life. Aircraft loads or the number of passes may be limited to extend the life of the pavement.
SI > 1.4	The pavement structure for the section will not support the mission traffic for the defined design life. Aircraft traffic must be closely monitored. Overlay or reconstruction must be performed if the pavement is required to support mission traffic for the defined design life.

4-3.9.4 Structural Index (SI) versus Critical PCI.

An SI ≥ 1.1 indicates that the section is structurally inadequate to support the mission traffic for the defined load and passes, but this fact alone will not typically drive overlay or reconstruction unless the pavement capability must be increased due to a mission change. If the pavement is above the critical PCI, continue preventive maintenance (PM), and when the pavement drops below critical, incorporate an increase in structural capability in your repair solution.

4-4 SURFACE FRICTION CHARACTRISTICS EVALUATIONS.

Surface friction characteristics evaluations are typically performed on runways but may be performed on taxiways in certain circumstances. They are used to determine the hydroplaning potential of a surface under standardized wet conditions. They are carried out on multiple sections, but the results for each section can be extrapolated.

The procedure includes friction tests using continuous friction measuring equipment (CFME), slope measurements, and texture measurements. Procedures and equipment generally correspond to those outlined in FAA Advisory Circular (AC) 150/5320-12C, *Measurement, Construction, and Maintenance of Skid Resistant Airport Pavement Surfaces*.

4-4.1 Mu (Friction) Values.

Mu (μ) numbers (friction values) measured by CFME operated at 40 and 60 mph (65 and 95 km/h) test speeds are used as guidelines for evaluating the surface friction deterioration of runway pavements, prioritizing M&R requirements when developing a PMP, and for identifying the appropriate corrective actions necessary for safe aircraft operations.

4-4.2 Friction Level Classification.

The friction value use varies in Service-specific pavement management processes based on mission requirements, but in all cases the friction level classification will correspond to the friction values defined in FAA AC 150/5320-12C, *Measurement, Construction, and Maintenance of Skid Resistant Airport Pavement Surfaces*. When used for pavement management, interpret the friction classification level as outlined in Table 4-7. According to these guidelines, poor friction conditions for short distances on the runway do not pose a safety problem to aircraft, but long stretches of “slippery” pavement are a serious concern and require prompt remedial action.

Table 4-7 Friction Level Classification

Friction Level Classification	Description
Minimum	When the averaged Mu value on the wet pavement surface is below the minimum friction level for a distance of 500 feet (152 m), and the adjacent 500-foot (152 m) segments are below the maintenance planning friction level, take corrective action immediately after determining the cause(s) of the friction deterioration.
Maintenance Planning	When the averaged Mu value on the wet pavement surface is less than the maintenance planning friction level for a distance of 1000 feet (305 m) or more, determine the cause(s) and extent of the friction deterioration and take appropriate corrective action.
New Construction	The averaged Mu value on the wet pavement surface for each 500-foot (152 m) segment is no less than the new design/construction friction level shown in the FAA AC 150/5320-12C friction level classification for runway pavement surfaces.

4-5 VOID DETECTION SURVEYS.

Void detection surveys determine the existence and extent of voids under pavements as well as their effect on the load-bearing capability of the pavement. They are typically conducted on a portion of a section or sections where there are indications of issues such as localized cracking or in areas with a greater potential for voids, such as near drainage structures or in areas where karst formations are present.

4-5.1 Void Detection Tools.

These surveys use some or all of the following tools: ground penetrating radar (GPR), falling/heavy weight deflectometer (FWD/HWD), coring, and dynamic cone penetrometer (DCP) testing. UFC 3-260-03 outlines void detection testing procedures.

While GPR can locate potential voids, the HWD is the primary tool for identifying weak areas. Coring and DCP testing are used to verify the existence of a void or weak subgrade area.

4-5.2 Impulse Stiffness Modulus (ISM).

HWD testing produces a value termed the impulse stiffness modulus (ISM) to assess the relative pavement strength at a test location. Determine ISMs by dividing the load by the deflection at the respective deflection sensor (typically D1 through D7). Manually compute or use the PCASE FWD module to determine ISMs for sensors D1 through D7.

The deflection at sensor D1 reflects the state of the pavement, whereas D7 reflects the state of the subgrade. Using D1 alone is not sufficient to successfully detect voids under the pavement. Analyze the data by plotting the ISMs for sensors one through seven. If required, normalize the data by dividing each plot by the highest value in the plot to determine relative effects of pavement weaknesses on each sensor.

4-5.3 ISM Interpretation.

Once the data are plotted, use the following rules to determine potentially weak areas:

- An ISM value below 1000 kips per inch on a concrete pavement is of concern
- An ISM value below 300 kips per inch on an asphalt pavement is of concern
- Relative ISM decay indicates an unexpected weakness
- Weakness in ISM1 indicates it is shallow (less than 3 feet [0.9 m])
- Weakness in ISM7 indicates it is deep (3 to 20 feet [0.9 to 6 m])
- Weakness in both ISM1 and ISM7 indicates a general lack of support

4-5.4 Void Verification.

The DCP is the primary tool used to verify the existence of near-surface voids and determine the void’s depth and extent. UFC 3-260-03 and TM 3-34.48-2, *Theater of Operations: Roads, Airfields, and Heliports – Airfield and Heliport Design*, describe the DCP and how to use it. The DCP is designed to reach a depth of 4 feet (1.2 m), but extensions can increase testing depth for voids.

Plot DCP results as CBR versus depth at each test location. The CBR indicates the strength of the underlying soil. Soil with CBR values below 8 are marginal and CBR values below 4 are of concern. CBR values approaching 1 indicate no strength, very loose soil, or an actual void (sinkhole). Since the main concern is the effect on load-carrying capacity, no distinction is made between very loose soil and actual voids if their effect on load-carrying capacity is equal.

4-5.5 Void Risk Categories.

Table 4-8 Risk Categories

Risk	Description
Low	No weakness or voids detected. No action required.
Moderate	Test results did not definitively determine the presence of a weak area or void. Take action to conduct additional testing, perform maintenance or repair, or monitor section for changes, depending on the situation. **Additional Testing:** When GPR scan encounters suspect areas deeper than DCP testing can reach or DCP results indicate soft pockets of soils, perform a video scan of drainage structures. If GPR test results are inconclusive and standing water was noted in structures, indicating a loss of drainage, conduct a drainage study to identify drainage paths and determine if drainage structure connections and sizes are adequate. **Perform Maintenance:** Testing did not indicate a structural weakness, but there are medium- or high-severity pavement distresses or nearby drainage structures need maintenance or repair. Perform pavement maintenance, repair broken structures, or clean inlets and outfalls as required **Monitor Area:** Testing did not indicate a structural weakness and the pavement has only low-severity distresses. Monitor the area for changes such as depressions, cracking, or ponding.
High	Void detected with GPR and verified with the HWD and/or DCP. Take immediate action for full-depth repair of pavement and drainage structure, if applicable.

4-6 ROUGHNESS SURVEYS.

The highway industry defines pavement roughness in terms of the ride quality experienced by a passenger. Automotive manufacturers design suspension systems to reduce the impact of common surface irregularities and improve overall ride quality. In contrast, the primary purpose of an aircraft suspension system is to absorb energy expended during landing. Aircraft suspension systems have less capacity to dampen the impact of surface irregularities compared to the magnitude of the energy that must be addressed during landing. Airfield pavement roughness is defined in terms of fatigue on aircraft components (increased stress and wear) and/or other factors that impair the safe operation of the aircraft (e.g., cockpit vibrations, excessive g-forces).

4-6.1 Airfield Roughness Survey.

A runway roughness evaluation examines the elevation profile of the runway surface and evaluates aircraft response to this profile. Newly constructed runway pavements are evaluated to help ensure longitudinal slopes meet established design criteria. Longitudinal and transverse slope criteria for airfields are defined in UFC 3-260-01, *Airfield and Heliport Planning and Design*. As a pavement ages, the longitudinal surface profile may vary from the original design standards due to factors such as frost heave or subgrade settlement and cause excessive roughness. When roughness evaluations are performed on multiple sections, the results for each section can be extrapolated.

The Services do not routinely conduct this type of evaluation, but, when performed, use the guidance in FAA AC 150/5380-9, *Guidelines and Procedures for Measuring Airfield Pavement Roughness*. Installations requiring a runway roughness evaluation can contact their Service POCs for assistance (see paragraph 2-9.3).

4-6.1.1 Single Event Bump.

Single event bumps are isolated events where changes in pavement elevation occur over a relatively short distance of 100 meters (328 feet) or less. Such elevation changes may occur as an abrupt vertical lip or as a more gradual deviation from a planned pavement profile. A basic “virtual straightedge” analysis as outlined in FAA AC 150/5380-9 can identify single event bumps. Riding the pavement in a passenger vehicle might reveal shorter length bumps but finding longer length bumps may require a thorough analysis of the pavement profile.

4-6.1.2 Profile Roughness.

Profile roughness is the surface profile deviations present over a portion of the runway that cause airplanes to respond in ways that can increase fatigue on airplane components, reduce braking action, or impair cockpit operations. Response depends on airplane size, weight, and operation speed. Roughness may affect the fatigue life of airplane components or decrease operational safety of the airplane. Depending upon airplane characteristics and operating speed, an airplane may be excited into harmonic resonance due to profile roughness, which can increase inertial forces or vibrations within the airplane structure.

4-6.1.3 Boeing Bump Index (BBI).

While not routinely conducted by DoD, FAA AC 150/5380-9 calls for using the “Boeing Bump” procedure and uses the results of this procedure to develop the BBI. The BBI procedure defines three evaluation zones—acceptable, excessive, and unacceptable—that are defined based on a relationship between the BBI and the bump length. BBI values below 1.0 are in the acceptable zone. Values of BBI greater than 1.0 fall in either the excessive or unacceptable zones. The BBI may be used in Service-specific pavement management guidance. When used, the guidance in Table 4-9 defines required maintenance action.

Table 4-9 Boeing Bump Index (BBI) Roughness Levels

Roughness Levels	Description
Acceptable	Newly constructed or rehabilitated pavement to result in bump height and length combinations that fall within the lower region of the acceptable range. No repair is required on existing pavement.
Excessive	Immediate pavement repairs are necessary at this level, but closure of the affected pavement is not required.
Unacceptable	Roughness levels in the unacceptable zone warrant immediate closure of the affected pavement. Repairs are necessary to restore the pavement to an acceptable level.

4-6.2 Roughness Criteria for Aircraft Arresting Systems.

The 200 feet (60 m) of pavement on both the approach and departure sides of an arresting system pendant is a critical area. Protruding objects and undulating surfaces are detrimental to successful tail hook engagements and are prohibited. The roughness criteria for aircraft arresting systems are defined in UFC 3-260-01. Determine conformance with these requirements using differential leveling that may be performed by installation personnel or contractors.

4-6.3 Road Roughness Surveys.

UFC 3-201-01, *Civil Engineering*, calls for roads to be designed in accordance with SDDCTEA Pamphlet 55-17, AASHTO *A Policy on Geometric Design of Highways and Streets* (also known as The Green Book), AASHTO *Roadside Design Guide*, and AASHTO *Guidelines for Geometric Design of Low-Volume Roads*, as applicable. Just as with airfields, as a pavement ages, the longitudinal surface profile may vary from the original design standards due to factors such as frost heave or subgrade settlement and cause excessive roughness. Roughness evaluations are typically carried out on multiple sections, but the results for each section can be extrapolated. DoD does not currently make extensive use of roughness surveys because the “automated” surveys used to determine the International Roughness Index (IRI) (see paragraph 4-6.4) may not be cost-effective for military installations and the vehicle operating speeds on military installations as well as issues with items like utility appurtenances (manholes) raise questions about the viability of the IRI results. Information on roughness and the IRI is presented in this UFC for use when the IRI data is available.

4-6.4 International Roughness Index (IRI).

The IRI is the standard for expressing pavement smoothness on roads. It can be computed using profile measurements obtained from devices such as the inertial profiler, Dipstick®, and rod and level. There are documents that provide standardized methods to compute the IRI, including AASHTO R 43M/R 43-07, *Standard Practice for Quantifying Roughness of Pavements*, and ASTM E1926, *Standard Practice for*

Computing International Roughness Index of Roads from Longitudinal Profile Measurements.

The IRI is computed from a longitudinal profile measurement using a quarter-car simulation at a speed of 50 mph (80 km/h). The IRI is reported in either inches per mile (in./mile) or meters per kilometer (m/km; **note:** 1 m/km = 63.36 in./mile). The IRI scale starts at zero for a road with no roughness and covers positive numbers that increase in proportion to roughness. Table 4-10 provides typical IRI values with verbal descriptors of required maintenance actions when the IRI is used in Service-specific pavement management guidance.

Table 4-10 IRI Ranges and Maintenance Actions

IRI Range (in./mile)	Description
$0 < IRI \leq 380$	No repairs are required based solely on IRI.
$380 < IRI \leq 500$	Pavement repairs are necessary at this level, but reduction of traffic speed or closure of the affected pavement is not required.
$IRI > 500$	Immediate pavement repairs are necessary to restore the pavement to an acceptable level. Consider reduction of traffic speed or closure of the affected pavement if pavement repairs cannot be performed.

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CHAPTER 5 DETERIORATION MODELS AND PERFORMANCE ANALYSIS

5-1 INTRODUCTION.

Pavement deterioration models are known as PCI family models. PCI family models are generated using the **PCI Deterioration Families** tool in PAVER as part of regularly scheduled airfield or road and parking PCI surveys. These deterioration models are based on past pavement performance and are used to predict future pavement condition to determine repair requirements based on that condition. Installation personnel may review or update PCI family models to determine where a pavement section is in its life cycle, determine effectiveness of maintenance actions, or determine deterioration rates for a specific subset of the pavement network.

5-2 PCI FAMILY MODEL PARAMETERS.

The DoD typically uses the pavement type and section rank as the primary parameters to define PCI Family Models for both airfield and road and parking pavement. When the Coefficient of Correlation is low and the standard deviation of error is high for a model, refine the model by creating separate models for different pavement types, e.g., AC and AAC, creating models for each Branch Use, or using other parameters such as whether the pavement has had localized preventive or global M&R performed, to create families with reasonable accuracy.

5-2.1 Pavement Surface Type.

The most important parameter for a deterioration model is the surface type, given that the deterioration rate of asphalt will typically be higher (average 2 to 3 points per year) than concrete (average 0.5 to 1.5 points per year).

5-2.2 Pavement Rank.

The pavement rank is the recommended standard for the second parameter. Group primary asphalt pavements, primary concrete pavements, etc. Secondary and tertiary pavement may be grouped together if model statistics are acceptable. Otherwise, create separate models for secondary and tertiary asphalt and concrete pavements as required.

5-2.3 Branch Use.

If model statistics do not meet the requirements outlined below, refine the models further to include the branch use. For example, when modeling statistics indicate the deterioration rate of the runway varies significantly from other primary pavements.

5-3 PCI FAMILY MODEL NAMING STANDARD.

Naming standards ensue the user can distinguish between models for a specific installation and are critical when distinguishing between family models in a rollup database. The standard is to use the convention **Site NameYr_Pavement Type_Rank** as the PCI family model name. For example, the deterioration model for Tyndall AFB primary PCC pavements last inspected in 2018 is **Tyndall18_PCC_P**.

If the branch use is used to create a family model for a specific reason as described above, name the model **Site NameYr_Pavement Type_Rank_Branch Use**; for Example, **Tyndall18_PCC_P_Road**. If the model must be created for specific branches rather than rank to achieve the required model statistics, replace the rank with the branch use; for example, **Tyndall18_PCC_Apron**.

5-4 PCI FAMILY MODEL PROCESS STANDARDS.

The PCI family model defines the deterioration rate of a pavement by plotting the condition of sections with similar characteristics against the age of the pavement in those sections. A minimum of five data points is required to define a deterioration model. This can be five inspections over time for one section, one inspection for five sections with similar surface types, or some other variation to get five points.

The PAVER user manual provides a description of the process of creating and assigning PCI family models. Following are supplemental instructions and standards for creating PCI family models for pavements on DoD installations.

5-4.1 Family Modeling - Review Model Data.

a. The **Review Model Data** tab (Figure 5-1) in the PAVER **PCI Deterioration Families** tool allows the user to create, copy, rename, or delete family models as well as review model data and add or delete specific data points.

Figure 5-1 Review Model Data Tab

b. When creating family models, PAVER gives the option of excluding inspection data based on backcalculated construction dates. Standard practice is to select **No** for this option unless there is evidence that using these points negatively affects the model, for example, when most of the points plot on a single line. In this case, rerun the model without the points with backcalculated construction dates.

c. As shown in Figure 5-1, data outliers are indicated by red triangles in the family model graph and identified in the status column of the table at the bottom of the form. Investigate outliers to determine if the age or PCI are accurate and correct any issues. If the age and PCI are correct, investigate the outliers from the current PCI inspection that are below the outlier boundary to determine the cause of the high rate of deterioration. Evaluation teams and consultants will document these issues in the report. These data may also be useful to determine when to refine the family model and when developing the PMP.

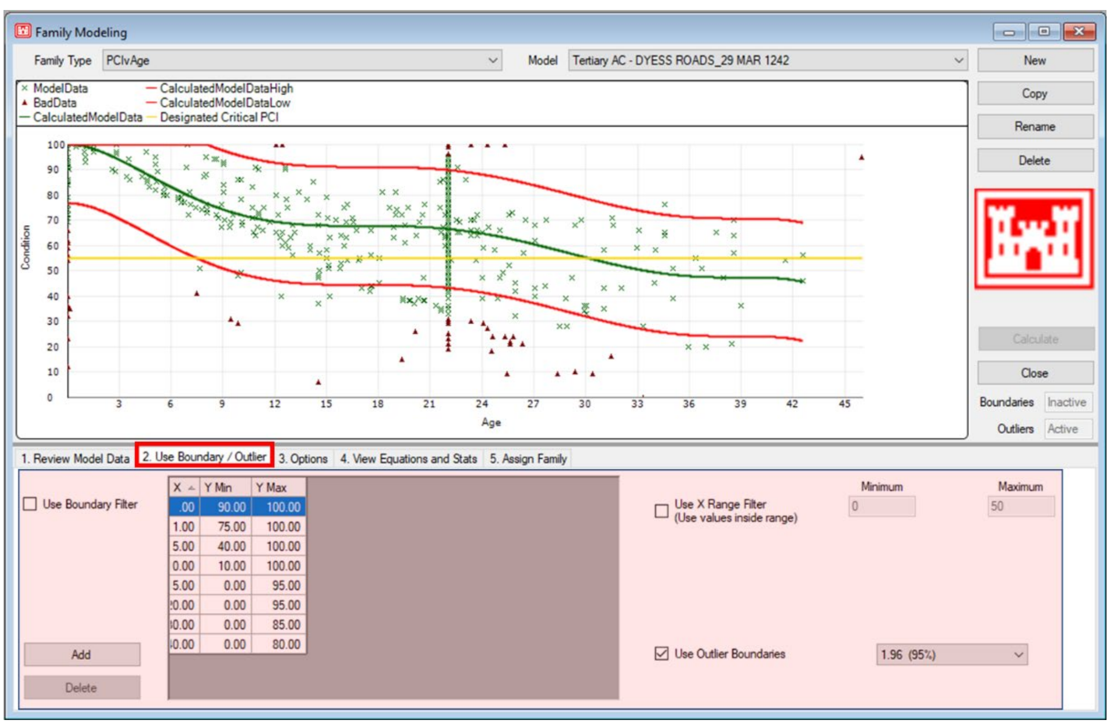
d. Review the data for the model when data points are “stacked,” as shown in Figure 5-1. A column of data points is a good indication that the age of the pavement (last construction date) is incorrect. Correct the issue by updating work using installation records or by backcalculating the last construction dates.

5-4.2 Family Modeling - Use Boundary / Outlier.

PAVER offers several options for filtering data used in deterioration models. As shown in Figure 5-2, the standard practice is to use the outlier boundary filter set at 1.96 (95 percent) confidence level. Only use the other filter options if there is a specific issue with the model that cannot be resolved by modifying the family parameters; for example, using a different model for AAC and AC surface types or separating secondary and tertiary pavement models.

The **Use Boundary Filter** option sets minimum and maximum PCI values for specified pavement ages. Any data points outside these values are filtered. Only use this option if there is a clear issue with the data model that filtering can resolve. The **Use X Range Filter** option defines the age range used for the model and filters any data points outside these values. Only use this option for DoD PCI Family Models when there is a clear issue with the data model that filtering can resolve, for example, when a deterioration model does not indicate any deterioration as it gets beyond 50 years. This can occur when the pavement in the model was designed in the 1950s or early 1960s for a much heavier load than it was subsequently used for and is therefore not seeing any deterioration, especially in a moderate climate.

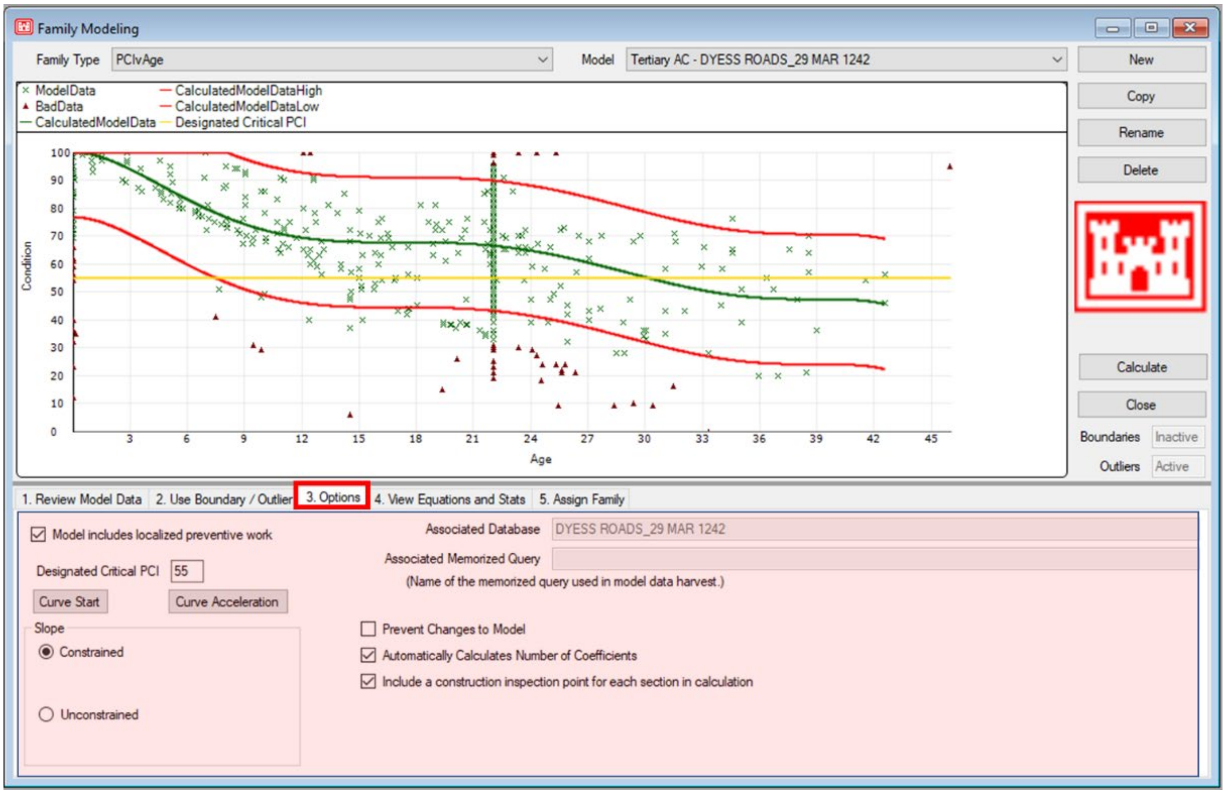
Figure 5-2 Use Boundary / Outlier Tab



5-4.3 Family Modeling - Options.

The **Options** tab is also called the Option card in the PAVER user manual. It plays a significant role in defining the deterioration model and has implications for work planning. Figure 5-3 shows the **Options** tab. Following are the key fields for this tab.

Figure 5-3 Options Tab



5-4.3.2 Model Includes Localized Preventive Work.

Unless there is specific information to the contrary, always check this box to indicate that PM is performed to indicate the deterioration model is based on this assumption. If PM is stopped, the rate of deterioration increases. Conversely, if PM was not previously performed and was subsequently started, the rate of deterioration decreases.

5-4.3.3 Critical Condition.

Theoretically, the critical condition is the point at which PM is no longer cost-effective and major M&R is triggered. The critical condition for all Services is currently set by policy at 70 for primary pavements. Service policies for critical condition on secondary and tertiary pavements range from 55 to 65, based on mission requirements.

5-4.3.4 Critical Condition Computation Tools.

The Services currently use the policy conditions outlined in paragraph 5-4.3.3 but PAVER has features to identify inflection points for consideration as a critical PCI. The

Curve Start and **Curve Acceleration** tools shown in Figure 5-3 can be used to validate the policy PCI or aid in prioritizing requirements for the PMP. They are only valid for fourth degree polynomials (4 coefficients) or higher. **Note:** A high degree model may have two inflection points.

5-4.3.5 Slope.

The constrained slope option will not allow the model to curve upward. The unconstrained option allows the model to curve upward as the pavement ages. Standard policy is to constrain the slope.

5-4.3.6 Automatically Calculates Number of Coefficients.

Once the points are plotted, the user can allow PAVER to determine a best-fit curve for the data that defines the changing rate of deterioration over time or the user can define the degree of the polynomial used to describe the deterioration. The user-defined option is typically used when the user wants to define a linear model (set the number of coefficients to two).

The linear model is useful when trying to define a simple rate of deterioration, but it does not take advantage of PAVER's ability to define the changing rate of deterioration over time. An example of both the linear and best fit models are shown in Figures 5-4 and 5-5 for the **View Equations and Stats** tab. The recommended practice is to run the linear model to calculate a rate of deterioration that can be incorporated into the report but assign the best fit model determined by PAVER to sections for M&R work planning.

5-4.3.7 Prevent Changes to Model.

Standard policy is to leave **Prevent Changes to Model** unchecked (allows changes to the model).

5-4.3.8 Include a Construction Inspection Point for Each Section in Calculation.

This option allows the user to include a data point for PCI = 100 at age 0 for each pavement section in the model that reflects the condition at construction. When not selected, you can experience issues with the standard deviation, especially when pavement construction dates are grouped within a specific range rather than having a good age spread. Including a construction inspection point resolves these issues. The standard policy is to leave this checked.

5-4.4 Family Modeling - View Equations and Stats.

The **View Equations and Stats** tab shown in Figure 5-4 is also called the View Equations and Stats card in the PAVER user manual. It displays the intercept and coefficient values for the equation that best fits the data. It also lists various "goodness-of-fit" statistics for the model.

The minimum acceptable value for the coefficient of correlation is 0.70 and the maximum acceptable value for the standard deviation of error is 15.00. If statistics for a model are outside of these thresholds, review the model, determine potential causes, and revise the model. For example, the deterioration rate of milled and overlaid (AAC) pavements is typically higher than asphalt (AC) pavement. Creating separate models can resolve goodness-of-fit issues. **Note:** Five data points are required to create a model.

Figure 5-4 View Equations and Stats – Best Fit Model

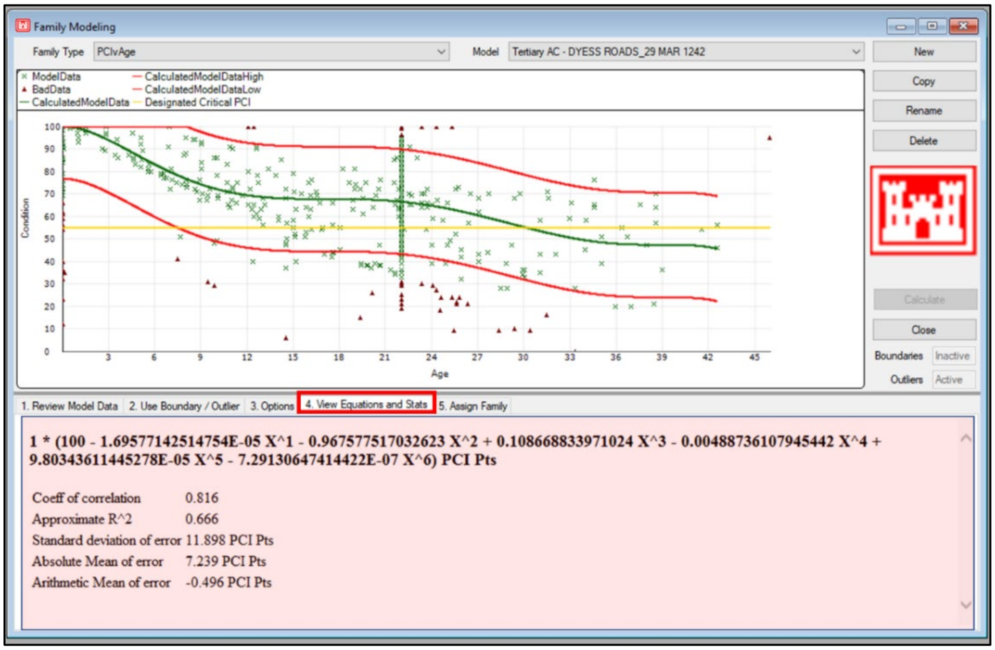
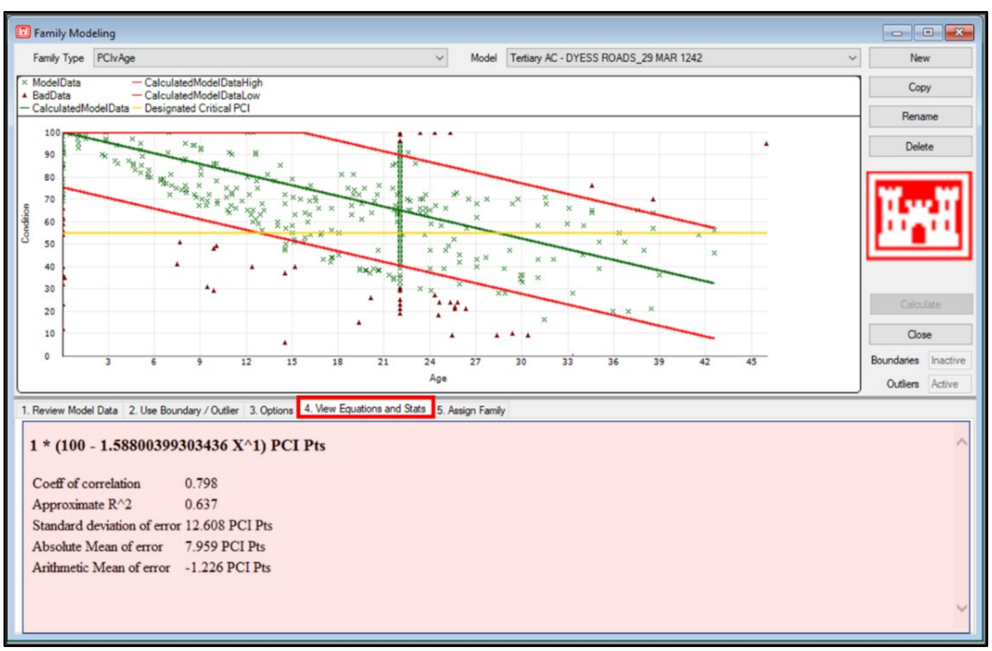


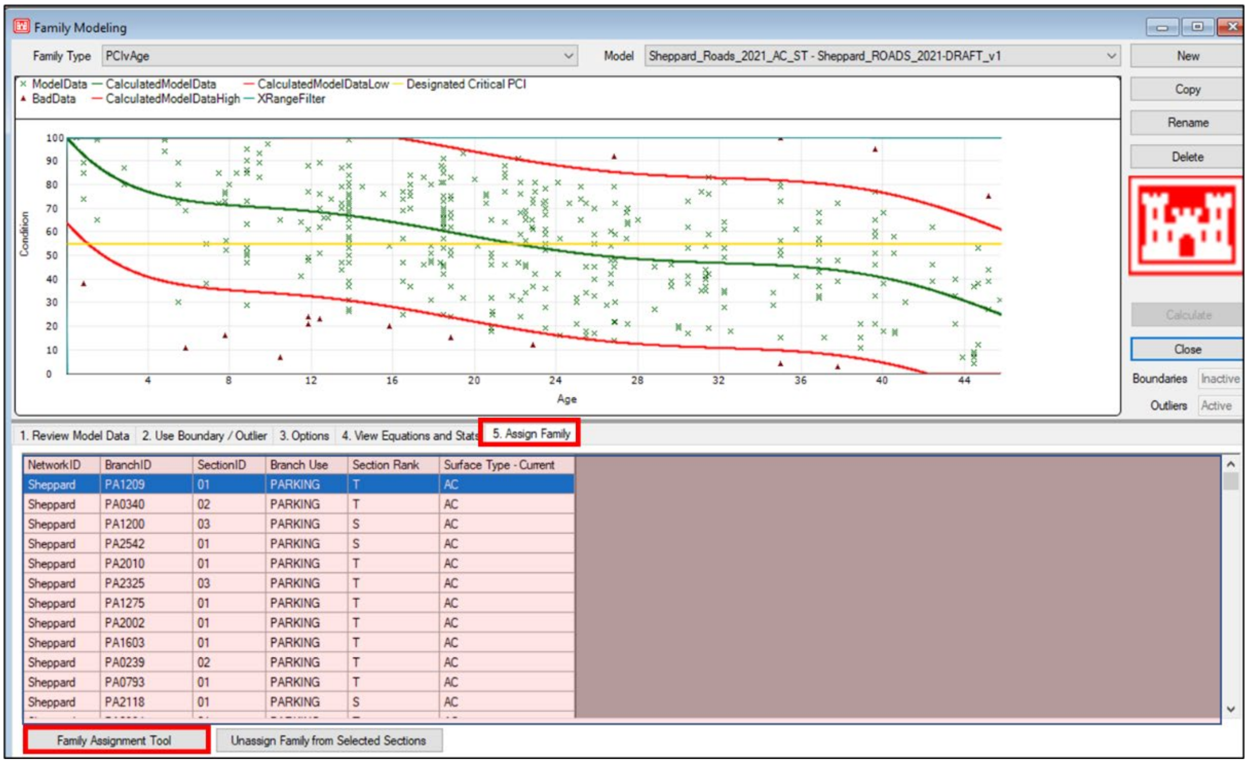
Figure 5-5 View Equations and Stats – Linear Model



5-4.5 Family Modeling - Assign Family.

After defining the PCI deterioration family model curves, go to Tab 5 and select the **Family Assignment Tool**. Select the **Show Subset** button to open the query tool and filter the data to the appropriate sections for the model, then assign the model to the sections.

Figure 5-6 Assign Family Model



5-4.5.1 Active Paved Section Model Assignment.

It is important to ensure that all active (section rank P, S, or T) paved sections are inspected and assigned to the appropriate family model. When doing work planning, PAVER uses the assigned family to determine future condition and bases M&R requirements on that condition.

5-4.5.2 Active Unpaved Section Model Assignment.

All unpaved (gravel) pavement sections are included in the inventory for use in reporting but are not typically inspected. Since there is no inspection, there is no data to determine a deterioration model, so, whether active or unused, these sections are assigned to a family model and are excluded from M&R work planning.

5-4.5.3 Unused Paved Section Model Assignment.

All unused pavement sections are included in the inventory for use in reporting but are not typically inspected, so unused (section rank of U) pavements are not assigned to a family model and not included in M&R work plans. Note that if there is a need to develop an M&R plan for currently unused pavement, a PCI family model based on data from other, similar sections can be assigned.

5-4.5.4 Unprivatized Housing Section Model Assignment.

Pavements in housing areas are included in the inventory for reporting purposes. Approaches between the Services vary on whether these pavements are inspected or not when the housing area is not privatized. If they are inspected, assign a family model. If they are not inspected, do not assign a model.

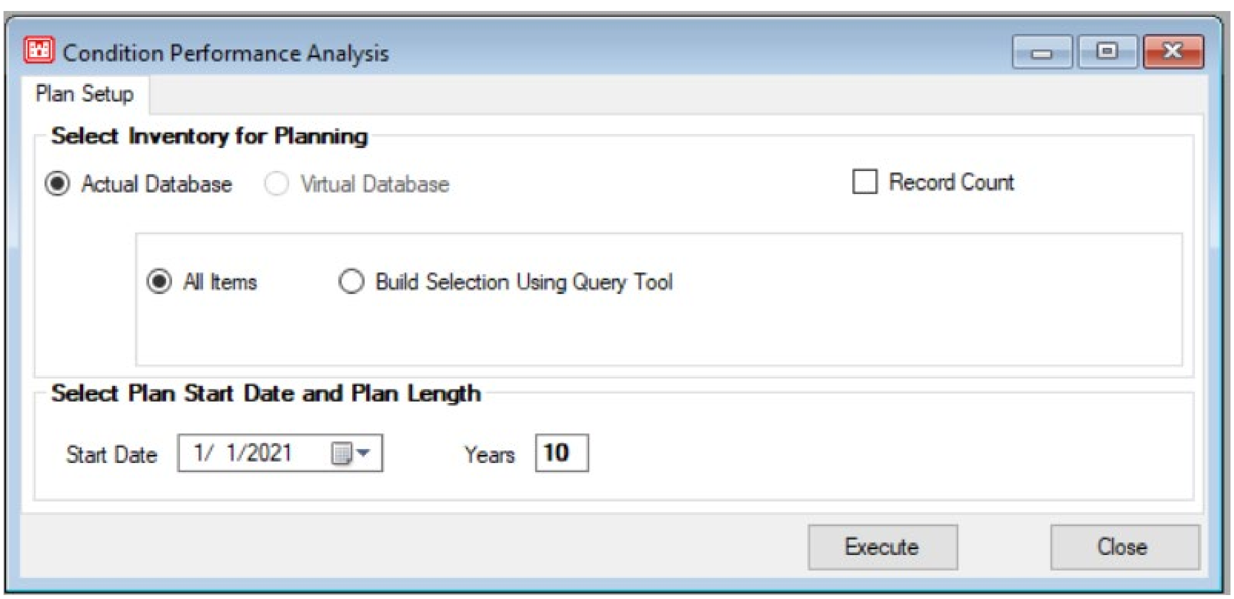
5-4.5.5 Privatized Housing Section Model Assignment.

Pavements in housing areas are included in the inventory for reporting purposes. Pavements may or may not be included in privatization agreements. If included in the privatization agreement, the pavement is typically not inspected and not included in M&R work plans, so do not assign a model for these sections. If not included in the privatization agreement and they are inspected, assign a family model and include them in the M&R work plans.

5-5 CONDITION PERFORMANCE ANALYSIS.

The **Condition Performance Analysis** feature in PAVER (Figure 5-7) uses the deterioration models assigned to each section to predict the future condition of the pavement networks in a database or any subset of the networks. The deterioration models are based on prior inspection data, so PAVER uses past performance to predict future condition. The user defines the pavements included in the analysis, the start date, and the duration of time for the analysis. PAVER produces summary, detail, and map views of the analysis results. The PAVER user guide describes each of these views.

Figure 5-7 Condition Performance Analysis



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CHAPTER 6 MAINTENANCE AND REPAIR (M&R) FAMILY MODELS

6-1 INTRODUCTION.

M&R family models are created for each M&R category. These M&R family models define work plan parameters. Just as with PCI family models, PAVER uses a two-step process: Create the M&R family model and assign the model to the appropriate sections.

6-2 MAINTENANCE AND REPAIR (M&R) CATEGORIES.

Each M&R category has a different focus for the type, scope, and timing of work. M&R categories include localized operational (aka safety or stopgap), localized preventive, global, and major M&R.

6-2.1 Localized Operational M&R.

Localized Operational (aka Safety or Stopgap) M&R is performed when a pavement is below the critical PCI to maintain the safety of operations by repairing individual distresses such as spalls, linear cracking, or alligator cracking at specific locations. Since the focus is on safety of operations, the maintenance and repair policy for operational M&R focuses on medium- and high-severity distresses that pose a risk to operations. Examples include repairing a large pothole at the main entrance to an installation or repairing high-severity spalling at the end of a runway to mitigate FOD risk.

6-2.2 Localized Preventive M&R.

Localized Preventive M&R is performed when a pavement is above the critical PCI. It includes maintenance actions performed on individual distresses intended to slow the rate of pavement deterioration and extend the life of the pavement. Localized preventive M&R may include repairs on low-, medium-, or high-severity distresses. An example is repairing medium- or high-severity longitudinal and transverse cracking on a parking area or apron. This action extends the life of the pavement by preventing water from migrating through cracks and damaging the base or causing other issues such as pumping.

6-2.3 Global Preventive M&R.

Global preventive M&R retards or slows pavement deterioration but is generally applied across entire sections or branches rather than localized areas. There are two primary approaches to global M&R: condition-based and age-based. In the condition-based approach, global M&R is planned within a specified condition range. The age-based approach sets a minimum age before starting global M&R. In either case, the basic principle is that global M&R is most effective early in pavement life when climate-related distresses have not progressed. There are instances where global M&R is used later in the pavement life to address low- or medium-severity distresses. Global M&R is commonly performed on a recurring schedule without regard to the distresses present. Surface treatments on asphalt pavements are the primary example of global M&R.

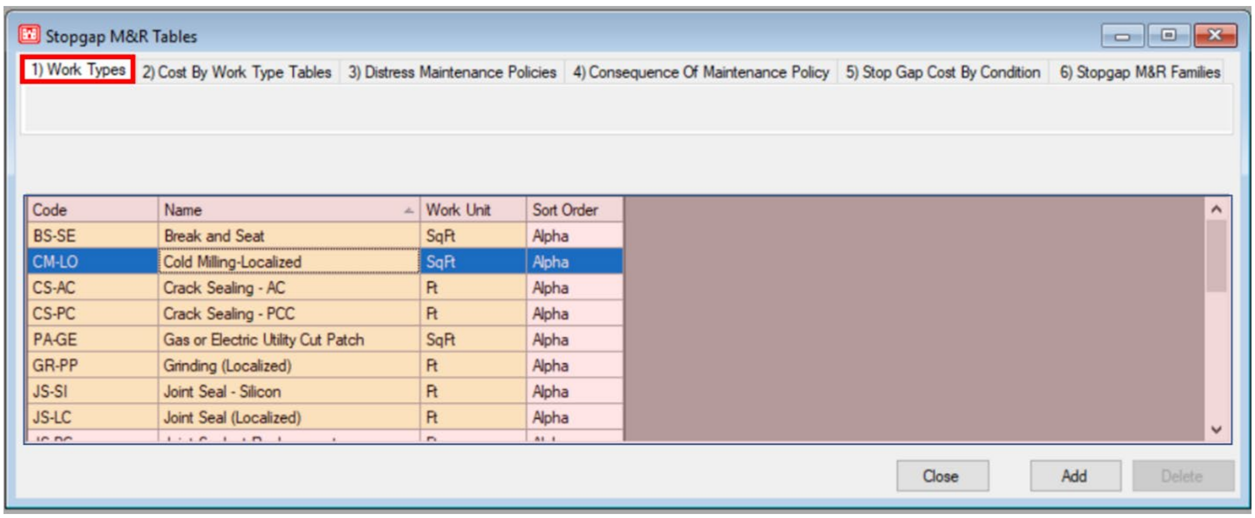
6-2.4 Major M&R.

Major M&R is defined as activities applied to an entire pavement section to correct or improve existing structural or functional issues. Functional issues include deteriorated pavement surfaces that pose a risk to aircraft or ground vehicles. Major M&R includes mill and overlay, structural overlay, or reconstruction of asphalt pavements and slab replacement or reconstruction for PCC pavement. The distinguishing feature is that any of these treatments bring the PCI value back to 100.

6-3 LOCALIZED M&R TABLES.

Localized preventive and operational (aka safety or stopgap) M&R tables define the preventive and operational work planning parameters. As shown in Figure 6-1, M&R tables include work types, cost by work type tables, distress maintenance policies, consequence of maintenance policy, and cost by condition. Standards for these tables are outlined below and in the appendices. M&R families are defined on **6) Stopgap M&R Families** using input from tabs 1 through 5. The example below is for stopgap, but preventive M&R tables are similar.

Figure 6-1 Localized M&R Tables



6-3.1 Localized M&R Work Types.

The **Work Types** table (tab 1) in Figure 6-1 lists the standard PAVER work types shown in Table 6-1. These work types are applicable to both localized preventive and operational M&R. While users can create user-defined work types in PAVER, they are not permitted in DoD PAVER databases. When doing work planning for a new inspection, user-defined work types in an existing database are changed to standard work types and the user-defined work types are deleted from the database. If a Service requires a work type that is not in the localized M&R table, submit the requirement to the Tri-Service Pavement Working Group for inclusion in PAVER.

The work types in Table 6-1 are used in the **Cost by Work Type Tables** (tab 2) and **Distress Maintenance Policies** (tab 3) tables in Figure 6-1. The same PAVER work types are used for both airfield and road and parking M&R, but the maintenance policies differ. Details for the work elements for most work types are outlined in UFC 3-270-01, *O&M Manual: Asphalt and Concrete Pavement Maintenance and Repair*, and in UFC 3-250-08FA, *Standard Practice for Sealing Joints and Cracks in Rigid and Flexible Pavements*.

Table 6-1 Localized M&R Work Types

Code	Name	Work Unit	Description
BS-SE	Break and Seat	SqFt	Crack or break and seat are fractured slab technologies used to minimize the occurrence and severity of reflection cracks. They involve breaking the concrete pavement and seating the broken slabs using a pneumatic roller to reestablish support between the base and the slabs prior to overlaying. Crack and seat is performed on plain, jointed concrete. Break and seat is used on reinforced PCC and breaks the slabs into smaller pieces. Both fractured slab technologies are typically performed on entire sections and rarely used for localized repair.
CM-LO	Cold Milling-Localized	SqFt	Pavement milling (cold planing, asphalt milling, or profiling) is the process of removing at least part of the surface of a paved area using milling machines or cold planers. When used for localized repair, milling removes just enough thickness to level and smooth the surface but may also be used to remove the full depth of the pavement. See UFC 3-270-01, Chapter 13.
CS-AC	Crack Sealing - AC	Ft	Remove old sealant (if any), saw/route cracks, clean crack reservoir, install backer rod to control depth of sealant, and seal using an approved hot-applied sealant. Note that the procedure will vary depending on the width of the crack. See UFC 3-270-01, Chapter 9.
CS-PC	Crack Sealing - PCC	Ft	Remove old sealant (if any), saw/route cracks, clean crack reservoir, install backer rod to control depth of sealant, and seal using an approved hot- or cold-applied sealant. Note that the procedure will vary depending on the width of the crack. See UFC 3-270-01, Chapter 12.
ED-RF	Retrofitted Edge Drain	Ft	Retrofitting edge drains is typically done for an entire section but may be done for localized areas. It involves removing existing edge drains, trenching, and placing the new edge drain system. A good candidate for retrofitted edge drainage is a pavement showing early signs of moisture-related damage. Additionally, pavements with acceptable surface geometrics (longitudinal grades and transverse cross-slopes) and adequate depth and condition of roadside ditches are good candidates for retrofitted edge drainage. See UFC 3-270-01, Chapter 19.
GR-AC	Grinding - AC (Localized)	Ft	Diamond grinding, using closely spaced diamond saw blades mounted on a rotating shaft, removes a thin layer of the asphalt surface to correct for heaving at PCC interface locations and correct surface defects, such as wheel path rutting. The diamond-grinding process results in less impact than milling. See UFC 3-270-01, Chapter 11.

Code	Name	Work Unit	Description
GR-PC	Grinding – PCC (Localized)	Ft	Diamond grinding, using closely spaced diamond saw blades mounted on a rotating shaft, removes a thin layer of the concrete surface to correct for faulting at joints and crack locations. The diamond-grinding process results in less impact than milling. See UFC 3-270-01, Chapter 17.
HR-PD	Partial Depth Heat Resistant PCC Repair	SqFt	A partial-depth heat-resistant PCC repair applies to pavement in vertical landing zones subject to deterioration from heat by aircraft with vectored thrust such as the V-22, F-35B, and AV-8 aircraft. There are restrictions on where a partial-depth repair is allowed. It involves sawing and removing concrete to a minimum depth of 3 inches or to sound concrete, but not more than 1/3 the thickness of the pavement, then cleaning the repair area, placing new heat-resistant concrete, and re-sealing the surface with sodium silicate. Note that maintaining the joint is critical on any repair adjacent to a joint. See UFC 3-270-01, Chapter 20.
HR-FD	Full Depth Heat Resistant PCC Repair	SqFt	A full-depth heat-resistant PCC repair applies to pavement in vertical landing zones subject to deterioration from heat by aircraft with vectored thrust such as the V-22, F-35B, and AV-8 aircraft. There are instances when a full-depth repair is required. It involves sawing and removing the full depth of the concrete, repairing and recompacting the base or subgrade below the slab, placing dowels and tie-bars, then placing new heat-resistant concrete and re-sealing the surface with sodium silicate. Note that maintaining the joint is critical on any repair adjacent to a joint. See UFC 3-270-01, Chapter 20.
HR-CR	Partial Depth Continuously Reinforced Heat Resistant PCC Repair	SqFt	A partial-depth continuously reinforced heat-resistant PCC repair applies to pavement in vertical landing zones subject to deterioration from heat by aircraft with vectored thrust such as the V-22, F-35B, and AV-8 aircraft. There are restrictions on where a partial-depth repair is allowed. It involves sawing and removing concrete and reinforcement then replacing the reinforcement and tie bars, placing new heat-resistant concrete, and re-sealing the surface with sodium silicate. Note that maintaining the joint is critical on any repair adjacent to a joint. See UFC 3-270-01, Chapter 20.
JS-LC	Joint Seal (Localized)	Ft	Joint seal replacement is typically done on entire sections but may be done for localized areas. The procedure varies depending on type of seal: hot pour, silicone, or preformed compression seals, but in general involves removing the old sealant, cleaning the reservoir, and placing new joint seal. See UFC 3-270-01, Chapter 12.
LT-PC	Load Transfer Restoration – PCC (Localized)	Ft	Load transfer restoration is typically done for an entire section but may be done for localized areas. It involves saw-cutting and chipping concrete to create slots at the joints, placing load transfer devices, typically dowel bars, into the slots and properly aligning the bars, placing repair material into the slots, restoring the joint at the slot locations, sealing the joints, and grinding at joint locations or over the full pavement width and length to improve smoothness. It is used to retard further deterioration of the concrete pavement by reducing the potential for joint-related distresses. Restoration of load transfer can improve pavement performance by reducing pumping, faulting, and corner breaks, and by retarding the deterioration of transverse cracks. See UFC 3-270-01, Chapter 18.

Code	Name	Work Unit	Description
NONE	No Localized M & R	SqFt	When the severity of the distress does not negatively impact the operational safety of the pavement or trying to repair a distress (especially a low-severity distress) will potentially create more of a risk than the existing distress, the best choice is to take no action and monitor the distress for further deterioration.
PA-AD	Patching - AC Deep	SqFt	Full-depth asphalt repairs involve removing the pavement down to the subgrade or to an intermediate base or subbase layer that is intact then replacing the base or subbase with materials that meet the specifications for these respective layers and replacing the wearing surface with HMA concrete (cold mix asphalt is not preferred but may be used if hot mix is not available). See UFC 3-270-01, Chapter 3.
PA-AL	Patching - AC Leveling	SqFt	Patching AC leveling is used to address depressions or rutting by placing microsurfacing to level the pavement when the rutting or depression is stabilized.
PA-AS	Patching - AC Shallow	SqFt	Partial-depth repairs involve removing the asphalt surface to the base, recompacting the base, and replacing the wearing surface with HMA concrete (cold mix asphalt is not preferred but may be used if hot mix is not available). See UFC 3-270-01, Chapter 4.
PA-IR	Patching-Infrared	SqFt	Infrared patching involves heating the asphalt to a working temperature of 300 °F, penetrating the asphalt to a depth of 3 to 4 inches. After removing deteriorated asphalt and raking in new asphalt, the area is compacted with a vibratory roller.
PA-PF	Patching - PCC Full Depth	SqFt	Full-depth PCC repair involves sawing and removing the full depth of the concrete, repairing and recompacting the base or subgrade below the slab, placing dowels and tie-bars, then placing new concrete. Note that maintaining the joint is critical on any repair adjacent to a joint. See UFC 3-270-01, Chapter 14.
PA-PP	Patching - PCC Partial Depth	SqFt	Partial-depth PCC repair involves sawing and removing concrete to a minimum depth of 2 inches or to sound concrete, but not more than 1/3 the thickness of the pavement, then cleaning the repair area and placing new concrete. Note that maintaining the joint is critical on any repair adjacent to a joint. See UFC 3-270-01, Chapter 13.
PA-PL	Patching – PCC Partial Depth POL Damage Repair	SqFt	PCC partial-depth POL damage repair applies to pavement areas subject to deterioration from a combination of POL and heat, which results in scaling or spalling of the top 1 to 2 inches (25 to 50 millimeters) of the pavement as can be generated by POL and heat from B-1, F-18, F-35, and V-22 operations. This work type involves sawing and removing concrete to a minimum depth of 2 inches or to sound concrete, but not more than 1/3 the thickness of the pavement, then cleaning the repair area and placing new magnesium phosphate cement. Once the repair is in place, the area may be sealed using a sodium silicate surface treatment. See UFC 3-270-01, Chapter 21.
SH-LE	Shoulder leveling	Ft	Shoulder leveling involves removing loose materials, placing, grading, and compacting aggregate to correct shoulder drop-off caused by shoulder erosion, settlement, or by building up the roadway without adjusting the shoulder level.

Code	Name	Work Unit	Description
SL-PC	Slab Replacement - PCC	SqFt	PCC slab replacement involves sawing and removing the full depth of the concrete, repairing and recompacting the base or subgrade below the slab, placing dowels, then placing new concrete and sealing the joints. Procedures generally follow those outlined in UFC 3-270-01, Chapter 14.
SS-SG	Spread Sand or Gravel	SqFt	Sand seal is used to address a bleeding asphalt pavement surface. Hot sand is placed with a spreader to blot up the excess binder on the surface. The sand is rolled with a pneumatic roller then the excess sand is removed with a vacuum sweeper. See UFC 3-270-01, Chapter 7.
ST-AL	Surface Treatment – AC (Localized)	SqFt	Surface treatments for asphalt pavement are typically applied to entire sections (global) but may be done for localized areas. Different types of surface treatment are used depending on the age, condition, and use (airfield vs. road) of the pavement. These treatments include fog seals, rejuvenators, single or double bituminous surface treatments, slurry seals, and microsurfacing. See UFC 3-270-01, Chapters 5, 6, 7, 8, and 21.
ST-PL	Surface Treatment – PCC (Localized)	SqFt	Surface treatments for concrete pavement may be applied to entire sections but may also be done for localized areas. Surface treatments for PCC pavement surfaces (e.g., sodium silicate) are used to prevent deterioration from the effects of a combination of heat and POL contamination. Optimally, the surface is cleaned and sealed as a preventative measure within 6 months of commencing operations but may be used in conjunction with other appropriate repairs such as crack sealing and patching using magnesium phosphate cement. See UFC 3-270-01, Chapters 5, 6, 7, 8, and 21.
SJ-PC	Slab Jacking - PCC	SqFt	Slab jacking involves injection of a grout or polyurethane foam under a settled slab or multiple slabs to raise the slabs slowly under pressure to the desired elevation. It is used to address settlement or improve support under the pavement. See UFC 3-270-01, Chapter 15.
UN-PC	Undersealing - PCC	SqFt	Undersealing is used to stabilize the pavement slab by restoring support under the slab, typically at joint and crack locations. Undersealing is also called slab sealing, subsealing, slab stabilization, and pavement grouting. See UFC 3-270-01, Chapter 16.

6-3.2 Localized M&R Cost by Work Type Tables.

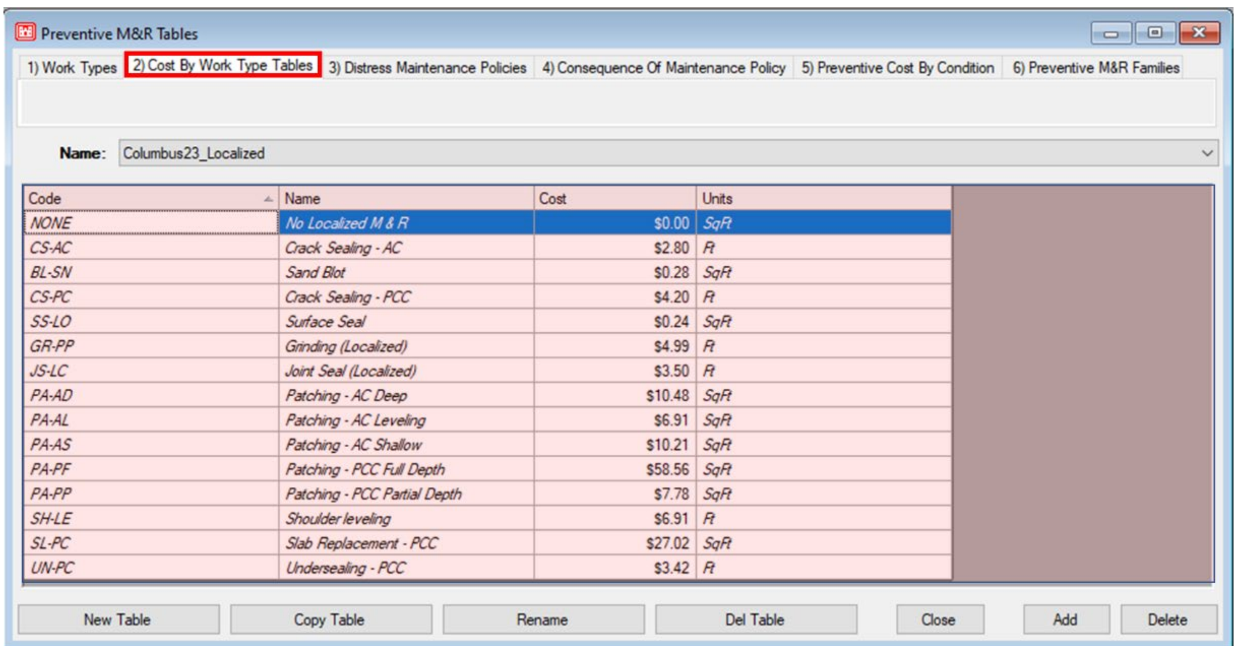
Historically the Services created standard cost by work type tables and updated them annually or used consultants to create or update them, but these tables did not follow a specific standard. This UFC defines a standard for creating and updating cost by work type tables for use by Service evaluation teams and consultants. Paragraph A-2 includes standard localized preventive and operational cost by work type tables for airfields and roads and parking pavements. This UFC defines the work elements for each of the standard work types. Based on the work element assumptions for each standard work type, generate fully burdened unit costs including O&M escalation factors using Tri-Service Automated Cost Engineering System (TRACES) applications such as the Parametric Cost Engineering System (PACES) or the Micro-Computer Aided Cost Estimating System Second Generation (MII).

Service evaluation teams and consultants performing PCI surveys use the standard cost by work type tables for each new PCI survey and apply area cost factors to adjust the standard unit costs for each work type for the specific installation. Adjust these standard cost tables when there is specific cost data available for work types at an installation. When adjusting costs, document any changes to specific work component assumptions for a given standard work type in the report. The intent is to clearly define changes to the unit cost basis. When doing work planning for a new inspection, use the updated cost table and delete any cost by work type tables used in previous inspections. Figure 6-2 is an example table.

Use the standard naming convention shown below for cost by work type tables. Costs for both AC and PCC pavement work types are included in the same table:

- **Site NameYr_Maintenance Category**
- For example, **Columbus23_AC_Localized**

Figure 6-2 Localized M&R Cost by Work Type Tables



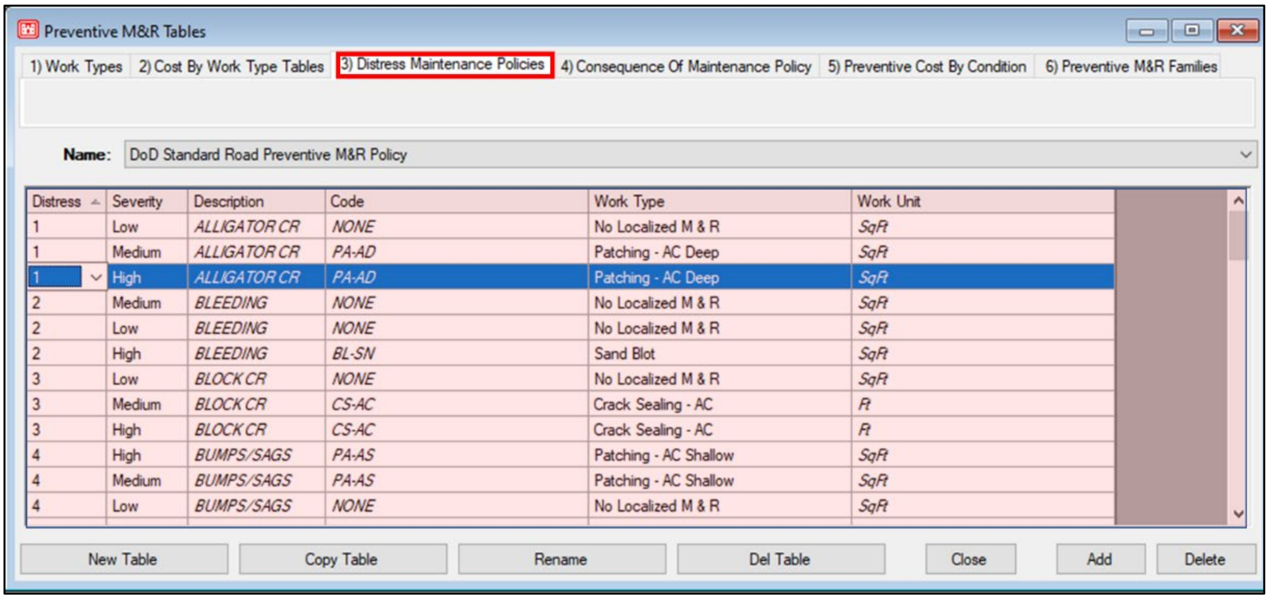
Code	Name	Cost	Units
NONE	No Localized M & R	$0.00	SqFt
CS-AC	Crack Sealing - AC	$2.80	Ft
BL-SN	Sand Blot	$0.28	SqFt
CS-PC	Crack Sealing - PCC	$4.20	Ft
SS-LO	Surface Seal	$0.24	SqFt
GR-PP	Grinding (Localized)	$4.99	Ft
JS-LC	Joint Seal (Localized)	$3.50	Ft
PA-AD	Patching - AC Deep	$10.48	SqFt
PA-AL	Patching - AC Leveling	$6.91	SqFt
PA-AS	Patching - AC Shallow	$10.21	SqFt
PA-PF	Patching - PCC Full Depth	$58.56	SqFt
PA-PP	Patching - PCC Partial Depth	$7.78	SqFt
SH-LE	Shoulder leveling	$6.91	Ft
SL-PC	Slab Replacement - PCC	$27.02	SqFt
UN-PC	Undersealing - PCC	$3.42	Ft

6-3.3 Localized M&R Distress Maintenance Policies.

Distress maintenance policies prescribe specific work types to repair specific distress types at each severity level. For example, in Figure 6-3 the first row shows high-severity alligator cracking as the distress. The **Code** and **Work Type** columns indicate to PAVER that when it encounters this distress at this severity level, it creates a requirement to perform a full-depth patch. Use separate policy tables for airfields and roads and parking pavements for both localized preventive and operational M&R. Paragraph A-3 includes standard distress maintenance policy tables.

Service evaluation teams and consultants performing PCI surveys will use the appropriate standard maintenance policy and the standard naming convention for each new PCI survey. Delete any distress maintenance policy tables from previous evaluations from the database. If a Service wants to change a standard maintenance policy, submit a change request using the UFC change request procedure on the Whole Building Design Guide (WBDG) website: https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc

Figure 6-3 Example Distress Maintenance Policies



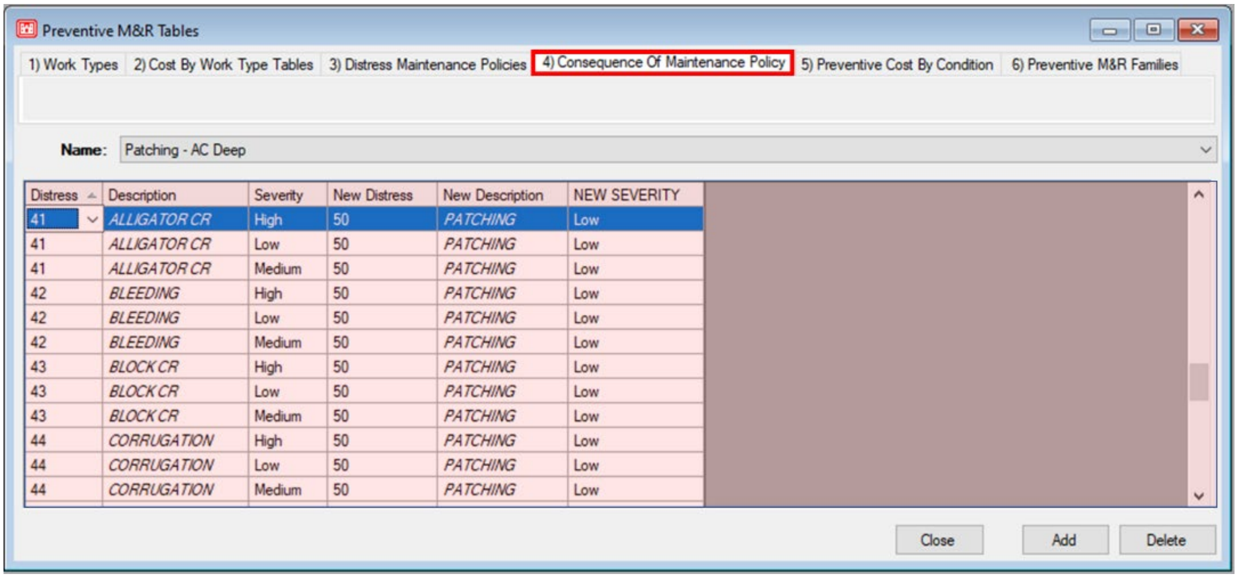
Distress	Severity	Description	Code	Work Type	Work Unit
1	Low	ALLIGATOR CR	NONE	No Localized M & R	SqFt
1	Medium	ALLIGATOR CR	PA-AD	Patching - AC Deep	SqFt
1	High	ALLIGATOR CR	PA-AD	Patching - AC Deep	SqFt
2	Medium	BLEEDING	NONE	No Localized M & R	SqFt
2	Low	BLEEDING	NONE	No Localized M & R	SqFt
2	High	BLEEDING	BL-SN	Sand Blot	SqFt
3	Low	BLOCK CR	NONE	No Localized M & R	SqFt
3	Medium	BLOCK CR	CS-AC	Crack Sealing - AC	Ft
3	High	BLOCK CR	CS-AC	Crack Sealing - AC	Ft
4	High	BUMPS/SAGS	PA-AS	Patching - AC Shallow	SqFt
4	Medium	BUMPS/SAGS	PA-AS	Patching - AC Shallow	SqFt
4	Low	BUMPS/SAGS	NONE	No Localized M & R	SqFt

6-3.4 Localized M&R Consequence of Maintenance Policy.

For every standard work type, there is an associated consequence of maintenance policy table. Each table consists of a list of all distresses related to a work type and the distress produced after performing the specified repair. This table informs PAVER about the distresses present after repair and is used to predict the condition after work is performed. For example, in Figure 6-4, when performing Patching - AC Deep to repair high-severity alligator cracking, the resulting distress is a low-severity patch. Standard consequence of maintenance policy tables are included in paragraph A-4.

Service evaluation teams and consultants performing PCI surveys will use the standard consequence of maintenance policy tables for each new PCI survey. Replace or update any consequence of maintenance policy tables from previous evaluations to match the standard consequence of maintenance policy and delete any tables for non-standard work types from the database. If a Service wants to change a standard consequence of maintenance policy, they can submit a change request using the UFC change request procedure on the WBDG website: https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc

Figure 6-4 Consequence of Maintenance Policy



Distress	Description	Severity	New Distress	New Description	NEW SEVERITY
41	ALLIGATOR CR	High	50	PATCHING	Low
41	ALLIGATOR CR	Low	50	PATCHING	Low
41	ALLIGATOR CR	Medium	50	PATCHING	Low
42	BLEEDING	High	50	PATCHING	Low
42	BLEEDING	Low	50	PATCHING	Low
42	BLEEDING	Medium	50	PATCHING	Low
43	BLOCK CR	High	50	PATCHING	Low
43	BLOCK CR	Low	50	PATCHING	Low
43	BLOCK CR	Medium	50	PATCHING	Low
44	CORRUGATION	High	50	PATCHING	Low
44	CORRUGATION	Low	50	PATCHING	Low
44	CORRUGATION	Medium	50	PATCHING	Low

6-3.5 Localized M&R Cost by Condition.

a. While PAVER can predict the future condition of a pavement section based on the PCI deterioration family model, it cannot predict specific distress types, severities, and quantities beyond the first year after a PCI survey. PAVER uses the cost by work type tables to determine the cost of required localized repairs when running a consequence of localized distress maintenance work plan. However, it uses cost by condition tables to determine M&R costs based on the future predicted condition of the pavement when running a critical PCI work plan.

b. Cost by condition tables are derived from the estimated cost of repairs developed from the cost by work type tables at the time of the most recent PCI. Cost by condition tables are created for operational, preventive, and major M&R. Each of these categories have separate tables for asphalt and PCC pavements. The results are cost by condition tables based on the current survey data and work type costs. Note that global M&R will always use cost by work type tables.

c. When running the work plan for future years, PAVER uses the cost per square foot from the table at the predicted PCI for the specified year multiplied by the true area of the section to predict the cost of M&R for each M&R category. Costs to repair a pavement increases as the pavement condition (PCI) decreases.

d. Service evaluation teams and consultants performing PCI surveys will develop standard cost by condition tables for each new PCI survey as outlined in paragraph 6-3.5.1. Create a new cost by condition table for the current inspection and delete any cost by condition tables used in previous inspections from the database when developing M&R Family Models for a new inspection.

e. Use the following standard naming convention for cost by condition type tables:

- Site **NameYr_Pavement Type_Maintenance Category**
- For example, **Columbus23_AC_PRV**

6-3.5.1 Developing Localized M&R Cost by Condition Tables.

Once the PCI survey is complete and the cost by work type and distress maintenance policy tables are updated, use the **Family Modeling** tool to create a **Cost by Condition Table**. After opening the **Family Modeling** tool, select **Local Cost v PCI Family Type**, then select **New** to open the **Options** form. Name the model using the naming convention and select the current **Distress Maintenance Policy** and **Cost by Work Type** as shown in Figure 6-5. When the **Query** tool opens, select the pavement type for the model. This generates a model like the one shown in Figure 6-6. Check the **View Equations and Stats** tab to ensure the coefficient of correlation is above 0.70. Selecting **Generate Cost Table** creates a Cost by Condition table in Excel.

Figure 6-5 Policy Unit Cost per Section

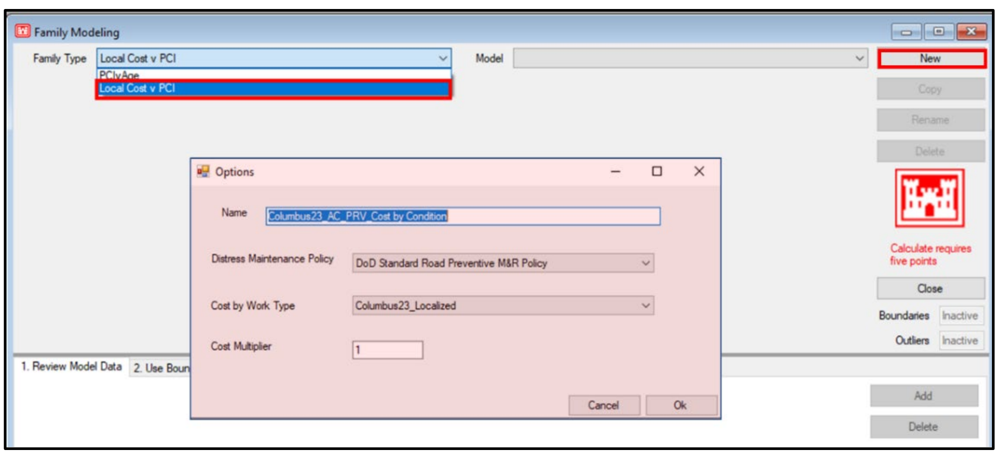
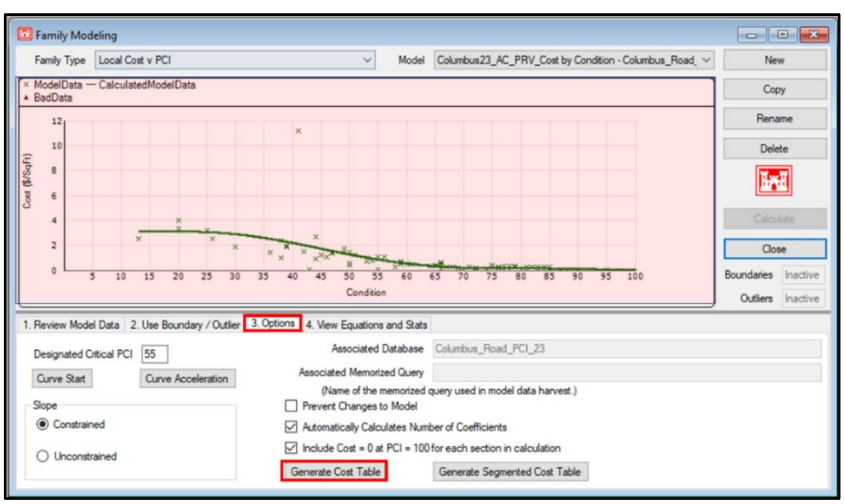


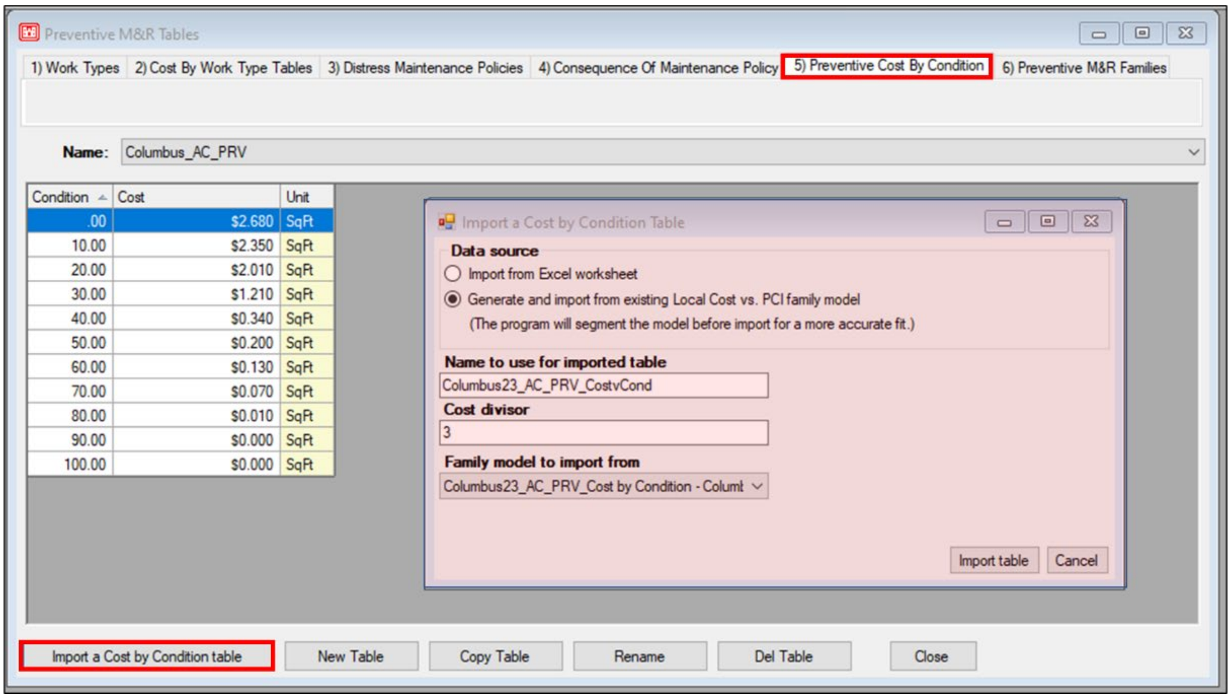
Figure 6-6 Policy Unit Cost per Section Trend Line



6-3.5.2 Cost by Condition Table.

After creating the Local Cost v PCI Family Model, reopen the **M&R Family Models** form, select the **Preventive Cost by Condition** tab (tab 5), then select **Import a Cost by Condition Table**. This opens the form shown in Figure 6-7 from which the user can import the Cost by Condition table from the Family Model or import it from an Excel worksheet. This results in a table that lists the cost by condition at 10-PCI intervals. When doing work planning, PAVER will interpolate the costs between these intervals. Repeat the process to create a separate table for operational AC, preventive AC, operational PCC, and preventive PCC.

Figure 6-7 Cost by Condition Table



6-3.6 Localized M&R Families.

The final step of the localized M&R family model process is creating the M&R families and assigning the distress maintenance policy, cost by work type, and cost by condition tables to the families, then assigning the model to the appropriate sections.

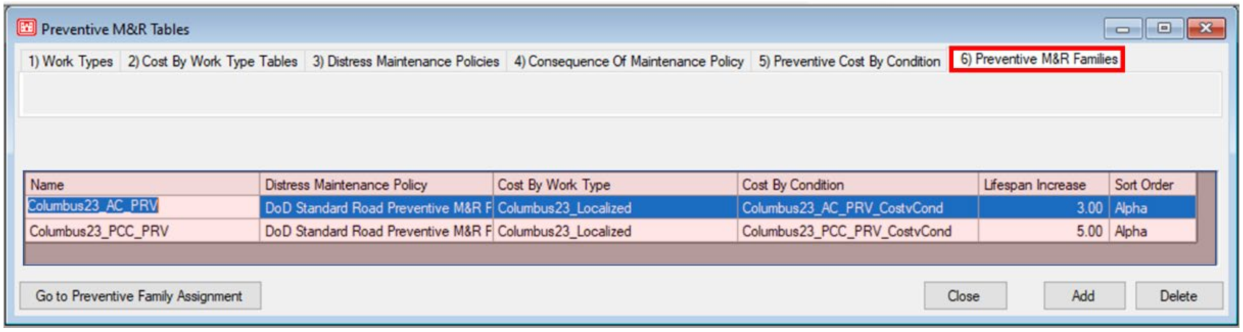
6-3.6.1 Create Localized M&R Families.

Create an asphalt and PCC family for both the preventive and operational M&R categories. Name the families using the standard convention below. Use the acronym STP for operational (aka safety or stopgap) and PRV for preventive.

- Site **NameYr_Pavement Type_M&R Category**
- For example, **Columbus23_AC_PRV**

Assign the tables to the family model using the drop-down in the **Distress Maintenance Policy**, **Cost By Work Type**, and **Cost By Condition** columns to select the appropriate table as shown in Figure 6-8. Delete all old/unused M&R family models and all unused tables.

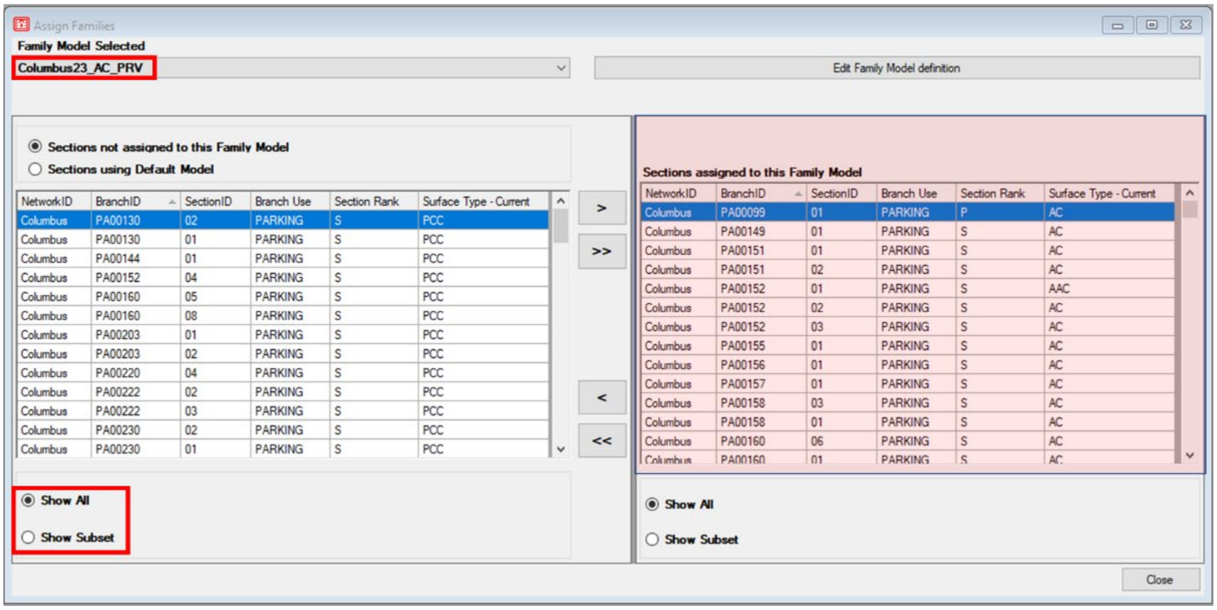
Figure 6-8 Creating a Localized M&R Family



6-3.6.2 Assign Localized M&R Families to Sections.

Use the **Go to Preventive Family Assignment** button in the lower left-hand corner of the form shown in Figure 6-8 to assign family models. Assign each of the M&R families to the appropriate sections. For example, the asphalt preventive family is assigned to all AC sections, as shown in Figure 6-9. Every paved section that was inspected must be assigned to a family. Filter sections using the **Query** tool, then use the arrows to move the selected sections from the unassigned list on the left side of the form in Figure 6-9 to the assigned list on the right. Unpaved or unused sections that did not have a PCI inspection are unassigned. In PAVER you will see these identified as **Sections using the Default Model**. These sections are excluded when running the M&R work plans.

Figure 6-9 Assigning a Localized M&R Family to Section



6-4 GLOBAL M&R TABLES.

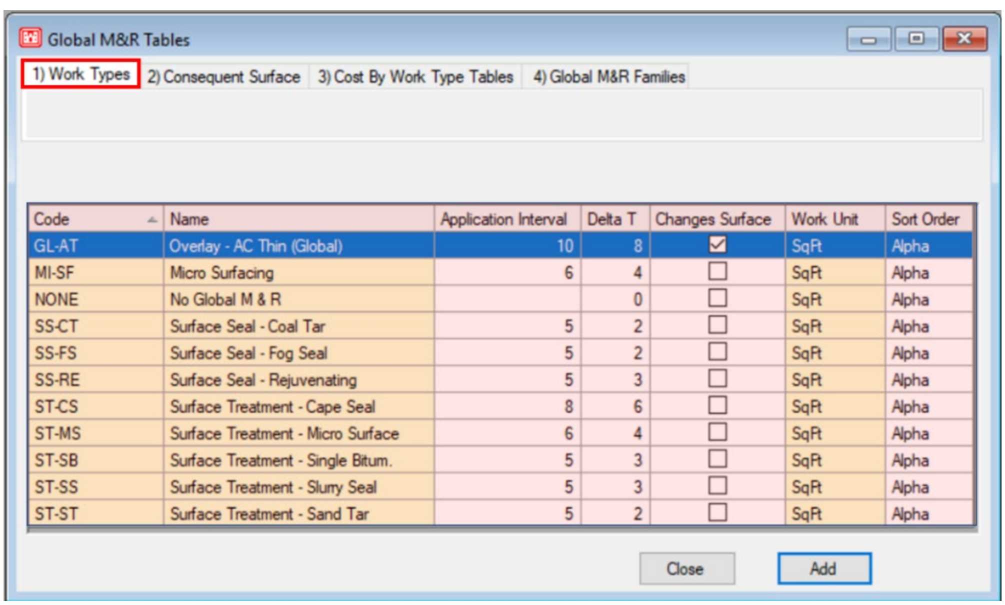
Historically, global M&R applied only to asphalt pavement. This UFC introduces global M&R for concrete pavement joint seals. The global M&R tables define global M&R work planning parameters. Tables include work types, cost by work type, and consequent surface. Standards for these tables are outlined below and in the appendices. In both the condition and time-based approach to global M&R described earlier, M&R is performed on an entire section without regard to the distresses present in that section. PAVER uses the cost by work type table to estimate costs for all future years rather than using a cost by condition table. Note that any localized maintenance identified by PAVER is done in conjunction with global to repair distresses that global maintenance will not address effectively.

6-4.1 Global M&R Work Types.

The Global M&R **Work Types** table (Tab 1) in Figure 6-10 lists standard PAVER work types. While users can create user-defined work types in PAVER, they are not permitted in DoD PAVER databases. Change any user-defined work types in a database to standard work types when doing a new inspection and delete the user-defined work types from the work type table. If a Service requires a new global work type, submit the requirement to the Tri-Service Pavement Working Group for inclusion in PAVER.

The work types shown in Figure 6-10 are used in **Cost By Work Type Tables** (tab 3) and the **Global M&R Families** table (tab 4). The same global work types are used for both airfield and road and parking M&R, although there are different policies for when and where to use these work types. Details for performing most work types are outlined in UFC 3-270-01 and UFC 3-250-03, *Standard Practice Manual for Flexible Pavements*. Table 6-2 provides a description of standard global work types.

Figure 6-10 Global M&R Work Types



Code	Name	Application Interval	Delta T	Changes Surface	Work Unit	Sort Order
GL-AT	Overlay - AC Thin (Global)	10	8	☑	SqFt	Alpha
MI-SF	Micro Surfacing	6	4	☐	SqFt	Alpha
NONE	No Global M & R		0	☐	SqFt	Alpha
SS-CT	Surface Seal - Coal Tar	5	2	☐	SqFt	Alpha
SS-FS	Surface Seal - Fog Seal	5	2	☐	SqFt	Alpha
SS-RE	Surface Seal - Rejuvenating	5	3	☐	SqFt	Alpha
ST-CS	Surface Treatment - Cape Seal	8	6	☐	SqFt	Alpha
ST-MS	Surface Treatment - Micro Surface	6	4	☐	SqFt	Alpha
ST-SB	Surface Treatment - Single Bitum.	5	3	☐	SqFt	Alpha
ST-SS	Surface Treatment - Slurry Seal	5	3	☐	SqFt	Alpha
ST-ST	Surface Treatment - Sand Tar	5	2	☐	SqFt	Alpha

Table 6-2 Global M&R Work Types

Code	Name	Application Interval (yrs.)	Delta T (yrs.)	Work Unit	Description
NONE	No Global M & R	0	0	SqFt	The no global work type allows the user to establish a policy in which there are cases or periods when global M&R is not used; for example, a policy in which Global M&R is not applied to runways.
GL-AT	Overlay - AC Thin (Global)	10	8	SqFt	Thin HMA overlays are commonly used to correct minor to moderate pavement surface defects to restore ride quality and improve friction while protecting the underlying pavement structure. Thin overlays may be applied to either concrete or asphalt pavements or over existing surface treatments and are typically not considered a structural layer. Industry convention generally defines thin overlays as no more than 1.5 to 2 inches thick, typically constructed as a single lift. See UFC 3-250-03 for more information.
GL-FR	Overlay - Fuel-Resistant AC (Global)	10	8	SqFt	Fuel-resistant HMA overlays composed of mineral aggregate, polymer-modified asphalt binder, and additives mixed in a central mixing plant are used as a surface course for locations that need a fuel-resistant surface while protecting the underlying pavement structure. Thin overlays may be applied to either concrete or asphalt pavements and are typically not considered a structural layer when less than 2 inches thick. Industry convention generally defines fuel-resistant overlays as no more than 1.5 to 3 inches thick, constructed as a single lift. See UFGS 32 12 17.19, *Fuel Resistant Asphalt Paving for Airfields - Surface Course*.
JS-CP	Joint Seal – Compression			Ft	This work type specifically addresses replacing compression seals for an entire section(s). The procedure involves removing the old sealant, routing the reservoir to achieve the correct shape factor, cleaning the reservoir, and placing new joint seal. See UFC 3-270-01, Chapter 12.
JS-HP	Joint Seal – Hot Pour			Ft	This work type specifically addresses replacing hot pour sealant for an entire section(s). The procedure involves removing the old sealant, routing the reservoir to achieve the correct shape factor, cleaning the reservoir, and placing new joint seal. See UFC 3-270-01, Chapter 12.

Code	Name	Application Interval (yrs.)	Delta T (yrs.)	Work Unit	Description
JS-SI	Joint Seal - Silicone			Ft	This work type specifically addresses replacing silicone sealant for an entire section(s). The procedure involves removing the old sealant, routing the reservoir to achieve the correct shape factor, cleaning the reservoir, and placing new joint seal. See UFC 3-270-01, Chapter 12.
SS-CT	Surface Seal - Coal Tar	5	2	SqFt	A coal-tar surface seal is a coal-tar emulsion used as a fuel-resistant sealer (FRS), which is a combination of coal-tar emulsion, fine aggregate, water, and occasionally other additives. Consider use only where the need is for a fuel-resistant surface, such as aprons where pavements are subject to fuel spills. These materials are mixed in batches and applied to HMA surfaces by hand, sprayer, or mechanical squeegee. The FRS is placed in thin layers, usually 1/16 inch (2 mm) or less. See UFC 3-250-03, paragraph 4-4. **Important:** Coal tar is a human carcinogen. Consult local and state environmental/safety regulations. Many locations prohibit the use of coal tar products. Verify the selected materials comply with federal, state, and local authority requirements.
SS-FS	Surface Seal - Fog Seal	3	2	SqFt	A fog seal is a light application of diluted asphalt emulsion (including natural asphalt such as Gilsonite), often containing polymer additives. It is used to renew old asphalt surfaces, seal small cracks and surface voids, and inhibit weathering. Consider fog seals for environmental surface distresses such as non-structural cracking or before raveling begins. Continue applying the fog seal on an approximately three-year cycle, depending on environment and pavement condition. Current guidance does not support the use of fog seals on runways without approval. See UFC 3-270-01, paragraph 5-4, and UFC 3-250-03, paragraph 3-4.
SS-RE	Surface Seal - Rejuvenating	5	3	SqFt	A “rejuvenator” is a solvent-based asphalt material (including natural asphalt such as Gilsonite), often containing polymer additives and light oils. They are used for PM to slightly soften and partially restore oxidized pavement surfaces. They do not solve raveling issues or reduce cracking problems. There are numerous commercially available products for use on roads, parking areas, airfield shoulders, and overruns. Current guidance does not support the use of rejuvenators on airfield pavement without approval. See UFC 3-270-01, paragraph 5-4, and UFC 3-250-03, paragraph 3-5.

Code	Name	Application Interval (yrs.)	Delta T (yrs.)	Work Unit	Description
ST-CS	Surface Treatment - Cape Seal	8	6	SqFt	A cape seal is surface treatment in which a bituminous surface treatment (often called a chip seal) is followed by the application of either slurry seal or micro-surfacing. The advantage of this treatment is that the chip seal seals and protects the underlying pavement, while the slurry seal helps to protect the chip seal, locking the chip seal aggregate in place to minimize chip/aggregate loss and providing a smoother final surface. Cape seals are used on roads and parking lots. Do not use cape seals on airfield pavements except for overruns and not within 200 feet (61 m) of the threshold. See guidance on bituminous surface treatment in UFC 3-270-01, Chapter 6, and UFC 3-250-03, Chapter 4.
ST-MS	Surface Treatment - Micro Surface	6	4	SqFt	Microsurfacing is a mixture of polymer-modified asphalt emulsion, crushed dense graded aggregate, mineral filler, additives, and water. It provides a thin resurfacing of 3/8 to 3/4 inch (10 to 20 mm). It is very similar to slurry seal but is typically a more durable treatment. Microsurfacing is primarily used to mitigate raveling and oxidation of asphalt pavement surfaces, but also improves friction and appearance of both asphalt and concrete surfaces. Microsurfacing can be designed with larger aggregate for use in filling shallow to moderate depth ruts in asphalt pavement and can also seal low-severity cracks. See UFC 3-250-03, Chapter 4, and UFC 3-270-01, Chapter 8.
ST-SB	Surface Treatment – Single Bituminous	5	3	SqFt	A single bituminous surface treatment (SBST) consists of a sprayed asphalt application followed immediately by a layer of aggregate. This treatment is used to retard deterioration of raveling, improve skid resistance, seal small cracks, and waterproof the surface on light-traffic roads and parking lots. Do not use SBST on airfield pavements except for overruns and not within 200 feet (61 meters) of the threshold. See UFC 3-270-01, Chapter 6, and UFC 3-250-03, Chapter 4.
ST-DB	Surface Treatment - Double Bituminous				A double bituminous surface treatment (DBST) is essentially the same as the SBST, except that more than one application of binder and aggregate is used. DBSTs are used to retard deterioration of raveling, improve skid resistance, seal small cracks, and waterproof the surface of roads and parking areas. Do not use DBST on airfield pavements except for overruns and not within 200 feet (61 meters) of the threshold. See UFC 3-270-01, Chapter 7, and UFC 3-250-03, Chapter 4.

Code	Name	Application Interval (yrs.)	Delta T (yrs.)	Work Unit	Description
ST-SS	Surface Treatment - Slurry Seal	5	3	SqFt	A slurry seal is a mixture of asphalt emulsion, aggregate, water, and mineral filler applied or screeded onto the pavement surface in a thin layer using squeegees or a spreader box. Slurry seals are used to protect the underlying surface from water infiltration, fill surface cracks and voids, and improve friction and appearance of an existing pavement. Slurry seals do not provide any structural benefit to the pavement but are a very cost-effective treatment for preserving the existing pavement surface, improving appearance, and restoring or enhancing friction. See UFC 3-250-03, Chapter 4, and UFC 3-270-01, Chapter 8.
ST-ST	Surface Treatment - Sand Tar	5	2	SqFt	Sand seal can be used to address a bleeding pavement surface or provide a thin sealer using sprayed application of asphalt emulsion followed by a covering of clean sand or fine aggregate. A pneumatic-tire roller is often used after applying the sand. Excess sand is removed from the pavement surface after rolling.

6-4.2 Global M&R Consequent Surface.

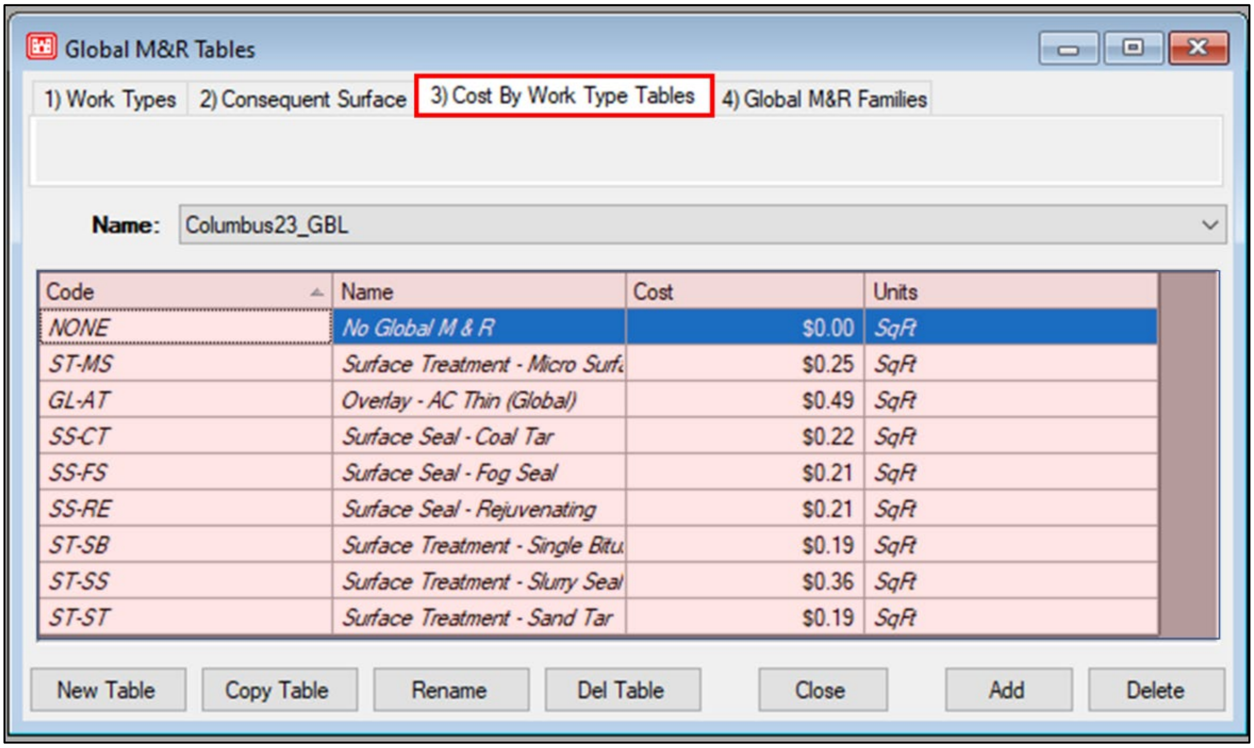
Tab 2 of the Global M&R Tables form defines the consequent (resultant) surface produced when a given work type is performed over different surface types. Only PAVER default surface types and global work types are permitted. Currently, the only work types that result in a change in surface type are Overlay – AC Thin (Global) and Overlay - Fuel-Resistant AC (Global).

6-4.3 Global M&R Cost by Work Type.

Paragraph A-2 includes global cost by work type tables for airfields and roads and parking pavements. Historically, the Services have either had consultants create cost by work type tables that did not follow a specific standard or they created their own standard cost by work type tables and updated them annually for use by their evaluation teams and consultants. This UFC defines the work elements for each of the standard work types. Fully burdened unit costs for each of these work types, including any O&M escalation factors, are generated using Tri-Service Automated Cost Engineering System (TRACES) applications such as the Parametric Cost Engineering System (PACES) or the Micro-Computer Aided Cost Estimating System Second Generation (MII), based on the work element assumptions for each standard work type.

Service evaluation teams and consultants performing PCI surveys use the standard global cost by work type tables for each new PCI survey and apply area cost factors to adjust the standard unit costs for each work type for the specific installation. Adjust these standard cost tables when there is specific cost data available for work types at an installation. When adjusting costs, clearly define and document any changes to specific work component assumptions in the report so users understand the unit cost basis for a given standard work type. Use the updated cost table when developing work plans for a new inspection and delete any cost by work type tables used in previous inspections. An example table is shown in Figure 6-11.

Figure 6-11 Global Cost by Work Type Tables



6-4.4 Global M&R Families.

The final step of the global M&R family model process involves creating the M&R families and assigning the work types and cost by work type tables to the families then assigning the model to the appropriate sections.

6-4.4.1 Create Global M&R Families.

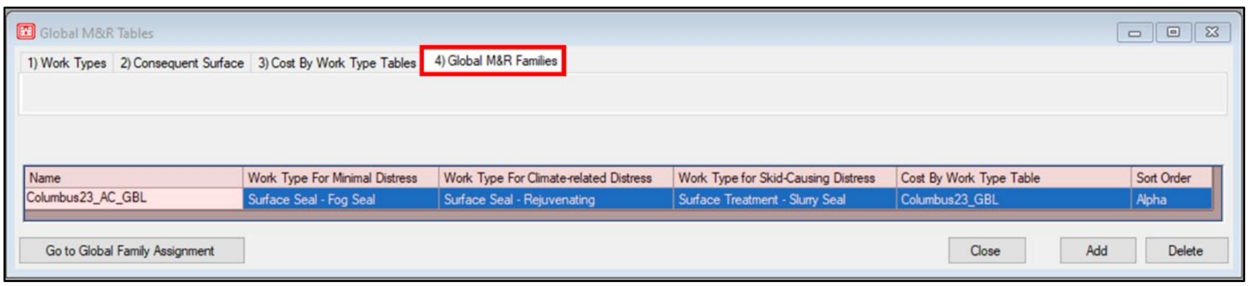
At a minimum, create a global M&R family for AC and one for PCC pavement. It is often desirable to create different global M&R families for pavements with different branch uses when required. For example, a different family can be created for roads than is used for parking pavements. The families are named using the standard convention below. Use the acronym GBL for the M&R category and include the branch use at the end of the name, if used.

- Site **NameYr_Pavement Type_M&R Category**
- For example, **Columbus23_AC_GBL**

6-4.4.2 Global Maintenance Policies.

The process for setting the maintenance policies for global M&R is integral to creating a family. After creating the family, assign the global work type using the drop-down menu for each category shown in Figure 6-12: **Work Type for Minimal Distress**, **Work Type for Climate-related Distress**, and **Work Type for Skid-Causing Distress**. Assigning the **Global Cost by Work Type Table** completes the process. Delete all old or unused global M&R family models and all unused cost by work type tables. Global maintenance policies for airfields and road and parking pavements differ; see the standard global M&R polices in paragraph A-3.3. See details on global policy in UFC 3-270-01 and UFC 3-250-03.

Figure 6-12 Global M&R Maintenance Policy Example



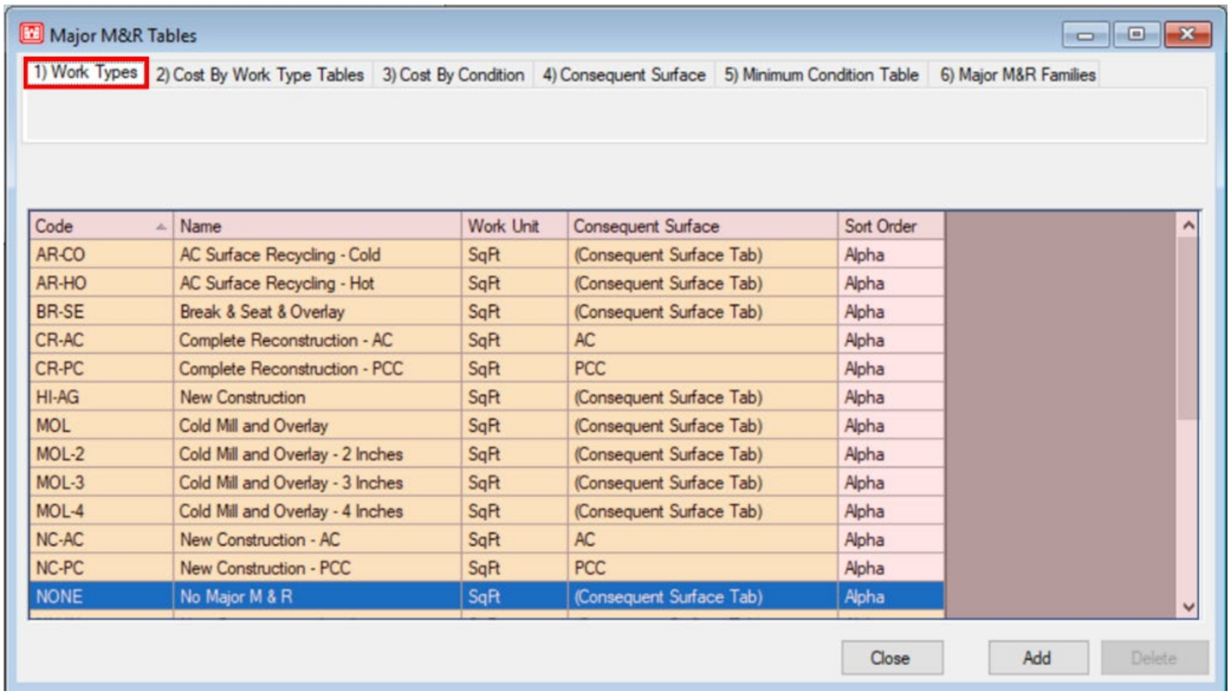
6-4.4.3 Assign Global M&R Families to Sections.

Each of the families created above are assigned to the appropriate sections. For example, assign all asphalt sections in a road and parking network to the global AC family model. Every paved section that was inspected must be assigned to a family. The default family model can be used for unpaved or unused sections as well as sections that did not have a PCI inspection, but these sections are excluded using the **Query** tool when running M&R work plans.

6-5 MAJOR M&R TABLES.

The major M&R tables define major M&R work planning parameters. Figure 6-13 shows the **Major M&R Tables** form. Tables include **Work Types** (tab 1), **Cost By Work Type Tables** (tab 2), **Cost By Condition** (tab 3), **Consequent Surface** (tab 4), and **Minimum Condition Table** (tab 5). **Major M&R Families** are defined on tab 6 using the tables on tabs 1 through 5. Standards for these tables are outlined below and in the appendices.

Figure 6-13 Major M&R Tables



Code	Name	Work Unit	Consequent Surface	Sort Order
AR-CO	AC Surface Recycling - Cold	SqFt	(Consequent Surface Tab)	Alpha
AR-HO	AC Surface Recycling - Hot	SqFt	(Consequent Surface Tab)	Alpha
BR-SE	Break & Seat & Overlay	SqFt	(Consequent Surface Tab)	Alpha
CR-AC	Complete Reconstruction - AC	SqFt	AC	Alpha
CR-PC	Complete Reconstruction - PCC	SqFt	PCC	Alpha
HI-AG	New Construction	SqFt	(Consequent Surface Tab)	Alpha
MOL	Cold Mill and Overlay	SqFt	(Consequent Surface Tab)	Alpha
MOL-2	Cold Mill and Overlay - 2 Inches	SqFt	(Consequent Surface Tab)	Alpha
MOL-3	Cold Mill and Overlay - 3 Inches	SqFt	(Consequent Surface Tab)	Alpha
MOL-4	Cold Mill and Overlay - 4 Inches	SqFt	(Consequent Surface Tab)	Alpha
NC-AC	New Construction - AC	SqFt	AC	Alpha
NC-PC	New Construction - PCC	SqFt	PCC	Alpha
NONE	No Major M & R	SqFt	(Consequent Surface Tab)	Alpha

6-5.1 Major M&R Work Types.

The **Work Types** Table (tab 1) in Figure 6-13 lists a set of standard Major M&R work types. While users can create user-defined major M&R work types in PAVER, they are not permitted in DoD PAVER databases. Change any user-defined work types in an existing database to standard work types and delete the user-defined work types from the Major M&R Work Type table when defining planning parameters for a new inspection. If a Service requires a work type that is not in the major M&R work type table, they will submit the requirement to the Tri-Service Pavement Working Group for inclusion in PAVER.

Work types in Table 6-3 are used in the **Cost By Work Type Tables** (tab 2) and **Consequent Surface** tables (tab 4). This work type table is used for airfield and road and parking M&R, but implementation varies according to this UFC, UFC 3-250-03, UFC 3-250-04, *Standard Practice for Concrete Pavements*, UFC 3-260-02, and UFC 3-250-01, *Pavement Design for Roads and Parking Areas*.

Table 6-3 Major M&R Work Types

Code	Name	Work Unit	Description
AR-CO	AC Surface Recycling - Cold	SqFt	Cold-mix recycling involves removing the existing asphalt, crushing to specified particle size, mixing with virgin material, and using it to pave secondary roads or parking areas (if a seal coat is applied) or as a base course. See UFC 3-250-07 and UFC 3-270-01.
AR-HO	AC Surface Recycling - Hot	SqFt	Hot-mix recycling involves removing the existing HMA, crushing it, and mixing it in a hot-mix plant with new aggregate, asphalt, and recycling agent, when required. This work type can be used for airfields (with restrictions noted in UFC 3-260-02), roads, or parking areas. This work type can also be accomplished with in-place recycling. See UFC 3-250-07 and UFC 3-270-01.
BR-SE	Break & Seat & Overlay	SqFt	Break and seat and crack and seat are both fractured slab technologies used on concrete pavement. Both minimize the size of the concrete slabs and then seat the broken concrete pieces. The pavement is then overlaid with HMA. See Asphalt Institute MS-4, *The Asphalt Handbook*, and MS-17, *Asphalt Overlays for Highway and Street Rehabilitation*.
BR-RB	Rubblization & Overlay	SqFt	Rubblization is a fractured slab technology used on concrete pavement. It eliminates the slab movement by converting the old concrete pavement to aggregate-size pieces. The resulting rubblized pavement layer functions as an aggregate base course. The pavement is then overlaid with HMA. This work type assumes the subgrade is strong enough for the process to work correctly, e.g., the subgrade will not quicken due to pore pressure and thus weaken it and that an underdrain design is installed prior to rubblization to relieve pore pressure and prevent settlement (unless the geotechnical analysis indicates an underdrain is not required). Ensure a geotechnical assessment is done before using rubblization. See Asphalt Institute manuals MS-4 and MS-17.
CR-AC-4	Complete Reconstruction, 4 inches AC	SqFt	Complete reconstruction AC-4 involves removing the existing pavement structure to the subgrade and replacing it. The assumption for this work type is that both the existing and new AC layer are greater than 2 inches and less than or equal to 4 inches, the existing and new base are equal to 6 inches, and there is no subbase. See 3-260-02 and UFC 3-250-03.

Code	Name	Work Unit	Description
CR-AC-6	Complete Reconstruction, 6 inches AC	SqFt	Complete reconstruction AC-6 involves removing the existing pavement structure to the subgrade and replacing it. The assumption for this work type is that both the existing and new AC layer are greater than 4 inches and less than or equal to 6 inches, the existing and new base are equal to 6 inches, and there is a 4-inch subbase. See 3-260-02 and UFC 3-250-03.
CR-AC-8	Complete Reconstruction, 8 inches AC	SqFt	Complete reconstruction AC-8 involves removing the existing pavement structure to the subgrade and replacing it. The assumption for this work type is that both the existing and new AC layer are greater than 6 inches and less than or equal to 8 inches, the existing and new base are equal to 8 inches, and there is a 6-inch subbase. See 3-260-02 and UFC 3-250-03.
CR-PC-8	Complete Reconstruction, 8 inches PCC	SqFt	Complete reconstruction PC-8 involves removing the existing pavement structure to the subgrade and replacing it. The assumption for this work type is that both the existing and new PCC layer are greater than 6 inches and less than or equal to 8 inches, the existing and new base are greater than 4 inches and less than or equal to 6 inches. See 3-260-02 and UFC 3-250-04.
CR-PC-12	Complete Reconstruction, 12 inches PCC	SqFt	Complete reconstruction PC-12 involves removing the existing pavement structure to the subgrade and replacing it. The assumption for this work type is that both the existing and new PCC layer are greater than 8 inches and less than or equal to 12 inches, the existing and new base are equal to greater than 6 inches and less than or equal to 8 inches. See 3-260-02 and UFC 3-250-04.
CR-PC-18	Complete Reconstruction, 18 inches PCC	SqFt	Complete reconstruction PC-18 involves removing the existing pavement structure to the subgrade and replacing it. The assumption for this work type is that both the existing and new PCC layer are greater than 12 inches and less than or equal to 18 inches, the existing and new base are greater than 8 inches and less than or equal to 12 inches. See 3-260-02 and UFC 3-250-04.
CR-PC-24	Complete Reconstruction, 24 inches PCC	SqFt	Complete reconstruction PC-24 involves removing the existing pavement structure to the subgrade and replacing it. The assumption for this work type is that both the existing and new PCC layer are greater than 18 inches and less than or equal to 24 inches, the existing and new base are greater than 12 inches and less than or equal to 16 inches. See 3-260-02 and UFC 3-250-04.

Code	Name	Work Unit	Description
HI-AG	New Construction	SqFt	This PAVER work type does not have a specific pavement type and is not used by DoD. If included in a DoD database, replace it with the appropriate work type for the section based on the pavement type.
MOL	Cold Mill and Overlay	SqFt	This PAVER work type does not define a specific pavement thickness and is not used by DoD. If included in a DoD database, replace it with the appropriate work type for the section based on the asphalt pavement thickness.
MOL-2	Cold Mill and Overlay - 2 Inches	SqFt	This work type involves milling 2 inches of the existing asphalt surface and replacing it with 2 inches of HMA. See UFC 3-250-07 and UFC 3-260-02.
MOL-3	Cold Mill and Overlay - 3 Inches	SqFt	This work type involves milling 3 inches of the existing asphalt surface and replacing it with 3 inches of HMA. See UFC 3-250-07 and UFC 3-260-02.
MOL-4	Cold Mill and Overlay - 4 Inches	SqFt	This work type involves milling 4 inches of the existing asphalt surface and replacing it with 4 inches of HMA. See UFC 3-250-07 and UFC 3-260-02.
NC-AC-4	New Construction, 4 inches AC	SqFt	New construction AC-4 involves constructing a new AC pavement structure. The assumption for this work type is that the AC layer is greater than 2 inches and less than or equal to 4 inches, the base is equal to 6 inches, and there is no subbase. See UFC 3-250-03 and UFC 3-260-02.
NC-AC-6	New Construction, 6 inches AC	SqFt	New construction AC-6 involves constructing a new AC pavement structure. The assumption for this work type is that the AC layer is greater than 4 inches and less than or equal to 6 inches, the base is equal to 6 inches, and there is a 4-inch subbase. See UFC 3-250-03 and UFC 3-260-02.
NC-AC-8	New Construction, 8 inches AC	SqFt	New construction AC-8 involves constructing a new AC pavement structure. The assumption for this work type is that the AC layer is greater than 6 inches and less than or equal to 8 inches, the base is equal to 8 inches, and there is a 6-inch subbase. See UFC 3-250-03 and UFC 3-260-02.
NC-PC-8	New Construction, 8 inches PCC	SqFt	New construction PC-8 involves constructing a new PCC pavement structure. The assumption for this work type is that the PCC layer is greater than 6 and less than or equal to 8 inches, the base is greater than 4 inches and less than or equal to 6 inches. See UFC 3-250-04 and UFC 3-260-02.

Code	Name	Work Unit	Description
NC-PC-12	New Construction, 12 inches PCC	SqFt	New construction PC-12 involves constructing a new PCC pavement structure. The assumption for this work type is that the PCC layer is greater than 8 and less than or equal to 12 inches, the base is greater than 6 inches and less than or equal to 8 inches. See UFC 3-250-04 and UFC 3-260-02.
NC-PC-18	New Construction, 18 inches PCC	SqFt	New construction PC-18 involves constructing a new PCC pavement structure. The assumption for this work type is that the PCC layer is greater than 12 and less than or equal to 18 inches, the base is greater than 8 inches and less than or equal to 12 inches. See UFC 3-250-04 and UFC 3-260-02.
NC-PC-24	New Construction, 24 inches PCC	SqFt	New construction PC-24 involves constructing a new PCC pavement structure. The assumption for this work type is that the PCC layer is greater than 18 and less than or equal to 24 inches, the base is greater than 12 inches and less than or equal to 16 inches. See UFC 3-250-04 and UFC 3-260-02.
NONE	No Major M & R	SqFt	When a pavement is above the critical PCI there is typically no major M&R requirement unless the pavement is being overlaid to increase the structural capacity such as when there is a mission change or when the usage pattern of a road is changed.
NU-IN	New Construction - Initial	SqFt	This is the default work type used when a new section is created. If there is no other major M&R in the work history, this item cannot be updated to reflect the specific construction, e.g., New Construction AC, but the material type field can be edited and the surface type is defined in the inventory.
NU-US	New Construction - Unsurfaced	SqFt	New construction unsurfaced involves constructing a new unpaved (gravel) structure. The assumption for this work type is that the aggregate wearing surface layer is 4 inches and the base is 6 inches.
OL-AF	Overlay - AC Fabric	SqFt	This work type involves placing an overlay to address pavement surface distresses and/or to increase the structural capability of a pavement. This overlay includes the use of a geofabric to mitigate reflective cracking issues and assumes a 2-inch overlay thickness. When thicknesses are less than or greater than these values, adjust the cost for this work type proportionately. See UFC 3-250-03 and UFC 3-260-02.

Code	Name	Work Unit	Description
OL-AS	Overlay - AC Structural	SqFt	This work type involves placing an overlay to address the surface condition of the pavement and/or to increase the structural capability of a pavement. It assumes a 4-inch overlay thickness. When the thickness is less than or greater than this, adjust the cost for this work type proportionately. See UFC 3-250-03 and UFC 3-260-02.
OL-AT	Overlay - AC Thin	SqFt	This work type involves placing an overlay to address the surface condition of the pavement but does not typically significantly increase the structural capability of a pavement. It assumes a 2-inch overlay thickness. See UFC 3-250-03 and UFC 3-260-02.
OL-PF	Overlay - PCC Fully Bonded	SqFt	This work type involves placing a fully bonded PCC overlay to increase the structural capability of a pavement. This overlay type is typically used when the existing slab is in Good condition. Action must be taken to ensure the bond. It assumes an overlay thickness greater than 2 inches and less than 5 inches. See UFC 3-250-04, Appendix B, and UFC 3-260-02.
OL-PP	Overlay - PCC Partially Bonded	SqFt	This work type involves placing a partially bonded PCC overlay to increase the structural capability of a pavement but may be used to address other issues. This overlay type is typically used when the existing slab is in Fair to Good condition. It assumes an overlay thickness of 6 inches. See UFC 3-260-02.
OL-PU	Overlay - PCC Unbonded	SqFt	This work type involves placing a bond breaker and a PCC overlay to increase the structural capability of a pavement but may be used to address other issues. This overlay type is typically used when the existing slab is in Poor to Fair condition. It assumes an overlay thickness of 6 inches. See UFC 3-260-02.
SR-AC	Surface Reconstruction - AC	SqFt	This work type involves milling the full depth of the existing asphalt surface, scarifying and recompacting the base, and placing HMA. The assumption for this work type is that the asphalt is 4 inches. When thicknesses are less than or greater than these values, adjust the cost for this work type proportionately. See UFC 3-250-07 and UFC 3-260-02.

Code	Name	Work Unit	Description
SR-PC	Surface Reconstruction - PCC	SqFt	This work type involves removing existing PCC, repairing and recompacting the base, and placing plain, jointed concrete. It assumes the pavement thickness for the existing and new concrete is greater than 6 inches and less than 8 inches. When thicknesses are greater than these values, adjust the cost for this work type proportionately. See UFC 3-250-04 and UFC 3-260-02.
SU-AC	Surface Course - AC	SqFt	This PAVER work type is intended to be used when defining work requirements for the AC surface course and leveling course separately. It is not used by DoD. If included in a DoD database, replace it with the appropriate work type for the section based on one of the approved asphalt pavement work types.
SU-DB	Surface Course - Double Bituminous.	SqFt	A double bituminous surface course is essentially the same as the single bituminous surface course, except that more than one application of binder and aggregate is used. It is not used on airfield pavements except for overruns and not within 200 feet (61 meters) of the threshold. See UFC 3-270-01, Chapter 7, and UFC 3-250-03, Chapter 4.
SU-PC	Surface Course - PCC	SqFt	This PAVER work type is intended to be used when defining work requirements for the surface course and a base course separately. It is not used by DoD. If included in a DoD database, replace it with the appropriate work type for the section based on one of the approved asphalt pavement work types.
SU-PF	Surface Course - Porous Friction	SqFt	A porous friction course is an open-graded, free-draining asphalt mixture that can be placed on an existing pavement to minimize hydroplaning and improve skid resistance. See UFC 3-260-02, Chapter 21, and UFC 3-250-03, Chapter 2.

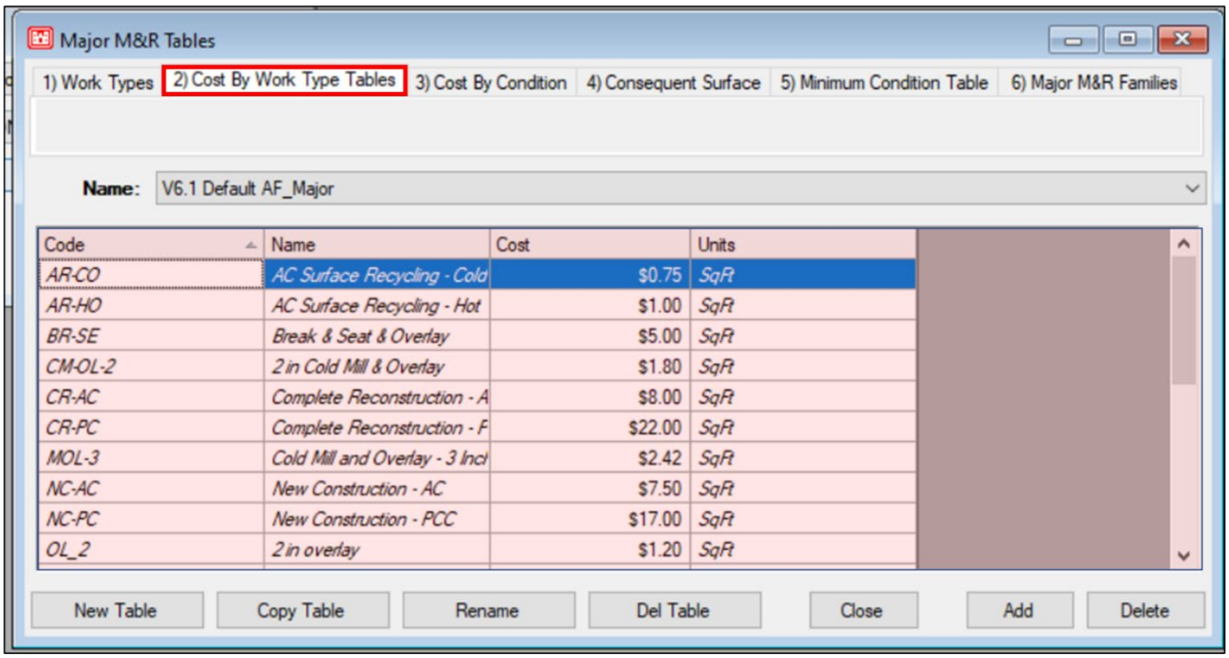
6-5.2 Major M&R Cost by Work Type.

This UFC defines the work elements for each of the standard work types. These work elements are used to define standard Major M&R cost by work type tables for airfields and roads and parking pavements. Paragraph A-2 includes cost by work type templates.

Service Evaluation Teams will update standard cost by work type tables annually using RS Means cost data or Tri-Service Automated Cost Engineering System (TRACES) applications such as the Parametric Cost Engineering System (PACES) or the Micro-Computer Aided Cost Estimating System Second Generation (MII). Use fully burdened unit costs for each of these work types, including O&M escalation factors.

Service Evaluation Teams and consultants performing a PCI survey apply the area cost factor published for that location (e.g., in RS Means) for each work type in the standard tables to adjust the standard unit costs for the specific installation. When there is specific cost data available at an installation for a specific work type, adjust the cost tables to reflect the known costs. Document changes to work component assumptions for a given standard work type in the report so clearly understand the unit cost basis. Use the most recent cost table when defining work planning parameters for a new inspection and delete any cost by work type tables used in previous inspections. An example table is shown in Figure 6-14.

Figure 6-14 Major M&R Cost by Work Type Table



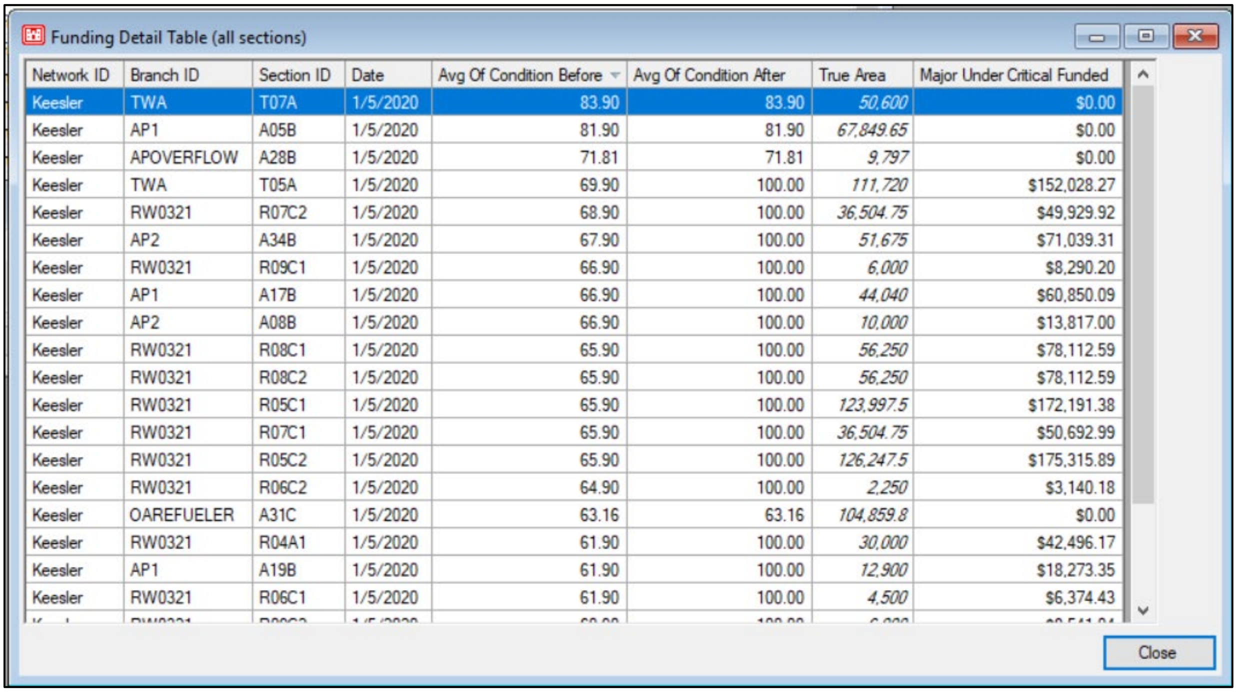
Code	Name	Cost	Units
AR-CO	AC Surface Recycling - Cold	$0.75	SqFt
AR-HO	AC Surface Recycling - Hot	$1.00	SqFt
BR-SE	Break & Seat & Overlay	$5.00	SqFt
CM-OL-2	2 in Cold Mill & Overlay	$1.80	SqFt
CR-AC	Complete Reconstruction - A	$8.00	SqFt
CR-PC	Complete Reconstruction - F	$22.00	SqFt
MOL-3	Cold Mill and Overlay - 3 Inc	$2.42	SqFt
NC-AC	New Construction - AC	$7.50	SqFt
NC-PC	New Construction - PCC	$17.00	SqFt
OL_2	2 in overlay	$1.20	SqFt

6-5.3 Major M&R Cost by Condition.

After completing the PCI survey, updating the work types and cost by work type tables, and assigning the M&R families, run a “One-year Unconstrained Budget” work plan for Major M&R on asphalt and one for concrete without “major above critical,” as described in Chapter 7.

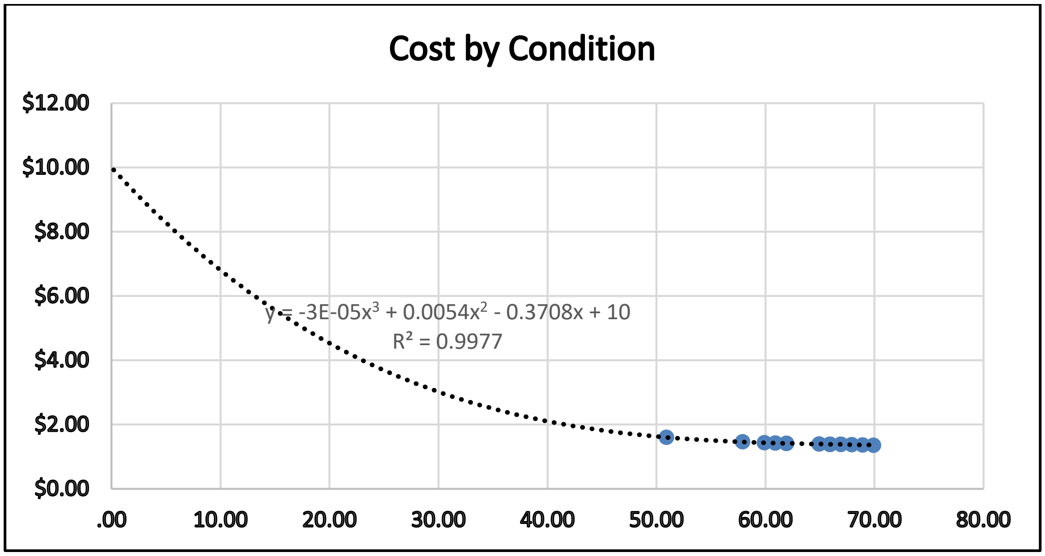
After running the work plan, select the **Funding Detail Table (all sections)** work plan view and export it to Excel. In Excel, unhide all columns, create a column to compute the major M&R unit cost (Major Under Critical Funded / True Area) for each section, then delete the remaining unneeded columns to create a report like the one in Figure 6-15. Create a scatter plot of the unit cost versus the condition, use the Excel trend line function to create a best-fit curve for the data as shown in Figure 6-16, and display the equation. Use the equation that describes the cost by condition relationship to create the cost by condition table at a minimum of 10-PCI intervals from 0 to 100. Adjust the costs to reflect $0 at PCI 100. Use the unit cost of reconstruction for all PCI values below the Service-defined trigger point PCI for reconstruction. PAVER will interpolate the costs between the intervals when you are above this point at which reconstruction is recommended. Repeat the process to create a separate table for both AC and PCC pavement and populate the cost by condition tables in PAVER.

Figure 6-15 Major M&R Funding by Section



Network ID	Branch ID	Section ID	Date	Avg Of Condition Before	Avg Of Condition After	True Area	Major Under Critical Funded
Keesler	TWA	T07A	1/5/2020	83.90	83.90	50,600	$0.00
Keesler	AP1	A05B	1/5/2020	81.90	81.90	67,849.65	$0.00
Keesler	APOVERFLOW	A28B	1/5/2020	71.81	71.81	9,797	$0.00
Keesler	TWA	T05A	1/5/2020	69.90	100.00	111,720	$152,028.27
Keesler	RW0321	R07C2	1/5/2020	68.90	100.00	36,504.75	$49,929.92
Keesler	AP2	A34B	1/5/2020	67.90	100.00	51,675	$71,039.31
Keesler	RW0321	R09C1	1/5/2020	66.90	100.00	6,000	$8,290.20
Keesler	AP1	A17B	1/5/2020	66.90	100.00	44,040	$60,850.09
Keesler	AP2	A08B	1/5/2020	66.90	100.00	10,000	$13,817.00
Keesler	RW0321	R08C1	1/5/2020	65.90	100.00	56,250	$78,112.59
Keesler	RW0321	R08C2	1/5/2020	65.90	100.00	56,250	$78,112.59
Keesler	RW0321	R05C1	1/5/2020	65.90	100.00	123,997.5	$172,191.38
Keesler	RW0321	R07C1	1/5/2020	65.90	100.00	36,504.75	$50,692.99
Keesler	RW0321	R05C2	1/5/2020	65.90	100.00	126,247.5	$175,315.89
Keesler	RW0321	R06C2	1/5/2020	64.90	100.00	2,250	$3,140.18
Keesler	OAREFUELER	A31C	1/5/2020	63.16	63.16	104,859.8	$0.00
Keesler	RW0321	R04A1	1/5/2020	61.90	100.00	30,000	$42,496.17
Keesler	AP1	A19B	1/5/2020	61.90	100.00	12,900	$18,273.35
Keesler	RW0321	R06C1	1/5/2020	61.90	100.00	4,500	$6,374.43

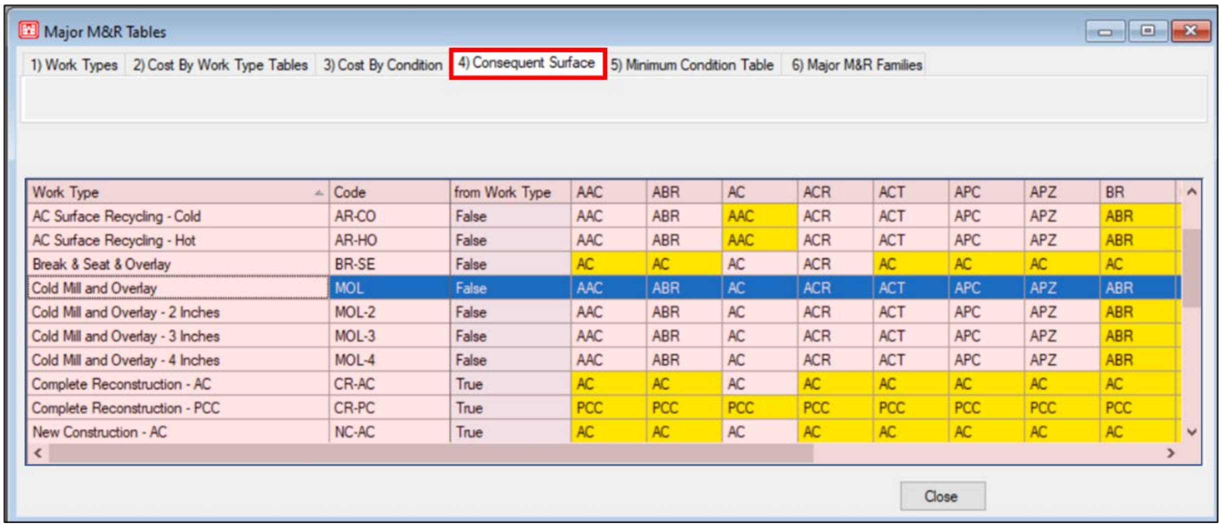
Figure 6-16 Major M&R Unit Cost by Condition Trend Line



6-5.4 Major M&R Consequent Surface.

The Major M&R Consequent Surface table defines the consequent (resultant) surface produced when a given work type is performed over different surface types. Only PAVER default surface types and Major M&R work types are permitted. Go to **System Tables and Tools**>>**Edit Inventory Picklists**>>**Engineering Fields** and delete any user-defined surface types from the database when doing a new PCI evaluation. Figure 6-17 shows an example consequent surface table.

Figure 6-17 Major M&R Consequent Surface Table



Work Type	Code	from Work Type	AAC	ABR	AC	ACR	ACT	APC	APZ	BR
AC Surface Recycling - Cold	AR-CO	False	AAC	ABR	AAC	ACR	ACT	APC	APZ	ABR
AC Surface Recycling - Hot	AR-HO	False	AAC	ABR	AAC	ACR	ACT	APC	APZ	ABR
Break & Seat & Overlay	BR-SE	False	AC	AC	AC	ACR	AC	AC	AC	AC
Cold Mill and Overlay	MOL	False	AAC	ABR	AC	ACR	ACT	APC	APZ	ABR
Cold Mill and Overlay - 2 Inches	MOL-2	False	AAC	ABR	AC	ACR	ACT	APC	APZ	ABR
Cold Mill and Overlay - 3 Inches	MOL-3	False	AAC	ABR	AC	ACR	ACT	APC	APZ	ABR
Cold Mill and Overlay - 4 Inches	MOL-4	False	AAC	ABR	AC	ACR	ACT	APC	APZ	ABR
Complete Reconstruction - AC	CR-AC	True	AC	AC	AC	AC	AC	AC	AC	AC
Complete Reconstruction - PCC	CR-PC	True	PCC	PCC	PCC	PCC	PCC	PCC	PCC	PCC
New Construction - AC	NC-AC	True	AC	AC	AC	AC	AC	AC	AC	AC

6-5.5 Major M&R Minimum Condition.

The Major M&R Minimum Condition table allows the user to set the minimum acceptable condition for each year. Update this table when a Minimum Condition M&R Work Plan is required when doing M&R Work Planning. Note that the Services do not typically use Minimum Condition M&R Work Plans.

6-5.6 Major M&R Families.

The final steps of the major M&R family model process involve creating the M&R family, assigning the minimum condition and cost by condition tables to the family, and then assigning the model to the appropriate sections.

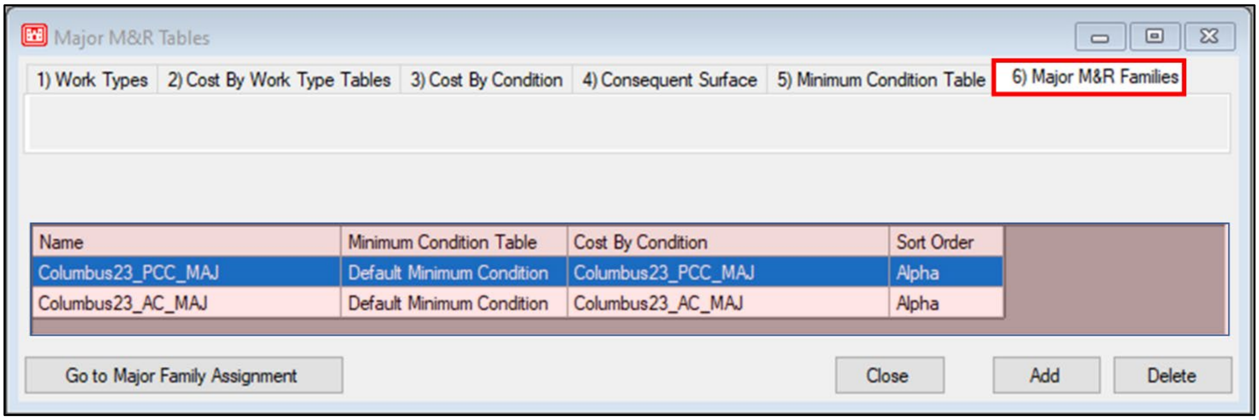
6-5.6.1 Create Major M&R Families.

Add an asphalt and PCC family using the standard convention below, with the acronym MAJ for major M&R.

- Site **NameYr_Pavement Type_M&R Category**
- For example, **Columbus23_AC_MAJ**

Assign the default minimum condition table to the major M&R family and assign the appropriate cost by condition table created in the previous section using the drop-down in the **Minimum Condition Table** and **Cost By Condition** columns as shown in Figure 6-18. Delete all old or unused major M&R family models and all unused tables.

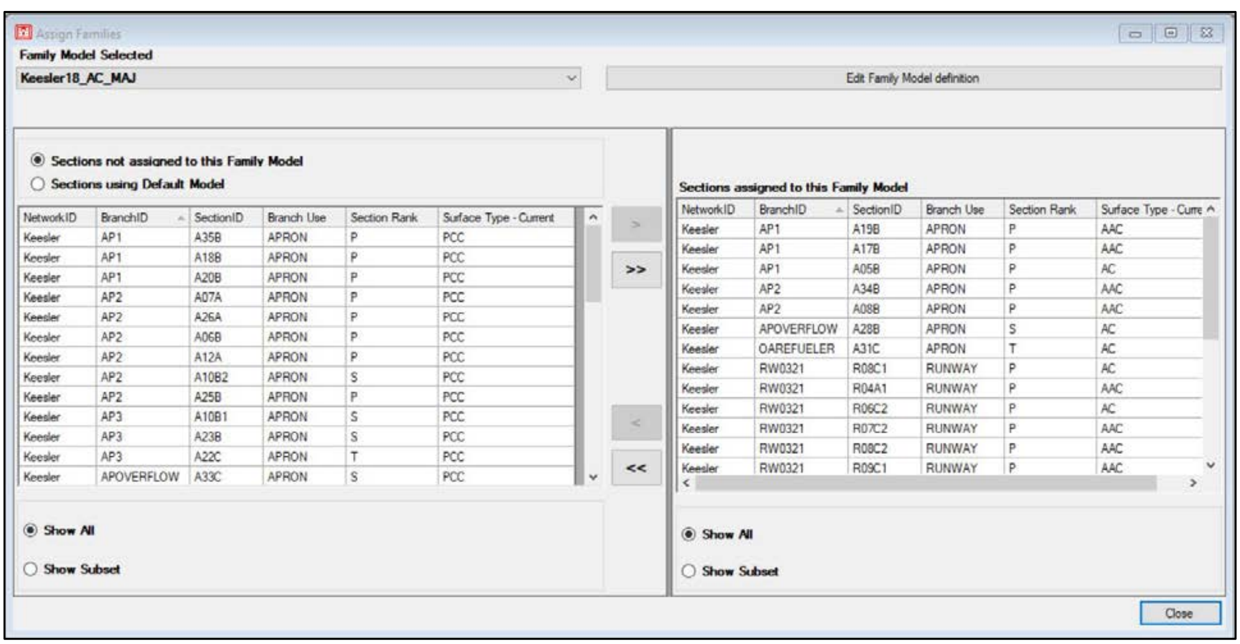
Figure 6-18 Major M&R Families



6-5.6.2 Assign Major M&R Families to Sections.

Each of the families created above are assigned to the appropriate sections by selecting the **Go to Major Family Assignment** button. For example, the asphalt major M&R family is assigned to all AC sections using the PAVER query tool. Open the query tool by selecting the **Show Subset** radio button in Figure 6-19. Assign a family to every paved section that was inspected. Unpaved or unused sections and sections that did not have a PCI inspection may be assigned to the default family model and excluded when running the M&R work plans.

Figure 6-19 Assign Sections to Major M&R Families

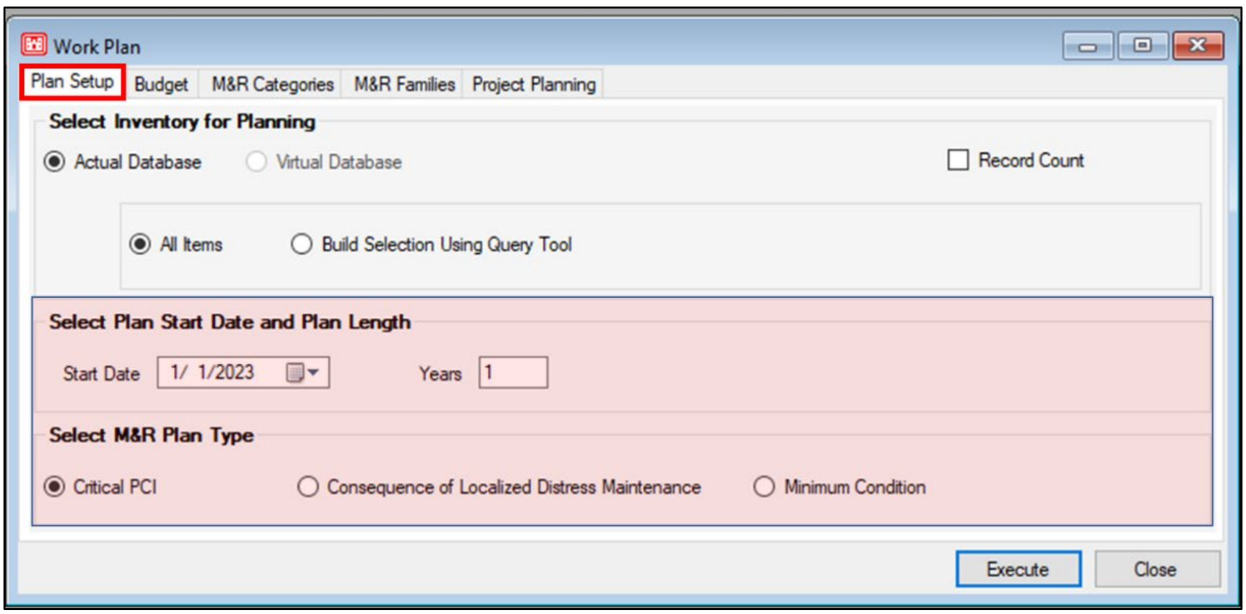


CHAPTER 7 MAINTENANCE AND REPAIR WORK PLANNING

7-1 INTRODUCTION.

M&R work plans outline the M&R requirements for each section based on the assigned PCI deterioration families, M&R family models, and parameters defined on the five work plan tabs as shown in Figure 7-1. The Services use several standard work plans described in this chapter, including consequence of localized distress maintenance, one-year unconstrained, eliminate backlog, maintain current condition, and operational (stopgap/safety) only.

Figure 7-1 M&R Work Plan Form



7-2 WORK PLAN SETUP.

Use the **Plan Setup** tab shown in Figure 7-1 to define the sections included in the work plan, set the plan start date and length, and select the M&R plan type. The other tabs and options shown on these tabs will change based on the selected M&R plan type.

7-2.1 Select Sections for Planning.

Standard practice is to use the **Actual Database** option to run work plans. When all sections in the inventory are inspected and assigned to families, use the **All Items** option, as shown in Figure 7-1. When there are sections that were not inspected or assigned to families, filter these sections using the **Build Selection Using Query Tool** option. The **Virtual Database** option runs work plans on aggregated sections in a virtual inventory. This option is not typically used for individual installations but is useful when analyzing rollup databases. This option is only active when the user creates a virtual inventory (database).

7-2.2 Select Plan Start Date and Plan Length.

As shown in Figure 7-1, standard practice is to use January first of the year following the current inspection year as the plan start date. Run both the Critical PCI Unconstrained work plan and the Consequence of Localized Distress Maintenance work plan for one year. Run Constrained Critical PCI work plans for a minimum of five years as described in paragraph 7.5.4 or for longer periods to meet Service-specific requirements.

7-2.3 Select M&R Plan Type.

There are three M&R work plan types as shown in Figure 7-1: **Critical PCI**, **Consequence of Localized Distress Maintenance**, and the **Minimum Condition** work plans. Each is described below.

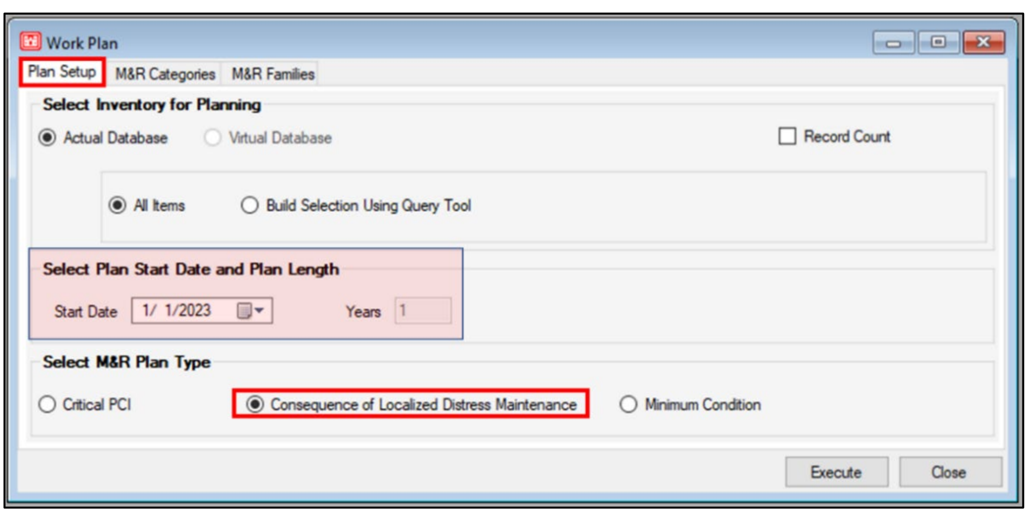
7-3 MINIMUM CONDITION WORK PLAN.

The minimum condition work plan lets the user set the lowest pavement condition (PCI) that is allowed per year using the minimum condition table (defined in the major M&R family model). The Services do not use the Minimum Condition work plan, so this UFC does not discuss the details of the Minimum Condition approach.

7-4 CONSEQUENCE OF LOCALIZED DISTRESS MAINTENANCE.

The consequence of localized distress maintenance work plan generates a list of all the localized work requirements based on the assigned distress maintenance policy, calculates the cost of each requirement based on the cost by work type tables, and computes the resulting conditions when the distresses are repaired based on the consequence of maintenance policy. The plan is set to one year by default, as shown in Figure 7-2, and is based on the PCI data from the most recent inspection. Note, the **Budget** and **Project Planning** tabs are not used when running a Consequence of Localized Distress Maintenance work plan.

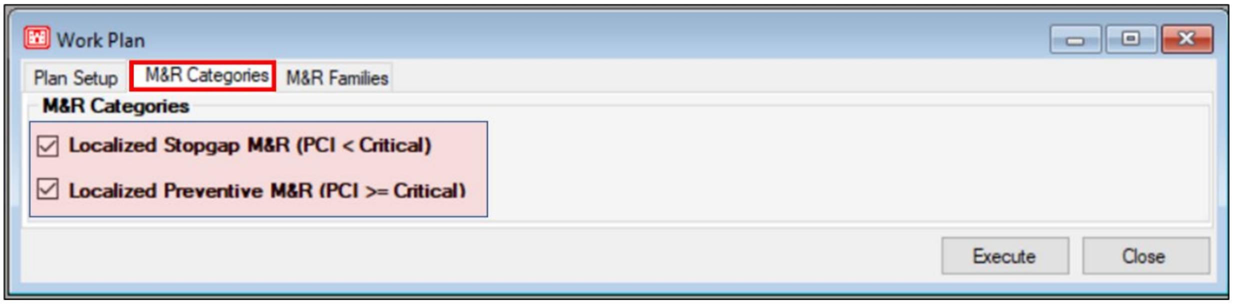
Figure 7-2 Consequence of Localized Distress Maintenance Work Plan



7-4.1 M&R Categories Tab.

Select both **Localized Stopgap M&R** and **Localized Preventive M&R** when running the consequence of localized distress maintenance work plan. Note that global and major M&R are not options on this tab since the focus is on localized M&R.

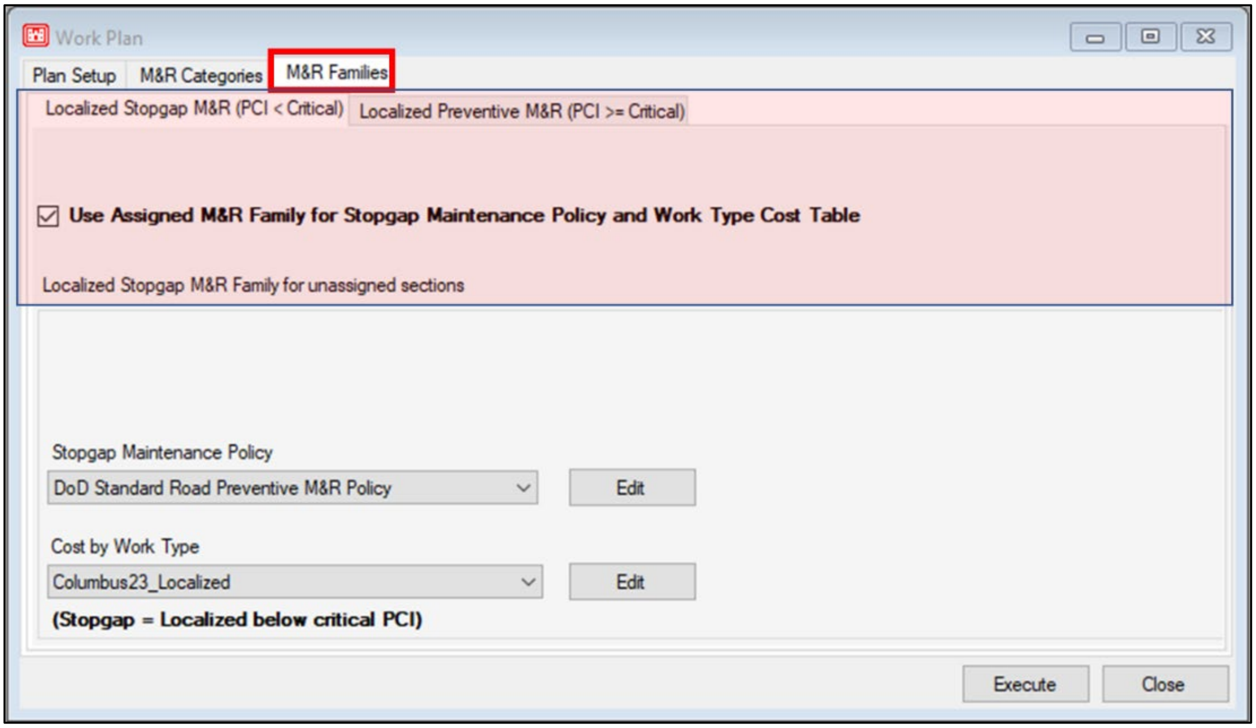
Figure 7-3 M&R Categories Tab



7-4.2 M&R Families Tab.

As shown in Figure 7-4, the **Use Assigned M&R Family for Stopgap Maintenance Policy and Work Type Cost Table** checkbox is checked by default for both **Localized Stopgap M&R** and **Localized Preventive M&R**. The option to define a default policy and cost by work type table for any unassigned sections is not typically used by the DoD since only sections with a current PCI inspection, an assigned PCI family, and an assigned M&R family are included in the work plan.

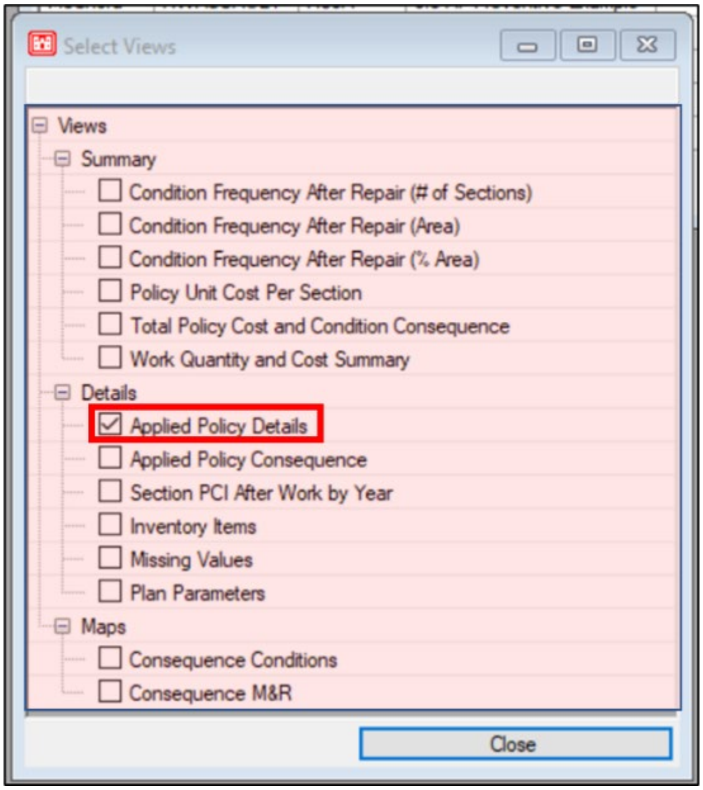
Figure 7-4 M&R Families Tab



7-4.3 Consequence of Localized Distress Maintenance Reports.

PAVER generates several reports (views) for the consequence of localized distress maintenance work plan as shown in Figure 7-5. The **Applied Policy Details** view is used to define specific work types and estimated quantities when developing a PMP, as described in paragraph 8-7. See paragraphs A-6 and A-7 for examples.

Figure 7-5 M&R Work Plan Views



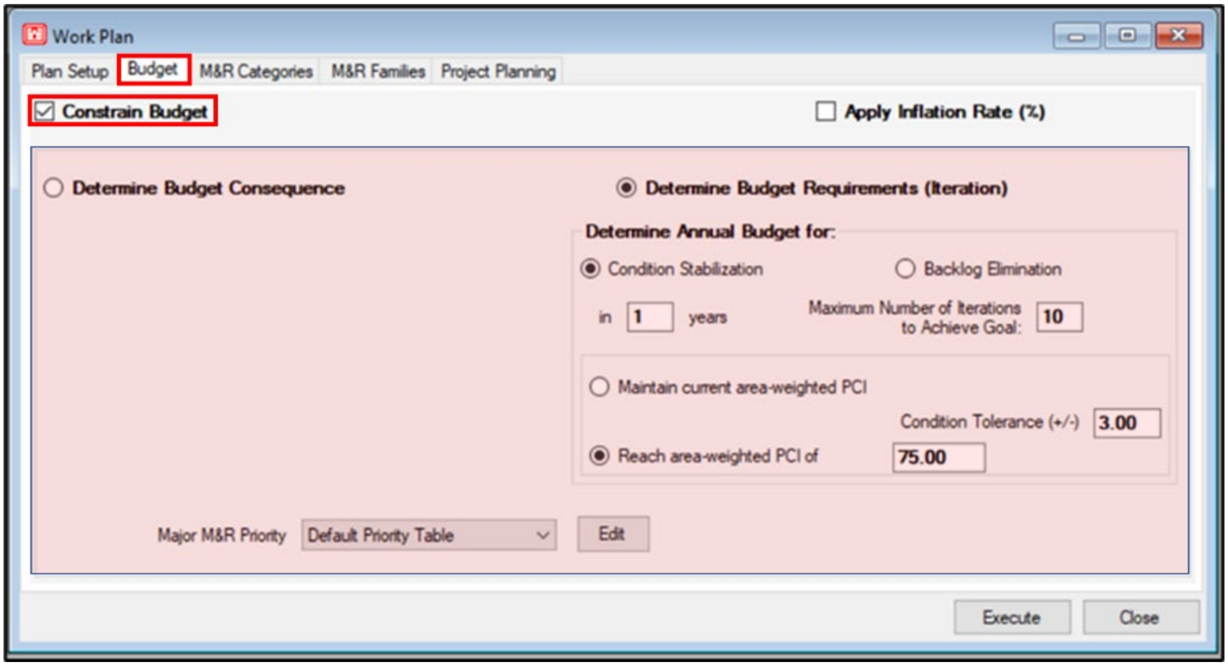
7-5 CRITICAL PCI WORK PLANS.

Select the Critical PCI M&R Plan Type on the **Plan Setup** tab to run Critical PCI work plans. These plans use the critical PCI of the section determined by the section rank, as described in paragraphs 3-4 and 5-4 as the mechanism for triggering Major M&R requirements. Select one of the critical PCI work plans as the optimal critical PCI work plan as described in Paragraph 8-5 to develop the PMP. See paragraphs A-5 and A-7 for examples.

7-5.1 Budget.

The **Budget** tab provides options to select a constrained (checked) or unconstrained (unchecked) budget. When checked, other options to define constrained budget parameters are available, as shown in Figure 7-6.

Figure 7-6 M&R Work Plan Budget Tab



7-5.2 Apply Inflation Rate.

Leave the **Apply Inflation Rate (%)** box unchecked. When selected, PAVER applies a user-defined inflation rate percentage to all work plans. Inflation rates are applied to budget requirements as part of the DoD budgeting process, so checking this box results in a double application of an inflation rate.

7-5.3 Unconstrained Budgets.

Leave the **Constrain Budget** box unchecked to create an unconstrained work plan. Set the plan length to one year on the **Plan Setup** tab to generate a work plan that addresses all current M&R requirements based on the parameters defined in the M&R family models. Grouping all M&R requirements for each section in a pavement facility provides an estimate of the total real property M&R requirements for each facility. This total facility M&R cost can be used as the numerator in the facility condition index computation for each facility when Service real property guidance permits.

The one-year unconstrained work plan is also used to develop Major M&R cost by condition tables as described in paragraph 6-5.3. Unlike running a consequence of localized distress maintenance work plan, where PAVER uses the cost by work type table to generate cost data, when running a critical PCI type plan, PAVER uses the cost by condition table to generate cost data. Therefore, you can see a cost difference for localized M&R between a one-year unconstrained work plan and the consequence of localized distress maintenance work plan. The latter is typically more accurate when running work plans at the time of a PCI inspection. An example of an unconstrained work plan is included in paragraph A-5.

7-5.4 Constrained Budget.

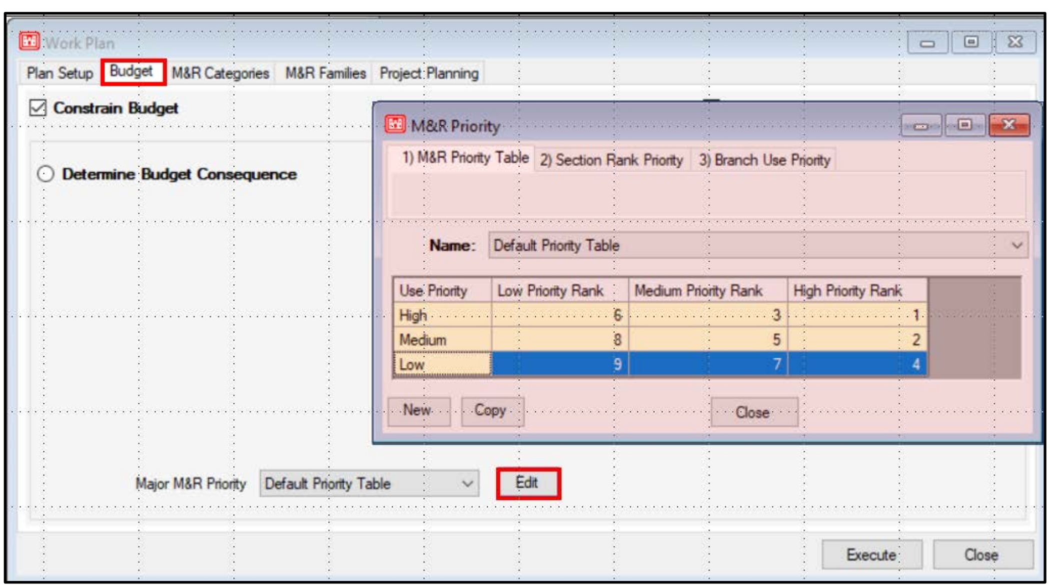
When the **Constrain Budget** box is checked on the **Budget** tab, PAVER develops a work plan to address all M&R requirements based on the parameters defined on the work plan **Budget** and **M&R Categories** tabs, as well as the M&R family models. DoD uses the eliminate backlog work plan and maintain current condition M&R work plan. The standard timeline for constrained budgets used by the DoD is five years, although circumstances or specific mission requirements may require increasing this timeline Constrained work plans are explained in more detail below and examples of constrained work plans are included in paragraph A-6.

7-5.5 Major M&R Priority Table.

When the **Constrain Budget** box is checked, the **Major M&R Priority** option is activated at the bottom of the form as shown in Figure 7-7. Select the **Edit** button to view priority tables. Only use the standard DoD priority tables defined in the UFC when doing major M&R work planning for airfield or road and parking pavements.

The **Major M&R Priority** option shown on the **Budget** tab is activated when the **Constrain Budget** box is checked, as shown in Figure 7-7. This table sets the priority PAVER uses to determine the order of requirements when running a constrained workplan. Selecting the **Edit** button brings up the form. Define the **Section Rank Priority** and **Branch Use Priority** (High, Medium, or Low) on tabs 2 and 3, then set the priority hierarchy on tab 1. Only use the standard DoD priority tables defined in this UFC.

Figure 7-7 Major M&R Priority Table



7-5.5.1 Branch Use Priority Table.

Table 3-2 defines branch use categories for both airfields and roads and parking. The priorities associated with these branch uses are defined in Table 7-1.

Table 7-1 Branch Use Priority Table

Airfield Branch Use Priority			Road and Parking Branch Use Priority		
Use Code	**Description**	**Priority**	**Use Category**	**Description**	**Priority**
RUNWAY	RUNWAY	High	ROADWAY	ROADWAY	High
TAXIWAY	TAXIWAY	Medium	MTRPOOL	MTRPOOL	Medium
HELIPAD	HELIPAD	Medium	OTHER	OTHER	Medium
APRON	APRON	Low	ROUND	ROUNDABOUT	Medium
BLAST PAD	BLAST PAD	Low	CLOSED-RD	CLOSED ROADWAY	Low
CARGO	CARGO	Low	DRIVEWAY	DRIVEWAY	Low
CLOSED-AF	CLOSED AIRFIELD	Low	PARKING	PARKING	Low
DEICING	DEICING	Low	SHOULDER-RD	ROAD SHOULDER	Low
OVERRUN	OVERRUN	Low	STORAGE	STORAGE	Low
SHOULDER-AF	AIRFIELD SHOULDER	Low			
LINE VEHICLE	GROUND EQUIPMENT	Low			

7-5.5.2 Section Rank Priority Table.

Table 3-4 defines the section ranks for both airfields and roads and parking. The priorities associated with these section ranks are defined in Table 7-2.

Table 7-2 Section Use Priority Table

Section Rank Priority Airfields, Road, and Parking		
Section Rank	**Description**	**Priority**
P	Primary	High
S	Secondary	Medium
T	Tertiary	Low
U	Unused	Low

7-5.5.3 Major M&R Priority Table.

The M&R priority hierarchy is the same for both airfields and roads and parking as shown in Table 7-3. An example implementation for an airfield is shown in Table 7-4 and a road and parking example is shown in Table 7-5.

Table 7-3 Major M&R Priority Table

M&R Priority Table			
Use Priority	High Priority Rank	Medium Priority Rank	Low Priority Rank
High	1	3	6
Medium	2	5	8
Low	4	7	9

Table 7-4 Airfield M&R Priority Table Example

Airfield M&R Priority Table Example			
Use Priority	High Priority Rank	Medium Priority Rank	Low Priority Rank
High	1 Main Runway	3 Crosswind Runway	6 Auxiliary Runway
Medium	2 Parallel Taxiway	5 Ladder Taxiway	8 Occasional Use Helipad
Low	4 Primary Apron	7 Transient Apron	9 Wash Rack

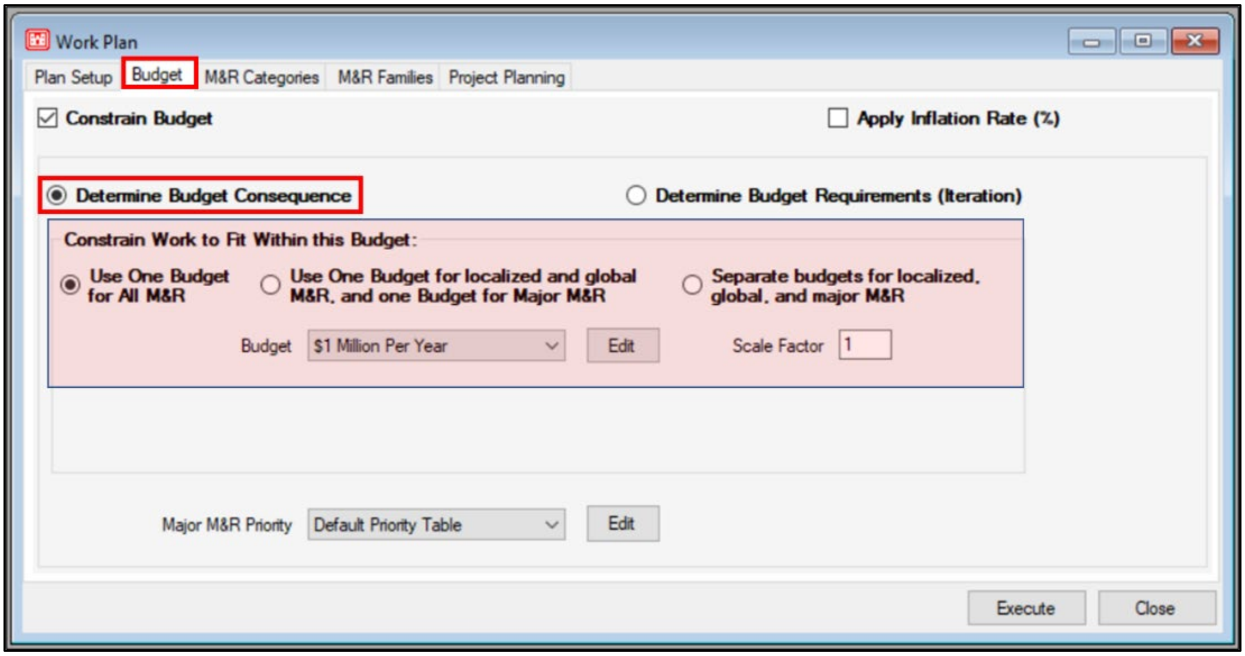
Table 7-5 Section Use Priority Table

Road and Parking M&R Priority Table Example			
Use Priority	High Priority Rank	Medium Priority Rank	Low Priority Rank
High	1 Primary Road (Arterial)	3 Collector Streets	6 Local Streets
Medium	2 Roundabout	5 Motor Pool	8 Other Pavement
Low	4 Hospital Parking Area	7 Facility Parking	9 Driveway

7-5.6 Determine Budget Consequence.

The **Determine Budget Consequence** option is activated when the **Constrain Budget** box is checked. This option allows the user to apply a known budget and have PAVER generate a work plan to fit that budget. DoD installations cannot typically predict future budgets with any level of accuracy so this option is not used by the Services.

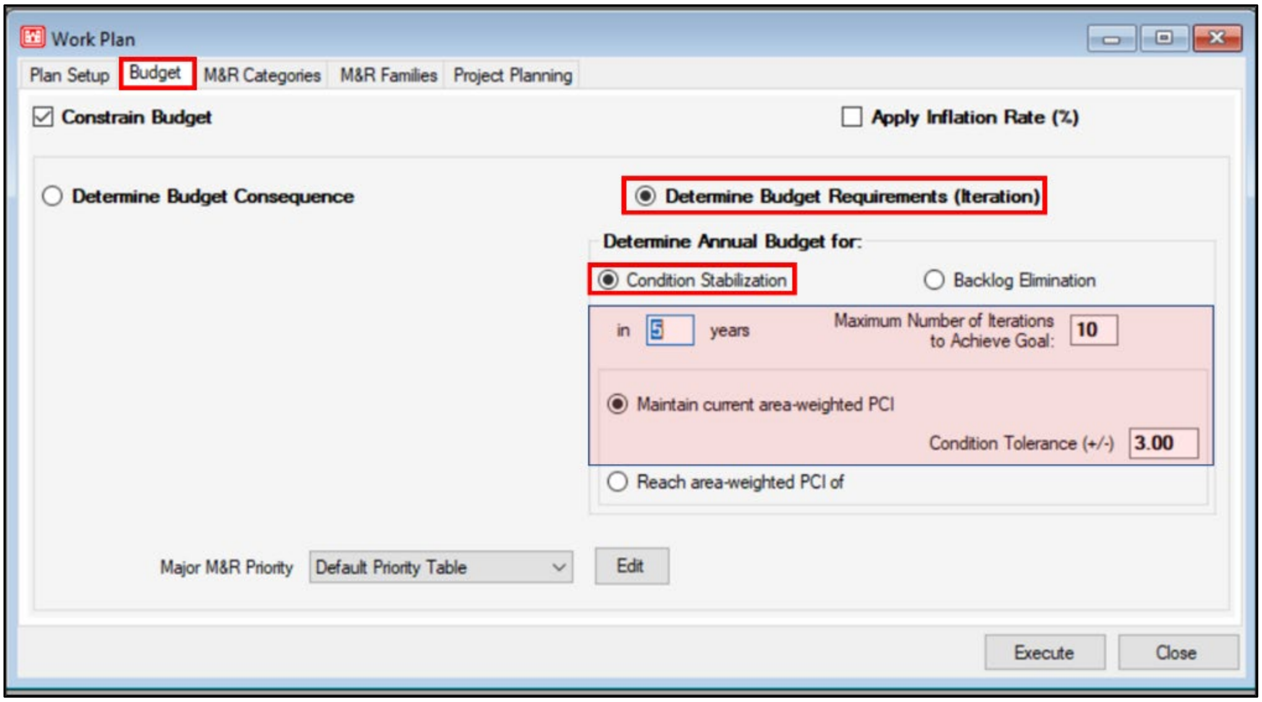
Figure 7-8 Determine Budget Consequence



7-5.7 Determine Budget Requirements.

The **Determine Budget Requirements (Iteration)** option is activated when the **Constrain Budget** box is checked. This option allows the user to determine an annual budget required to maintain the current condition (condition stabilization) or eliminate the M&R backlog, as shown in Figure 7-9. In either case, the goal is to balance the M&R work plan budget over the period of the work plan using the parameters defined on the work plan **Budget** and **M&R Categories** tabs as well as the M&R family models. PAVER generates an initial plan, but if the plan does not meet the goal, PAVER adjusts the plan and goes through another iteration until the goal is achieved.

Figure 7-9 Determine Budget Requirements – Condition Stabilization



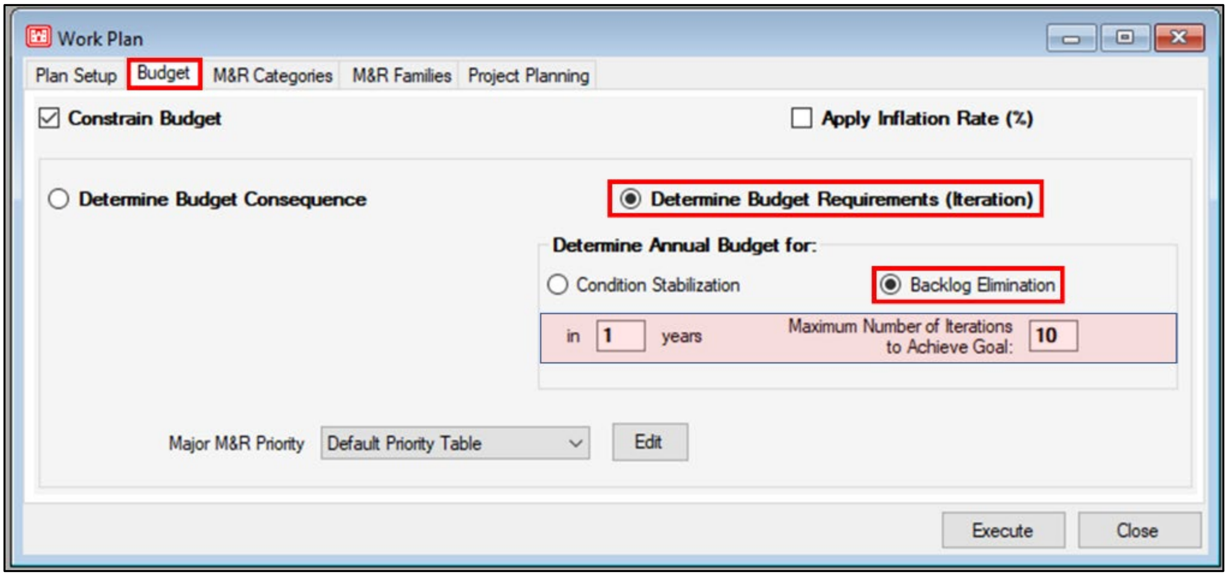
7-5.7.1 Determine Annual Budget for Condition Stabilization.

The Annual Condition Stabilization Budget is a standard work plan for DOD. This option generates a work plan that either reaches a defined area-weighted PCI within a specified period and condition tolerance or maintains the current area-weighted PCI within a specified condition and tolerance. The **Maintain current area weighted PCI** is typically used. As shown in Figure 7-9, set the plan length to five years and set the condition tolerance to ±3.00. This plan is typically the optimal critical PCI work plan when the current area-weighted PCI of the network is above 85.

7-5.7.2 Determine Annual Budget for Backlog Elimination.

The Determine Annual Backlog Elimination budget is also a standard work plan for DOD This option generates a work plan that includes Major M&R requirements for all sections below the critical PCI within the specified time frame. The plan length is set at a minimum of five years on the **Plan Setup** tab and the period is set at five years on the **Budget** tab. This plan is typically the optimal critical PCI work plan when the current area weighted PCI of the network is below 85.

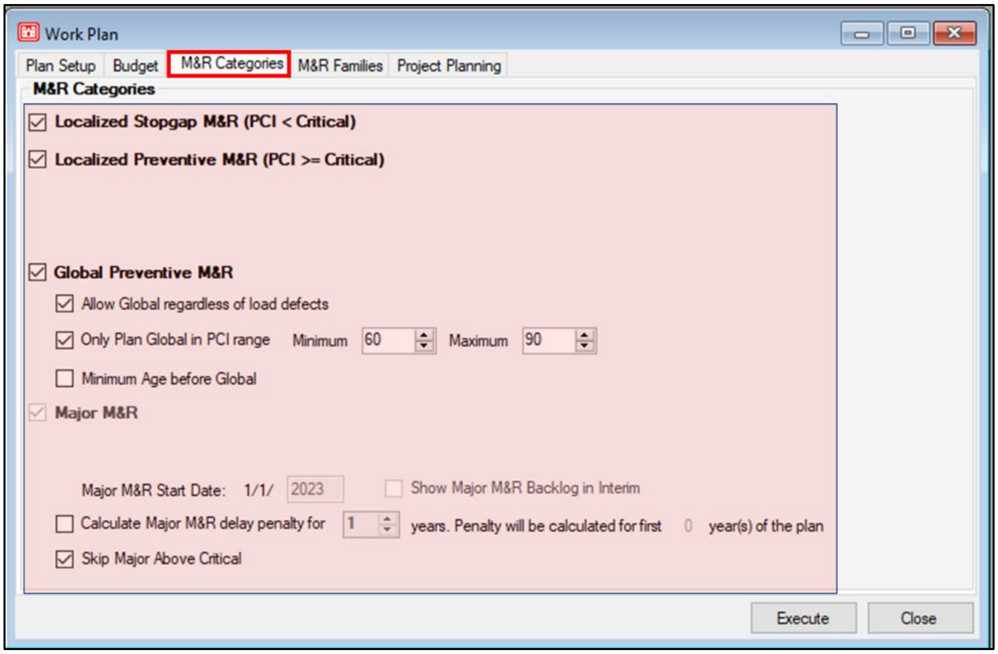
Figure 7-10 Determine Budget Requirements – Backlog Elimination



7-6 M&R CATEGORIES.

The **M&R Categories** tab allows the user to define the type of M&R included in the work plan. The standard approach is to select all M&R types when running any of the critical PCI M&R type plans, as shown in Figure 7-11.

Figure 7-11 M&R Categories Tab



7-6.1 Localized Operational (aka Safety or Stopgap) M&R.

When the **Localized Stopgap M&R (PCI < Critical)** box is checked, PAVER generates an operational M&R requirement for any section with a PCI below critical that does not have a major M&R requirement included in the work plan. This occurs when PAVER is going through the iteration process and cannot plan a major M&R requirement within the defined constraints. While the operational M&R work types are the same as those used for preventive M&R, the maintenance policy is different. The objective is to maintain safety of operations rather than pavement preservation. All cost projections are based on the cost by condition tables.

7-6.2 Localized Preventive M&R.

When the **Localized Preventive M&R (PCI > Critical)** box is checked, PAVER generates preventive M&R requirements for any section with a PCI above critical and distresses that require repair according to the preventive M&R maintenance policy. Just as with Operational M&R, PAVER uses the cost by condition table to generate cost data for localized preventive as opposed to running a Consequence of Localized Distress Maintenance work plan that uses the cost by work type table to generate cost data. When there is a difference, the Consequence of Localized Distress Maintenance work plan is typically more accurate when running work plans at the time of a PCI inspection, but may be less accurate in out-years.

7-6.3 Global Preventive M&R.

When the **Global Preventive M&R** box is checked, PAVER generates global M&R requirements for all sections included on the **Plan Setup** tab using the parameters defined in the global M&R family model and the standard global PCI range. Note that all global preventive M&R costs are generated using cost by work type tables.

7-6.3.1 Only Plan Global in PCI Range.

Set the global PCI range maximum value to 95. The minimum varies according to Service policies based on the mission aircraft. For example, a primary pavement could have a range of 70 to 95, so once the PCI of a section drops below 95, PAVER generates a global M&R requirement using the work type for the respective distress category (minimal, climate-related, and skid causing) and the application interval defined in the family model. Once the PCI drops below 70 for this example, PAVER will not generate a Global M&R requirement.

7-6.3.2 Minimum Age Before Global.

Leave the **Minimum Age before Global** box unchecked. It defines the minimum age before Global Preventive M&R is applied but is not used in DoD work plans.

7-6.4 Major M&R.

As shown in Figure 7-12, the **Major M&R** box is checked by default and is inactive because Major M&R is required to achieve the critical PCI work plan objective. PAVER generates Major M&R requirements for any section below the critical PCI.

7-6.4.1 Calculate Major M&R Delay Penalty.

PAVER reports any delay costs associated with delaying the start date of Major M&R over the length of the work plan when the **Calculate Major M&R Delay Penalty** box is checked, as shown in Figure 7-12. When the user defines the delay length, PAVER generates a report like the one in Figure 7-13. This example shows the cost for section R04A1 goes up by 7 percent if we delay Major M&R for one year, so the cost for the project after a one-year delay would be $43,104.6 * 1.07 = $46,121.92. Delay penalties are a deciding factor when scheduling PMP projects.

Figure 7-12 Critical PCI Work Plan – Major M&R Settings

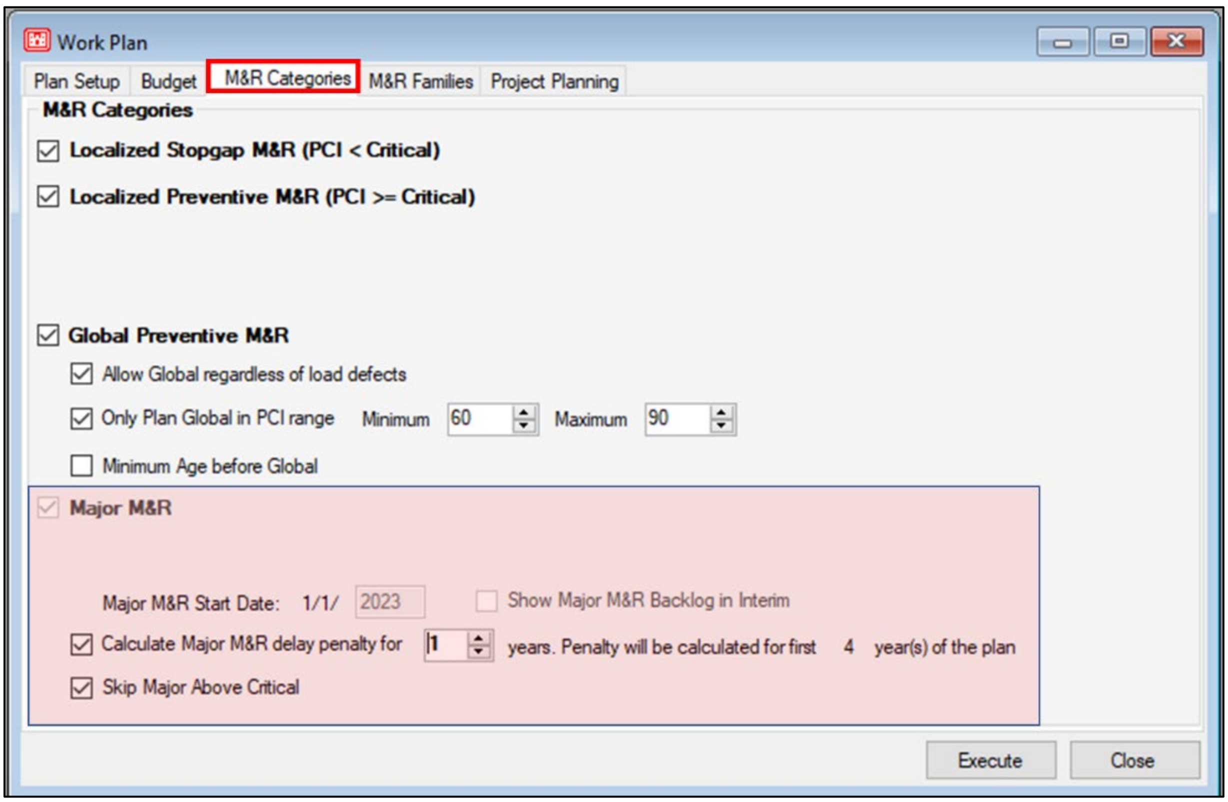
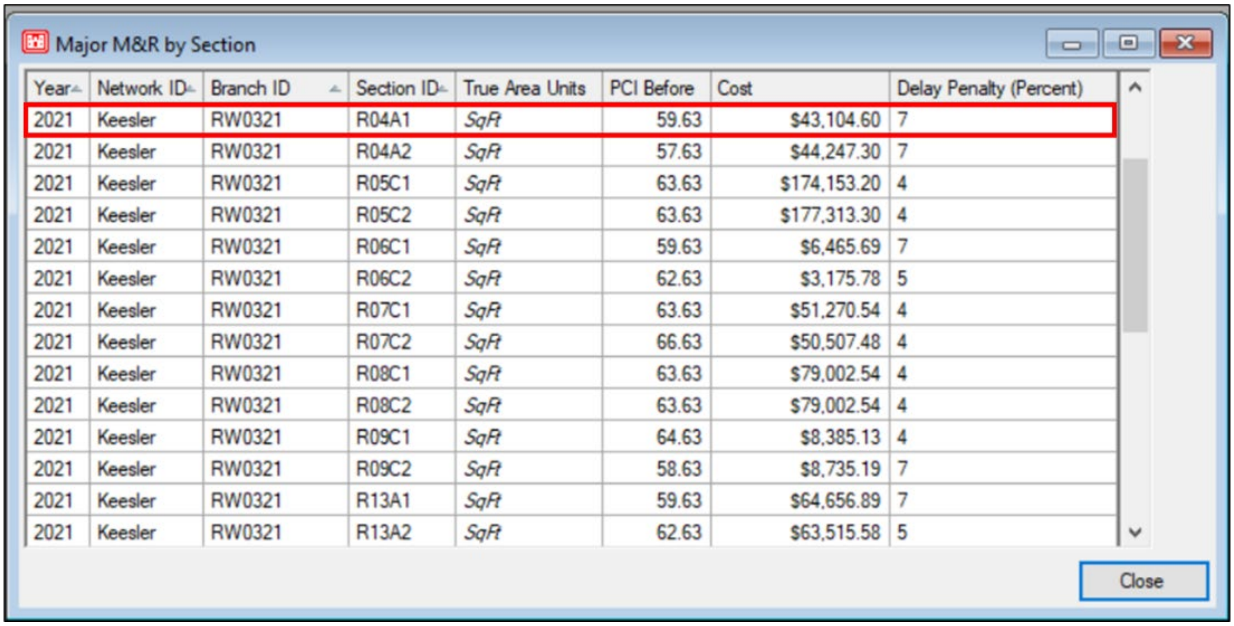


Figure 7-13 Delay Penalty



Year	Network ID	Branch ID	Section ID	True Area Units	PCI Before	Cost	Delay Penalty (Percent)
2021	Keesler	RW0321	R04A1	SqFt	59.63	$43,104.60	7
2021	Keesler	RW0321	R04A2	SqFt	57.63	$44,247.30	7
2021	Keesler	RW0321	R05C1	SqFt	63.63	$174,153.20	4
2021	Keesler	RW0321	R05C2	SqFt	63.63	$177,313.30	4
2021	Keesler	RW0321	R06C1	SqFt	59.63	$6,465.69	7
2021	Keesler	RW0321	R06C2	SqFt	62.63	$3,175.78	5
2021	Keesler	RW0321	R07C1	SqFt	63.63	$51,270.54	4
2021	Keesler	RW0321	R07C2	SqFt	66.63	$50,507.48	4
2021	Keesler	RW0321	R08C1	SqFt	63.63	$79,002.54	4
2021	Keesler	RW0321	R08C2	SqFt	63.63	$79,002.54	4
2021	Keesler	RW0321	R09C1	SqFt	64.63	$8,385.13	4
2021	Keesler	RW0321	R09C2	SqFt	58.63	$8,735.19	7
2021	Keesler	RW0321	R13A1	SqFt	59.63	$64,656.89	7
2021	Keesler	RW0321	R13A2	SqFt	62.63	$63,515.58	5

7-6.4.2 Skip Major Above Critical.

Standard policy is to check the **Skip Major Above Critical** box, let the PCI deteriorate to the critical PCI before generating a Major M&R requirement, and then address any structural issues. The exception to this is when there is a mission change at an installation that requires an increase in the structural capability of the pavement. When this box is unchecked, PAVER will generate Major M&R requirements when the PCI of a section is above critical, but the section has a structural distress density above 10 percent.

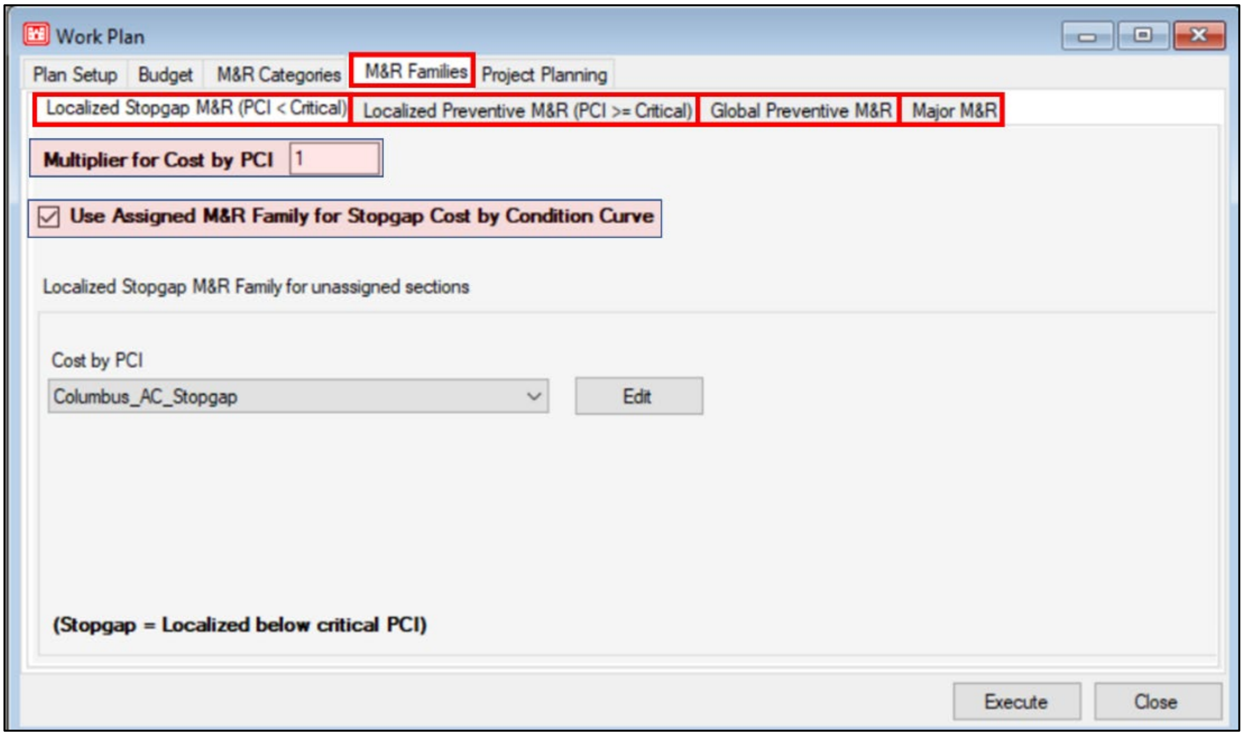
7-7 M&R FAMILIES.

The **M&R Families** tab allows the user to define the M&R family models to be used in the M&R plan. As shown in Figure 7-12, there is a tab for each M&R category. On each tab is a **Use Assigned M&R Family for Stopgap Cost Curve** checkbox. Each box is checked by default. Ensure every section that has been inspected is assigned to the appropriate family models for each M&R category. There is also an option to define a default M&R category or rule set (in the case of global). Since the standard approach is to assign all sections, the default settings are not needed. Filter out any sections that have not been inspected in the last two PCI cycles when running the work plan.

Define the M&R Family Models used in the M&R work plan on the **M&R Families** tab as shown in Figure 7-14. There is a tab for each M&R category, with the checkbox to **Use Assigned M&R Family for Stopgap Cost by Condition Curve** checked by default. So, when every inspected section is assigned to the appropriate family model for each M&R category, PAVER automatically applies the defined parameters. There is also an option to define a default M&R category or rule set (in the case of Global). Since the standard approach is to assign all sections, the default settings are not needed.

When running the work plan, use the **Query** tool to filter out any sections not inspected in the last two PCI cycles.

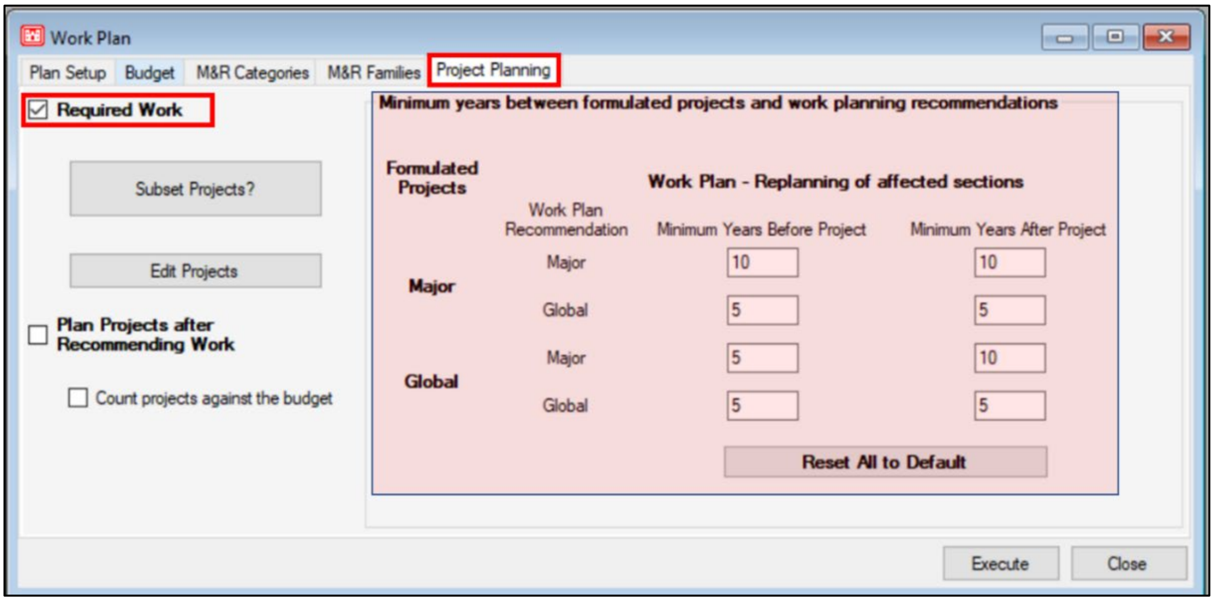
Figure 7-14 M&R Families Tab



7-8 PROJECT PLANNING

When the **Required Work** box is checked on the **Project Planning** tab, PAVER includes all or a subset of projects defined with the Required Work tool or the Project Formulation Wizard in the work plans. The **Project Planning** tab also allows the user to define other work planning parameters, such as the minimum time between projects and other work planning recommendations. Chapter 8 and paragraph A-9 discuss the process of using the M&R requirements from work plans to develop a pavement management plan (PMP). A PMP can be developed using spreadsheets or other tools but developing projects in PAVER and incorporating them into work plans to develop a PMP is considered a best practice.

Figure 7-15 Project Planning Tab



CHAPTER 8 PRIORITIZING REQUIREMENTS

8-1 OBJECTIVE

The level of detail in a pavement management plan (PMP) can range from a spreadsheet with a prioritized list of work tasks and projects in each year of the plan to a detailed document that outlines the team composition and development process, including limiting factors, assumptions, and analysis of alternatives. The objective of this UFC is to define the minimum PMP requirement, a prioritized list of work items and projects required to maintain pavements for each year in the next five calendar years.

8-2 BACKGROUND.

The goal of a PMP is to define and document M&R actions required to maintain operational safety, preserve and extend the life of pavements, and optimize life-cycle costs and pavement condition. The best approach to achieve this goal is to prioritize localized and global preventive maintenance and implement policies to perform Major M&R at the appropriate time as opposed to a "worst first" approach. In a "worst first" approach, pavements are allowed to deteriorate, localized M&R is just used to address issues that pose a safety concern, and Major M&R is prioritized based on which pavement is in the worst condition, with some consideration given to the use (e.g., runway versus taxiway or road versus parking). This UFC is intended to move the DoD away from a "worst first" approach.

8-3 RESPONSIBILITY FOR PAVEMENT MANAGEMENT PLANS.

8-3.1 Service Responsibility.

Each Service centrally manages their pavement evaluation programs and performs pavement evaluations on a regular cycle. These evaluations provide the baseline data to establish a PMP. The Services define specific PMP requirements in Service guidance to supplement the minimum standard outlined in this UFC, e.g., PMP content, development and execution responsibility, timelines, prioritization rules, and format.

8-3.2 Installation Responsibility.

Service teams or consultants gather data during regularly scheduled pavement evaluations and can provide expertise and support for developing a PMP. Installations use this data to develop the PMP in-house or assisted by a consultant, but in either case, installation-level knowledge is the key to developing an effective PMP. So, whether a Service evaluation team, a consultant, or installation personnel develop the PMP, the installation personnel are the only ones that can provide local knowledge and therefore must be fully engaged in the process of developing and maintaining their PMPs for airfield and road and parking pavement. The installation is also responsible for executing PMP projects ranging from day-to-day preventive maintenance performed in-house to larger-scale projects performed by the in-house workforce, by contract, or a combination of both.

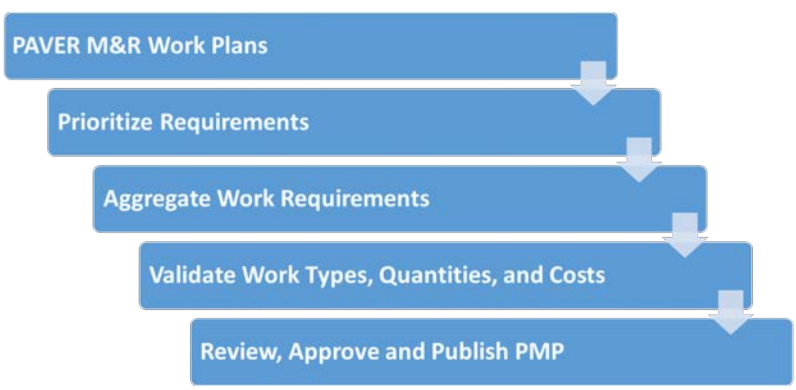
8-3.3 Team Approach.

There are many considerations that go into developing a PMP. Finding effective solutions to these considerations requires knowledge of the mission as well as knowledge of pavement management, design, and construction. The best approach to developing a PMP is to establish a team that brings the necessary skill sets and knowledge to the table. At a minimum, this team will include, if present, installation pavement engineers and technicians responsible for pavements M&R and planning, personnel responsible for managing real property and geospatial information system data, and personnel responsible for airfield management (when developing an airfield PMP).

8-4 PROCESS OVERVIEW.

Previous chapters described the tasks involved in organizing the inventory, determining pavement condition, defining deterioration rates, cost by work type and condition tables, and other work plan parameters culminating in the PAVER M&R work plans discussed in Chapter 7. These initial work plans provide the starting point for a PMP. A PMP can be developed using spreadsheets, PAVER, or other tools, but the overall process is similar for all. As shown in Figure 8-1, developing a PMP involves prioritizing the M&R requirements identified in the work plans, organizing the prioritized M&R requirements into executable work tasks and projects, and validating the work types, quantities, and costs for each year in the PMP. The final phase of the process is coordinating the PMP with the team, sending it forward for installation leadership approval (or higher approval if required by the Service), and publishing the PMP. At a minimum, review and update the PMP annually. Paragraph A-9.9 provides PMP examples.

Figure 8-1 PMP Development Process



8-5 PAVER M&R WORK PLANS.

The consequence of localized distress maintenance and optimal constrained critical PCI work plans generated by PAVER define all near-term and long-term localized, global, and Major M&R requirements. Prior to developing the PMP, decide whether the eliminate backlog, maintain condition, or other critical PCI work plan is optimal for the installation. As a general guideline, use the eliminate backlog work plan when the weighted area average PCI of all sections is below 85 and use the maintain condition workplan when this value is above 85.

8-6 PRIORITIZING REQUIREMENTS.

Using the optimal critical PCI work plan, prioritize all M&R requirements for each section by stratifying them based on risk and return on investment.

8-6.1 Defining Risk.

This UFC defines risk using the process described in paragraph 7-5.5 that assigns a use priority (based on the Branch use) and a rank priority. Combining these factors results in an indication of the level of risk, with 1 being the highest risk and 9 being the lowest risk in the priority matrix, as shown in Table 8-1. This approach is highly dependent on reasonable rank stratification. Without this stratification, there is no way to objectively prioritize requirements for different branch use categories, e.g., when most pavements are given a primary rank, the prioritization matrix does not provide sufficient differentiation. While this approach provides an objective, repeatable measure of risk, each Service can define other risk metrics to use based on the priority of the asset or impact on the mission.

Table 8-1 Maintenance and Repair Priority Table

M&R Priority Table			
Use Priority	**High Priority Rank**	**Medium Priority Rank**	**Low Priority Rank**
High	1	3	6
Medium	2	5	8
Low	4	7	9

8-6.2 Defining Return on Investment.

The fundamental concept to define the return on investment for pavements is that applying localized and global preventive maintenance when a pavement is in Good condition provides the greatest return on investment by extending the life of the pavement and the time before the pavement reaches the critical PCI. In addition, performing major M&R at the appropriate time is more cost-effective and provides a better return on investment than allowing a pavement to deteriorate to Poor condition that requires more extensive repairs. So, conceptually, the return on investment is defined by the condition of the pavement, as shown in Figure 8-2.

Figure 8-2 Return on Investment vs. Pavement Condition

≥ 0	≥ 10	≥ 20	≥ 30	≥ 40	≥ 50	≥ 60	≥ 70	≥ 80	≥ 90
Red/Unsatisfactory				Yellow/Degraded			Green/Adequate		
Low ------------------------------> Return on Investment -----------------------------------> High									

This basic approach provides an objective, repeatable measure of return on investment using the predicted condition in the planned year of execution. The Services can refine this procedure by using a composite index that incorporates other factors, such as the Structural Index (SI) and FOD Potential Rating for airfields or the International Roughness Index for roads to define this basic approach to return on investment. Alternatively, Services can define other return on investment metrics that provide greater fidelity, including the more complex “risk analysis procedure” outlined in paragraph A-10 to determine return on investment. While it is called the “risk analysis procedure,” it evaluates the M&R cost benefit. This procedure is currently implemented using spreadsheets but will be incorporated in a future version of PAVER. Regardless of the metric used, the overall objective is to define the return on investment.

8-6.3 Risk vs. Return on Investment.

Comparing the risk determined in the priority matrix in Table 8-1 to the return on investment based on the condition of the section in Figure 8-2 provides a means of determining a value in the matrix shown in Table 8-2. This value can be used to stratify the M&R requirements for each section in each year of the plan. Note that performing the sort procedure on the optimal critical PCI work plan as described in paragraphs A-6.6 and A-7.6 achieves the same result without assigning a value from the matrix to each section.

Table 8-2 Risk – Return Matrix

M&R Priority		Risk - Return Matrix									
Low ------------> Risk ------------> High	1	81	82	83	84	85	86	87	88	89	90
	2	71	72	73	74	75	76	77	78	79	80
	3	61	62	63	64	65	66	67	68	69	70
	4	51	52	53	54	55	56	57	58	59	60
	5	41	42	43	44	45	46	47	48	49	50
	6	31	32	33	34	35	36	37	38	39	40
	7	21	22	23	24	25	26	27	28	29	30
	8	11	12	13	14	15	16	17	18	19	20
	9	1	2	3	4	5	6	7	8	9	10
ROI as Indicated by PCI		≥ 0	≥ 10	≥ 20	≥ 30	≥ 40	≥ 50	≥ 60	≥ 70	≥ 80	≥ 90
		Red/Unsatisfactory				Yellow/Degraded			Green/Adequate		
		Low ----------------------------------> Return on Investment --> High									

8-6.4 Risk – Return Categories.

The risk - return categories shown in Figure 8-3 assume that return on investment declines once the PCI at the time of execution drops below the critical PCI of 70 and that there is minimal return on investment when the PCI drops below 40. Services can adjust the scale based on mission requirements or, for secondary or tertiary pavements, have lower critical PCI. The key concept is that in the absence of a more detailed return on investment computation, this basic approach serves as an objective measure to aggregate requirements and prioritize work tasks and projects for planning purposes. Using the risk analysis procedure described in paragraph A-10 to define return on investment provides more fidelity but the process remains the same. Once projects are defined, perform a life-cycle cost analysis to further refine return on investment.

The sequence of the risk - return categories in Figure 8-3 reflects the need to balance risk and return while furthering the goal of maintaining operational safety, preserving and extending the life of pavements, while optimizing life-cycle costs and pavement condition. Table 8-3 provides the recommended execution hierarchy to achieve these goals by placing a priority on localized and global preventive maintenance while implementing policies to perform Major M&R at the appropriate time. This execution hierarchy also recognizes there are instances when a requirement with a low return is given a higher execution priority. For example, while operational repairs on high-priority sections are not cost-effective, the risk associated with not doing them is high, especially on an airfield, so these repairs should be reviewed and placed at the top of the priority list when warranted.

Figure 8-3 Risk – Return Categories

M&R Priority		Risk - Return Categories		
Low ---------------> Risk ---------------> High	1 2 3	E High Risk Low Return	C High Risk Moderate Return	A High Risk High Return
	4 5 6	H Moderate Risk Low Return	F Moderate Risk Moderate Return	B Moderate Risk High Return
	7 8 9	I Low Risk Low Return	G Low Risk Moderate Return	D Low Risk High Return
ROI as Indicated by PCI		≥ 0 ≥ 10 ≥ 20 ≥ 30	≥ 40 ≥ 50 ≥ 60	≥ 70 ≥ 80 ≥ 90
		Red/Unsatisfactory	Yellow/Degraded	Green/Adequate
		Low --------------------------------------> Return on Investment	--	------> High

Table 8-3 Risk – Return Category Description

Risk-Return Category	Requirements Description
C & E	Operational M&R - High Risk - Low Return
A & B	Localized and Global Preventive M&R - High to Moderate Risk - High Return
C	Major M&R - High - Risk - Moderate Return
D	Localized and Global Preventive M&R Low Risk - High Return
E	Major M&R High Risk - Low Return
F	Operational or Major M&R Moderate Risk - Moderate Return
G	Operational or Major M&R Low Risk - Moderate Return
H	Operational or Major M&R Moderate Risk - Low Return
I	Operational or Major M&R Low Risk - Low Return

8-7 AGGREGATE WORK REQUIREMENTS.

Once a prioritized requirements list is generated using the guidance above and in Chapters 6 and 7, the next step is to aggregate work requirements. This involves investigating opportunities to combine line items in the prioritized requirements list into executable tasks and projects (see Figure 8-4). Best practice is to combine requirements within each of the risk - return categories in Table 8-3, taking into consideration factors such as method of execution, specific work types, operational impacts, economies of scale, and phasing. Other considerations include opportunities to include pavement work in drainage, lighting, fuels, or other projects as well as addressing any outstanding waivers. PAVER provides tools to assist with setting up projects and incorporating them into critical PCI work plans. Paragraphs A-6, A-7, and A-9 provide examples of this process.

Figure 8-4 Prioritized Requirements List Example

Network ID	Branch ID	Section ID	Work Year	Branch Use	Section Rank	Work Type	Surface Type Current	Stop Gap Funded	Preventive Funded	Global Funded	Major Under Critical Funded	Total Funded
Sheppard	RW15C33C	R04A1	2023	RUNWAY	P	Preventive	PCC	$0.00	$7,455.88	$0.00	$0.00	$7,455.88
Sheppard	RW15C33C	R04A2	2023	RUNWAY	P	Preventive	PCC	$0.00	$7,455.88	$0.00	$0.00	$7,455.88
Sheppard	RW15C33C	R05C1	2023	RUNWAY	P	Major Below Critical	AC	$0.00	$0.00	$0.00	$109,264.93	$109,264.93
Sheppard	RW15C33C	R05C2	2023	RUNWAY	P	Preventive + Global MR	AC	$0.00	$3,598.83	$14,238.68	$0.00	$17,837.51
Sheppard	RW15C33C	R06C1	2023	RUNWAY	P	Major Below Critical	AC	$0.00	$0.00	$0.00	$33,249.59	$33,249.59
Sheppard	RW15C33C	R06C2	2023	RUNWAY	P	Preventive + Global MR	AC	$0.00	$1,349.12	$4,271.68	$0.00	$5,620.80
Sheppard	RW15C33C	R07C1	2023	RUNWAY	P	Major Below Critical	AC	$0.00	$0.00	$0.00	$717,011.18	$717,011.18
Sheppard	RW15C33C	R07C2	2023	RUNWAY	P	Preventive + Global MR	AC	$0.00	$29,230.76	$92,552.75	$0.00	$121,783.51
Sheppard	RW15C33C	R08A1	2023	RUNWAY	P	Preventive	PCC	$0.00	$4,932.77	$0.00	$0.00	$4,932.77
Sheppard	RW15C33C	R08A2	2023	RUNWAY	P	Preventive	PCC	$0.00	$3,288.53	$0.00	$0.00	$3,288.53
Sheppard	RW15L33R	R01A1	2023	RUNWAY	P	Preventive	PCC	$0.00	$11,058.28	$0.00	$0.00	$11,058.28
Sheppard	RW15L33R	R01A2	2023	RUNWAY	P	Preventive	PCC	$0.00	$19,413.79	$0.00	$0.00	$19,413.79
Sheppard	RW15L33R	R02C1	2023	RUNWAY	P	Preventive	AC	$0.00	$2,300.37	$0.00	$0.00	$2,300.37
Sheppard	RW15L33R	R02C2	2023	RUNWAY	P	Preventive	AC	$0.00	$2,300.37	$0.00	$0.00	$2,300.37
Sheppard	RW15L33R	R03A1	2023	RUNWAY	P	Preventive	PCC	$0.00	$14,052.28	$0.00	$0.00	$14,052.28
Sheppard	RW15L33R	R03A2	2023	RUNWAY	P	Preventive	PCC	$0.00	$17,179.11	$0.00	$0.00	$17,179.11
Sheppard	RW15R33L	R09A1	2023	RUNWAY	P	Preventive	PCC	$0.00	$11,659.60	$0.00	$0.00	$11,659.60
Sheppard	RW15R33L	R09A2	2023	RUNWAY	P	Preventive	PCC	$0.00	$7,987.54	$0.00	$0.00	$7,987.54
Sheppard	RW15R33L	R10A1	2023	RUNWAY	P	Preventive	PCC	$0.00	$7,712.88	$0.00	$0.00	$7,712.88
Sheppard	RW15R33L	R10A2	2023	RUNWAY	P	Preventive	PCC	$0.00	$20,295.54	$0.00	$0.00	$20,295.54
Sheppard	RW15R33L	R11C1	2023	RUNWAY	P	Preventive	PCC	$0.00	$170,972.59	$0.00	$0.00	$170,972.59
Sheppard	RW15R33L	R11C2	2023	RUNWAY	P	Preventive	PCC	$0.00	$394,637.32	$0.00	$0.00	$394,637.32
Sheppard	RW15R33L	R12A1	2023	RUNWAY	P	Preventive	PCC	$0.00	$6,726.84	$0.00	$0.00	$6,726.84

8-7.1 Method of Execution.

The method of execution is a primary consideration when combining requirements that drives how the requirements are aggregated into projects. The recommended approach adds a method of execution column to the prioritized requirements list for each work type in each section (see Figure 8-5). The detailed procedure is provided in paragraph A-9.5. Understanding the availability and capability of each of the alternatives listed below is key to developing an effective plan.

- Evaluate and maximize use of available in-house capabilities. In general, in-house capability is limited to localized Operational and Preventive Repairs but there can be instances where in-house work forces have more robust capabilities.
- Determine availability of installation and Service-level indefinite delivery / indefinite quantity (IDIQ) contracts. Generally, installation-level IDIQ contracts are used for localized repairs but can be considered for Global M&R if the contractor has the required equipment and expertise. Service-level contracts such as multiple award task order contracts (MATOC) are generally used for larger projects that include localized, global, or Major M&R.
- Competitive bid contracts are used for projects that include localized, global, or Major M&R.

Figure 8-5 Method of Execution Example

Network ID	Branch ID	Section ID	Date	Branch Use	Section Rank	Risk - Return Category	Work Type	Method of Execution	Surface Type Current	M&R Priority	Avg Condition Before	Avg Condition After	Stop Gap Funded	Preventive Funded	Global Funded	Major Under Critical Funded	Total
Keesler	RDFIFTHST	05	2023	ROADWAY	P	A	Preventive	IDIQ	AC	1	97.54	97.83	$0.00	$124.20	$0.00	$0.00	$124.20
Keesler	RDFIFTHST	06	2023	ROADWAY	P	A	Preventive + Global MR	IDIQ	AC	1	79.54	83.62	$0.00	$197.48	$1,704.61	$0.00	$1,902.09
Keesler	RDFIRST	01	2023	ROADWAY	P	C	Major Below Critical	Contract	AC	1	45.14	100.00	$0.00	$0.00	$0.00	$190,283.40	$190,283.40
Keesler	RDFIRST	02	2023	ROADWAY	P	C	Major Below Critical	Contract	AC	1	51.24	100.00	$0.00	$0.00	$0.00	$39,667.24	$39,667.24
Keesler	RDFIRST	03	2023	ROADWAY	P	C	Major Below Critical	Contract	AC	1	47.44	100.00	$0.00	$0.00	$0.00	$62,236.49	$62,236.49
Keesler	RDFISHER	01	2023	ROADWAY	P	A	Preventive	In-House	AC	1	95.04	95.33	$0.00	$144.90	$0.00	$0.00	$144.90
Keesler	RDFISHER	02	2023	ROADWAY	P	A	Preventive	In-House	AC	1	95.54	95.83	$0.00	$168.42	$0.00	$0.00	$168.42
Keesler	RDFISHER	03	2023	ROADWAY	P	A	Major Below Critical	Contract	AC	1	49.44	100.00	$0.00	$0.00	$0.00	$71,448.66	$71,448.66
Keesler	RDGENCHAPP	01	2023	ROADWAY	P	A	Preventive + Global MR	IDIQ	AC	1	78.84	82.92	$0.00	$722.39	$5,286.04	$0.00	$6,008.43
Keesler	RDGENCHAPP	02	2023	ROADWAY	P	C	Major Below Critical	Contract	AC	1	58.74	100.00	$0.00	$0.00	$0.00	$74,172.69	$74,172.69
Keesler	RDGENCHAPP	03	2023	ROADWAY	P	C	Major Below Critical	Contract	AC	1	52.94	100.00	$0.00	$0.00	$0.00	$96,747.59	$96,747.59
Keesler	RDHANGAR	01	2023	ROADWAY	P	C	Major Below Critical	Contract	AC	1	40.24	100.00	$0.00	$0.00	$0.00	$606,313.00	$606,313.00
Keesler	RDHSTREET	01	2023	ROADWAY	P	C	Major Below Critical	Contract	AC	1	59.74	100.00	$0.00	$0.00	$0.00	$24,277.94	$24,277.94
Keesler	RDHSTREET	02	2023	ROADWAY	P	C	Major Below Critical	Contract	AC	1	64.24	100.00	$0.00	$0.00	$0.00	$27,682.46	$27,682.46
Keesler	RDHSTREET	03	2023	ROADWAY	P	E	Major Below Critical	Contract	AC	1	38.14	100.00	$0.00	$0.00	$0.00	$105,875.24	$105,875.24
Keesler	RDHSTREET	04	2023	ROADWAY	P	E	Major Below Critical	Contract	AC	1	39.54	100.00	$0.00	$0.00	$0.00	$110,359.76	$110,359.76
Keesler	RDHSTREET	05	2023	ROADWAY	P	C	Major Below Critical	Contract	AC	1	45.04	100.00	$0.00	$0.00	$0.00	$60,890.96	$60,890.96
Keesler	RDHSTREET	06	2023	ROADWAY	P	A	Preventive + Global MR	IDIQ	AC	1	80.34	84.42	$0.00	$769.96	$7,663.26	$0.00	$8,433.22
Keesler	RDJSTREET	01	2023	ROADWAY	P	E	Major Below Critical	Contract	AC	1	34.84	100.00	$0.00	$0.00	$0.00	$29,773.20	$29,773.20
Keesler	RDJSTREET	02	2023	ROADWAY	P	A	Preventive	In-House	PCC	1	81.63	81.80	$0.00	$1,094.44	$0.00	$0.00	$1,094.44
Keesler	RDJSTREET	03	2023	ROADWAY	P	A	Preventive	In-House	AC	1	91.34	91.63	$0.00	$523.98	$0.00	$0.00	$523.98
Keesler	RDJSTREET	04	2023	ROADWAY	P	A	Preventive	In-House	AC	1	90.64	90.93	$0.00	$18.30	$0.00	$0.00	$18.30
Keesler	RDLARCHER	01	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.44	92.73	$0.00	$318.33	$0.00	$0.00	$318.33
Keesler	RDLARCHER	02	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.44	92.73	$0.00	$325.30	$0.00	$0.00	$325.30
Keesler	RDLARCHER	03	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.54	92.83	$0.00	$347.56	$0.00	$0.00	$347.56
Keesler	RDLARCHER	04	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.54	92.83	$0.00	$261.23	$0.00	$0.00	$261.23
Keesler	RDLARCHER	05	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.54	92.83	$0.00	$333.14	$0.00	$0.00	$333.14
Keesler	RDLARCHER	06	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.64	92.93	$0.00	$244.64	$0.00	$0.00	$244.64

8-7.2 Grouping Work Requirements.

The best practice for grouping requirements into executable tasks and projects is to combine requirements within each risk - return category as shown in Figure 8-3 and defined in Table 8-3. Start by aggregating work requirements executed by in-house work forces, then proceed to aggregating localized, global, and Major M&R

requirements that will be performed by contract. Each of these steps are discussed in more detail below and in paragraph A-9.2 provides examples of this process.

8-7.2.1 Identify In-House Work Requirements.

Determine requirements that can reasonably be performed in-house from a manpower and capability perspective in each year of the PMP. These are typically localized operational or preventive repairs, so consider maximizing use of in-house work forces for repairs in risk - return categories A and B. Ensure the in-house work force has the capability to perform all of the repairs on a given section. Avoid situations where part of the work on a section is done in-house and the rest by IDIQ task order or another contract. For example, do not include any sections that call for a combination of localized and global if the in-house work force does not have the capability to do global. Best practice is to create a prioritized in-house requirements task list for each year in the PMP by extracting the requirements from the prioritized requirements list for execution by the in-house work force as shown in Figure 8-6 and described in paragraphs A-9.5 and A-9.6.

Figure 8-6 In-House Work List

Network ID	Branch ID	Section ID	Work Year	Branch Use	Section Rank	Risk - Return Category	Work Type	Method of Execution	Surface Type - Current	M&R Priority	Avg Condition Before	Avg Condition After	Stop Gap Funded	Preventive Funded	Global Funded	Major Under Critical Funded	Total
Keesler	RDASTREET	01	2023	ROADWAY	S	C	Stopgap	In-House	AC	3	41.49	41.49	$4,347.32	$0.00	$0.00	$0.00	$4,347.32
Keesler	RDGALAXY	01	2023	ROADWAY	S	E	Stopgap	In-House	AC	3	12.49	12.49	$12,528.14	$0.00	$0.00	$0.00	$12,528.14
Keesler	RDUNKNOWN3	01	2023	ROADWAY	S	E	Stopgap	In-House	AC	3	27.49	27.49	$4,275.51	$0.00	$0.00	$0.00	$4,275.51
Keesler	RDFISHER	01	2023	ROADWAY	P	A	Preventive	In-House	AC	1	95.04	95.33	$0.00	$144.90	$0.00	$0.00	$144.90
Keesler	RDFISHER	02	2023	ROADWAY	P	A	Preventive	In-House	AC	1	95.54	95.83	$0.00	$168.42	$0.00	$0.00	$168.42
Keesler	RDLARCHER	01	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.44	92.73	$0.00	$318.33	$0.00	$0.00	$318.33
Keesler	RDLARCHER	02	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.44	92.73	$0.00	$325.30	$0.00	$0.00	$325.30
Keesler	RDLARCHER	03	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.54	92.83	$0.00	$347.56	$0.00	$0.00	$347.56
Keesler	RDLARCHER	04	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.54	92.83	$0.00	$261.23	$0.00	$0.00	$261.23
Keesler	RDLARCHER	05	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.54	92.83	$0.00	$333.14	$0.00	$0.00	$333.14
Keesler	RDLARCHER	06	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.64	92.93	$0.00	$244.64	$0.00	$0.00	$244.64
Keesler	RDLARCHER	07	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.24	92.53	$0.00	$71.99	$0.00	$0.00	$71.99
Keesler	RDLARCHER	08	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.44	92.73	$0.00	$277.92	$0.00	$0.00	$277.92
Keesler	RDLARCHER	09	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.44	92.73	$0.00	$284.11	$0.00	$0.00	$284.11
Keesler	RD5022	01	2023	ROADWAY	S	C	Preventive	In-House	PCC	3	68.52	68.64	$0.00	$961.09	$0.00	$0.00	$961.09
Keesler	RDBAUGHMAN	01	2023	ROADWAY	S	C	Preventive	In-House	AC	3	59.59	59.76	$0.00	$2,663.40	$0.00	$0.00	$2,663.40
Keesler	RDBAUGHMAN	02	2023	ROADWAY	S	A	Preventive	In-House	AC	3	92.89	93.06	$0.00	$44.83	$0.00	$0.00	$44.83
Keesler	RDPARADELN	01	2023	ROADWAY	S	A	Preventive	In-House	AC	3	92.89	93.06	$0.00	$354.95	$0.00	$0.00	$354.95
Keesler	RDTINGLE	01	2023	ROADWAY	S	A	Preventive	In-House	AC	3	92.79	92.96	$0.00	$139.34	$0.00	$0.00	$139.34
Keesler	RDTSTREET	01	2023	ROADWAY	S	C	Preventive	In-House	AC	3	55.89	56.05	$0.00	$12,432.39	$0.00	$0.00	$12,432.39
Keesler	PA00237	01	2023	PARKING	P	B	Preventive	In-House	AC	4	91.01	91.22	$0.00	$23.74	$0.00	$0.00	$23.74
Keesler	PA00237	02	2023	PARKING	P	B	Preventive	In-House	AC	4	90.11	90.32	$0.00	$62.09	$0.00	$0.00	$62.09

8-7.2.2 Combine Major M&R Requirements.

Major M&R requirements fall into all risk - return categories other than A, B, and D, with categories C, F, and G having the highest return on investment. Combine Major M&R requirements in these respective categories for each section in each year to determine opportunities to combine them for execution. Some examples are provided below.

- Mill and overlay requirements for various sections of a parking area are triggered when these sections drop below the critical PCI in different years, as shown in Figure 8-7. Aggregating these requirements into a single project provides economy of scale and avoids multiple road closures.
- Localized and global M&R are not performed on sections scheduled for Major M&R, but including sections in the same vicinity that require

localized or global M&R in a Major M&R project can provide both operational and cost benefits.

Figure 8-7 Combining Major M&R Requirements Example

Network ID	Branch ID	Section ID	Work Year	Branch Use	Section Rank	Risk - Return Category	Work Type	Method of Execution	Surface Type - Current	M&R Priority	Avg Condition Before	Avg Condition After	Stop Gap Funded	Preventive Funded	Global Funded	Major Under Critical Funded	Total
Keesler	PA00308	01	2023	PARKING	S	I	Stopgap	In-House	AC	7	31.90	31.90	$2,961.33	$0.00	$0.00	$0.00	$2,961.33
Keesler	PA00308	01	2024	PARKING	S	I	Stopgap	In-House	AC	7	30.06	30.06	$3,172.41	$0.00	$0.00	$0.00	$3,172.41
Keesler	PA00308	01	2025	PARKING	S	I	Stopgap	In-House	AC	7	28.22	28.22	$3,571.62	$0.00	$0.00	$0.00	$3,571.62
Keesler	PA00308	01	2026	PARKING	S	I	Major Below Critical	Contract	AC	7	26.38	100.00	$0.00	$0.00	$0.00	$49,565.80	$49,565.80
Keesler	PA00308	01	2027	PARKING	S	D	Preventive	In-House	AC	7	98.16	98.36	$0.00	$16.55	$0.00	$0.00	$16.55
Keesler	PA00308	03	2023	PARKING	S	G	Stopgap	In-House	AC	7	49.20	49.20	$1,903.17	$0.00	$0.00	$0.00	$1,903.17
Keesler	PA00308	03	2024	PARKING	S	G	Stopgap	In-House	AC	7	47.36	47.36	$2,024.12	$0.00	$0.00	$0.00	$2,024.12
Keesler	PA00308	03	2025	PARKING	S	G	Major Below Critical	Contract	AC	7	45.52	100.00	$0.00	$0.00	$0.00	$36,715.34	$36,715.34
Keesler	PA00308	03	2026	PARKING	S	D	Preventive	In-House	AC	7	98.16	98.36	$0.00	$20.43	$0.00	$0.00	$20.43
Keesler	PA00308	03	2027	PARKING	S	D	Preventive	In-House	AC	7	96.53	96.73	$0.00	$38.63	$0.00	$0.00	$38.63
Keesler	PA00308	05	2023	PARKING	S	G	Stopgap	In-House	AC	7	53.80	53.80	$1,634.78	$0.00	$0.00	$0.00	$1,634.78
Keesler	PA00308	05	2024	PARKING	S	G	Major Below Critical	Contract	AC	7	51.96	100.00	$0.00	$0.00	$0.00	$17,225.61	$17,225.61
Keesler	PA00308	05	2025	PARKING	S	D	Preventive	In-House	AC	7	98.16	98.36	$0.00	$20.86	$0.00	$0.00	$20.86
Keesler	PA00308	05	2026	PARKING	S	D	Preventive	In-House	AC	7	96.52	96.72	$0.00	$39.55	$0.00	$0.00	$39.55
Keesler	PA00308	05	2027	PARKING	S	D	Preventive	In-House	AC	7	94.88	95.08	$0.00	$58.14	$0.00	$0.00	$58.14
Keesler	PA00308	06	2023	PARKING	S	G	Preventive + Global MR	In-House	AC	7	69.40	73.28	$0.00	$1,339.40	$2,519.62	$0.00	$3,859.02
Keesler	PA00308	06	2024	PARKING	S	D	Preventive	In-House	AC	7	71.44	71.64	$0.00	$898.63	$0.00	$0.00	$898.63
Keesler	PA00308	06	2025	PARKING	S	G	Preventive	In-House	AC	7	69.80	70.00	$0.00	$1,117.49	$0.00	$0.00	$1,117.49
Keesler	PA00308	06	2026	PARKING	S	G	Preventive	In-House	AC	7	68.16	68.36	$0.00	$2,027.35	$0.00	$0.00	$2,027.35
Keesler	PA00308	06	2027	PARKING	S	G	Preventive	In-House	AC	7	66.52	66.72	$0.00	$2,937.10	$0.00	$0.00	$2,937.10
Keesler	PA00308	07	2023	PARKING	S	G	Stopgap	In-House	AC	7	50.10	50.10	$1,310.88	$0.00	$0.00	$0.00	$1,310.88
Keesler	PA00308	07	2024	PARKING	S	G	Major Below Critical	Contract	AC	7	48.26	100.00	$0.00	$0.00	$0.00	$17,470.96	$17,470.96
Keesler	PA00308	07	2025	PARKING	S	D	Preventive	In-House	AC	7	98.16	98.36	$0.00	$14.52	$0.00	$0.00	$14.52
Keesler	PA00308	07	2026	PARKING	S	D	Preventive	In-House	AC	7	96.52	96.72	$0.00	$27.53	$0.00	$0.00	$27.53
Keesler	PA00308	07	2027	PARKING	S	D	Preventive	In-House	AC	7	94.88	95.08	$0.00	$40.47	$0.00	$0.00	$40.47
Keesler	PA00308	08	2023	PARKING	S	G	Preventive	In-House	AC	7	55.10	55.30	$0.00	$6,482.38	$0.00	$0.00	$6,482.38
Keesler	PA00308	08	2024	PARKING	S	G	Major Below Critical	Contract	AC	7	53.46	100.00	$0.00	$0.00	$0.00	$12,192.43	$12,192.43
Keesler	PA00308	08	2025	PARKING	S	D	Preventive	In-House	AC	7	98.16	98.36	$0.00	$14.77	$0.00	$0.00	$14.77
Keesler	PA00308	08	2026	PARKING	S	D	Preventive	In-House	AC	7	96.52	96.72	$0.00	$28.00	$0.00	$0.00	$28.00
Keesler	PA00308	08	2027	PARKING	S	D	Preventive	In-House	AC	7	94.88	95.08	$0.00	$41.15	$0.00	$0.00	$41.15
Keesler	PA00308	09	2023	PARKING	S	G	Stopgap	In-House	AC	7	51.90	51.90	$1,468.86	$0.00	$0.00	$0.00	$1,468.86
Keesler	PA00308	09	2024	PARKING	S	G	Major Below Critical	Contract	AC	7	50.06	100.00	$0.00	$0.00	$0.00	$14,357.25	$14,357.25
Keesler	PA00308	09	2025	PARKING	S	D	Preventive	In-House	AC	7	98.16	98.36	$0.00	$17.39	$0.00	$0.00	$17.39
Keesler	PA00308	09	2026	PARKING	S	D	Preventive	In-House	AC	7	96.52	96.72	$0.00	$32.97	$0.00	$0.00	$32.97

8-7.2.3 Combine Localized and Global M&R Requirements.

Localized and global work requirements are often executed via IDIQ or included in a competitive bid contract with Major M&R. Combine requirements within each of these respective categories for each year in the PMP. Consider the following when combining localized and global M&R requirements.

- Consider using IDIQ contract vehicles for operational repairs when in-house work forces are unavailable or do not have the capability.
- Avoid combining work requirements in widely varying risk - return categories.
- Avoid situations where part of the work on a section is done by one execution method and the remainder by another.
- Identify sections with the same M&R requirements within a given risk - return category that can be combined into a project. For example, combine requirements for several aprons that all require joint seal replacement.

8-7.2.4 Input Required Projects in PAVER.

Leverage PAVER capabilities by creating required projects in PAVER using the **Required Work** tool or the **Project Formulation Wizard** for the projects identified in the previous paragraphs. Once entered into PAVER, re-run the Critical PCI Work Plan with the required projects. PAVER will attempt to develop a balanced budget around these required projects for each year in the work plan. Use an iterative approach for a large network. Combine the highest priority requirements into required projects, then rerun the work plan and combine the lower priority requirements. Paragraph A-9 provides examples of creating required projects in PAVER and re-running the work plans.

8-7.3 Defining Work Types and Estimated Quantities.

Recall that an optimal critical PCI work plan defines a general M&R category, e.g., Major Localized Preventive, but does define specific repair requirements. Use the Applied Policy Details view of the PAVER Consequence of Localized Distress Maintenance work plan to identify specific work types for each section in each year in the PMP. The Consequence of Localized Distress Maintenance work plan outlines all localized M&R requirements and includes the extrapolated distress quantities, the policy (operational or preventive), and estimated cost based on the cost by work type tables defined in the M&R Family models.

Note: This report is based on the distress data from the most recent PCI inspection, so it provides a reasonable estimate of distress types, severities, and quantities at the time of the last inspection. The severity and quantity estimates lose fidelity as time passes, but this report still provides a good indication of the distress types and required work types for each section. An example of a using the Consequence of Localized Distress Maintenance work plan to define work types and estimated quantities in the prioritized requirements list is provided in paragraphs A-9.6 and A-9.7.

8-8 VALIDATE REQUIREMENTS, QUANTITIES, AND COSTS.

A PCI inspection uses a statistical approach to determine the pavement condition, as described in UFC 3-260-16 and paragraph 4-2 of this UFC. The types, severities, and quantities of distresses are measured for a sufficient subset of the total samples in a section to attain the desired confidence level. PAVER extrapolates the quantities for each type and severity of distress for the entire section based on the samples inspected. These extrapolated distresses are good estimates but need to be validated for projects for several reasons.

8-8.1 Validating Rigid Pavement Repair Requirements.

Rigid pavement distresses are counted at the slab level per the PCI inspection rules outlined in UFC 3-260-16. This means that a slab may have multiple distresses of the same type but only one instance of a distress is recorded at the highest severity level. This can lead to underestimating quantities in certain circumstances.

8-8.2 Validating Extrapolated Distress Quantities.

While we can predict pavement condition in future years and the extrapolated distresses provide a reasonable estimate of quantities at the time of the inspection, there is no way to accurately predict quantities for specific distress types and severities in future years.

8-8.3 Validation Procedure.

At a minimum, perform a visual inspection to validate the distress types, severities and quantities identified in the last PCI inspection. Use this data to update the in-house work tasks and projects. Verify that the distress types present during the visual inspection are the same identified in the previous inspection. Look for distress types that were not recorded in the previous inspection and determine if there has been a significant increase in the severity or quantity of distresses. The PAVER Inspection Report generated with the Inspection Report/Forms/Setup wizard described in paragraph 4-2.1 is a useful tool for project validation. Run the report for the sections of interest as a reference when performing the validation. Other considerations include the following.

- Determine if the repair recommended in the distress maintenance policy is appropriate or if there are other underlying issues that call for a different work type to address the issue. Update the PMP to reflect the appropriate work type.
- Recall that critical PCI work plan cost estimates are based on cost by condition tables and the consequence of localized distress maintenance work plan costs are based on cost by work type tables. These approaches typically provide estimates that vary and that should be validated based on current costs and quantities. Update the PMP to reflect the current costs and quantities.
- Marking distresses to be repaired while doing the validation is a good approach when work is performed by in-house work forces or pavement IDIQ.
- A good practice when validating quantities for a localized M&R project is to generate a map that shows the distress locations (commonly known as a crack map).

8-8.4 Review, Approve, and Publish PMP.

Provide an opportunity for the PMP development team to perform a final review, resolve any comments or issues, then submit the plan to leadership for approval. The approval level is dictated by the Service. Update the approved PMP as the work tasks and projects are executed. Revise work plans and update the PMP on at least an annual basis. A best practice is to update the PAVER work history to document projects as they are completed and then updating work plans.

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APPENDIX A BEST PRACTICES

The Best Practices Appendix is considered to be guidance and not requirements. Its main purpose is to communicate proven facility solutions, systems, and lessons learned, but may not be the only solution to meet the requirement.

A-1 DESCRIPTIVE AND USER-DEFINED FIELDS.

This section discusses the use of descriptive and user-defined fields at the network, branch, and section levels.

A-1.1 Network-level Fields.

The Network-level user-defined fields listed below allow users to define the networks to include or exclude from M&R work plans or other analyses and reports. The Service POCs identified in paragraph 2-9.3 responsible for the pavement management program must create these fields. When the fields are created, PAVER gives them a unique ID. Export this database for use as a template. When this database is combined with an installation database, the fields are available with original unique ID.

This is a one-time process. Once the fields are included in each database, they are only updated if something changes, e.g., an installation's assigned command changes. These fields are useful for individual databases and are essential for filtering data in a Service combined (rollup) database.

- Major Command (List of Commands as appropriate for Service)
- Privatized (Yes or No)
- Housing (Yes or No)

A-1.2 Branch-level Fields.

The Branch Use or Category Code (a descriptive field) fields cover the requirements, so no additional user-defined fields are recommended.

A-1.3 Section-level Fields.

A user-defined Status field at the section level, with values including those listed below, provides fidelity on the reason a section was or was not inspected and is used to filter out sections that should not be included in M&R work plans or other analyses. This user-defined field is imported into the database from a template created by the Service POC as described in paragraph 2-9.3. Alternatively, a Service could use the Section Category descriptive field for the same purpose. In either case, the Service defines a standard set of fields used in all databases.

- Inspected
- Maintained by Others
- Abandoned

- No Access
- Out of Scope
- Under Construction

A-2 COST BY WORK TYPE TABLES.

The following tables define the work elements used to develop standard costs for each PAVER standard work type used by DoD to develop airfield and road and parking M&R work plans and PMPs. These are fully burdened unit costs, including mobilization, overhead, materials, disposal, and labor costs, as well as any appropriate O&M escalation factors. They are based on RS Means or the Tri-Service Automated Cost Engineering System (TRACES) applications such as the Parametric Cost Engineering System (PACES) or the Micro-Computer Aided Cost Estimating System Second Generation (MII) using the current TRACES Cost Book/Unit Price Book (UPB). Each is based on the work element assumptions for each standard work type described below. Modify the values in these cost by work type tables using the area cost factor for the specific location.

If specific, well-documented local costs data exist or existing conditions differ from the assumptions used in Tables A-1, A-2, and A-3, adjust the unit costs but fully document all work element assumptions for the change in the pavement evaluation report and the PMP.

Table A-1 Localized M&R Cost by Work Type

Code	Name	Work Unit	Unit Cost ($)	Work Type Elements
BS-SE	Break and Seat	SqFt		Crack (plain PCC) or break (reinforced PCC) slabs, seat slabs with a pneumatic roller, Overlay pavement with HMA. Overlay thickness must meet minimum thickness requirements in UFC 3-260-02, but will not be less than 4 inches, which is the assumed thickness for this line item.
CM-LO	Cold Milling-Localized	SqFt		Mill (aka cold plane) asphalt pavement just enough thickness to level and smooth the surface. This line item assumes less than or equal to 2 inches of pavement are milled and that the material is stockpiled on installation for re-use so no disposal costs are incurred.
CS-AC	Crack Sealing - AC	Ft		Remove old sealant (if any), saw/route cracks, clean crack reservoir, install backer rod to control depth of sealant, and seal using an approved hot-applied sealant.
CS-PC	Crack Sealing - PCC	Ft		Remove old sealant (if any), saw/route cracks, clean crack reservoir, install backer rod to control depth of sealant, and seal using an approved silicone sealant.
GR-AC	Grinding - AC (Localized)	Ft		This line item assumes diamond grinding for localized repair using walk-behind diamond grinding equipment.
GR-PC	Grinding – PCC (Localized)	Ft		This line item assumes diamond grinding for localized repair using walk-behind diamond grinding equipment.

Code	Name	Work Unit	Unit Cost ($)	Work Type Elements
JS-LC	Joint Seal (Localized)	Ft		Joint seal replacement is typically done on entire sections (global) but may be done for localized areas. This line item includes routing the reservoir to achieve the correct shape factor, cleaning the reservoir, placing backer rod, and placing new silicone joint seal.
NONE	No Localized M & R	SqFt	0.00	No work performed
PA-AD	Patching - AC Deep	SqFt		Remove existing pavement (5 inches assumed) and base (18 inches assumed). Compact the subgrade, replace, and compact the base in lifts, apply prime coat, replace, and compact HMA with tack coat between lifts.
PA-AL	Patching - AC Leveling	SqFt		Remove loose material from rut or depression to be repaired, seal cracks, apply micro-surfacing in 1/4-inch lifts (curing between lifts), roll, and cure the micro-surfacing.
PA-AS	Patching - AC Shallow	SqFt		Remove existing pavement (5 inches assumed), recompact the base, apply prime coat, replace and compact HMA with tack coat between lifts.
PA-IR	Patching- Infrared	SqFt		Using an infrared heater for the asphalt repair, heat the asphalt to a working temperature of 300 °F, penetrating the asphalt to a depth of 3 to 4 inches. Remove deteriorated asphalt and rake in new HMA then compact the area with a vibratory roller.
PA-PF	Patching - PCC Full Depth	SqFt		Sawcut pavement to full depth (12-inch plain PCC assumed), remove the concrete, scarify and recompact the base or subgrade below the slab, place dowels at joints to adjacent slabs to match existing dowel layout (20-foot slabs with 15" spacing of 20" 1.25" dowels assumed). Place tie-bars to remainder of existing slab then place new concrete. Maintain all joints to adjacent slabs.
PA-PP	Patching - PCC Partial Depth	SqFt		Sawcut and remove partial depth of concrete (4 inches assumed), clean the repair area, and place new concrete. This line item assumes use of a rapid-setting concrete such as those found on the Tri-Service website below. Note that maintaining the joint is critical on any repair adjacent to a joint. https://transportation.erdc.dren.mil/cacsites/TriService/pavement_repair.aspx
PA-PL	Patching – PCC Partial Depth POL Damage Repair	SqFt		Sawcut and remove partial depth of concrete (4 inches assumed), clean the repair area, and place new magnesium phosphate cement. Once the repair is in place, seal the pavement using a sodium silicate surface treatment.
SH-LE	Shoulder leveling	Ft		Remove loose materials along the length of the shoulder, place, grade, and compact aggregate to eliminate shoulder drop-off while maintaining the slope of the unpaved shoulder away from the road. This item assumes a 10-foot-wide shoulder with an average thickness of 4 inches of aggregate required for the repair.
SL-PC	Slab Replacement - PCC	SqFt		Make multiple sawcuts for the full depth of the existing slab (12 inches of plain PCC assumed) and remove the concrete. Scarify and recompact the base or subgrade below the slab, place dowels according to UFC 3-270-01 requirements, then place new concrete and seal the joints.

Code	Name	Work Unit	Unit Cost ($)	Work Type Elements
ST-AL	Surface Treatment – AC (Localized)	SqFt		This line item assumes a slurry seal is applied to a localized area (e.g., a portion of a section like a parking area). Use the global work line item when the entire section(s) (e.g., a whole parking area of multiple parking areas) receives the surface treatment. Adjust the cost when a lower cost (e.g., fog seal or rejuvenator) or higher cost (e.g., cape seal or microsurface) surface treatment is used.
ST-PL	Surface Treatment – PCC (Localized)	SqFt		This line item assumes a localized area (e.g., one or more aircraft parking spots on an apron) are cleaned and sodium silicate is applied to prevent deterioration from heat and petroleum products. Use the global work line item when the entire section(s) (e.g., a whole apron) receives the surface treatment.
SS-SG	Spread Sand or Gravel	SqFt		Place hot sand with a spreader to blot up the excess binder on the surface, roll the sand with a pneumatic roller, then remove the excess sand with a vacuum sweeper.
UN-PC	Undersealing - PCC	SqFt		This line item assumes that a high-density polyurethane polymer material is used to underseal and restore support to the pavement slab. Drill holes in the area with voids, inject grout to fill the void, plug the drill holes, and grind surface to restore the profile of the affected joint(s) or crack(s).
SJ-PC	Slab Jacking - PCC	SqFt		This line item assumes that a high-density polyurethane polymer material is used to raise a slab or multiple slabs. Drill holes in the area(s) of the slab(s), inject grout to raise the slab(s) to the desired elevation, plug the drill holes, and grind surface to restore the profile of affected joint(s) or crack(s)
LT-PC	Load Transfer Restoration – PCC (Localized)	Ft		Sawcut and chip existing concrete at joints to mid-depth (12-inch plain PCC assumed) to create slots, place the dowel bars (20-foot slabs with 15" spacing of 20" 1.25" dowels assumed) into the slots, ensuring they are properly aligned. Place repair material into the slots (assumes use of a rapid-setting concrete such as those found on the Tri-Service Website below). Restore the joint at the slot locations, seal the joints, and grind any joint discontinuity. https://transportation.erdc.dren.mil/cacsites/TriService/pavement_repair.aspx
ED-RF	Retrofitted Edge Drain	Ft		Remove existing edge drains, trench (assume a 4-foot depth), place filter fabric, place new edge drain (6-inch flexible, corrugated polyethylene [CPE] pipe assumed), and backfill using procedures in UFC 3-270-01, Chapter 19.
HR-PD	Partial Depth Heat Resistant PCC Repair	SqFt		Sawcut and remove damaged concrete (4-inch depth assumed), clean the repair area, place new heat-resistant concrete, and re-seal the surface with sodium silicate. Note that maintaining the joint is critical on any repair adjacent to a joint.
HR-FD	Full Depth Heat Resistant PCC Repair	SqFt		Sawcut pavement to full depth (12-inch plain PCC assumed), remove the concrete, scarify and recompact the base or subgrade below the slab, place dowels at joints to adjacent slabs to match existing dowel layout (20-foot slabs with 15" spacing of 20" 1.25" dowels assumed). Place tie-bars to remainder of existing slab, then place new heat-resistant concrete and re-seal the surface with sodium silicate. Note that maintaining the joint is critical on any repair adjacent to a joint.

Code	Name	Work Unit	Unit Cost ($)	Work Type Elements
HR-CR	Partial Depth Continuously Reinforced Heat Resistant PCC Repair	SqFt		Sawcut and remove damaged concrete (6-inch depth assumed) and reinforcement, clean the repair area, replace the reinforcement and tie bars, then place new heat-resistant concrete and re-seal the surface with sodium silicate. Note that maintaining the joint is critical on any repair adjacent to a joint.

Table A-2 Global M&R Cost by Work Type

Code	Name	Work Unit	Unit Cost ($)	Work Type Elements
NONE	No Global M & R	SqFt	0.00	No work elements
GL-AT	Overlay - AC Thin (Global)	SqFt		Remove all loose material, place tack coat, and place HMA overlay. This line item assumes a 2-inch overlay with asphalt provided by a local central mixing plant. Compact pavement to specified density. All structural distresses and crack repairs are covered by separate localized repair line items. This line item does not include pavement markings.
GL-FR	Overlay - Fuel-Resistant AC (Global)	SqFt		Remove all loose material, place tack coat, place fuel-resistant HMA overlay. This line item assumes a 2-inch overlay with asphalt provided by a local central mixing plant. Compact pavement to specified density. All structural distresses and crack repairs are covered by separate localized repair line items. This line item does not include pavement markings.
JS-CP	Joint Seal – Compression	Ft		Remove old joint seal material, route the joint reservoir to achieve the correct shape factor, clean the reservoir, and place new compression joint seal.
JS-HP	Joint Seal – Hot Pour	Ft		Remove old joint seal material, route the joint reservoir to achieve the correct shape factor, clean the reservoir, and place new hot-pour joint seal.
JS-SI	Joint Seal - Silicon	Ft		Remove old joint seal material, route the joint reservoir to achieve the correct shape factor, clean the reservoir, and place new silicone joint seal.
SS-CT	Surface Seal - Coal Tar	SqFt		Remove all loose material on surface, mix the fuel-resistant sealer in batches, and place by pouring on pavement and using squeegees to spread the material. This line item assumes two layers are applied to the HMA. All structural distresses and crack repairs are covered by separate localized repair line items. This line item does not include pavement markings.

Code	Name	Work Unit	Unit Cost ($)	Work Type Elements
SS-FS	Surface Seal - Fog Seal	SqFt		Remove all loose material on surface and place fog seal using a distributor calibrated to deliver the fog seal at the specified rate. This line item assumes application dilution is 1 part emulsion to 1 part water with a 0.05 gallon per square yard application rate. All structural distresses and crack repairs are covered by separate localized repair line items. This line item does not include pavement markings.
SS-RE	Surface Seal - Rejuvenating	SqFt		Remove all loose material on surface and place rejuvenator using a distributor calibrated to deliver the material at the specified rate. This line item assumes a 0.1 gallon per square yard application rate. All structural distresses and crack repairs are covered by separate localized repair line items. This line item does not include pavement markings.
ST-CS	Surface Treatment - Cape Seal	SqFt		Remove all loose material on surface and place binder using a distributor calibrated to deliver the material at the specified rate. Apply the aggregate immediately after the binder and roll with a rubber-tired roller immediately after applying the aggregate to seat the aggregate in the binder. This line item assumes application of a slurry seal over the bituminous surface treatment using a truck-mounted continuous-mix slurry machine. Once the slurry seal is cured, roll with a pneumatic-tired roller. All structural distresses and crack repairs are covered by separate localized repair line items. This line item does not include pavement markings.
ST-MS	Surface Treatment - Micro Surface	SqFt		Remove all loose material on surface, apply tack coat, wet the pavement surface with water fogging, and place the micro-surface using a self-propelled mixing and placement vehicle. All structural distresses and crack repairs are covered by separate localized repair line items. This line item does not include pavement markings.
ST-SB	Surface Treatment - Single Bituminous	SqFt		Remove all loose material on surface and place binder using a distributor calibrated to deliver the material at the specified rate. Apply the aggregate immediately after the binder and roll with a rubber-tired roller immediately after applying the aggregate to seat the aggregate in the binder. All structural distresses and crack repairs are covered by separate localized repair line items. This line item does not include pavement markings.

Code	Name	Work Unit	Unit Cost ($)	Work Type Elements
ST-DB	Surface Treatment - Double Bituminous			Remove all loose material on surface and place binder using a distributor calibrated to deliver the material at the specified rate. Apply the aggregate immediately after the binder and roll with a rubber-tired roller immediately after applying the aggregate to seat the aggregate in the binder. Repeat the process, applying another layer of binder and aggregate, then roll with a rubber-tired roller immediately after applying the second layer of aggregate. All structural distresses and crack repairs are covered by separate localized repair line items. This line item does not include pavement markings.
ST-SS	Surface Treatment - Slurry Seal	SqFt		Remove all loose material on surface, apply tack coat, place the slurry seal using a truck-mounted continuous-mix slurry machine, and roll with a rubber-tired roller once the slurry seal has cured. All structural distresses and crack repairs are covered by separate localized repair line items. This line item does not include pavement markings.
ST-ST	Surface Treatment - Sand Tar (Seal)	SqFt		Remove all loose material on surface and apply asphalt emulsion. (When used to address bleeding, do not apply asphalt binder before the sand seal is placed since the primary purpose is to blot up the excess binder on the surface.) Apply hot sand, roll the sand with a pneumatic-tire roller, and remove excess sand using a vacuum sweeper once the surface treatment is cooled. All structural distresses and crack repairs are covered by separate localized repair line items. This line item does not include pavement markings.

Table A-3 Major M&R Cost by Work Type

Code	Name	Work Unit	Unit Cost ($)	Work Type Elements
AR-CO	AC Surface Recycling - Cold	SqFt		Mill the existing asphalt, haul to crusher, and crush to specified particle size. Mix with virgin material and reuse material to pave secondary roads or parking areas (if a seal coat is applied) or as a base course. This work type assumes that both the existing and new pavement thickness is 3 inches and 4 inches when used as a base.
AR-HO	AC Surface Recycling - Hot	SqFt		Mill the existing HMA, haul millings to plant, crush millings, and mix millings in a hot-mix plant with new aggregate, asphalt, and recycling agent. Transport recycled asphalt to site, place and compact HMA, and place pavement markings. This line item assumes both the existing and new pavement thickness is 3 inches for roads or parking areas and 5 inches for an airfield. Adjust cost if in-place recycling is used but assume same thicknesses unless there is specific information regarding thickness.
BR-SE	Break & Seat & Overlay	SqFt		Minimize the size of the concrete slabs using a breaking or cracking procedure. Seat the broken concrete pieces with a heavily weighted rubber-tire roller. Overlay the pavement with HMA and place pavement markings. This work type assumes the existing plain concrete pavement is 6 inches for roads and parking and 12 inches for airfields and that the AC overlay is 3 inches for roads and parking and 5 inches for an airfield.
BR-RB	Rubblization & Overlay	SqFt		Install underdrain to relieve pressure during the rubblization process: trench (assume a 4-foot depth), place filter fabric, place new edge drain (6-inch flexible, CPE pipe assumed), and backfill using procedures in UFC 3-270-01, Chapter 19. Rubblize pavement using a multiple-head breaker or resonant pavement breaker, seat the broken pieces with a pneumatic roller, overlay the pavement with HMA, and place pavement markings. This work type assumes the geotechnical assessment cost is not included in this line item and that the existing concrete pavement is 6 inches for roads and parking and 12 inches for airfields. It also assumes the AC overlay is 3 inches for roads and parking and 5 inches for an airfield.
CR-AC-4	Complete Reconstruction, 4 inches AC	SqFt		Mill 4 inches of asphalt to base and remove existing 6-inch base to subgrade. Compact subgrade to meet UFC 3-260-02 requirements, place and compact 6 inches of base course, place and compact 4 inches of HMA in 2-inch lifts, and place pavement markings.

Code	Name	Work Unit	Unit Cost ($)	Work Type Elements
CR-AC-6	Complete Reconstruction, 6 inches AC	SqFt		Mill 6 inches of asphalt to base, remove existing 6-inch base to subbase, and remove existing 4-inch subbase to subgrade. Compact subgrade to UFC 3-260-02 requirements, place and compact 4 inches of subbase and 6 inches of base course, place and compact 6 inches of HMA in 2-inch lifts, and place pavement markings.
CR-AC-8	Complete Reconstruction, 8 inches AC	SqFt		Mill 8 inches of asphalt to base, remove existing 8-inch base to subbase, and remove existing 6-inch subbase to subgrade. Compact subgrade to UFC 3-260-02 requirements, place and compact 6 inches of subbase and 8 inches of base course, place and compact 8 inches of HMA in 2-inch lifts, and place pavement markings.
CR-PC-8	Complete Reconstruction, 8 inches PCC	SqFt		Demolish existing 8-inch plain PCC slabs, remove existing 6-inch base to subgrade, and compact top 6 inches of subgrade to UFC 3-260-02 requirements. Place and compact 6 inches of new base course and place new 8-inch plain PCC using slip form paving procedures with dowels at longitudinal joints and sawn transverse joints, apply curing compound, saw transverse joints, place compression joint seals at all joints, and place pavement markings.
CR-PC-12	Complete Reconstruction, 12 inches PCC	SqFt		Demolish existing 12-inch plain PCC slabs, remove existing 8-inch base to subgrade, and compact top 6 inches of subgrade to UFC 3-260-02 requirements. Place and compact 8 inches of new base course and place new 12-inch plain PCC using slip form paving procedures with dowels at longitudinal joints and sawn transverse joints, apply curing compound, saw transverse joints, place compression joint seals at all joints, and place pavement markings.
CR-PC-18	Complete Reconstruction, 18 inches PCC	SqFt		Demolish existing 18-inch plain PCC slabs, remove existing 12-inch base to subgrade, compact top 6 inches of subgrade to UFC 3-260-02 requirements. Place and compact 12 inches of new base course and place new 18-inch plain PCC using slip form paving procedures with dowels at longitudinal joints and sawn transverse joints, apply curing compound, saw transverse joints, place compression joint seals at all joints, and place pavement markings.
CR-PC-24	Complete Reconstruction, 24 inches PCC	SqFt		Demolish existing 24-inch plain PCC slabs, remove existing 16-inch base to subgrade, compact top 6 inches of subgrade to UFC 3-260-02 requirements. Place and compact 16 inches of new base course and place new 24-inch plain PCC using slip form paving procedures with dowels at longitudinal joints and sawn transverse joints, apply curing compound, saw transverse joints, place compression joint seals at all joints, and place pavement markings.
HI-AG	New Construction	SqFt	0.00	No work type elements
MOL	Cold Mill and Overlay	SqFt	0.00	No work type elements

Code	Name	Work Unit	Unit Cost ($)	Work Type Elements
MOL-2	Cold Mill and Overlay - 2 Inches	SqFt		Mill 2 inches of the existing asphalt surface, remove all loose material, place tack coat, place and compact 2 inches of HMA, and place pavement markings. All structural distress and crack repairs are covered by separate localized repair line items.
MOL-3	Cold Mill and Overlay - 3 Inches	SqFt		Mill 3 inches of the existing asphalt surface, remove all loose material, place tack coat, place and compact 3 inches of HMA, and place pavement markings. All structural distress and crack repairs are covered by separate localized repair line items.
MOL-4	Cold Mill and Overlay - 4 Inches	SqFt		Mill 4 inches of the existing asphalt surface, remove all loose material, place tack coat, place and compact 4 inches of HMA in 2-inch lifts, and place pavement markings. All structural distress and crack repairs are covered by separate localized repair line items.
NC-AC-4	New Construction, 4 inches AC	SqFt		Perform site preparation and grading, compact subgrade to UFC 3-260-02 requirements, place and compact 6 inches of base course, place and compact 4 inches of HMA in 2-inch lifts, and place pavement markings.
NC-AC-6	New Construction, 6 inches AC	SqFt		Perform site preparation and grading, compact subgrade to UFC 3-260-02 requirements, place and compact 4 inches of subbase, place and compact 6 inches of base course, place and compact 6 inches of HMA in 2-inch lifts, and place pavement markings.
NC-AC-8	New Construction, 8 inches AC	SqFt		Perform site preparation and grading, compact subgrade to UFC 3-260-02 requirements, place and compact 6 inches of subbase, place and compact 8 inches of base course, place and compact 8 inches of HMA in 2-inch lifts, and place pavement markings.
NC-PC-8	New Construction, 8 inches PCC	SqFt		Perform site preparation and grading, compact top 6 inches of subgrade to UFC 3-260-02 requirements. Place and compact 6 inches of new base course and place new 8-inch plain PCC using slip form paving procedures with dowels at longitudinal joints and sawn transverse joints, apply curing compound, saw transverse joints, place compression joint seals at all joints, and place pavement markings.
NC-PC-12	New Construction, 12 inches PCC	SqFt		Perform site preparation and grading, compact top 6 inches of subgrade to UFC 3-260-02 requirements Place and compact 8 inches of new base course and place new 12-inch plain PCC using slip form paving procedures with dowels at longitudinal joints and sawn transverse joints, apply curing compound, saw transverse joints, place compression joint seals at all joints, and place pavement markings.

Code	Name	Work Unit	Unit Cost ($)	Work Type Elements
NC-PC-18	New Construction, 18 inches PCC	SqFt		Perform site preparation and grading, compact top 6 inches of subgrade to UFC 3-260-02 requirements. Place and compact 12 inches of new base course and place new 18-inch plain PCC using slip form paving procedures with dowels at longitudinal joints and sawn transverse joints, apply curing compound, saw transverse joints, place compression joint seals at all joints, and place pavement markings.
NC-PC-24	New Construction, 24 inches PCC	SqFt		Perform site preparation and grading, compact top 6 inches of subgrade to UFC 3-260-02 requirements. Place and compact 16 inches of new base course and place new 24-inch plain PCC using slip form paving procedures with dowels at longitudinal joints and sawn transverse joints, apply curing compound, saw transverse joints, place compression joint seals at all joints, and place pavement markings.
NONE	No Major M & R	SqFt	0.00	No work type elements
NU-IN	New Construction - Initial	SqFt		No work type elements
NU-US	New Construction - Unsurfaced	SqFt		Perform site preparation and grading, compact subgrade to UFC 3-260-09 requirements, place and compact 6 inches of base course, place and compact 4 inches of aggregate surface layer.
OL-AF	Overlay - AC Fabric	SqFt		Remove all loose material, place tack coat, place geofabric, place and compact 2 inches of HMA, and place pavement markings. All structural distress and crack repairs are covered by separate localized repair line items.
OL-AS	Overlay - AC Structural	SqFt		Remove all loose material, place tack coat, place and compact 4 inches of HMA in 2-inch lifts, and place pavement markings. All structural distress and crack repairs are covered by separate localized repair line items.
OL-AT	Overlay - AC Thin	SqFt		Remove all loose material, place tack coat, place geofabric, place and compact 2 inches of HMA, and place pavement markings. All structural distress and crack repairs are covered by separate localized repair line items.
OL-PF	Overlay - PCC Fully Bonded	SqFt		Cold mill or shotblast the base slab to remove all deteriorated or defective concrete and all surface contamination and thoroughly clean the surface by sandblasting followed by air blasting and water blasting. Pneumatically apply a portland cement grout ahead of the concrete placement, ensuring the grout is not dry prior to placement. Place a 5-inch plain PCC overlay, apply curing compound, saw joints to match joints in base slabs, place compression joint seals at all joints, and place pavement markings.

Code	Name	Work Unit	Unit Cost ($)	Work Type Elements
OL-PP	Overlay - PCC Partially Bonded	SqFt		Remove all loose material, place a 6-inch plain PCC overlay, apply curing compound, saw joints to match joints in base slabs, place compression joint seals at all joints, and place pavement markings. All structural distress and crack repairs in the existing pavement are covered by separate localized repair line items.
OL-PU	Overlay - PCC Unbonded	SqFt		Remove all loose material, place a 2-inch asphalt bond-breaker and a 6-inch plain PCC overlay, apply curing compound, saw joints to match joints in base slabs, place compression joint seals at all joints, and place pavement markings. All structural distress and crack repairs in the existing pavement are covered by separate localized repair line items.
SR-AC	Surface Reconstruction - AC	SqFt		Mill the full depth of the existing asphalt surface to the base course, scarify and recompact the base, place a prime coat and place and compact 4 inches of HMA in 2-inch lifts, and place pavement markings.
SR-PC	Surface Reconstruction - PCC	SqFt		Remove existing plain PCC pavement, scarify and recompact the base, place new 8-inch plain PCC using slip form paving procedures with dowels at longitudinal joints and sawn transverse joints, apply curing compound, saw transverse joints, place compression joint seals at all joints, and place pavement markings.
SU-AC	Surface Course - AC	SqFt		No work type elements
SU-DB	Surface Course - Double Bitum.	SqFt		Remove all loose material on surface, place binder using a distributor calibrated to deliver the material at the specified rate. Apply the aggregate immediately after the binder and roll with a rubber-tired roller immediately after applying the aggregate to seat the aggregate in the binder. Repeat the process, applying another layer of binder and aggregate then roll with a rubber-tired roller immediately after applying the second layer of aggregate and place pavement markings. All structural distresses and crack repairs are covered by separate localized repair line items.
SU-PC	Surface Course - PCC	SqFt		No work type elements
SU-PF	Surface Course - Porous Friction	SqFt		Remove all loose material from existing AC pavement, place tack coat, place and compact 1 inch of porous friction course, and place pavement markings. All structural distresses and crack repairs are covered by separate localized repair line items.

A-3 M&R DISTRESS MAINTENANCE POLICY TABLES.

Service POCs drafted and agreed to the following Maintenance Policy tables. These policies cover most typical situations. Notes are provided to clarify alternatives.

A-3.1 Localized Operational Maintenance Policies.

Tables A-4 through A-7 provide standard localized operational maintenance policies for airfields, roads, and parking.

Table A-4 Asphalt Airfield Operational M&R Policy

Operational M&R Distress Maintenance Policy - Airfield Asphalt					
Distress	**Distress Severity**	**Description**	**Code**	**Work Type**	**Work Unit**
41	Low	ALLIGATOR CRACKING	NONE	No Localized M & R	---
41	Medium	ALLIGATOR CRACKING	NONE	No Localized M & R	---
41	High	ALLIGATOR CRACKING	PA-AD	Patching - AC Deep	SqFt
42	N/A	BLEEDING	NONE	No Localized M & R	---
43	Low	BLOCK CRACKING	NONE	No Localized M & R	---
43	Medium	BLOCK CRACKING	NONE	No Localized M & R	---
43	High	BLOCK CRACKING	PA-AS	Patching - AC Shallow	SqFt
44	Low	CORRUGATION	NONE	No Localized M & R	---
44	Medium	CORRUGATION	NONE	No Localized M & R	---
44	High	CORRUGATION	PA-AS	Patching - AC Shallow	SqFt
45	Low	DEPRESSION	NONE	No Localized M & R	---
45	Medium	DEPRESSION	NONE	No Localized M & R	---
45	High	DEPRESSION	PA-AS	Patching - AC Shallow	SqFt
46	N/A	JET BLAST	PA-AS	Patching - AC Shallow	SqFt
47	Low	JOINT REFLECTIVE CRACKING	NONE	No Localized M & R	---
47	Medium	JOINT REFLECTIVE CRACKING	NONE	No Localized M & R	Ft
47	High	JOINT REFLECTIVE CRACKING	PA-AS	Crack Sealing - AC	SqFt
48	Low	LONGITUDINAL AND TRANSVERSE CRACKING	NONE	No Localized M & R	---
48	Medium	LONGITUDINAL AND TRANSVERSE CRACKING	NONE	No Localized M & R	---
48	High	LONGITUDINAL AND TRANSVERSE CRACKING	CS-AC	Crack Sealing - AC	Ft

Operational M&R Distress Maintenance Policy - Airfield Asphalt					
Distress	**Distress Severity**	**Description**	**Code**	**Work Type**	**Work Unit**
49	N/A	OIL SPILLAGE	NONE	No Localized M & R	---
50	Low	PATCHING	NONE	No Localized M & R	---
50	Medium	PATCHING	PA-AS	Patching - AC Shallow	SqFt
50	High	PATCHING	PA-AS	Patching - AC Shallow	SqFt
51	N/A	POLISHED AGGREGATE	NONE	No Localized M & R	---
52	Low	RAVELING	NONE	No Localized M & R	---
52	Medium	RAVELING	NONE	No Localized M & R	---
52	High	RAVELING	NONE	No Localized M & R	---
53	Low	RUTTING	NONE	No Localized M & R	---
53	Medium	RUTTING	NONE	No Localized M & R	---
53	High	RUTTING	PA-AD	Patching - AC Deep	SqFt
54	Low	SHOVING	NONE	No Localized M & R	---
54	Medium	SHOVING	NONE	No Localized M & R	---
54	High	SHOVING	PA-AD	Patching - AC Deep	SqFt
55	N/A	SLIPPAGE CRACKING	NONE	No Localized M & R	---
56	Low	SWELLING	NONE	No Localized M & R	---
56	Medium	SWELLING	NONE	No Localized M & R	---
56	High	SWELLING	PA-AD	Patching - AC Deep	SqFt
57	Low	WEATHERING	NONE	No Localized M & R	---
57	Medium	WEATHERING	NONE	No Localized M & R	---
57	High	WEATHERING	NONE	No Localized M & R	---

Table A-5 Concrete Airfield Operational M&R Policy

Operational Pavement Distress Maintenance Policy - Airfield Concrete					
Distress	Distress Severity	Description	Code	Work Type	Work Unit
61	Low	BLOW-UP	NONE	No Localized M & R	---
61	Medium	BLOW-UP	NONE	No Localized M & R	---
61	High	BLOW-UP	PA-PF	Patching - PCC Full Depth	SqFt
62	Low	CORNER BREAK	NONE	No Localized M & R	---
62	Medium	CORNER BREAK	NONE	No Localized M & R	---
62	High	CORNER BREAK	PA-PF	Patching - PCC Full Depth	SqFt
63	Low	LINEAR CRACKING	NONE	No Localized M & R	---
63	Medium	LINEAR CRACKING	NONE	No Localized M & R	---
63	High	LINEAR CRACKING	CS-PC	Crack Sealing - PCC	Ft
64	Low	DURABILITY CRACKING	NONE	No Localized M & R	---
64	Medium	DURABILITY CRACKING	PA-PF	Patching - PCC Full Depth	SqFt
64	High	DURABILITY CRACKING	SL-PC	Slab Replacement - PCC	SqFt
65	Low	JOINT SEAL DAMAGE	NONE	No Localized M & R	---
65	Medium	JOINT SEAL DAMAGE	NONE	No Localized M & R	---
65	High	JOINT SEAL DAMAGE	NONE	No Localized M & R	---
66	Low	SMALL PATCH	NONE	No Localized M & R	---
66	Medium	SMALL PATCH	PA-PP	Patching - PCC Partial Depth	SqFt
66	High	SMALL PATCH	PA-PP	Patching - PCC Partial Depth	SqFt
67	Low	LARGE PATCH	NONE	No Localized M & R	---
67	Medium	LARGE PATCH	NONE	No Localized M & R	---
67	High	LARGE PATCH	PA-PF	Patching - PCC Full Depth	SqFt
68	N/A	POPOUTS	NONE	No Localized M & R	---
69	N/A	PUMPING	NONE	No Localized M & R	---
70	Low	SCALING	NONE	No Localized M & R	---
70	Medium	SCALING	NONE	No Localized M & R	---
70	High	SCALING	SL-PC	Slab Replacement - PCC	SqFt
71	Low	FAULTING	NONE	No Localized M & R	---
71	Medium	FAULTING	NONE	No Localized M & R	---

Operational Pavement Distress Maintenance Policy - Airfield Concrete					
Distress	**Distress Severity**	**Description**	**Code**	**Work Type**	**Work Unit**
71	High	FAULTING	GR-PP	Grinding (Localized)	Ft
72	Low	SHATTERED SLAB	NONE	No Localized M & R	---
72	Medium	SHATTERED SLAB	NONE	No Localized M & R	---
72	High	SHATTERED SLAB	SL-PC	Slab Replacement - PCC	SqFt
73	N/A	SHRINKAGE CRACKING	NONE	No Localized M & R	---
74	Low	JOINT SPALL	NONE	No Localized M & R	---
74	Medium	JOINT SPALL	PA-PP	Patching - PCC Partial Depth	SqFt
74	High	JOINT SPALL	PA-PP	Patching - PCC Partial Depth	SqFt
75	Low	CORNER SPALL	NONE	No Localized M & R	---
75	Medium	CORNER SPALL	PA-PP	Patching - PCC Partial Depth	SqFt
75	High	CORNER SPALL	PA-PP	Patching - PCC Partial Depth	SqFt
76	Low	ASR	NONE	No Localized M & R	---
76	Medium	ASR	PA-PP	Patching - PCC Partial Depth	SqFt
76	High	ASR	SL-PC	Slab Replacement - PCC	SqFt

Table A-6 Asphalt Road and Parking Operational M&R Policy

Operational Pavement Distress Maintenance Policy - Asphalt Road and Parking					
Distress	**Distress Severity**	**Description**	**Code**	**Work Type**	**Work Unit**
1	Low	ALLIGATOR CR	NONE	No Localized M & R	---
1	Medium	ALLIGATOR CR	NONE	No Localized M & R	---
1	High	ALLIGATOR CR	PA-AD	Patching - AC Deep	SqFt
2	Low	BLEEDING	NONE	No Localized M & R	---
2	Medium	BLEEDING	NONE	No Localized M & R	---
2	High	BLEEDING	NONE	No Localized M & R	---
3	Low	BLOCK CRACKING	NONE	No Localized M & R	---
3	Medium	BLOCK CRACKING	NONE	No Localized M & R	---
3	High	BLOCK CRACKING	NONE	No Localized M & R	---
4	Low	BUMPS AND SAGS	NONE	No Localized M & R	---

Operational Pavement Distress Maintenance Policy - Asphalt Road and Parking					
Distress	**Distress Severity**	**Description**	**Code**	**Work Type**	**Work Unit**
4	Medium	BUMPS AND SAGS	NONE	No Localized M & R	---
4	High	BUMPS AND SAGS	PA-AS	Patching-AC Shallow	SqFt
5	Low	CORRUGATION	NONE	No Localized M & R	---
5	Medium	CORRUGATION	NONE	No Localized M & R	---
5	High	CORRUGATION	PA-AS	Patching - AC Shallow	SqFt
6	Low	DEPRESSION	NONE	No Localized M & R	---
6	Medium	DEPRESSION	NONE	No Localized M & R	---
6	High	DEPRESSION	PA-AD	Patching - AC Deep	SqFt
7	Low	EDGE CRACKING	NONE	No Localized M & R	---
7	Medium	EDGE CRACKING	NONE	No Localized M & R	---
7	High	EDGE CRACKING	PA-AS	Patching - AC Shallow	SqFt
8	Low	JOINT REFLECTION CRACKING	NONE	No Localized M & R	---
8	Medium	JOINT REFLECTION CRACKING	NONE	No Localized M & R	---
8	High	JOINT REFLECTION CRACKING	CS-AC	Crack Sealing - AC	SqFt
9	Low	LANE/SHOULDER DROP-OFF	NONE	No Localized M & R	---
9	Medium	LANE/SHOULDER DROP-OFF	SH-LE	Shoulder leveling	Ft
9	High	LANE/SHOULDER DROP-OFF	SH-LE	Shoulder leveling	Ft
10	Low	LONG & TRANS CRACKING	NONE	No Localized M & R	---
10	Medium	LONG & TRANS CRACKING	NONE	No Localized M & R	---
10	High	LONG & TRANS CRACKING	CS-AC	Crack Sealing - AC	SqFt
11	Low	PATCHING & UTILITY CUT PATCHING	NONE	No Localized M & R	---
11	Medium	PATCHING & UTILITY CUT PATCHING	NONE	No Localized M & R	---
11	High	PATCHING & UTILITY CUT PATCHING	PA-AD	Patching - AC Deep	SqFt
12	N/A	POLISHED AGGREGATE	NONE	No Localized M & R	---
13	Low	POTHOLES	NONE	No Localized M & R	---
13	Medium	POTHOLES	PA-AD	Patching - AC Deep	SqFt
13	High	POTHOLES	PA-AD	Patching - AC Deep	SqFt
14	Low	RAILROAD CROSSING	NONE	No Localized M & R	---
14	Medium	RAILROAD CROSSING	NONE	No Localized M & R	---

Operational Pavement Distress Maintenance Policy - Asphalt Road and Parking					
Distress	**Distress Severity**	**Description**	**Code**	**Work Type**	**Work Unit**
14	High	RAILROAD CROSSING	NONE	No Localized M & R	---
15	Low	RUTTING	NONE	No Localized M & R	---
15	Medium	RUTTING	NONE	No Localized M & R	---
15	High	RUTTING	PA-AD	Patching - AC Deep	SqFt
16	Low	SHOVING	NONE	No Localized M & R	---
16	Medium	SHOVING	NONE	No Localized M & R	---
16	High	SHOVING	PA-AS	Patching - AC Shallow	SqFt
17	Low	SLIPPAGE CRACKING	NONE	No Localized M & R	---
17	Medium	SLIPPAGE CRACKING	NONE	No Localized M & R	---
17	High	SLIPPAGE CRACKING	NONE	No Localized M & R	---
18	Low	SWELL	NONE	No Localized M & R	---
18	Medium	SWELL	NONE	No Localized M & R	---
18	High	SWELL	PA-AS	Patching-AC Shallow	SqFt
19	Low	RAVELING	NONE	No Localized M & R	---
19	Medium	RAVELING	NONE	No Localized M & R	---
19	High	RAVELING	NONE	No Localized M & R	---
20	Low	WEATHERING	NONE	No Localized M & R	---
20	Medium	WEATHERING	NONE	No Localized M & R	---
20	High	WEATHERING	NONE	No Localized M & R	---

Table A-7 Concrete Road and Parking Operational M&R Policy

Operational Pavement Distress Maintenance Policy - Concrete Road and Parking					
Distress	Distress Severity	Description	Code	Work Type	Work Unit
21	Low	BLOWUP/BUCKLING	NONE	No Localized M & R	---
21	Medium	BLOWUP/BUCKLING	NONE	No Localized M & R	SqFt
21	High	BLOWUP/BUCKLING	PA-PF	Patching - PCC Full Depth	SqFt
22	Low	CORNER BREAK	NONE	No Localized M & R	-
22	Medium	CORNER BREAK	NONE	No Localized M & R	SqFt
22	High	CORNER BREAK	PA-PF	Patching - PCC Full Depth	SqFt
23	Low	DIVIDED SLAB	NONE	No Localized M & R	-
23	Medium	DIVIDED SLAB	NONE	No Localized M & R	SqFt
23	High	DIVIDED SLAB	SL-PC	Slab Replacement - PCC	SqFt
24	Low	DURABILITY CRACK	NONE	No Localized M & R	-
24	Medium	DURABILITY CRACK	PA-PP	Patching - PCC Partial Depth	SqFt
24	High	DURABILITY CRACK	PA-PF	Patching - PCC Full Depth	SqFt
25	Low	FAULTING	NONE	No Localized M & R	-
25	Medium	FAULTING	NONE	No Localized M & R	SqFt
25	High	FAULTING	GR-PC	Grinding (Localized)	Ft
26	Low	JOINT SEAL DAMAGE	NONE	No Localized M & R	-
26	Medium	JOINT SEAL DAMAGE	NONE	No Localized M & R	Ft
26	High	JOINT SEAL DAMAGE	NONE	No Localized M & R	Ft
27	Low	LANE/SHOULDER DROP	NONE	No Localized M & R	-
27	Medium	LANE/SHOULDER DROP	SH-LE	Shoulder leveling	Ft
27	High	LANE/SHOULDER DROP	SH-LE	Shoulder leveling	Ft
28	Low	LINEAR CRACKING	NONE	No Localized M & R	-
28	Medium	LINEAR CRACKING	NONE	No Localized M & R	Ft
28	High	LINEAR CRACKING	CS-PC	Crack Sealing - PCC	SqFt
29	Low	PATCHING (LARGE)	NONE	No Localized M & R	-
29	Medium	PATCHING (LARGE)	NONE	No Localized M & R	-
29	High	PATCHING (LARGE)	PA-PF	Patching - PCC Full Depth	SqFt
30	Low	PATCHING (SMALL)	NONE	No Localized M & R	-

Operational Pavement Distress Maintenance Policy - Concrete Road and Parking					
Distress	**Distress Severity**	**Description**	**Code**	**Work Type**	**Work Unit**
30	Medium	PATCHING (SMALL)	NONE	No Localized M & R	-
30	High	PATCHING (SMALL)	PA-PP	Patching - PCC Partial Depth	SqFt
31	NA	POLISHED AGGREGATE	NONE	No Localized M & R	-
32	NA	POPOUTS	NONE	No Localized M & R	-
33	NA	PUMPING	NONE	No Localized M & R	Ft
34	Low	PUNCHOUT	NONE	No Localized M & R	-
34	Medium	PUNCHOUT	NONE	No Localized M & R	SqFt
34	High	PUNCHOUT	PA-PF	Patching-PCC Full Depth	SqFt
35	Low	RAILROAD CROSSING	NONE	No Localized M & R	-
35	Medium	RAILROAD CROSSING	NONE	No Localized M & R	-
35	High	RAILROAD CROSSING	NONE	No Localized M & R	-
36	Low	SCALING	NONE	No Localized M & R	-
36	Medium	SCALING	NONE	No Localized M & R	-
36	High	SCALING	PA-PP	Patching - PCC Partial Depth	SqFt
37	NA	SHRINKAGE CRACKS	NONE	No Localized M & R	-
38	Low	SPALLING, CORNER	NONE	No Localized M & R	-
38	Medium	SPALLING, CORNER	NONE	No Localized M & R	SqFt
38	High	SPALLING, CORNER	PA-PP	Patching - PCC Partial Depth	SqFt
39	Low	SPALLING, JOINT	NONE	No Localized M & R	-
39	Medium	SPALLING, JOINT	NONE	No Localized M & R	SqFt
39	High	SPALLING, JOINT	PA-PP	Patching - PCC Partial Depth	SqFt

A-3.2 Localized Preventive Maintenance (PM) Policies.

Tables A-8 through A-13 provide standard localized PM policies for airfields, roads, and parking as well as notes to supplement the policies based on other considerations for specific scenarios.

Table A-8 Asphalt Airfield Preventive M&R Policy

Preventive Pavement Distress Maintenance Policy - Asphalt Airfield					
Distress	**Distress Severity**	**Description**	**Code**	**Work Type**	**Work Unit**
41	Low	ALLIGATOR CRACKING	NONE	No Localized M & R	---
41	Medium	ALLIGATOR CRACKING	PA-AD	Patching - AC Deep	SqFt
41	High	ALLIGATOR CRACKING	PA-AD	Patching - AC Deep	SqFt
42	N/A	BLEEDING	NONE	No Localized M & R	---
43	Low	BLOCK CRACKING	NONE	No Localized M & R	---
43	Medium	BLOCK CRACKING	CS-AC	Crack Sealing - AC	Ft
43	High	BLOCK CRACKING	PA-AS	Patching - AC Shallow	SqFt
44	Low	CORRUGATION	NONE	No Localized M & R	---
44	Medium	CORRUGATION	GR-PP	Grinding (Localized)	Ft
44	High	CORRUGATION	PA-AD	Patching - AC Deep	SqFt
45	Low	DEPRESSION	NONE	No Localized M & R	---
45	Medium	DEPRESSION	PA-AD	Patching - AC Deep	SqFt
45	High	DEPRESSION	PA-AD	Patching - AC Deep	SqFt
46	N/A	JET BLAST	PA-AS	Patching - AC Shallow	SqFt
47	Low	JOINT REFLECTIVE CRACKING	NONE	No Localized M & R	---
47	Medium	JOINT REFLECTIVE CRACKING	CS-AC	Crack Sealing - AC	Ft
47	High	JOINT REFLECTIVE CRACKING	CS-AC	Crack Sealing - AC	SqFt
48	Low	LONGITUDINAL AND TRANSVERSE CRACKING	NONE	No Localized M & R	---
48	Medium	LONGITUDINAL AND TRANSVERSE CRACKING	CS-AC	Crack Sealing - AC	Ft
48	High	LONGITUDINAL AND TRANSVERSE CRACKING	CS-AC	Crack Sealing - AC	Ft
49	N/A	OIL SPILLAGE	PA-AS	Patching - AC Shallow	SqFt
50	Low	PATCHING	NONE	No Localized M & R	---
50	Medium	PATCHING	PA-AD	Patching - AC Deep	SqFt
50	High	PATCHING	PA-AD	Patching - AC Deep	SqFt
51	N/A	POLISHED AGGREGATE	NONE	No Localized M & R	---
52	Low	RAVELING	NONE	No Localized M & R	---

Preventive Pavement Distress Maintenance Policy - Asphalt Airfield					
Distress	**Distress Severity**	**Description**	**Code**	**Work Type**	**Work Unit**
52	Medium	RAVELING	PA-AS	Patching - AC Shallow	SqFt
52	High	RAVELING	PA-AS	Patching - AC Shallow	SqFt
53	Low	RUTTING	NONE	No Localized M & R	---
53	Medium	RUTTING	PA-AD	Patching - AC Deep	SqFt
53	High	RUTTING	PA-AD	Patching - AC Deep	SqFt
54	Low	SHOVING	NONE	No Localized M & R	---
54	Medium	SHOVING	PA-AS	Patching - AC Shallow	SqFt
54	High	SHOVING	PA-AD	Patching - AC Deep	SqFt
55	N/A	SLIPPAGE CRACKING	PA-AS	Patching - AC Shallow	SqFt
56	Low	SWELLING	NONE	No Localized M & R	---
56	Medium	SWELLING	PA-AD	Patching - AC Deep	SqFt
56	High	SWELLING	PA-AD	Patching - AC Deep	SqFt
57	Low	WEATHERING	NONE	No Localized M & R	---
57	Medium	WEATHERING	NONE	No Localized M & R	---
57	High	WEATHERING	PA-AS	Patching - AC Shallow	SqFt

Table A-9 Other Considerations - Asphalt Airfield Preventive M&R Policy

<table>
<tr><th colspan="4">Airfield Asphalt Pavement Localized Preventive M&R Policy - Other Considerations</th></tr>
<tr><th>Distress</th><th>Distress Severity</th><th>Description</th><th>Work Type Adjustments</th></tr>
<tr><td>41</td><td>Low</td><td>ALLIGATOR CRACKING</td><td>Alligator (fatigue) cracking is a structural distress. Ideally, we want to slow the progression of the distress, but sealing a low-severity asphalt crack typically requires overbanding, which presents a FOD hazard to some aircraft so the "No Localized" work type is recommended. Depending on the extent of the alligator cracking, a global surface treatment can be effective, e.g., with >1% low severity alligator cracking the PCI would drop to an 80.</td></tr>
<tr><td>43</td><td>Low</td><td>BLOCK CRACKING</td><td rowspan="3">When aircraft operating on an airfield use thrust vectoring, e.g., the F-35, the jet blast can cause delamination of the pavement when block cracking is present. When a high percentage of the area is block cracked, the PCI will go below critical, which will trigger major M&R, e.g., mill and overlay. If the block cracking is localized, Patching AC-Deep is recommended.</td></tr>
<tr><td>43</td><td>Medium</td><td>BLOCK CRACKING</td></tr>
<tr><td>43</td><td>High</td><td>BLOCK CRACKING</td></tr>
<tr><td>44</td><td>Low</td><td>CORRUGATION</td><td rowspan="3">Corrugation is an indication of delaminated asphalt layers or instability in the base or subbase. It can be caused by an unstable mix or improper compaction. Depending on the cause, grinding may be used as an initial treatment; however, it will not address the root cause, so a shallow or deep patch is recommended. When aircraft operating on an airfield use thrust vectoring, e.g., the F-35, the jet blast can cause delamination of the pavement when corrugation is present. In these cases, use Patching AC-Deep for all severity levels.</td></tr>
<tr><td>44</td><td>Medium</td><td>CORRUGATION</td></tr>
<tr><td>44</td><td>High</td><td>CORRUGATION</td></tr>
<tr><td>46</td><td></td><td>JET BLAST</td><td>When aircraft operating on an airfield use thrust vectoring, e.g., the F-35, the jet blast can be eroded up to 0.5 inch in depth. This causes smoothness and FOD concerns for any FOD-susceptible aircraft due to the greater potential of raveling. However, the treatment may range from no localized M&R to AC shallow patch and include surface treatments or shallow depth fuel-resistant asphalt for V-22 FARPs. When the standard shallow patch is applied, it must have a seal around the edge and a surface treatment to reduce the possibility of re-occurrence or at least slow the progression.</td></tr>
<tr><td>47</td><td>High</td><td>JOINT REFLECTIVE CRACKING</td><td>When joint reflective cracks are greater than 0.25 inch and less than 2 inches, routing and sealing the cracks is the standard policy. However, when cracks are greater than or equal to 2 inches or with significant raveling (FOD potential for susceptible aircraft) that cannot be mitigated by routing and sealing, the distress should be repaired using a shallow patch. UFC 3-270-01 requires the use of a well-compacted sand asphalt or a fine-grained asphalt mix when repairing cracks 2 inches wide and larger, which qualifies as a shallow patch. Note: In tertiary areas or LZs used by C-130s and C-17s, crack sealing high-severity cracks is permissible.</td></tr>
</table>

Airfield Asphalt Pavement Localized Preventive M&R Policy - Other Considerations			
Distress	**Distress Severity**	**Description**	**Work Type Adjustments**
48	High	LONGITUDINAL AND TRANSVERSE CRACKING	When longitudinal and transverse cracks are greater than 0.25 inch and less than 2 inches, routing and sealing the cracks is the standard policy. However, when cracks are greater than or equal to 2 inches or with significant raveling (FOD potential for susceptible aircraft) that cannot be mitigated by routing and sealing, the distress should be repaired using a shallow patch. UFC 3-270-01 requires the use of a well-compacted sand asphalt or a fine-grained asphalt mix when repairing cracks 2 inches wide and larger, which qualifies as a shallow patch. **Note:** In tertiary areas or LZs used by C-130s and C-17s, crack sealing high-severity cracks is permissible.
51	N/A	POLISHED AGGREGATE	While the standard policy is No Localized M&R, if the extent of distress is significant enough that it poses a safety issue to aircraft when braking, consider water blasting, grinding, microsurfacing, or shallow patch. The repair will depend on the quality of the asphalt. Oftentimes, if the aggregate is polished then the asphalt is likely too oxidized for water blasting or grinding. If so, then consider mill and overlay or microsurfacing (depending on the location on the airfield and the FOD susceptibility of the mission aircraft).
52	Low	RAVELING	While the standard policy is No Localized M&R, when the distress density exceeds 4 percent and the section PCI is above critical, global M&R is recommended
52	Medium	RAVELING	While the standard policy is Patching - AC Shallow, when the distress density exceeds 1 percent and the section PCI is above critical, global M&R is recommended. if the distress density exceeds 1 percent and the section PCI is below critical, major M&R is recommended, e.g., mill and overlay.
52	High	RAVELING	While the standard policy is Patching - AC Shallow, when the distress density exceeds 0.5 percent and the section PCI is above critical, global M&R is recommended. If the distress density exceeds 0.5 percent and the section PCI is below critical, major M&R is recommended, e.g., mill and overlay.
54	Medium	SHOVING	The standard policy is Patching - AC Shallow because it addresses the AC to PCC interface issues but, depending on the thickness of the pavement and the aircraft operating on the airfield, grinding and reestablishing and sealing the joint at the AC to PCC interface can be an acceptable solution.
55	N/A	SLIPPAGE CRACKING	The standard policy is Patching - AC Shallow, but the depth of the repair is a function of where the slip occurred. Slippage crack repair would likely not expose the base but, if the issue was a degraded underlying layer, then Patching - AC Deep is the appropriate solution.
56	Medium	SWELLING	The standard policy is Patching - AC Deep based on the assumption that the swelling is occurring due to frost action in the subgrade or by swelling soil, but a small swell can also occur on the surface of an asphalt overlay (over PCC) as a

Airfield Asphalt Pavement Localized Preventive M&R Policy - Other Considerations			
Distress	Distress Severity	Description	Work Type Adjustments
56	High	SWELLING	result of a blowup in the PCC. In this case, the appropriate repair is to replace the AC and PCC to the base. Swelling can also occur when there is delamination and water infiltration in the asphalt or AC/PCC interface combined with extreme high or freezing temperatures. In this case, Patching - AC Shallow is appropriate to replace the delaminated asphalt.
57	Low	WEATHERING	While the standard policy is No Localized M&R, global M&R is recommended to slow the rate of weathering/deterioration of the asphalt.
57	Medium	WEATHERING	While the standard policy is No Localized M&R, global M&R is recommended to slow the rate of weathering/deterioration of the asphalt.
57	High	WEATHERING	While the standard policy is Patching - AC Shallow, when the distress density exceeds 0.5 percent and the section PCI is above critical, global M&R is recommended. If the distress density exceeds 0.5 percent and the section PCI is below critical, major M&R is recommended, e.g., mill and overlay.

Table A-10 Concrete Airfield Preventive M&R Policy

Pavement Distress Maintenance Policy – Concrete Airfield					
Distress	Distress Severity	Description	Code	Work Type	Work Unit
61	Low	BLOW-UP	PA-PF	Patching - PCC Full Depth	SqFt
61	Medium	BLOW-UP	PA-PF	Patching - PCC Full Depth	SqFt
61	High	BLOW-UP	SL-PC	Slab Replacement - PCC	SqFt
62	Low	CORNER BREAK	NONE	No Localized M & R	---
62	Medium	CORNER BREAK	CS-PC	Crack Sealing - PCC	Ft
62	High	CORNER BREAK	PA-PF	Patching - PCC Full Depth	SqFt
63	Low	LINEAR CRACKING	NONE	No Localized M & R	---
63	Medium	LINEAR CRACKING	CS-PC	Crack Sealing - PCC	Ft
63	High	LINEAR CRACKING	CS-PC	Crack Sealing - PCC	Ft
64	Low	DURABILITY CRACKING	NONE	No Localized M & R	---
64	Medium	DURABILITY CRACKING	PA-PF	Patching - PCC Full Depth	SqFt
64	High	DURABILITY CRACKING	SL-PC	Slab Replacement - PCC	SqFt
65	Low	JOINT SEAL DAMAGE	NONE	No Localized M & R	---
65	Medium	JOINT SEAL DAMAGE	JS-LC	Joint Seal (Localized)	Ft
65	High	JOINT SEAL DAMAGE	JS-LC	Joint Seal (Localized)	Ft
66	Low	SMALL PATCH	NONE	No Localized M & R	---
66	Medium	SMALL PATCH	PA-PP	Patching - PCC Partial Depth	SqFt
66	High	SMALL PATCH	PA-PP	Patching - PCC Partial Depth	SqFt

Pavement Distress Maintenance Policy – Concrete Airfield					
Distress	**Distress Severity**	**Description**	**Code**	**Work Type**	**Work Unit**
67	Low	LARGE PATCH	NONE	No Localized M & R	---
67	Medium	LARGE PATCH	PA-PP	Patching - PCC Partial Depth	SqFt
67	High	LARGE PATCH	PA-PF	Patching - PCC Full Depth	SqFt
68	N/A	POPOUTS	NONE	No Localized M & R	---
69	N/A	PUMPING	JS-LC	Joint Seal Localized	Ft
70	Low	SCALING	NONE	No Localized M & R	---
70	Medium	SCALING	PA-PP	Patching - PCC Partial Depth	SqFt
70	High	SCALING	SL-PC	Slab Replacement - PCC	SqFt
71	Low	FAULTING	NONE	No Localized M & R	---
71	Medium	FAULTING	GR-PP	Grinding (Localized)	Ft
71	High	FAULTING	GR-PP	Grinding (Localized)	Ft
72	Low	SHATTERED SLAB	NONE	No Localized M & R	---
72	Medium	SHATTERED SLAB	SL-PC	Slab Replacement - PCC	SqFt
72	High	SHATTERED SLAB	SL-PC	Slab Replacement - PCC	SqFt
73	N/A	SHRINKAGE CRACKING	NONE	No Localized M & R	---
74	Low	JOINT SPALL	NONE	No Localized M & R	---
74	Medium	JOINT SPALL	PA-PP	Patching - PCC Partial Depth	SqFt
74	High	JOINT SPALL	PA-PP	Patching - PCC Partial Depth	SqFt
75	Low	CORNER SPALL	NONE	No Localized M & R	---
75	Medium	CORNER SPALL	PA-PP	Patching - PCC Partial Depth	SqFt
75	High	CORNER SPALL	PA-PP	Patching - PCC Partial Depth	SqFt
76	Low	ASR	NONE	No Localized M & R	---
76	Medium	ASR	PA-PP	Patching - PCC Partial Depth	SqFt
76	High	ASR	SL-PC	Slab Replacement - PCC	SqFt

Table A-11 Other Considerations - Concrete Airfield Preventive M&R Policy

Airfield Concrete Pavement Localized Preventive M&R Policy - Other Considerations			
Distress	**Distress Severity**	**Description**	**Work Type Adjustments**
61	Low	BLOW-UP	The standard policy is Patching - PCC Full Depth, but depending on the location, thickness, and the aircraft using the pavement, a partial-depth PCC patch can be used on pavement greater than 12 inches when the pavement is outside the traffic area or when the aircraft using the aircraft are not susceptible to roughness or FOD issues. The primary concern is that a partial-depth patch may not address the root cause and may have shear/delamination issues.
61	High	BLOW-UP	The standard policy is slab replacement, but in some cases a full-depth patch can be used, depending on the existing damage. Whether you are doing a full-depth patch or slab replacement, it is important to install compression boards to prevent reoccurrence of the distress.
62	Low	CORNER BREAK	The standard policy is No Localized M&R because trying to do a repair on very narrow cracks can do more harm than good, but if cracks are approaching 1/8 inch (bordering on medium severity), crack sealing is appropriate to reduce the infiltration of water and slow the progression of the distress. The decision to seal the crack is also a function of the environment/pavement design. Does it have a working drainage layer or does the soil drain well? Is it subject to freeze thaw or snow plows? How will it affect the mission, e.g., is it close to arresting system or is it on a tertiary pavement?
62	Medium	CORNER BREAK	The standard policy is crack sealing, however in cases where there is faulting or the airfield is used by fighter aircraft, use a full-depth repair.
63	High	LINEAR CRACKING	The standard policy is crack sealing, but if the crack is greater than 2 inches, a full-depth patch or slab replacement is recommended, depending on the location of the crack and other factors. For instance, sympathetic cracking on a number of slabs would warrant full-depth repairs or slab replacement with a reinforced slab to stop crack propagation.
65	Medium	JOINT SEAL DAMAGE	The standard policy is Joint Seal (Localized) repair when the distress density is less than 33 percent medium and high severity. If the distress density is more than 33 percent and less than 66 percent, plan for global joint seal replacement in two to three years. When the medium- and high-severity density is greater than 66 percent, plan for global joint seal replacement in year one. For sections that do not have a drainage layer and have a history of pumping, faulting, swelling soils, or that require undersealing, plan for immediate localized repairs or global repairs in year one when the distress density is more than 33 percent and less than 66 percent.
65	High	JOINT SEAL DAMAGE	
66	Medium	SMALL PATCH	The standard policy is Patching PCC - Partial Depth, but when aircraft operating on an airfield use thrust vectoring, e.g., the F-35, the jet blast can cause delamination of partial-depth pavement repairs so a full-depth patch is required.

Airfield Concrete Pavement Localized Preventive M&R Policy - Other Considerations			
Distress	**Distress Severity**	**Description**	**Work Type Adjustments**
66	High	SMALL PATCH	The standard policy is Patching PCC - Partial Depth, but when the aircraft operating on an airfield use thrust vectoring, e.g., the F-35, the jet blast can cause delamination of partial-depth pavement repairs so a full-depth patch is required.
67	Medium	LARGE PATCH	The standard policy is Partial Depth PCC Patch, but if the patch is already full depth or if the pavement thickness is less than 8 inches, a full-depth patch is recommended. A partial-depth repair over an entire slab is, in effect, a fully bonded overlay, which is not typically allowed but may be considered for V-22 and B-1 parking positions. Note that if the base slab is damaged when doing a partial-depth repair, a full-depth repair is required. When aircraft operating on an airfield use thrust vectoring, e.g., the F-35, the jet blast can cause delamination of partial-depth pavement repairs so a full-depth patch is required.
69	N/A	PUMPING	The standard policy is Joint Seal (Localized) repair, but when pumping is significant or small voids are suspected, undersealing is required in addition to the joint seal.
70	Low	SCALING	In cases where scaling is widespread, grinding can be used to mitigate ponding issues and plow damage.
70	Medium	SCALING	The standard is a partial-depth patch, but when the scaling occurs on more than 50 percent of the slab, consider grinding or slab replacement.
71	Low	FAULTING	The standard is No Localized M&R, but when Low Severity Faulting occurs within 200 feet of an arresting system, it must be repaired. Consider grinding, slab jacking, or slab replacement to reestablish grade in these areas. Microsurfacing may be considered as an expedient solution until permanent repairs can be conducted.
71	Medium	FAULTING	The standard policy is grinding, but depending on the mission aircraft, location, and environment, consider slab jacking or slab replacement. Microsurfacing may be considered as an expedient solution until permanent repairs can be conducted.
71	High	FAULTING	The standard policy is grinding, but depending on the mission aircraft, location, and environment, consider slab jacking or slab replacement. For example, if faulting is greater than 1 inch on a runway or 2 inches on an apron, if the faulting is in a corner or if multiple slabs have faulting, replace slabs. Microsurfacing may be considered as an expedient solution until permanent repairs can be conducted.

Airfield Concrete Pavement Localized Preventive M&R Policy - Other Considerations			
Distress	**Distress Severity**	**Description**	**Work Type Adjustments**
72	Low	SHATTERED SLAB	The standard policy is No Localized because trying to do a repair on very narrow cracks can do more harm than good, but if cracks are approaching 1/8 inch (bordering on medium severity), crack sealing is appropriate to reduce the infiltration of water, which reduces potential of damage to the subgrade, freeze thaw damage, and reduces the likelihood that incompressible material will enter the crack and spall. In many cases, the cracking is not load related but a result of poor joint lay out, warping and curling, improper doweling, or other non-load-related stresses on the slab. This is especially true with 25-foot slabs that are less than 10 inches thick. As a result, the cracks may not be working cracks that generate FOD, but are functioning as joints.
72	Medium	SHATTERED SLAB	The standard policy is slab replacement, but if cracks are a result of slab geometry and are not working cracks (generating FOD), crack sealing is appropriate to reduce the infiltration of water, which reduces potential of damage to the subgrade, freeze thaw damage, and reduce the likelihood that incompressible material will enter the crack and spall. In many cases, the cracking is not load related but a result of poor joint lay out, warping and curling, improper doweling, or other non-load-related stresses on the slab. This is especially true with 25-foot slabs that are less than 10 inches thick. As a result, the cracks may not be working cracks that generate FOD, but are functioning as joints.
74	Low	JOINT SPALL	The standard policy is No Localized M&R, but some low-severity spalls may be repaired during joint resealing projects. The joint face preparation may remove some of the spall and joint seal material can be used to fill it. Note that if a joint spall is small enough to be filled during a joint seal repair, it is typically not recorded.
74	Medium	JOINT SPALL	The standard policy is Patching PCC - Partial Depth, but when aircraft operating on an airfield use thrust vectoring, e.g., the F-35, the jet blast can cause delamination of partial-depth pavement repairs so a full-depth patch is required.
74	High	JOINT SPALL	The standard policy is Patching PCC - Partial Depth, but when aircraft operating on an airfield use thrust vectoring, e.g., the F-35, the jet blast can cause delamination of partial-depth pavement repairs so a full-depth patch is required.
75	Low	CORNER SPALL	The standard policy is No Localized M&R, but if the crack associated with the corner spall is approaching 1/8 inch, crack sealing may be appropriate. When aircraft operating on an airfield use thrust vectoring, e.g., the F-35, the jet blast can cause delamination of partial-depth pavement repairs so a full-depth patch is required.

Airfield Concrete Pavement Localized Preventive M&R Policy - Other Considerations			
Distress	Distress Severity	Description	Work Type Adjustments
75	High	CORNER SPALL	The standard policy is Patching - PCC Partial Depth, but a full-depth patch is required if the partial-depth repair requires removal of more than 1/3 the slab thickness or if the repair is deep enough to expose the dowels. When aircraft operating on an airfield use thrust vectoring, e.g., the F-35, the jet blast can cause delamination of partial-depth pavement repairs so a full-depth patch is required.
76	Low	ASR	The standard policy is No Localized M&R, but recommend when work is performed, cut additional expansion joints to accommodate expansion and isolate structures such as drains, sunshades, POL, and manholes.
76	Medium	ASR	The standard policy is Partial Depth PCC Patch, but if the ASR extends across more than half of the slab, slab replacement is appropriate. In addition, if replacing areas around patches that now have ASR, consider slab replacement.

Table A-12 Asphalt Road and Parking Preventive M&R Policy

Preventive Pavement Distress Maintenance Policy - Asphalt Road and Parking					
Distress	Distress Severity	Description	Code	Work Type	Work Unit
1	Low	ALLIGATOR CR	NONE	No Localized M & R	-
1	Medium	ALLIGATOR CR	PA-AD	Patching - AC Deep	SqFt
1	High	ALLIGATOR CR	PA-AD	Patching - AC Deep	SqFt
2	Low	BLEEDING	NONE	No Localized M & R	-
2	Medium	BLEEDING	NONE	No Localized M & R	-
2	High	BLEEDING	SS-SG	Spread Sand or Gravel	SqFt
3	Low	BLOCK CRACKING	NONE	No Localized M & R	-
3	Medium	BLOCK CRACKING	CS-AC	Crack Sealing - AC	Ft
3	High	BLOCK CRACKING	CS-AC	Crack Sealing - AC	Ft
4	Low	BUMPS AND SAGS	NONE	No Localized M & R	-
4	Medium	BUMPS AND SAGS	PA-AS	Patching - AC Shallow	SqFt
4	High	BUMPS AND SAGS	PA-AS	Patching-AC Shallow	SqFt
5	Low	CORRUGATION	NONE	No Localized M & R	-
5	Medium	CORRUGATION	PA-AS	Patching - AC Shallow	SqFt
5	High	CORRUGATION	PA-AS	Patching - AC Shallow	SqFt
6	Low	DEPRESSION	NONE	No Localized M & R	-
6	Medium	DEPRESSION	PA-AD	Patching - AC Deep	SqFt
6	High	DEPRESSION	PA-AD	Patching - AC Deep	SqFt
7	Low	EDGE CRACKING	CS-AC	Crack Sealing - AC	Ft
7	Medium	EDGE CRACKING	CS-AC	Crack Sealing - AC	Ft
7	High	EDGE CRACKING	PA-AS	Patching - AC Shallow	SqFt

Preventive Pavement Distress Maintenance Policy - Asphalt Road and Parking					
Distress	**Distress Severity**	**Description**	**Code**	**Work Type**	**Work Unit**
8	Low	JOINT REFLECTION CRACKING	NONE	No Localized M & R	-
8	Medium	JOINT REFLECTION CRACKING	CS-AC	Crack Sealing - AC	Ft
8	High	JOINT REFLECTION CRACKING	PA-AS	Patching - AC Shallow	SqFt
9	Low	LANE/SHOULDER DROP-OFF	NONE	No Localized M & R	-
9	Medium	LANE/SHOULDER DROP-OFF	SH-LE	Shoulder leveling	Ft
9	High	LANE/SHOULDER DROP-OFF	SH-LE	Shoulder leveling	Ft
10	Low	LONG & TRANS CRACKING	NONE	No Localized M & R	-
10	Medium	LONG & TRANS CRACKING	CS-AC	Crack Sealing - AC	Ft
10	High	LONG & TRANS CRACKING	PA-AS	Patching-AC Shallow	SqFt
11	Low	PATCHING & UTILITY CUT PATCHING	NONE	No Localized M & R	-
11	Medium	PATCHING & UTILITY CUT PATCHING	NONE	No Localized M & R	-
11	High	PATCHING & UTILITY CUT PATCHING	PA-AD	Patching - AC Deep	SqFt
12	N/A	POLISHED AGGREGATE	NONE	No Localized M & R	-
13	Low	POTHOLES	PA-AS	Patching - AC Shallow	SqFt
13	Medium	POTHOLES	PA-AD	Patching - AC Deep	SqFt
13	High	POTHOLES	PA-AD	Patching - AC Deep	SqFt
14	Low	RAILROAD CROSSING	NONE	No Localized M & R	-
14	Medium	RAILROAD CROSSING	NONE	No Localized M & R	-
14	High	RAILROAD CROSSING	NONE	No Localized M & R	-
15	Low	RUTTING	NONE	No Localized M & R	-
15	Medium	RUTTING	PA-AD	Patching - AC Deep	SqFt
15	High	RUTTING	PA-AD	Patching - AC Deep	SqFt
16	Low	SHOVING	NONE	No Localized M & R	-
16	Medium	SHOVING	PA-AS	Patching - AC Shallow	SqFt
16	High	SHOVING	PA-AS	Patching - AC Shallow	SqFt
17	Low	SLIPPAGE CRACKING	NONE	No Localized M & R	-
17	Medium	SLIPPAGE CRACKING	PA-AS	Patching – AC Shallow	SqFt
17	High	SLIPPAGE CRACKING	PA-AS	Patching- AC Shallow	SqFt
18	Low	SWELL	NONE	No Localized M & R	-
18	Medium	SWELL	NONE	No Localized M & R	-
18	High	SWELL	PA-AS	Patching-AC Shallow	SqFt
19	Low	RAVELING	NONE	No Localized M & R	-
19	Medium	RAVELING	NONE	No Localized M & R	-
19	High	RAVELING	NONE	No Localized M & R	-
20	Low	WEATHERING	NONE	No Localized M & R	-
20	Medium	WEATHERING	NONE	No Localized M & R	-
20	High	WEATHERING	NONE	No Localized M & R	-

Table A-13 Concrete Road and Parking Preventive M&R Policy

Road and Parking Concrete Pavement Distress Maintenance Policy					
Distress	**Distress Severity**	**Description**	**Code**	**Work Type**	**Work Unit**
21	Low	BLOWUP/BUCKLING	NONE	No Localized M & R	-
21	Medium	BLOWUP/BUCKLING	PA-PF	Patching - PCC Full Depth	SqFt
21	High	BLOWUP/BUCKLING	SL-PC	Slab Replacement - PCC	SqFt
22	Low	CORNER BREAK	NONE	No Localized M & R	-
22	Medium	CORNER BREAK	CS-PC	Crack Sealing - PCC	SqFt
22	High	CORNER BREAK	PA-PF	Patching - PCC Full Depth	SqFt
23	Low	DIVIDED SLAB	NONE	No Localized M & R	-
23	Medium	DIVIDED SLAB	SL-PC	Slab Replacement - PCC	SqFt
23	High	DIVIDED SLAB	SL-PC	Slab Replacement - PCC	SqFt
24	Low	DURABILITY CRACK	NONE	No Localized M & R	-
24	Medium	DURABILITY CRACK	PA-PP	Patching - PCC Partial Depth	SqFt
24	High	DURABILITY CRACK	PA-PF	Patching - PCC Full Depth	SqFt
25	Low	FAULTING	NONE	No Localized M & R	-
25	Medium	FAULTING	GR-PP	Grinding (Localized)	SqFt
25	High	FAULTING	GR-PP	Grinding (Localized)	Ft
26	Low	JOINT SEAL DAMAGE	NONE	No Localized M & R	-
26	Medium	JOINT SEAL DAMAGE	JS-LC	Joint Seal (Localized)	Ft
26	High	JOINT SEAL DAMAGE	JS-LC	Joint Seal (Localized)	Ft
27	Low	LANE/SHOULDER DROP	NONE	No Localized M & R	-
27	Medium	LANE/SHOULDER DROP	SH-LE	Shoulder leveling	Ft
27	High	LANE/SHOULDER DROP	SH-LE	Shoulder leveling	Ft
28	Low	LINEAR CRACKING	NONE	No Localized M & R	-
28	Medium	LINEAR CRACKING	CS-PC	Crack Sealing - PCC	Ft
28	High	LINEAR CRACKING	SL-PC	Slab Replacement - PCC	SqFt
29	Low	PATCHING (LARGE)	NONE	No Localized M & R	-
29	Medium	PATCHING (LARGE)	NONE	No Localized M & R	-
29	High	PATCHING (LARGE)	PA-PF	Patching - PCC Full Depth	SqFt
30	Low	PATCHING (SMALL)	NONE	No Localized M & R	-
30	Medium	PATCHING (SMALL)	NONE	No Localized M & R	-
30	High	PATCHING (SMALL)	PA-PP	Patching - PCC Partial Depth	SqFt
31	NA	POLISHED AGGREGATE	NONE	No Localized M & R	-
32	NA	POPOUTS	NONE	No Localized M & R	-
33	NA	PUMPING	JS-LC	Joint Seal (Localized)	Ft
34	Low	PUNCHOUT	NONE	No Localized M & R	-
34	Medium	PUNCHOUT	PA-PF	Patching-PCC Full Depth	SqFt
34	High	PUNCHOUT	SL-PC	Slab Replacement - PCC	SqFt
35	Low	RAILROAD CROSSING	NONE	No Localized M & R	-
35	Medium	RAILROAD CROSSING	NONE	No Localized M & R	-

Road and Parking Concrete Pavement Distress Maintenance Policy					
Distress	**Distress Severity**	**Description**	**Code**	**Work Type**	**Work Unit**
35	High	RAILROAD CROSSING	NONE	No Localized M & R	-
36	Low	SCALING	NONE	No Localized M & R	-
36	Medium	SCALING	NONE	No Localized M & R	-
36	High	SCALING	PA-PP	Patching - PCC Partial Depth	SqFt
37	NA	SHRINKAGE CRACKS	NONE	No Localized M & R	-
38	Low	SPALLING, CORNER	NONE	No Localized M & R	-
38	Medium	SPALLING, CORNER	PA-PP	Patching - PCC Partial Depth	SqFt
38	High	SPALLING, CORNER	PA-PP	Patching - PCC Partial Depth	SqFt
39	Low	SPALLING, JOINT	NONE	No Localized M & R	-
39	Medium	SPALLING, JOINT	PA-PP	Patching - PCC Partial Depth	SqFt
39	High	SPALLING, JOINT	PA-PP	Patching - PCC Partial Depth	SqFt

A-3.3 Global Maintenance Policies.

Tables A-14 through A-17 provide standard global maintenance and repair policies for asphalt and concrete airfield and road and parking pavement. See UFC 3-270-01 and UFC 3-250-03 for more details on global policy.

Table A-14 Asphalt Airfield Global M&R Policy

Global M&R Policy - Asphalt Airfield	
Distress Type	**Work Type**
Work type for minimal distress	Surface seal - fog seal
Work type for climate-related distress	Surface seal - rejuvenating
Work type for skid-causing distress	Surface treatment - slurry seal

Table A-15 Concrete Airfield Global M&R Policy

Global M&R Policy - Concrete Airfield	
Distress Type	**Work Type**
Work type for minimal distress	No global M&R
Work type for climate-related distress	Joint seal - silicone
Work type for skid-causing distress	No global M&R

Table A-16 Asphalt Road and Parking Global M&R Policy

Global M&R Policy - Asphalt Roads and Parking	
Distress Type	**Work Type**
Work type for minimal distress	Surface seal - fog seal
Work type for climate-related distress	Surface seal - rejuvenating
Work type for skid-causing distress	Surface treatment - slurry seal

Table A-17 Concrete Road and Parking Global M&R Policy

Global M&R Policy - Concrete Roads and Parking	
Distress Type	**Work Type**
Work type for minimal distress	No global M&R
Work type for climate-related distress	Joint seal - silicone
Work type for skid-causing distress	No global M&R

A-4 CONSEQUENCE OF MAINTENANCE POLICY TABLES.

The following consequence of maintenance policy tables (Tables A-18 through A-28) do not cover all potential alternatives for all distresses and work types but focus on the implementation of standard maintenance policy tables in this UFC.

Table A-18 Crack Sealing - AC

Crack Sealing - AC Consequence of Maintenance Policy					
Distress	**Description**	**Severity**	**New Distress**	**New Description**	**New Severity**
3	BLOCK CR	Low	3	BLOCK CR	Low
3	BLOCK CR	Medium	3	BLOCK CR	Low
3	BLOCK CR	High	3	BLOCK CR	Medium
7	EDGE CR	Low	7	EDGE CR	Low
7	EDGE CR	Medium	7	EDGE CR	Low
7	EDGE CR	High	7	EDGE CR	Medium
8	JT REF. CR	Low	8	JT REF. CR	Low
8	JT REF. CR	Medium	8	JT REF. CR	Low
8	JT REF. CR	High	8	JT REF. CR	Medium
10	L & T CR	Low	10	L & T CR	Low
10	L & T CR	Medium	10	L & T CR	Low
10	L & T CR	High	10	L & T CR	Medium
43	BLOCK CR	Low	43	BLOCK CR	Low
43	BLOCK CR	Medium	43	BLOCK CR	Low

Crack Sealing - AC Consequence of Maintenance Policy					
Distress	**Description**	**Severity**	**New Distress**	**New Description**	**New Severity**
43	BLOCK CR	High	43	BLOCK CR	Medium
47	JT REF. CR	Low	47	JT REF. CR	Low
47	JT REF. CR	Medium	47	JT REF. CR	Low
47	JT REF. CR	High	47	JT REF. CR	Medium
48	L & T CR	Low	48	L & T CR	Low
48	L & T CR	Medium	48	L & T CR	Low
48	L & T CR	High	48	L & T CR	Medium

Table A-19 Grinding (Localized)

Grinding (Localized) Consequence of Maintenance Policy					
Distress	**Description**	**Severity**	**New Distress**	**New Description**	**New Severity**
44	CORRUGATION	Low	0	0	N/A
44	CORRUGATION	Medium	0	0	N/A
44	CORRUGATION	High	0	0	N/A
25	FAULTING	Low	0	0	N/A
25	FAULTING	Medium	0	0	N/A
25	FAULTING	High	0	0	N/A
71	FAULTING	Low	0	0	N/A
71	FAULTING	Medium	0	0	N/A
71	FAULTING	High	0	0	N/A

Table A-20 Patching – AC Deep

Patching - AC Deep Consequence of Maintenance Policy					
Distress	**Description**	**Severity**	**New Distress**	**New Description**	**New Severity**
1	ALLIGATOR CR	Low	11	PATCH/UT CUT	Low
1	ALLIGATOR CR	Medium	11	PATCH/UT CUT	Low
1	ALLIGATOR CR	High	11	PATCH/UT CUT	Low
6	DEPRESSION	Low	11	PATCH/UT CUT	Low
6	DEPRESSION	Medium	11	PATCH/UT CUT	Low
6	DEPRESSION	High	11	PATCH/UT CUT	Low
11	PATCH/UT CUT	Low	11	PATCH/UT CUT	Low
11	PATCH/UT CUT	Medium	11	PATCH/UT CUT	Low
11	PATCH/UT CUT	High	11	PATCH/UT CUT	Low
13	POTHOLE	Low	11	PATCH/UT CUT	Low
13	POTHOLE	Medium	11	PATCH/UT CUT	Low
13	POTHOLE	High	11	PATCH/UT CUT	Low
15	RUTTING	Low	11	PATCH/UT CUT	Low
15	RUTTING	Medium	11	PATCH/UT CUT	Low
15	RUTTING	High	11	PATCH/UT CUT	Low
41	ALLIGATOR CR	Low	50	PATCHING	Low

Patching - AC Deep Consequence of Maintenance Policy					
Distress	**Description**	**Severity**	**New Distress**	**New Description**	**New Severity**
41	ALLIGATOR CR	Medium	50	PATCHING	Low
41	ALLIGATOR CR	High	50	PATCHING	Low
44	CORRUGATION	Low	50	PATCHING	Low
44	CORRUGATION	Medium	50	PATCHING	Low
44	CORRUGATION	High	50	PATCHING	Low
45	DEPRESSION	Low	50	PATCHING	Low
45	DEPRESSION	Medium	50	PATCHING	Low
45	DEPRESSION	High	50	PATCHING	Low
50	PATCHING	Low	50	PATCHING	Low
50	PATCHING	Medium	50	PATCHING	Low
50	PATCHING	High	50	PATCHING	Low
53	RUTTING	Low	50	PATCHING	Low
53	RUTTING	Medium	50	PATCHING	Low
53	RUTTING	High	50	PATCHING	Low
54	SHOVING	Low	50	PATCHING	Low
54	SHOVING	Medium	50	PATCHING	Low
54	SHOVING	High	50	PATCHING	Low
56	SWELLING	Low	50	PATCHING	Low
56	SWELLING	Medium	50	PATCHING	Low
56	SWELLING	High	50	PATCHING	Low

Table A-21 Patching – AC Shallow

Patching - AC Shallow Consequence of Maintenance Policy					
Distress	**Description**	**Severity**	**New Distress**	**New Description**	**New Severity**
4	BUMPS/SAGS	Low	11	PATCH/UT CUT	Low
4	BUMPS/SAGS	Medium	11	PATCH/UT CUT	Low
4	BUMPS/SAGS	High	11	PATCH/UT CUT	Low
5	CORRUGATION	Low	11	PATCH/UT CUT	Low
5	CORRUGATION	Medium	11	PATCH/UT CUT	Low
5	CORRUGATION	High	11	PATCH/UT CUT	Low
7	EDGE CR	Low	11	PATCH/UT CUT	Low
7	EDGE CR	Medium	11	PATCH/UT CUT	Low
7	EDGE CR	High	11	PATCH/UT CUT	Low
8	JT REF. CR	Low	11	PATCH/UT CUT	Low
8	JT REF. CR	Medium	11	PATCH/UT CUT	Low
8	JT REF. CR	High	11	PATCH/UT CUT	Low
10	L & T CR	Low	11	PATCH/UT CUT	Low
10	L & T CR	Medium	11	PATCH/UT CUT	Low
10	L & T CR	High	11	PATCH/UT CUT	Low

Patching - AC Shallow Consequence of Maintenance Policy					
Distress	**Description**	**Severity**	**New Distress**	**New Description**	**New Severity**
13	POTHOLE	Low	11	PATCH/UT CUT	Low
13	POTHOLE	Medium	11	PATCH/UT CUT	Low
13	POTHOLE	High	11	PATCH/UT CUT	Low
16	SHOVING	Low	11	PATCH/UT CUT	Low
16	SHOVING	Medium	11	PATCH/UT CUT	Low
16	SHOVING	High	11	PATCH/UT CUT	Low
17	SLIPPAGE CR	Low	11	PATCH/UT CUT	Low
17	SLIPPAGE CR	Medium	11	PATCH/UT CUT	Low
17	SLIPPAGE CR	High	11	PATCH/UT CUT	Low
18	SWELL	Low	11	PATCH/UT CUT	Low
18	SWELL	Medium	11	PATCH/UT CUT	Low
18	SWELL	High	11	PATCH/UT CUT	Low
19	RAVELING	Low	11	PATCH/UT CUT	Low
19	RAVELING	Medium	11	PATCH/UT CUT	Low
19	RAVELING	High	11	PATCH/UT CUT	Low
20	WEATHERING	Low	11	PATCH/UT CUT	Low
20	WEATHERING	Medium	11	PATCH/UT CUT	Low
20	WEATHERING	High	11	PATCH/UT CUT	Low
43	BLOCK CR	Low	50	PATCHING	Low
43	BLOCK CR	Medium	50	PATCHING	Low
43	BLOCK CR	High	50	PATCHING	Low
46	JET BLAST	X	50	PATCHING	Low
49	OIL SPILLAGE	X	50	PATCHING	Low
50	PATCHING	Low	50	PATCHING	Low
50	PATCHING	Medium	50	PATCHING	Low
50	PATCHING	High	50	PATCHING	Low
51	POLISHED AG	X	50	PATCHING	Low
52	RAVELING	Low	50	PATCHING	Low
52	RAVELING	Medium	50	PATCHING	Low
52	RAVELING	High	50	PATCHING	Low
54	SHOVING	Low	50	PATCHING	Low
54	SHOVING	Medium	50	PATCHING	Low
54	SHOVING	High	50	PATCHING	Low
55	SLIPPAGE CR	X	50	PATCHING	Low
56	SWELLING	Low	50	PATCHING	Low
56	SWELLING	Medium	50	PATCHING	Low
56	SWELLING	High	50	PATCHING	Low
57	WEATHERING	Low	50	PATCHING	Low
57	WEATHERING	Medium	50	PATCHING	Low
57	WEATHERING	High	50	PATCHING	Low

Table A-22 Shoulder Leveling

Shoulder Leveling Consequence of Maintenance Policy					
Distress	Description	Severity	New Distress	New Description	New Severity
9	LANE SH DROP	Low	0	0	N/A
9	LANE SH DROP	Medium	0	0	N/A
9	LANE SH DROP	High	0	0	N/A
27	LAND SH DROP	Low	0	0	N/A
27	LAND SH DROP	Medium	0	0	N/A
27	LAND SH DROP	High	0	0	N/A

Table A-23 Spread Sand or Gravel

Spread Sand or Gravel Consequence of Maintenance Policy					
Distress	Description	Severity	New Distress	New Description	New Severity
2	BLEEDING	Low	2	BLEEDING	Low
2	BLEEDING	Medium	2	BLEEDING	Low
2	BLEEDING	High	2	BLEEDING	Medium

Table A-24 Joint Seal Localized

Joint Seal (Localized) Consequence of Maintenance Policy					
Distress	Description	Severity	New Distress	New Description	New Severity
26	JT SEAL DMG	Low	0	0	N/A
26	JT SEAL DMG	Medium	0	0	N/A
26	JT SEAL DMG	High	0	0	N/A
33	PUMPING	X	0	0	N/A
65	JT SEAL DMG	Low	0	0	N/A
65	JT SEAL DMG	Medium	0	0	N/A
65	JT SEAL DMG	High	0	0	N/A
69	PUMPING	X	0	0	N/A

Table A-25 Crack Sealing PCC

Crack Sealing PCC Consequence of Maintenance Policy					
Distress	**Description**	**Severity**	**New Distress**	**New Description**	**New Severity**
22	CORNER BREAK	Low	22	CORNER BREAK	Low
22	CORNER BREAK	Medium	22	CORNER BREAK	Low
22	CORNER BREAK	High	22	CORNER BREAK	Medium
28	LINEAR CR	Low	28	LINEAR CR	Low
28	LINEAR CR	Medium	28	LINEAR CR	Low
28	LINEAR CR	High	28	LINEAR CR	Medium
62	CORNER BREAK	Low	62	CORNER BREAK	Low
62	CORNER BREAK	Medium	62	CORNER BREAK	Low
62	CORNER BREAK	High	62	CORNER BREAK	Medium
63	LINEAR CR	Low	63	LINEAR CR	Low
63	LINEAR CR	Medium	63	LINEAR CR	Low
63	LINEAR CR	High	63	LINEAR CR	Medium

Table A-26 Patching - PCC Full Depth

Patching - PCC Full Depth Consequence of Maintenance Policy					
Distress	**Description**	**Severity**	**New Distress**	**New Description**	**New Severity**
21	BLOW UP	High	29	LARGE PATCH	Low
21	BLOW UP	Low	29	LARGE PATCH	Low
21	BLOW UP	Medium	29	LARGE PATCH	Low
22	CORNER BREAK	High	29	LARGE PATCH	Low
22	CORNER BREAK	Low	29	LARGE PATCH	Low
22	CORNER BREAK	Medium	29	LARGE PATCH	Low
24	DURABIL. CR	High	29	LARGE PATCH	Low
24	DURABIL. CR	Low	29	LARGE PATCH	Low
24	DURABIL. CR	Medium	29	LARGE PATCH	Low
29	LARGE PATCH	High	29	LARGE PATCH	Low
29	LARGE PATCH	Medium	29	LARGE PATCH	Low
30	SMALL PATCH	High	30	SMALL PATCH	Low
34	PUNCHOUT	High	29	LARGE PATCH	Low
34	PUNCHOUT	Low	29	LARGE PATCH	Low
34	PUNCHOUT	Medium	29	LARGE PATCH	Low
61	BLOW-UP	High	67	LARGE PATCH	Low
61	BLOW-UP	Low	67	LARGE PATCH	Low
61	BLOW-UP	Medium	67	LARGE PATCH	Low
62	CORNER BREAK	High	67	LARGE PATCH	Low
62	CORNER BREAK	Low	67	LARGE PATCH	Low
62	CORNER BREAK	Medium	67	LARGE PATCH	Low
64	DURABIL. CR	High	67	LARGE PATCH	Low

Patching - PCC Full Depth Consequence of Maintenance Policy					
Distress	**Description**	**Severity**	**New Distress**	**New Description**	**New Severity**
64	DURABIL. CR	Low	67	LARGE PATCH	Low
64	DURABIL. CR	Medium	67	LARGE PATCH	Low
66	SMALL PATCH	High	67	LARGE PATCH	Low
66	SMALL PATCH	Low	67	LARGE PATCH	Low
66	SMALL PATCH	Medium	67	LARGE PATCH	Low
67	LARGE PATCH	High	67	LARGE PATCH	Low
67	LARGE PATCH	Medium	67	LARGE PATCH	Low
68	POPOUTS	X	67	LARGE PATCH	Low
76	ASR	High	67	LARGE PATCH	Low
76	ASR	Low	67	LARGE PATCH	Low
76	ASR	Medium	67	LARGE PATCH	Low

Table A-27 Patching – PCC Partial Depth

Patching - PCC Partial-Depth Consequence of Maintenance Policy					
Distress	**Description**	**Severity**	**New Distress**	**New Description**	**New Severity**
24	DURABIL. CR	Low	29	LARGE PATCH	Low
24	DURABIL. CR	Medium	29	LARGE PATCH	Low
24	DURABIL. CR	High	29	LARGE PATCH	Low
30	SMALL PATCH	Low	30	SMALL PATCH	Low
30	SMALL PATCH	Medium	30	SMALL PATCH	Low
30	SMALL PATCH	High	30	SMALL PATCH	Low
36	SCALING	Low	29	LARGE PATCH	Low
36	SCALING	Medium	29	LARGE PATCH	Low
36	SCALING	High	29	LARGE PATCH	Low
38	CORNER SPALL	Low	30	SMALL PATCH	Low
38	CORNER SPALL	Medium	30	SMALL PATCH	Low
38	CORNER SPALL	High	29	LARGE PATCH	Low
39	JOINT SPALL	Low	30	SMALL PATCH	Low
39	JOINT SPALL	Medium	29	LARGE PATCH	Low
39	JOINT SPALL	High	29	LARGE PATCH	Low
66	SMALL PATCH	Low	67	LARGE PATCH	Low
66	SMALL PATCH	Medium	67	LARGE PATCH	Low
66	SMALL PATCH	High	67	LARGE PATCH	Low
67	LARGE PATCH	Low	67	LARGE PATCH	Low
67	LARGE PATCH	Medium	67	LARGE PATCH	Low
67	LARGE PATCH	High	67	LARGE PATCH	Low
70	SCALING	Low	67	LARGE PATCH	Low
70	SCALING	Medium	67	LARGE PATCH	Low
70	SCALING	High	67	LARGE PATCH	Low
74	JOINT SPALL	Low	66	SMALL PATCH	Low

Patching - PCC Partial-Depth Consequence of Maintenance Policy					
Distress	Description	Severity	New Distress	New Description	New Severity
74	JOINT SPALL	Medium	67	LARGE PATCH	Low
74	JOINT SPALL	High	67	LARGE PATCH	Low
75	CORNER SPALL	Low	66	SMALL PATCH	Low
75	CORNER SPALL	Medium	66	SMALL PATCH	Low
75	CORNER SPALL	High	67	LARGE PATCH	Low
76	ASR	Low	67	LARGE PATCH	Low
76	ASR	Medium	67	LARGE PATCH	Low
76	ASR	High	67	LARGE PATCH	Low

Table A-28 Slab Replacement PCC

Slab Replacement - PCC Consequence of Maintenance Policy					
Distress	Description	Severity	New Distress	New Description	New Severity
21	BLOW UP	Low	0	0	N/A
21	BLOW UP	Medium	0	0	N/A
21	BLOW UP	High	0	0	N/A
22	CORNER BREAK	Low	0	0	N/A
22	CORNER BREAK	Medium	0	0	N/A
22	CORNER BREAK	High	0	0	N/A
23	DIVIDED SLAB	Low	0	0	N/A
23	DIVIDED SLAB	Medium	0	0	N/A
23	DIVIDED SLAB	High	0	0	N/A
24	DURABIL. CR	Low	0	0	N/A
24	DURABIL. CR	Medium	0	0	N/A
24	DURABIL. CR	High	0	0	N/A
25	FAULTING	Low	0	0	N/A
25	FAULTING	Medium	0	0	N/A
25	FAULTING	High	0	0	N/A
28	LINEAR CR	Low	0	0	N/A
28	LINEAR CR	Medium	0	0	N/A
28	LINEAR CR	High	0	0	N/A
29	LARGE PATCH	Low	0	0	N/A
29	LARGE PATCH	Medium	0	0	N/A
29	LARGE PATCH	High	0	0	N/A
30	SMALL PATCH	Low	0	0	N/A
30	SMALL PATCH	Medium	0	0	N/A
30	SMALL PATCH	High	0	0	N/A
32	POPOUTS	X	0	0	N/A
33	PUMPING	X	0	0	N/A
34	PUNCHOUT	Low	0	0	N/A
34	PUNCHOUT	Medium	0	0	N/A

Slab Replacement - PCC Consequence of Maintenance Policy					
Distress	Description	Severity	New Distress	New Description	New Severity
34	PUNCHOUT	High	0	0	N/A
36	SCALING	Low	0	0	N/A
36	SCALING	Medium	0	0	N/A
36	SCALING	High	0	0	N/A
37	SHRINK CR	X	0	0	N/A
61	BLOW-UP	Low	0	0	N/A
61	BLOW-UP	Medium	0	0	N/A
61	BLOW-UP	High	0	0	N/A
62	CORNER BREAK	Low	0	0	N/A
62	CORNER BREAK	Medium	0	0	N/A
62	CORNER BREAK	High	0	0	N/A
63	LINEAR CR	Low	0	0	N/A
63	LINEAR CR	Medium	0	0	N/A
63	LINEAR CR	High	0	0	N/A
64	DURABIL. CR	Low	0	0	N/A
64	DURABIL. CR	Medium	0	0	N/A
64	DURABIL. CR	High	0	0	N/A
66	SMALL PATCH	Low	0	0	N/A
66	SMALL PATCH	Medium	0	0	N/A
66	SMALL PATCH	High	0	0	N/A
67	LARGE PATCH	Low	0	0	N/A
67	LARGE PATCH	Medium	0	0	N/A
67	LARGE PATCH	High	0	0	N/A
68	POPOUTS	X	0	0	N/A
69	PUMPING	X	0	0	N/A
70	SCALING	Low	0	0	N/A
70	SCALING	Medium	0	0	N/A
70	SCALING	High	0	0	N/A
71	FAULTING	Low	0	0	N/A
71	FAULTING	Medium	0	0	N/A
71	FAULTING	High	0	0	N/A
72	SHAT. SLAB	Low	0	0	N/A
72	SHAT. SLAB	Medium	0	0	N/A
72	SHAT. SLAB	High	0	0	N/A
73	SHRINKAGE CR	X	0	0	N/A
76	ASR	Low	0	0	N/A
76	ASR	Medium	0	0	N/A
76	ASR	High	0	0	N/A

A-5 ONE-YEAR UNCONSTRAINED WORK PLAN.

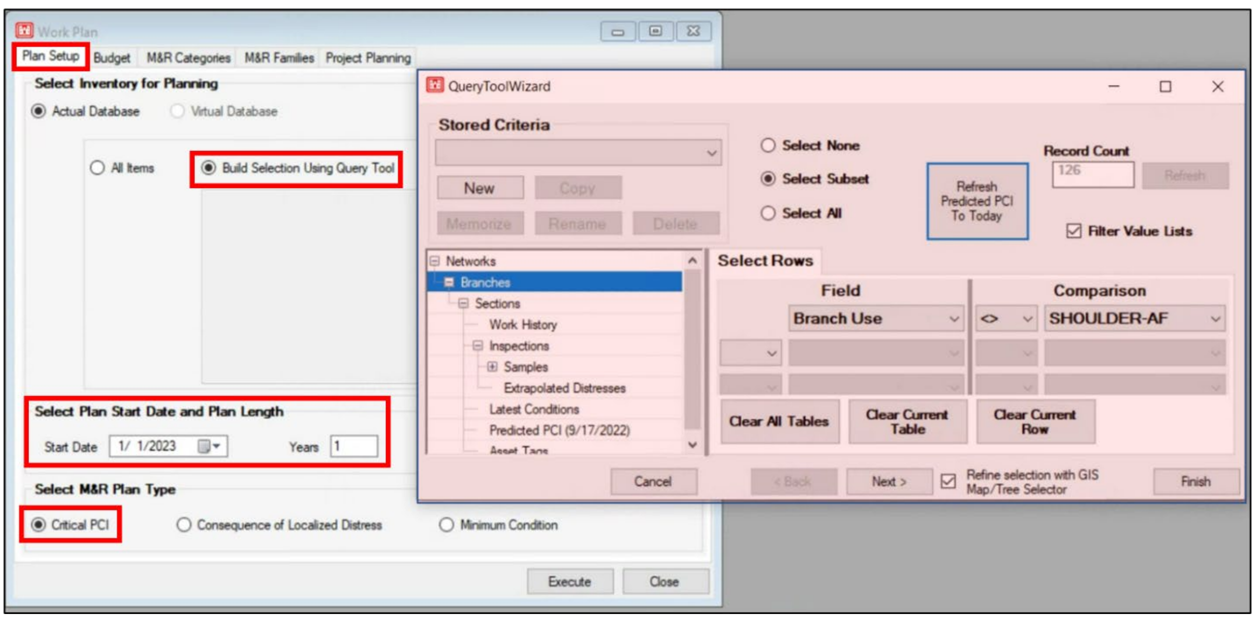
As described in paragraph 7-5.3, the one-year unconstrained work plan identifies all M&R requirements in all M&R categories to repair all sections in the current year. It is not typically used as the optimal critical PCI work plan because it is unrealistic to make all repairs in one year given funding, manpower, and contracting limitations. However, this work plan provides an indication of the magnitude of the requirements and, per paragraph 7-5.3, can be used to determine the facility condition index and develop Major M&R cost by condition tables.

A-5.1 Plan Setup Tab

This example demonstrates the steps to create a critical PCI unconstrained work plan for an airfield network. The procedure is the same for a road and parking area network. In this example, assume shoulders are not inspected, so there is no condition data available to define M&R requirements.

- Select the **Build Selection Using Query Tool** option to filter out the shoulders as shown in Figure A-1. If all sections in the network were inspected, including shoulders, select the **All Items** option on the **Plan Setup** tab.
- Set the plan start date to the first day of the next calendar year after the current PCI inspection date when the work plan is developed in conjunction with a PCI inspection. Use the first day of the calendar year after the current date when doing interim work plan updates.
- Set the plan length to one year.

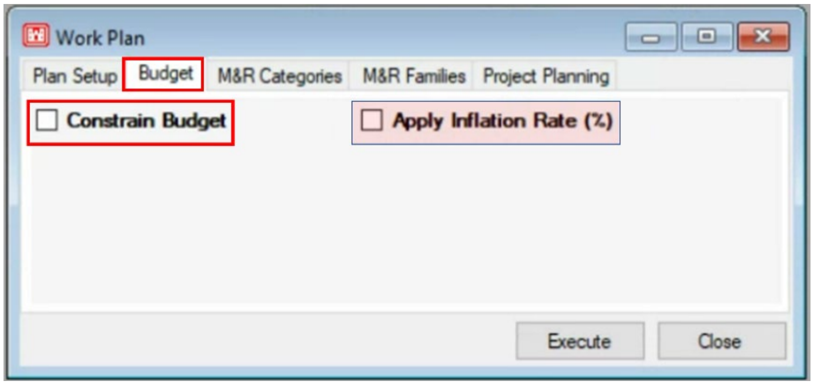
Figure A-1 Unconstrained Work Plan, Plan Setup Tab



A-5.2 Budget Tab.

Leave the **Constrain Budget** checkbox unchecked to develop an unconstrained budget. Leave the **Apply Inflation Rate (%)** checkbox unchecked as shown in Figure A-2 and discussed in paragraph 7-5.2.

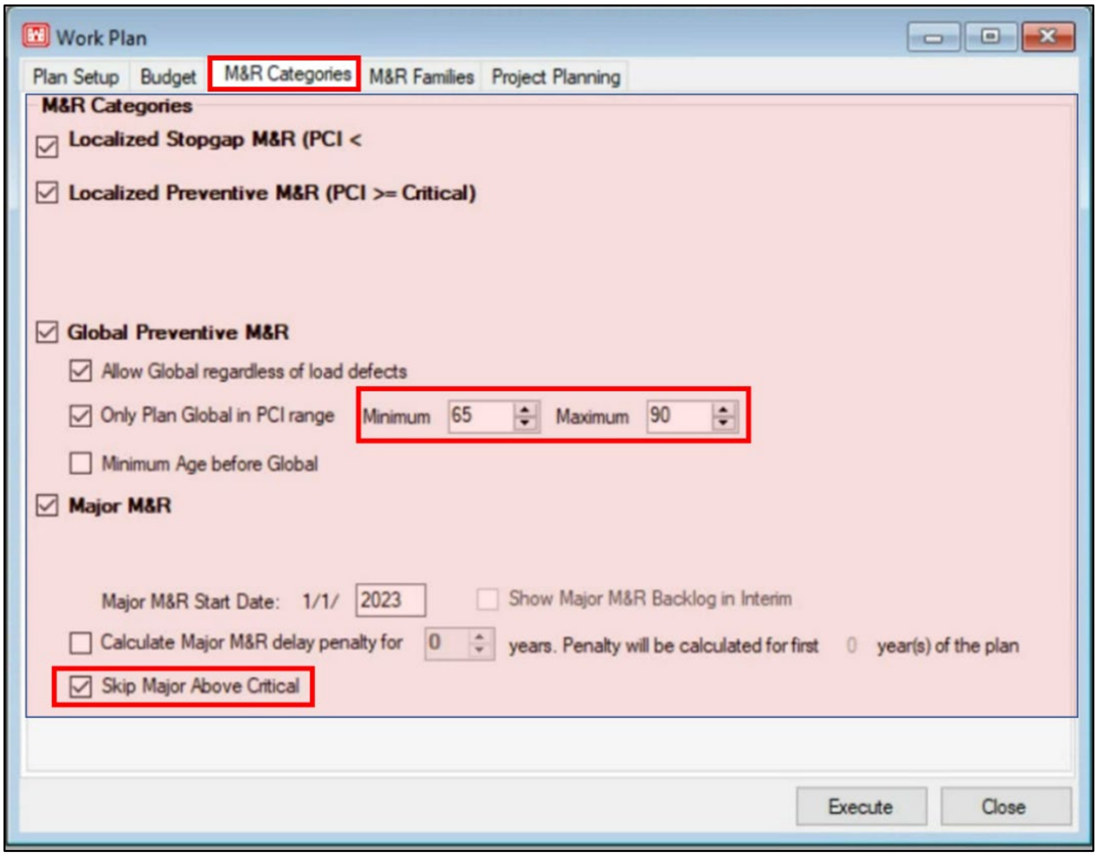
Figure A-2 Unconstrained Work Plan Setup Tab



A-5.3 M&R Categories Tab.

Since the unconstrained work plan identifies all current M&R requirements, select all M&R categories as shown in Figure A-3. This example applies global M&R regardless of load defects and generates global M&R requirements when the section PCI is between 65 and 90 (see paragraph 7-6.4). Check the **Skip Major Above Critical** box (see paragraph 7-6.4.2).

Figure A-3 Unconstrained Work Plan, M&R Categories Tab

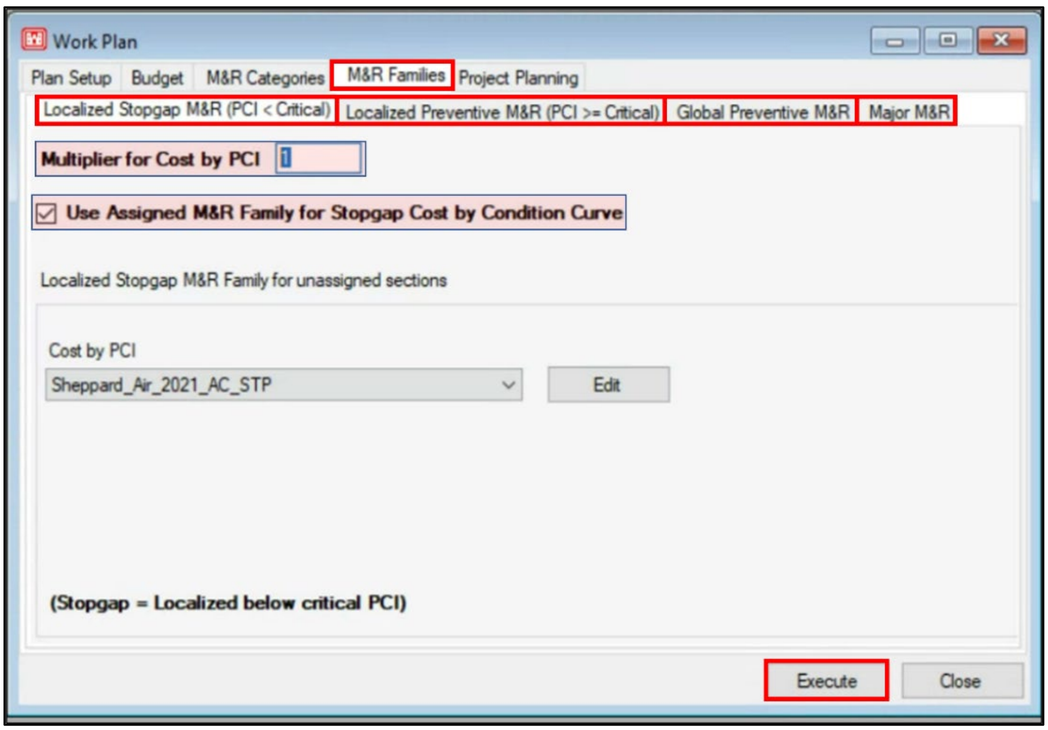


A-5.4 M&R Families Tab.

The example in Figure A-4 shows the **Localized Stopgap (M&R)** tab. Each tab for the other M&R families is similar.

- Set the value in the **Multiplier for Cost by PCI** box to 1.
- The **Use Assigned M&R Family for Stopgap Cost by Condition Curve** checkbox is checked by default for all M&R types. This example assumes all sections are assigned to the appropriate M&R families.
- The **Cost by PCI** option for unassigned sections is not used because all inspected sections are assigned to appropriate families.

Figure A-4 Unconstrained Work Plan, M&R Families Tab



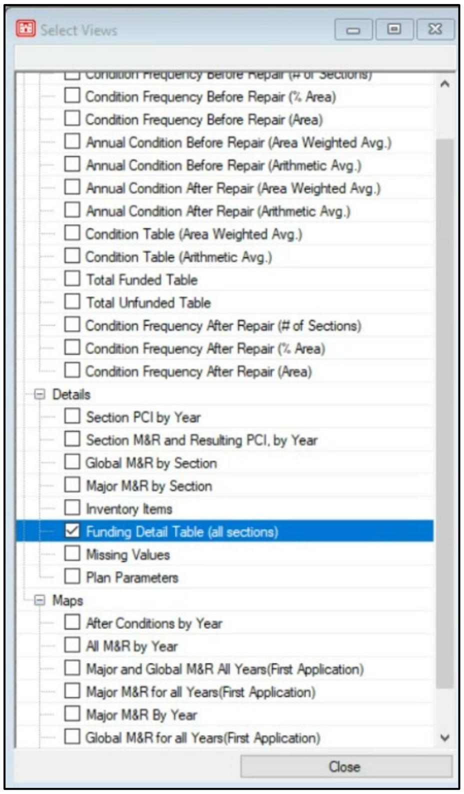
A-5.5 Project Planning Tab.

The **Project Planning** tab is not used when developing an unconstrained budget but is used when using PAVER to develop a PMP, as described in paragraph 7-8. Examples of how to use the **Project Planning** tab are provided in paragraphs A-5.5, A-6.5, A-7.5 and A-9.8.

A-5.6 Execute One-Year Unconstrained Work Plan.

Select **Execute** in the lower right-hand corner of the form as shown in Figure A-4. Once the work plan is generated, PAVER provides work plan views as shown in Figure A-5 at the Summary (Branch) level and the Detail (Section) level as well as map views of the data. These views are pre-defined reports that provide information on condition, plan parameters, missing values, M&R requirements, and costs. Any table in any of these views can be exported to Excel using a right-click and selecting the option to export to file (*.xlsx).

Figure A-5 One-Year Unconstrained Budget – Work Plan Views



- In this example, select **Funding Detail Table (all sections)**. When the table opens, right-click and select export to Excel.
- A pop-up window asks whether to include hidden columns. Respond yes.
- Open this report in Excel, unhide all of the columns.
- Find the **RPUID** column, select cut, and insert it between the **Branch ID** and **Section ID** columns.
- Sort the report by RPUID and arranging the columns as shown in Figure A-6. This allows the user to determine the M&R types and cost for each facility to determine the facility condition index or to develop Major M&R cost by condition tables, as described in paragraph 6-3.5 and paragraph 6-5.3.

Figure A-6 Funding Detail Table

Network ID	Branch ID	RPUID	Section ID	Avg Of Condition Before	Avg Of Condition After	Stop Gap Funded	Preventive Funded	Global Funded	Major Under Critical Funded	Work Type	Total
Sheppard	RW15R33L	524773	R09A1	85.09	85.09	$0.00	$11,659.60	$0.00	$0.00	Preventive	$11,659.60
Sheppard	RW15R33L	524773	R09A2	90.09	90.09	$0.00	$7,987.54	$0.00	$0.00	Preventive	$7,987.54
Sheppard	RW15R33L	524773	R10A1	86.09	86.09	$0.00	$7,712.88	$0.00	$0.00	Preventive	$7,712.88
Sheppard	RW15R33L	524773	R10A2	91.09	91.09	$0.00	$20,295.54	$0.00	$0.00	Preventive	$20,295.54
Sheppard	RW15R33L	524773	R11C1	88.09	88.09	$0.00	$170,972.59	$0.00	$0.00	Preventive	$170,972.59
Sheppard	RW15R33L	524773	R11C2	85.09	85.09	$0.00	$394,637.32	$0.00	$0.00	Preventive	$394,637.32
Sheppard	RW15R33L	524773	R12A1	85.09	85.09	$0.00	$6,726.84	$0.00	$0.00	Preventive	$6,726.84
Sheppard	RW15R33L	524773	R12A2	85.09	85.09	$0.00	$31,392.06	$0.00	$0.00	Preventive	$31,392.06
Sheppard	RW15R33L	524773	R13A1	82.09	82.09	$0.00	$12,708.28	$0.00	$0.00	Preventive	$12,708.28
Sheppard	RW15R33L	524773	R13A2	90.09	90.09	$0.00	$3,472.86	$0.00	$0.00	Preventive	$3,472.86
Sheppard	RW15C33C	524775	R04A1	94.09	94.09	$0.00	$7,455.88	$0.00	$0.00	Preventive	$7,455.88
Sheppard	RW15C33C	524775	R04A2	94.09	94.09	$0.00	$7,455.88	$0.00	$0.00	Preventive	$7,455.88
Sheppard	RW15C33C	524775	R05C1	67.42	100.00	$0.00	$0.00	$0.00	$109,264.93	Major Below Critical	$109,264.93
Sheppard	RW15C33C	524775	R05C2	75.42	78.81	$0.00	$3,598.83	$14,238.68	$0.00	Preventive + Global MR	$17,837.51
Sheppard	RW15C33C	524775	R06C1	64.42	100.00	$0.00	$0.00	$0.00	$33,249.59	Major Below Critical	$33,249.59
Sheppard	RW15C33C	524775	R06C2	72.42	75.81	$0.00	$1,349.12	$4,271.68	$0.00	Preventive + Global MR	$5,620.80
Sheppard	RW15C33C	524775	R07C1	65.42	100.00	$0.00	$0.00	$0.00	$717,011.18	Major Below Critical	$717,011.18
Sheppard	RW15C33C	524775	R07C2	72.42	75.81	$0.00	$29,230.76	$92,552.75	$0.00	Preventive + Global MR	$121,783.51
Sheppard	RW15C33C	524775	R08A1	96.09	96.09	$0.00	$4,932.77	$0.00	$0.00	Preventive	$4,932.77
Sheppard	RW15C33C	524775	R08A2	96.09	96.09	$0.00	$3,288.53	$0.00	$0.00	Preventive	$3,288.53
Sheppard	RW1735	524777	R14A1	86.42	89.81	$0.00	$1,100.63	$7,034.03	$0.00	Preventive + Global MR	$8,134.66

A-6 CONSTRAINED BACKLOG ELIMINATION WORK PLAN.

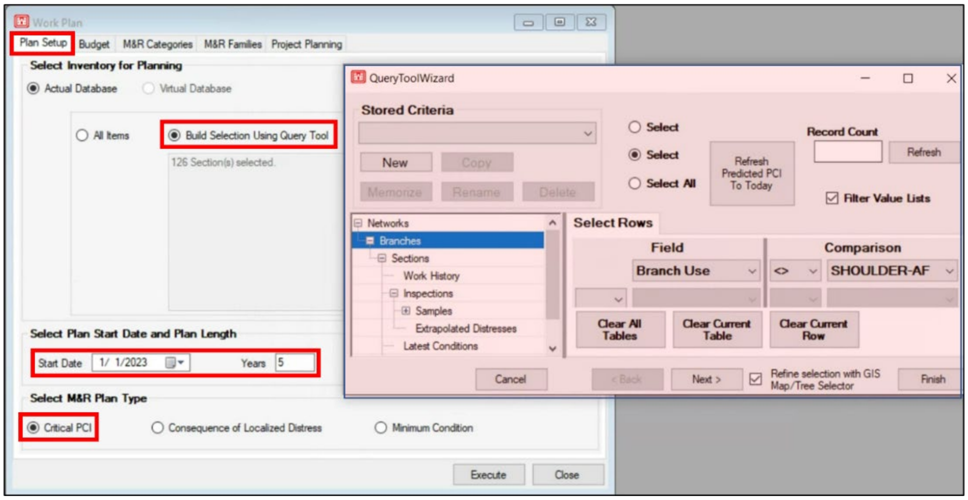
As described in paragraphs 7-5.4 and 7-5.7, the backlog elimination work plan identifies all M&R requirements in all M&R categories to repair all sections, but rather than doing it in one year, it addresses these requirements over multiple years. The standard used by the DoD is five years, although circumstances or specific mission requirements may require increasing this timeline. This work plan is typically selected as the optimal work plan used to develop the PMP when the average network PCI is below 85. The details of developing the PMP using the optimal critical PCI work plan are described in Chapter 8 and paragraph A-9.

A-6.1 Plan Setup Tab.

This example demonstrates the steps to create a critical PCI eliminate backlog work plan for an airfield network. The procedure is the same for a road and parking area network. In this example, assume shoulders are not inspected, so there is no condition data available to define M&R requirements.

- Select the **Build Selection Using Query Tool** option to filter out the shoulders, as shown in Figure A-7. If all sections in the network are inspected, select the **All Items** option on the **Plan Setup** tab.
- Set the plan start date to the first day of the next calendar year after the current PCI inspection date when the work plan is developed in conjunction with a PCI inspection. Use the first day of the calendar year after the current date when doing interim work plan updates.
- Set the plan length to five years.

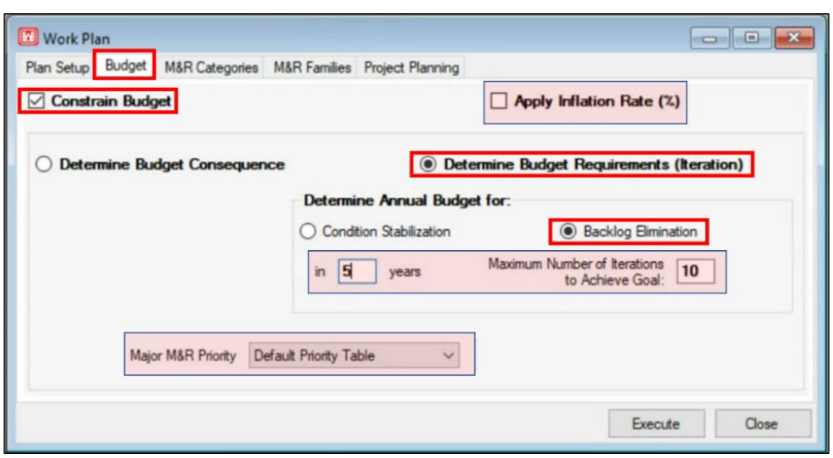
Figure A-7 Eliminate Backlog Work Plan, Plan Setup Tab



A-6.2 Budget Tab.

- Check the **Constrain Budget** checkbox to develop a constrained budget (Figure A-8).
- Leave the **Apply Inflation Rate (%)** checkbox unchecked (paragraph 7-5.2).
- Select the **Determine Budget Requirements (Iteration)** and **Backlog Elimination** options.
- Set up the plan to eliminate the backlog in five years.
- Leave **Maximum Number of Iterations to Achieve Goal** set to 10. This defines the number of times PAVER tries to develop a balanced budget in each of the five years.
- Use the **Default Priority Table** option in **Major M&R Priority** (paragraph 7-5.5).

Figure A-8 Eliminate Backlog Work Plan Setup Tab

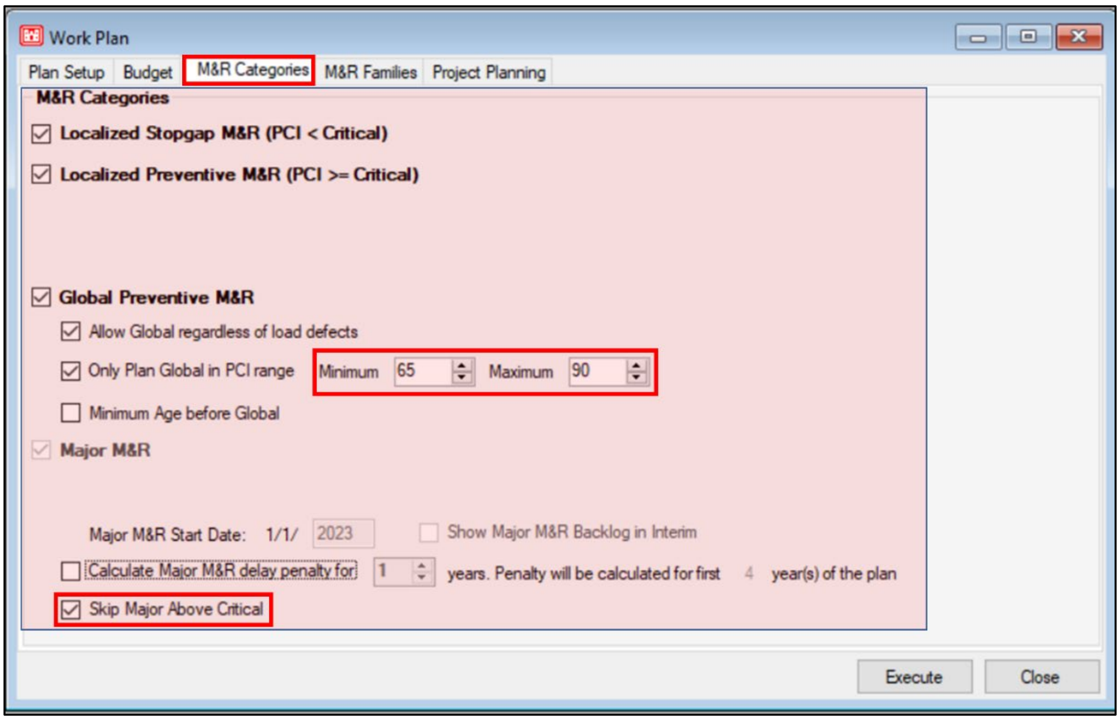


A-6.3 M&R Categories Tab.

Just as with the unconstrained work plan, the eliminate backlog work plan identifies all M&R requirements required to achieve the goal.

- Select all **M&R Categories** as shown in Figure A-9.
- This example applies global M&R regardless of load defects and generates global M&R requirements when the section PCI is between 65 and 90 (paragraph 7-6.3).
- Leave the **Calculate Major M&R delay penalty** box unchecked (paragraph 7-6.4).
- Check the **Skip Major Above Critical** box (paragraph 7-6.4.2).

Figure A-9 Eliminate Backlog Work Plan, M&R Categories Tab

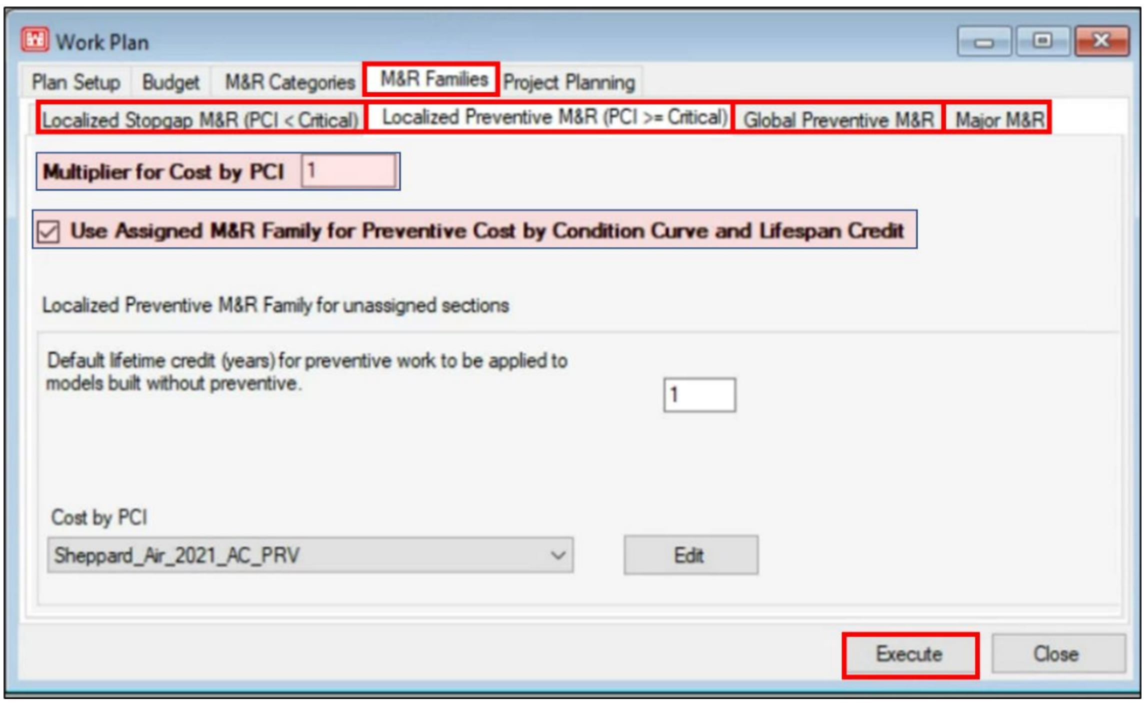


A-6.4 M&R Families Tab.

The example in Figure A-10 shows the **Localized Preventive M&R** tab. Each of the tabs for the other M&R families are similar.

- Set the value in the **Multiplier for Cost by PCI** box to 1.
- The **Use Assigned M&R Family for Preventive Cost by Condition Curve and Lifespan Credit** checkbox is checked by default for all M&R types. This example assumes all sections are assigned to the appropriate M&R families.
- The **Cost by PCI** option for unassigned sections is not used because all inspected sections are assigned to appropriate families.

Figure A-10 Eliminate Backlog Work Plan, M&R Families Tab



A-6.5 Project Planning Tab.

The **Project Planning** tab is used when using PAVER to develop a PMP, as described in paragraph 7-8. Examples of how to use the **Project Planning** tab are provided in paragraph A-9.

A-6.6 Execute Eliminate Backlog Work Plan.

Select **Execute** in the lower right-hand corner of the form, as shown in Figure A-10. Once the work plan is generated, as shown in Figure A-11, PAVER provides work plan views at the Summary (Branch) level and the Detail (Section) level as well as map views of the data. These views are pre-defined reports that provide information on condition, plan parameters, missing values, M&R requirements, and costs. Any table in any of these views can be exported to Excel using a right-click and selecting the option to export to file (*.xlsx).

- In this example, select **Funding Detail Table (all sections)**. When the table opens, right-click and select export to Excel.
- A pop-up window asks whether to include hidden columns. Respond yes.
- Open this report in Excel and unhide all of the columns.
- Use the Excel cut and insert cut functions to rearrange the columns in the table to look like the one in Figure A-12.
    - o Keep **Network ID**, **Branch ID**, and **Section ID** columns (C, D, and E) in the report.
    - o Either the **Date** column (F) or the **Work Year** column (I) can be used in the report to perform the sorting process outlined below.
    - o Hide the **Avg. of Condition Before** column and **After** column (G and H); they can be used later in the PMP development process.
    - o Move the **Branch Use** column (N), **Section Rank** column (O) and **Surface Type Current** column (P) to the right of the **Work Year** column (I).
    - o Move **Work Type** (column BB) to the right of the **Surface Type Current** column.
    - o Retain the **Stop Gap Funded**, **Preventive Funded**, **Global Funded**, **Major Under Critical Funded**, and **Total Funded** columns (J, L, AV, AY, and BE) in the report.
    - o Delete or hide the remaining columns.
- Use the Excel sort capability to sort the report by date, then **Branch Use**, then **Section Rank**. This procedure produces a prioritized list of requirements for each year in the plan.
- When the eliminate backlog work plan is selected as the optimal work plan, it is to develop the PMP as outlined in Chapter 8 and paragraph A-9.

Figure A-11 Eliminate Backlog Work Plan Views

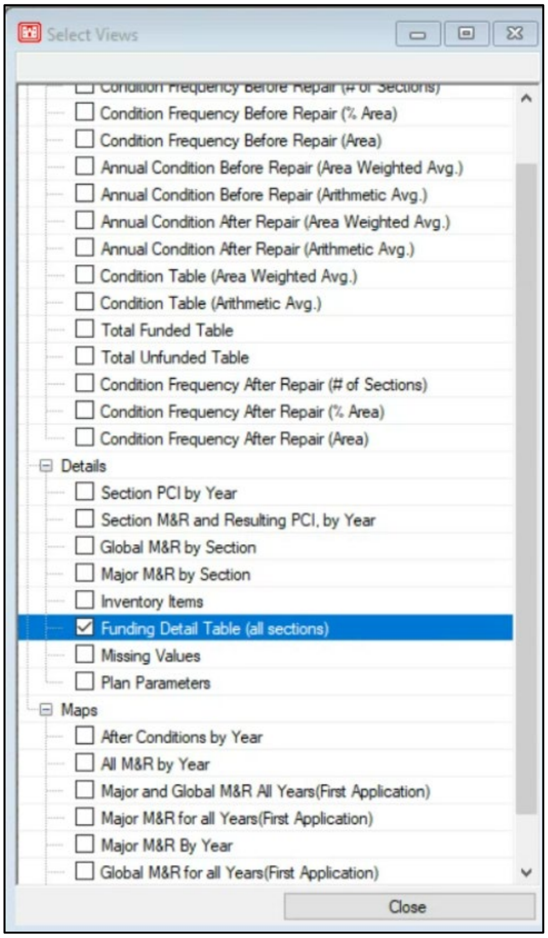


Figure A-12 Sorted Eliminate Backlog Work Plan

Network ID	Branch ID	Section ID	Work Year	Branch Use	Section Rank	Surface Type Current	Work Type	Stop Gap Funded	Preventive Funded	Global Funded	Major Under Critical Funded	Total Funded
Sheppard	RW15C33C	R04A1	2023	RUNWAY	P	PCC	Preventive	$0.00	$7,455.88	$0.00	$0.00	$7,455.88
Sheppard	RW15C33C	R04A2	2023	RUNWAY	P	PCC	Preventive	$0.00	$7,455.88	$0.00	$0.00	$7,455.88
Sheppard	RW15C33C	R05C1	2023	RUNWAY	P	AC	Major Below Critical	$0.00	$0.00	$0.00	$109,264.93	$109,264.93
Sheppard	RW15C33C	R05C2	2023	RUNWAY	P	AC	Preventive + Global MR	$0.00	$3,598.83	$14,238.68	$0.00	$17,837.51
Sheppard	RW15C33C	R06C1	2023	RUNWAY	P	AC	Major Below Critical	$0.00	$0.00	$0.00	$33,249.59	$33,249.59
Sheppard	RW15C33C	R06C2	2023	RUNWAY	P	AC	Preventive + Global MR	$0.00	$1,349.12	$4,271.68	$0.00	$5,620.80
Sheppard	RW15C33C	R07C1	2023	RUNWAY	P	AC	Major Below Critical	$0.00	$0.00	$0.00	$717,011.18	$717,011.18
Sheppard	RW15C33C	R07C2	2023	RUNWAY	P	AC	Preventive + Global MR	$0.00	$29,230.76	$92,552.75	$0.00	$121,783.51
Sheppard	RW15C33C	R08A1	2023	RUNWAY	P	PCC	Preventive	$0.00	$4,932.77	$0.00	$0.00	$4,932.77
Sheppard	RW15C33C	R08A2	2023	RUNWAY	P	PCC	Preventive	$0.00	$3,288.53	$0.00	$0.00	$3,288.53
Sheppard	RW15L33R	R01A1	2023	RUNWAY	P	PCC	Preventive	$0.00	$11,058.28	$0.00	$0.00	$11,058.28
Sheppard	RW15L33R	R01A2	2023	RUNWAY	P	PCC	Preventive	$0.00	$19,413.79	$0.00	$0.00	$19,413.79
Sheppard	RW15L33R	R02C1	2023	RUNWAY	P	AC	Preventive	$0.00	$2,300.37	$0.00	$0.00	$2,300.37
Sheppard	RW15L33R	R02C2	2023	RUNWAY	P	AC	Preventive	$0.00	$2,300.37	$0.00	$0.00	$2,300.37
Sheppard	RW15L33R	R03A1	2023	RUNWAY	P	PCC	Preventive	$0.00	$14,052.28	$0.00	$0.00	$14,052.28
Sheppard	RW15L33R	R03A2	2023	RUNWAY	P	PCC	Preventive	$0.00	$17,179.11	$0.00	$0.00	$17,179.11
Sheppard	RW15R33L	R09A1	2023	RUNWAY	P	PCC	Preventive	$0.00	$11,659.60	$0.00	$0.00	$11,659.60
Sheppard	RW15R33L	R09A2	2023	RUNWAY	P	PCC	Preventive	$0.00	$7,987.54	$0.00	$0.00	$7,987.54
Sheppard	RW15R33L	R10A1	2023	RUNWAY	P	PCC	Preventive	$0.00	$7,712.88	$0.00	$0.00	$7,712.88
Sheppard	RW15R33L	R10A2	2023	RUNWAY	P	PCC	Preventive	$0.00	$20,295.54	$0.00	$0.00	$20,295.54
Sheppard	RW15R33L	R11C1	2023	RUNWAY	P	PCC	Preventive	$0.00	$170,972.59	$0.00	$0.00	$170,972.59
Sheppard	RW15R33L	R11C2	2023	RUNWAY	P	PCC	Preventive	$0.00	$394,637.32	$0.00	$0.00	$394,637.32
Sheppard	RW15R33L	R12A1	2023	RUNWAY	P	PCC	Preventive	$0.00	$6,726.84	$0.00	$0.00	$6,726.84

A-7 CONSTRAINED CONDITION STABILIZATION WORK PLAN.

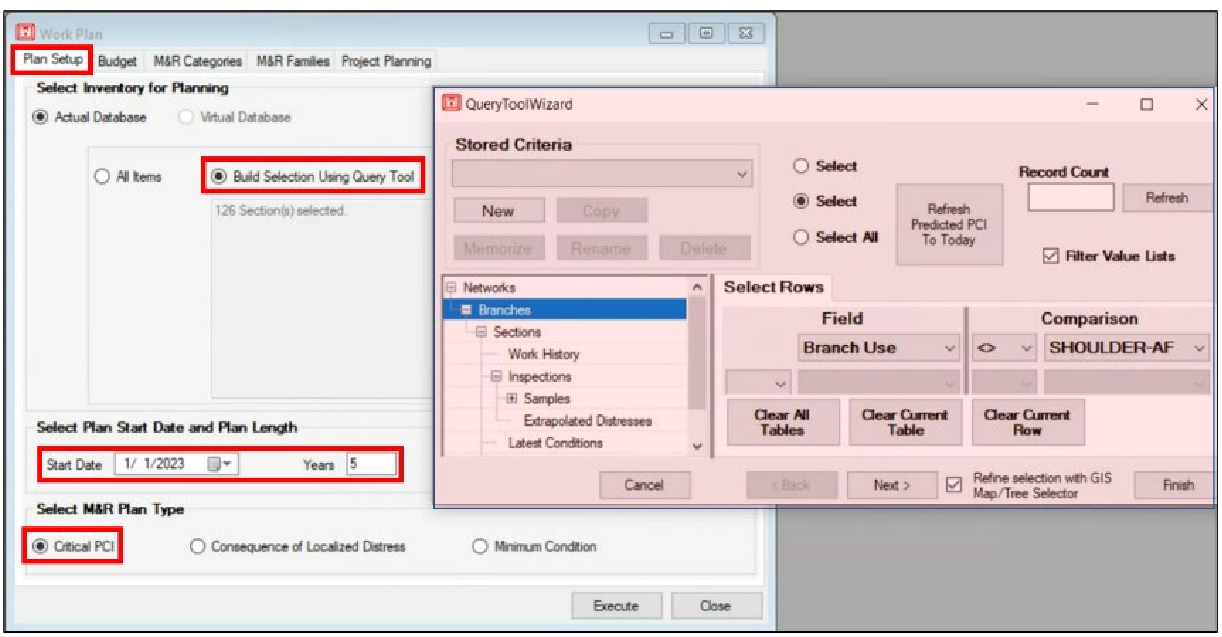
As described in paragraphs 7-5.4, 7-5.7, and 7-5.7.2, the condition stabilization work plan identifies all M&R requirements to maintain the condition of all sections within a defined tolerance for the defined number of years. The standard time frame used by the DoD is five years, although circumstances or specific mission requirements may require adjusting this timeline. This work plan is typically selected as the optimal work plan used to develop the PMP when the average network PCI is greater than or equal to 85. The details of developing the PMP using the optimal critical PCI work plan are described in Chapter 8 and paragraph A-9.

A-7.1 Plan Setup Tab.

This example demonstrates the steps to create a critical PCI condition stabilization work plan for an airfield network. The procedure is the same for a road and parking area network. In this example, assume shoulders are not inspected, so there is no condition data available to define M&R requirements.

- Select the **Build Selection Using Query Tool** option to filter out the shoulders, as shown in Figure A-13. If all sections in the network are inspected, select the **All Items** option on the **Plan Setup** tab.
- Set the plan start date to the first day of the next calendar year after the current PCI inspection date when the work plan is developed in conjunction with a PCI inspection. Use the first day of the calendar year after the current date when doing interim work plan updates.
- Set the plan length to five years.

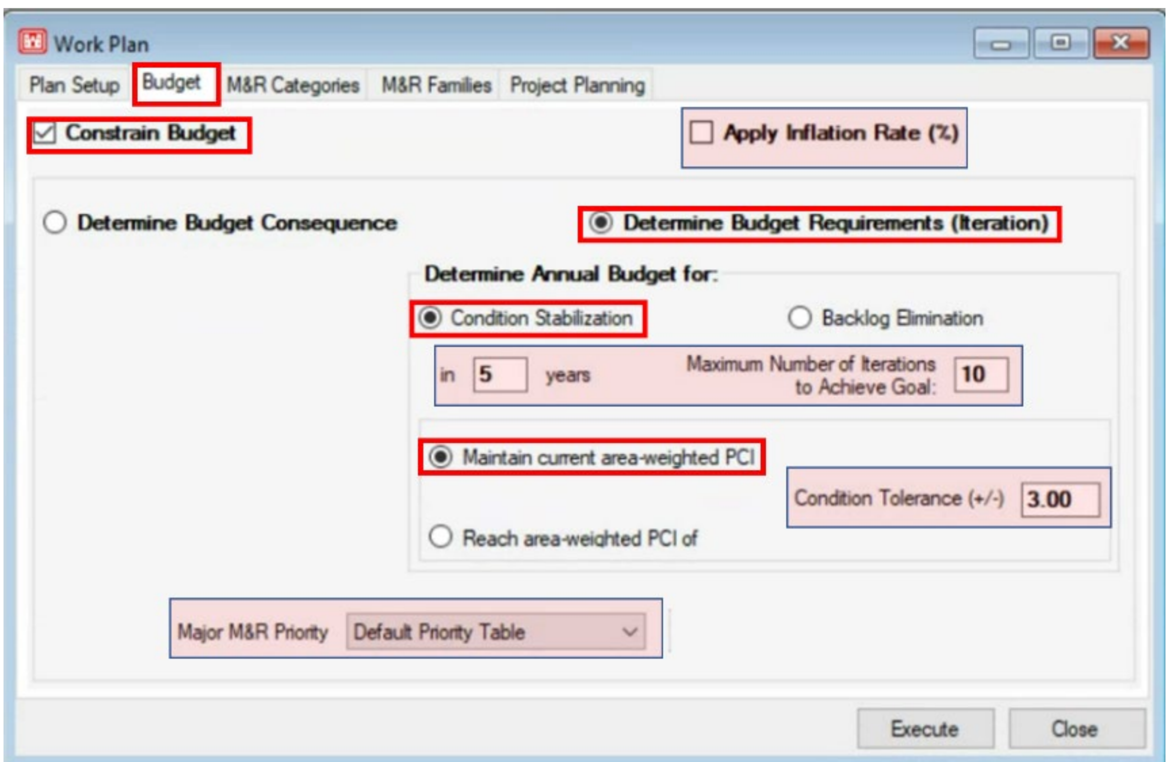
Figure A-13 Condition Stabilization Work Plan, Plan Setup Tab



A-7.2 Budget Tab.

- Check the **Constrain Budget** checkbox to develop a constrained budget, as shown in Figure A-14.
- Leave the **Apply Inflation Rate (%)** checkbox unchecked (see paragraph 7-5.2).
- Select the **Determine Budget Requirements (Iteration)** and **Condition Stabilization** options.
- Set the condition stabilization period to five years.
- Leave **Maximum Number of Iterations to Achieve Goal** set to 10. This defines the number times PAVER tries to develop a balanced budget in each of the five years.
- Select the **Maintain current area-weighted PCI** option.
- Set the **Condition Tolerance** to ±3. The tolerance can be adjusted if required.
- Use the **Default Priority Table** option in **Major M&R Priority** (see paragraph 7-5.5)

Figure A-14 Condition Stabilization Work Plan Setup Tab

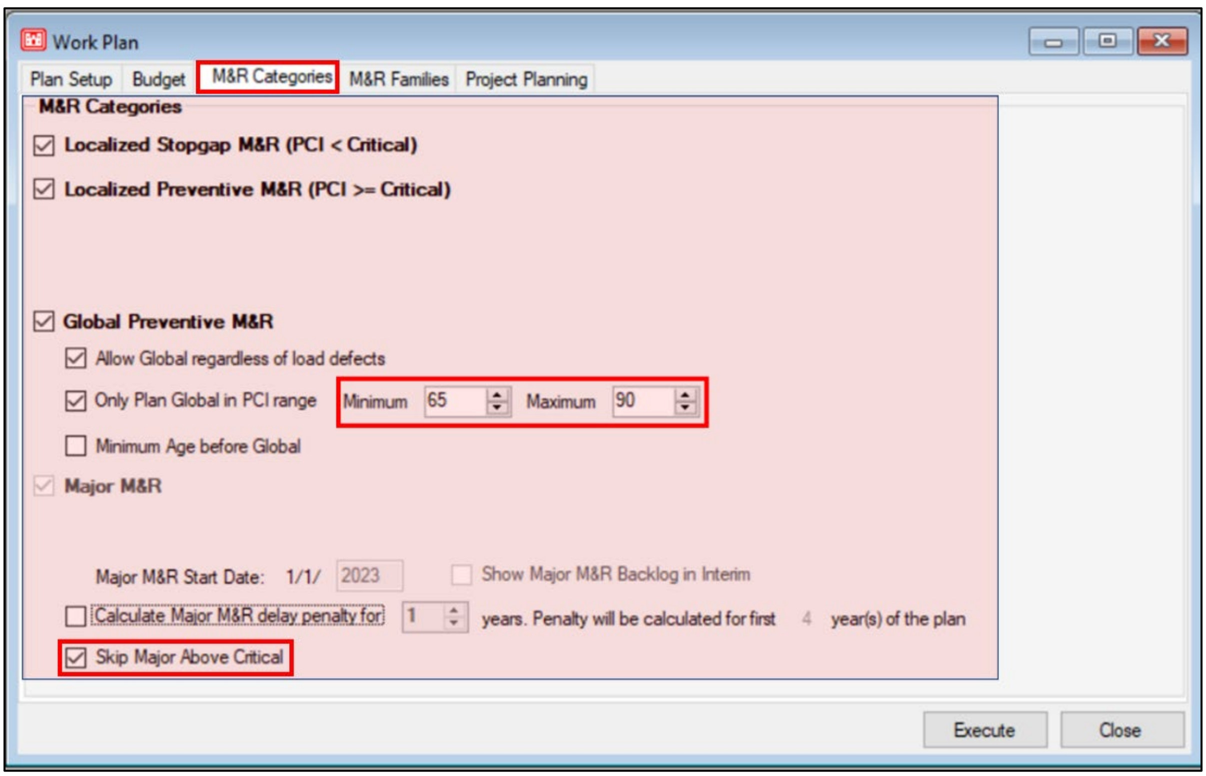


A-7.3 M&R Categories Tab.

Just as with the eliminate backlog work plan, the condition stabilization work plan identifies all M&R requirements required to achieve the goal.

- Select all M&R categories as shown in Figure A-15.
- This example applies global M&R regardless of load defects and generates global M&R requirements when the section PCI is between 65 and 90 (see paragraph 7-6.3).
- Leave the **Calculate Major M&R delay penalty** box unchecked (see paragraph 7-6.4.1).
- Check the **Skip Major M&R Above Critical** box (see paragraph 7-6.4.2).

Figure A-15 Condition Stabilization Work Plan, M&R Categories Tab

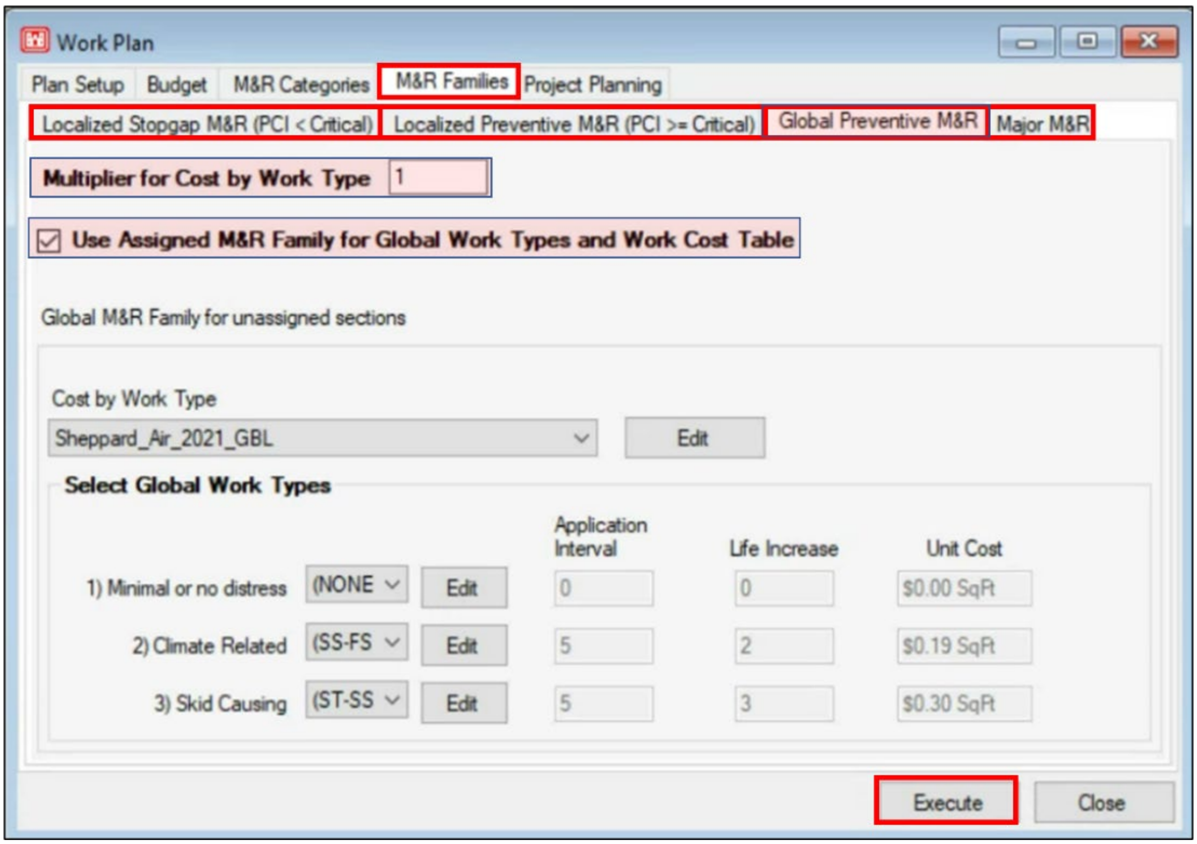


A-7.4 M&R Families Tab.

The example in Figure A-16 shows the **Global Preventive M&R** tab. Each of the tabs for the other M&R families are similar.

- Set the value in the **Multiplier for Cost by Work Type** box to 1.
- The **Use Assigned M&R Family for Global Work Types and Work Cost Table** checkbox is checked by default for all M&R types. This example assumes all sections are assigned to the appropriate M&R families.
- The **Cost by Work Type** option for unassigned sections is not used because all inspected sections are assigned to appropriate families.

Figure A-16 Condition Stabilization Work Plan, M&R Families Tab



A-7.5 Project Planning Tab.

The **Project Planning** tab is used when using PAVER to develop a PMP as described in paragraph 7-8. Examples of how to use the **Project Planning** tab are provided in paragraph A-9.

A-7.6 Execute Condition Stabilization Work Plan.

Select **Execute** in the lower right-hand corner of the form as shown in Figure A-16. Once the work plan is generated, as shown in Figure A-17, PAVER provides work plan views at the Summary (Branch) level and the Detail (Section) level as well as map views of the data. These views are pre-defined reports that provide information on condition, plan parameters, missing values, M&R requirements, and costs. Any table in any of these views can be exported to Excel using a right-click and selecting the option to export to file (*.xlsx).

- In this example, select **Funding Detail Table (all sections)**. When the table opens, right-click and select export to Excel.
- A pop-up window asks whether to include hidden columns. Respond yes.
- Open this report in Excel and unhide all of the columns.
- Use the Excel cut and insert cut functions to rearrange the columns in the table to look like the one in Figure A-18.
    - Keep **Network ID**, **Branch ID**, and **Section ID** columns (C, D, and E) in the report.
    - Either the **Date** column (F) or the **Work Year** column (I) can be used in the report to perform the sorting process outlined below.
    - Hide the **Avg. of Condition Before** column and **After** column (G and H); they can be used later in the PMP development process.
    - Move the **Branch Use** column (N), **Section Rank** column (O) and **Surface Type Current** column (P) to the right of the **Work Year** column (I).
    - Move **Work Type** (column BB) to the right of the **Surface Type Current** column.
    - Retain the **Stop Gap Funded**, **Preventive Funded**, **Global Funded**, **Major Under Critical Funded**, and **Total Funded** columns (J, L, AV, AY, and BE) in the report.
    - Delete or hide the remaining columns.
- Use the Excel sort capability to sort the report by **Work Year**, then **Branch Use**, then **Section Rank**. This procedure produces a prioritized list of requirements for each year in the plan.
- When the eliminate backlog work plan is selected as the optimal work plan, it is to develop the PMP as outlined in Chapter 8 and paragraph A-9.

Figure A-17 Condition Stabilization Work Plan Views

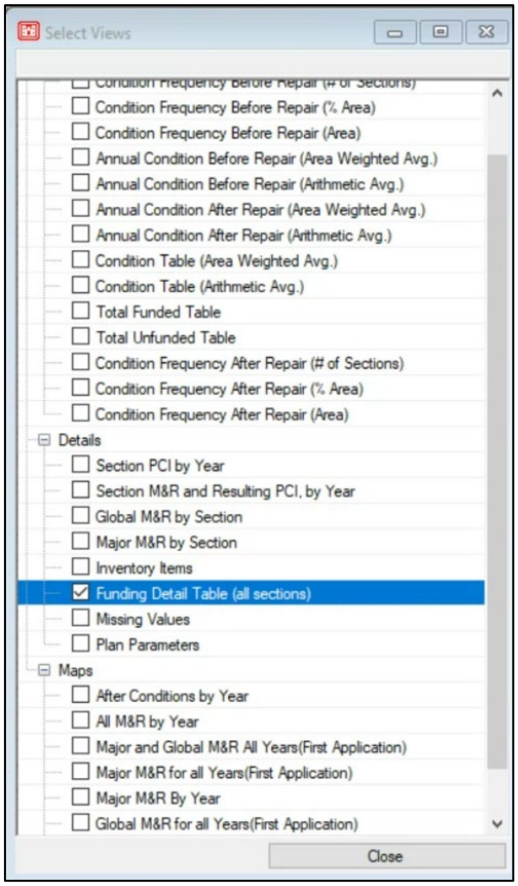


Figure A-18 Sorted Condition Stabilization Work Plan

Network ID	Branch ID	Section ID	Work Year	Branch Use	Section Rank	Surface Type Current	Work Type	Stop Gap Funded	Preventive Funded	Global Funded	Major Under Critical Funded	Total Funded
Sheppard	RW15C33C	R06C1	2023	RUNWAY	P	AC	Major Below Critical	$0.00	$0.00	$0.00	$33,249.59	$33,249.59
Sheppard	RW15C33C	R05C1	2023	RUNWAY	P	AC	Major Below Critical	$0.00	$0.00	$0.00	$109,264.93	$109,264.93
Sheppard	RW15C33C	R07C2	2023	RUNWAY	P	AC	Preventive + Global MR	$0.00	$29,230.76	$92,552.75	$0.00	$121,783.51
Sheppard	RW15C33C	R04A1	2023	RUNWAY	P	PCC	Preventive	$0.00	$7,455.88	$0.00	$0.00	$7,455.88
Sheppard	RW15C33C	R05C2	2023	RUNWAY	P	AC	Preventive + Global MR	$0.00	$3,598.83	$14,238.68	$0.00	$17,837.51
Sheppard	RW15C33C	R08A2	2023	RUNWAY	P	PCC	Preventive	$0.00	$3,288.53	$0.00	$0.00	$3,288.53
Sheppard	RW15C33C	R04A2	2023	RUNWAY	P	PCC	Preventive	$0.00	$7,455.88	$0.00	$0.00	$7,455.88
Sheppard	RW15C33C	R08A1	2023	RUNWAY	P	PCC	Preventive	$0.00	$4,932.77	$0.00	$0.00	$4,932.77
Sheppard	RW15C33C	R07C1	2023	RUNWAY	P	AC	Stopgap	$52,809.06	$0.00	$0.00	$0.00	$52,809.06
Sheppard	RW15C33C	R06C2	2023	RUNWAY	P	AC	Preventive + Global MR	$0.00	$1,349.12	$4,271.68	$0.00	$5,620.80
Sheppard	RW15L33R	R01A1	2023	RUNWAY	P	PCC	Preventive	$0.00	$11,058.28	$0.00	$0.00	$11,058.28
Sheppard	RW15L33R	R01A2	2023	RUNWAY	P	PCC	Preventive	$0.00	$19,413.79	$0.00	$0.00	$19,413.79
Sheppard	RW15L33R	R03A1	2023	RUNWAY	P	PCC	Preventive	$0.00	$14,052.28	$0.00	$0.00	$14,052.28
Sheppard	RW15L33R	R02C1	2023	RUNWAY	P	AC	Preventive	$0.00	$2,300.37	$0.00	$0.00	$2,300.37
Sheppard	RW15L33R	R02C2	2023	RUNWAY	P	AC	Preventive	$0.00	$2,300.37	$0.00	$0.00	$2,300.37
Sheppard	RW15L33R	R03A2	2023	RUNWAY	P	PCC	Preventive	$0.00	$17,179.11	$0.00	$0.00	$17,179.11
Sheppard	RW15R33L	R12A1	2023	RUNWAY	P	PCC	Preventive	$0.00	$6,726.84	$0.00	$0.00	$6,726.84
Sheppard	RW15R33L	R12A2	2023	RUNWAY	P	PCC	Preventive	$0.00	$31,392.06	$0.00	$0.00	$31,392.06
Sheppard	RW15R33L	R13A2	2023	RUNWAY	P	PCC	Preventive	$0.00	$3,472.86	$0.00	$0.00	$3,472.86
Sheppard	RW15R33L	R10A2	2023	RUNWAY	P	PCC	Preventive	$0.00	$20,295.54	$0.00	$0.00	$20,295.54
Sheppard	RW15R33L	R11C2	2023	RUNWAY	P	PCC	Preventive	$0.00	$394,637.32	$0.00	$0.00	$394,637.32
Sheppard	RW15R33L	R11C1	2023	RUNWAY	P	PCC	Preventive	$0.00	$170,972.59	$0.00	$0.00	$170,972.59
Sheppard	RW15R33L	R13A1	2023	RUNWAY	P	PCC	Preventive	$0.00	$12,708.28	$0.00	$0.00	$12,708.28
Sheppard	RW15R33L	R09A2	2023	RUNWAY	P	PCC	Preventive	$0.00	$7,987.54	$0.00	$0.00	$7,987.54
Sheppard	RW15R33L	R10A1	2023	RUNWAY	P	PCC	Preventive	$0.00	$7,712.88	$0.00	$0.00	$7,712.88

A-8 CONSEQUENCE OF LOCALIZED DISTRESS MAINTENANCE WORK PLAN.

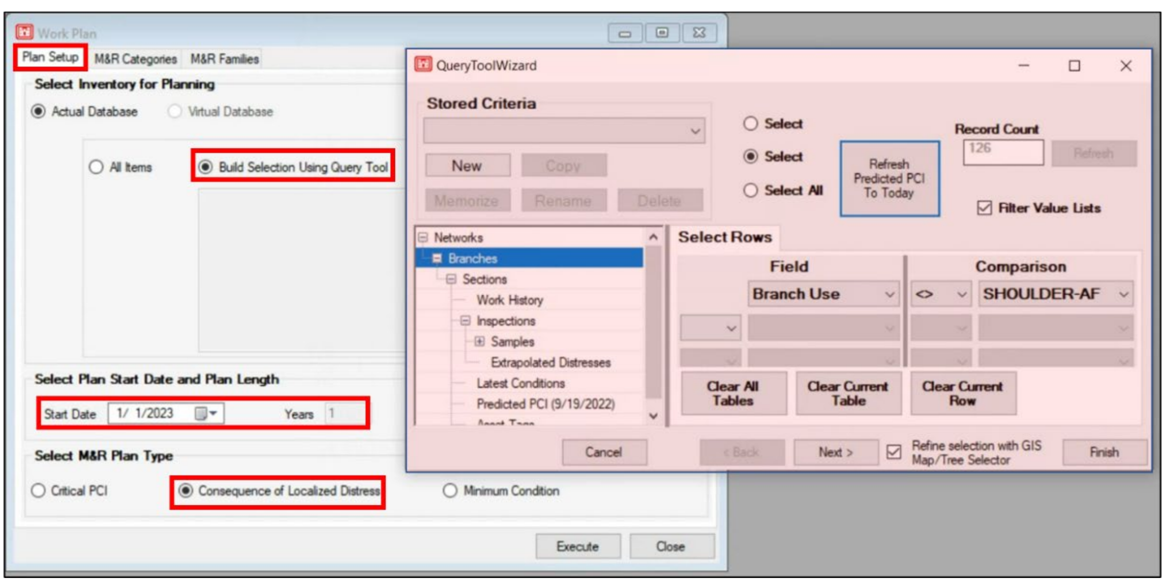
As described in paragraph 7-4, the consequence of localized distress maintenance work plan generates a list of all the localized work requirements based on the assigned distress maintenance policy, calculates the cost of each requirement based on the cost by work type tables, and computes the resulting conditions based on the consequence of maintenance policy when the distresses are repaired according to the distress maintenance policy. This work plan is used in conjunction with the optimal critical PCI work plan to develop the PMP, as described in Chapter 8 and paragraph A-9.

A-8.1 Plan Setup Tab.

This example demonstrates the steps to create a consequence of localized distress work plan for an airfield network. The procedure is the same for a road and parking area network. In this example, assume shoulders are not inspected, so there is no condition data available to define M&R requirements.

- Select the **Build Selection Using Query Tool** option to filter out the shoulders, as shown in Figure A-19. If all sections in the network were inspected, including shoulders, select the **All Items** option on the **Plan Setup** tab.
- Set the plan start date to the first day of the next calendar year after the current PCI inspection date when the work plan is developed in conjunction with a PCI inspection. Use the first day of the calendar year after the current date when doing interim work plan updates.
- The plan length is set to one year by default and cannot be changed.
- Note that the **Budget** and **Project Planning** tabs are no longer displayed.

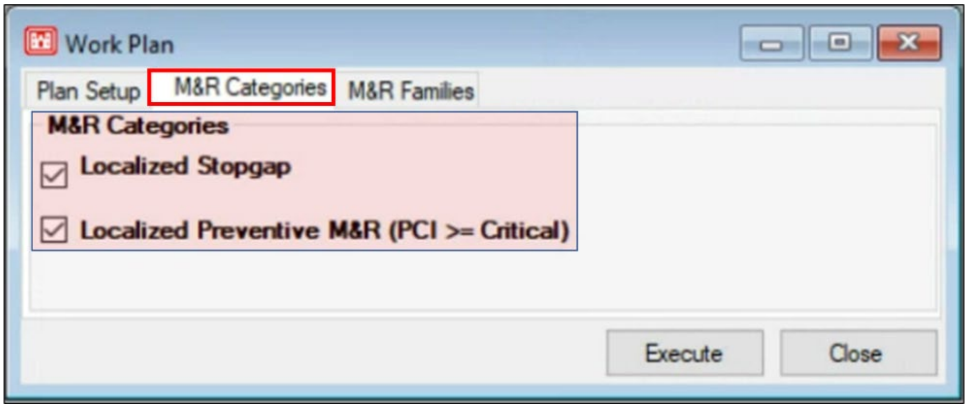
Figure A-19 Consequence of Localized M&R Work Plan, Plan Setup Tab



A-8.2 M&R Categories Tab.

The consequence of localized distress maintenance work plan just includes requirements for localized operational (stopgap) and localized preventive, as described in paragraph 7-4.

Figure A-20 Consequence of Localized M&R Work Plan, M&R Categories Tab

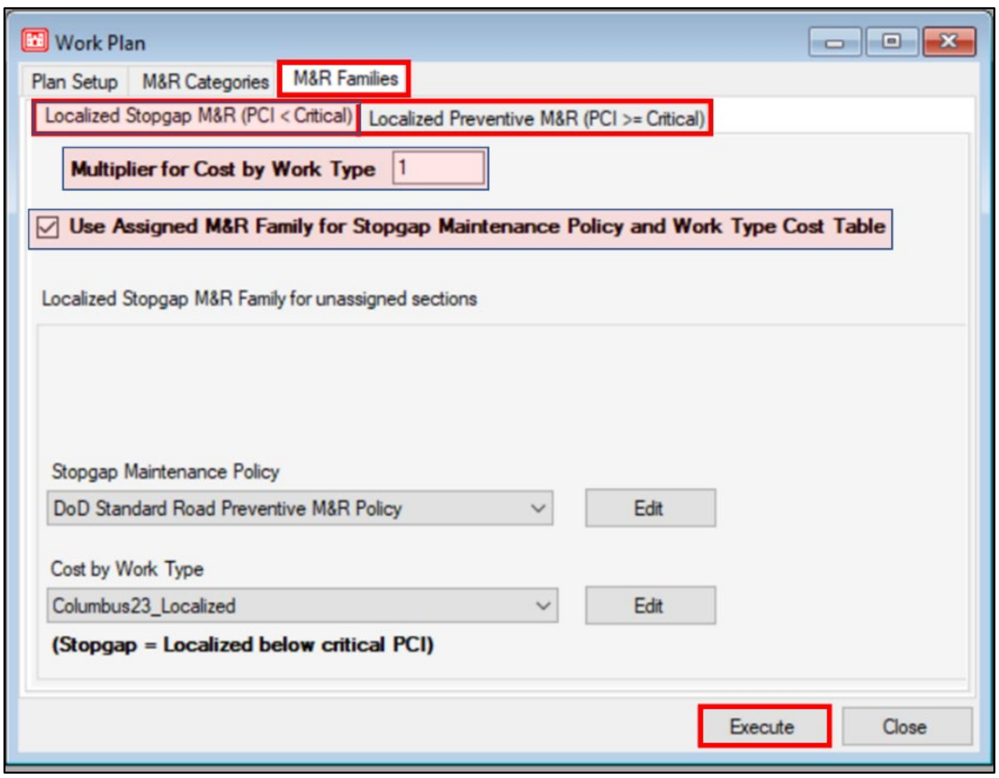


A-8.3 M&R Families Tab.

The example in Figure A-21 shows the **Localized Stopgap M&R** tab. The tab for **Localized Preventive M&R** is similar. **Note:** There are no tabs for Global or Major M&R because this work plan only considers localized.

- Set the value in the **Multiplier for Cost by Work Type** box to 1.
- The **Use Assigned M&R Family for Stopgap Maintenance Policy and Work Type Cost Table** checkbox is checked by default for all M&R types. This example assumes all sections are assigned to the appropriate M&R families.
- The **Stopgap Maintenance Policy** and **Cost by Work Type** options for unassigned sections are not used because all inspected sections are assigned to appropriate families.

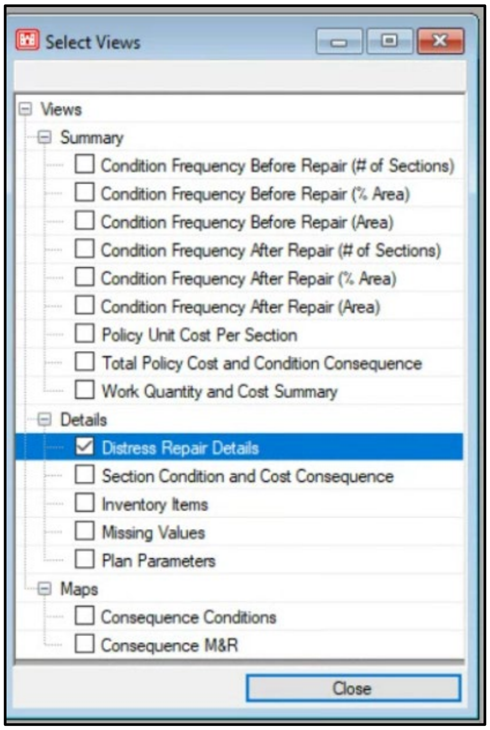
Figure A-21 Unconstrained Work Plan, M&R Families Tab



A-8.4 Execute Consequence of Localized M&R Work Plan.

Select **Execute** in the lower right-hand corner of the form as shown in Figure A-21. Once the work plan is generated, PAVER provides work plan views, as shown in Figure A-22, at the Summary (Branch) level and the Detail (Section) level as well as map views of the data. These views are pre-defined reports that provide information on condition, plan parameters, missing values, M&R requirements, and costs. Any table in any of these views can be exported to Excel using a right-click and selecting the option to export to file (*.xlsx).

Figure A-22 Condition Stabilization Work Plan Views



- In this example, select the **Distress Repair Details** view. When the table opens, right-click and select export to Excel.
- A pop-up window asks whether to include hidden columns. Respond yes.
- Open this report in Excel and unhide all of the columns.
- Use the Excel cut and insert cut functions to rearrange the columns in the table to look like the one in Figure A-23.
    - o Keep **Network ID**, **Branch ID**, and **Section ID** columns (B, D, and D) in the report.
    - o Move the **Branch Use** column (N) and **Section Rank** column (O) to the right of the **Section ID** column (D).
    - o Move the **Age at Inspection** column (AO) and the **Condition** column (AQ) to the right of the **Section Rank** column.

  - o Hide the **Distress Code** column.
  - o Move the **Work Qty**, **Work Unit**, **Unit Cost**, and **Work Cost** columns (AV, AW, AY, and AZ) to the right of the **Work Description** column.
  - o Other columns may be included in the report.
  - o Delete or hide any unused columns.
- Use the Excel sort capability to sort the report by **Branch Use**, **Section Rank**, then **Branch ID**. This procedure produces a prioritized list of requirements for each year in the plan.
- This prioritized list augments the information in the critical PCI work plan, as outlined in Chapter 7, paragraph A-6 and paragraph A-7.

Figure A-23 Sorted Consequence of Localized Work Plan

NetworkID	BranchID	SectionID	Branch Use	Section Rank	Age at Insp	Condition	Policy	Description	Severity	Distress Unit	Work Description	Work Qty	Work Unit	Unit Cost	Work Cost
Sheppard	RW15C33C	R04A1	RUNWAY	P	26	95.00	Sheppard_Air_2021_PRV	SMALL PATCH	Low	Slabs	No Localized M & R	0.	SqFt	$0.00	$0.00
Sheppard	RW15C33C	R04A1	RUNWAY	P	26	95.00	Sheppard_Air_2021_PRV	JT SEAL DMG	Low	Slabs	No Localized M & R	0.	SqFt	$0.00	$0.00
Sheppard	RW15C33C	R04A1	RUNWAY	P	26	95.00	Sheppard_Air_2021_PRV	CORNER SPALL	Low	Slabs	Crack Sealing - PCC	13.1	Ft	$3.78	$49.61
Sheppard	RW15C33C	R04A1	RUNWAY	P	26	95.00	Sheppard_Air_2021_PRV	SHRINKAGE CR	N/A	Slabs	No Localized M & R	0.	SqFt	$0.00	$0.00
Sheppard	RW15C33C	R04A1	RUNWAY	P	26	95.00	Sheppard_Air_2021_PRV	JOINT SPALL	Low	Slabs	Crack Sealing - PCC	31.2	Ft	$3.78	$117.82
Sheppard	RW15C33C	R04A2	RUNWAY	P	26	95.00	Sheppard_Air_2021_PRV	CORNER SPALL	Low	Slabs	Crack Sealing - PCC	8.2	Ft	$3.78	$31.00
Sheppard	RW15C33C	R04A2	RUNWAY	P	26	95.00	Sheppard_Air_2021_PRV	JT SEAL DMG	Low	Slabs	No Localized M & R	0.	SqFt	$0.00	$0.00
Sheppard	RW15C33C	R04A2	RUNWAY	P	26	95.00	Sheppard_Air_2021_PRV	JOINT SPALL	Low	Slabs	Crack Sealing - PCC	34.5	Ft	$3.78	$130.22
Sheppard	RW15C33C	R04A2	RUNWAY	P	26	95.00	Sheppard_Air_2021_PRV	LINEAR CR	Low	Slabs	No Localized M & R	0.	SqFt	$0.00	$0.00
Sheppard	RW15C33C	R04A2	RUNWAY	P	26	95.00	Sheppard_Air_2021_PRV	JOINT SPALL	Medium	Slabs	Patching - PCC Partial Depth	12.9	SqFt	$9.44	$121.93
Sheppard	RW15C33C	R04A2	RUNWAY	P	26	95.00	Sheppard_Air_2021_PRV	SMALL PATCH	Low	Slabs	No Localized M & R	0.	SqFt	$0.00	$0.00
Sheppard	RW15C33C	R04A2	RUNWAY	P	26	95.00	Sheppard_Air_2021_PRV	SHRINKAGE CR	N/A	Slabs	No Localized M & R	0.	SqFt	$0.00	$0.00
Sheppard	RW15C33C	R05C1	RUNWAY	P	16	70.00	Sheppard_Air_2021_STP	L & T CR	Low	Ft	No Localized M & R	0.		$0.00	$0.00
Sheppard	RW15C33C	R05C1	RUNWAY	P	16	70.00	Sheppard_Air_2021_STP	WEATHERING	Low	SqFt	No Localized M & R	0.		$0.00	$0.00
Sheppard	RW15C33C	R05C1	RUNWAY	P	16	70.00	Sheppard_Air_2021_STP	L & T CR	Medium	Ft	No Localized M & R	0.		$0.00	$0.00
Sheppard	RW15C33C	R05C1	RUNWAY	P	16	70.00	Sheppard_Air_2021_STP	PATCHING	Low	SqFt	No Localized M & R	0.		$0.00	$0.00
Sheppard	RW15C33C	R05C1	RUNWAY	P	16	70.00	Sheppard_Air_2021_STP	ALLIGATOR CR	Low	SqFt	No Localized M & R	0.		$0.00	$0.00
Sheppard	RW15C33C	R05C2	RUNWAY	P	16	78.00	Sheppard_Air_2021_PRV	L & T CR	Medium	Ft	Crack Sealing - AC	966.9	Ft	$1.05	$1,015.25
Sheppard	RW15C33C	R05C2	RUNWAY	P	16	78.00	Sheppard_Air_2021_PRV	L & T CR	Low	Ft	No Localized M & R	0.		$0.00	$0.00

A-9 DEVELOPING PAVEMENT MANAGEMENT PLANS.

A-9.1 Objective.

The level of detail in a pavement management plan (PMP) can range from a spreadsheet with a prioritized list of work tasks and projects in each year of the plan to a detailed document that outlines the team composition and development process, including limiting factors, assumptions, and analysis of alternatives. The objective of this UFC is to define the minimum PMP requirement, a prioritized list of work items and projects required to maintain pavements for each year in the next five calendar years.

A-9.2 Background.

A PMP is the end product of a team effort to prioritize and group pavement M&R requirements into executable work tasks and projects, as described in Chapter 8. There are different approaches to developing a PMP. This appendix uses the optimal critical PCI work plan and the consequence of localized work plan described in Chapter 7 and paragraphs A-6 and A-7 as the starting point for the process below.

1. Determine whether the eliminate backlog or condition stabilization work plan is optimal.
2. Export the optimal work plan and the consequence of localized M&R work plan to Excel, retaining all hidden columns.
3. Prioritize requirements in each work plan as described in paragraphs A-6 and A-7.
4. Add columns for the Priority, Risk-Return Category, and Method of Execution to the optimal work plan as described in this appendix and in Chapter 8.
5. Sort the optimal work plan and the consequence of localized work plan as described in this appendix and in Chapter 8 and group requirements into a prioritized list of executable work tasks and projects.
6. The prioritized list of executable work tasks and projects can serve as the PMP, but inputting the required work from the project list into PAVER provides a means of making the PMP development process easier over time.
    a. Enter the work tasks and projects into PAVER using the **Required Work** tool or **Project Planning Wizard**.
    b. Rerun the optimal work plan with the required work and repeat process, as required.
    c. For large installations, enter high-priority projects into PAVER, rerun the work plans, enter medium-priority projects, rerun work plans, etc.
7. Whether the PMP development team uses the PAVER project planning tools or not, the final result is a prioritized list of executable tasks and projects that is approved by leadership, maintained as work is completed, and updated at least annually.

When an installation has both an airfield network and a road and parking network, select an optimal critical PCI work plan for each; do not combine airfield and road and parking networks.

The examples in this appendix use a five-year eliminate backlog work plan for a road and parking network as the optimal critical PCI work plan. These examples do not attempt to address all the scenarios that might arise in developing a PMP, but rather provide guidance on the general process and addresses some common issues that might arise.

A-9.3 Initial Optimal Critical PCI Work Plan View.

The optimal critical PCI work plan used for this example is the eliminate backlog work plan for a road and parking network developed following the same procedure outlined in paragraphs A-6.1 to A-6.6. The result is the initial prioritized list of requirements shown in Figure A-24.

Figure A-24 Critical PCI Work Plan Funding Detail Table (All Sections)

Network ID	Branch ID	Section ID	Work Year	Branch Use	Section Rank	Work Type	Surface Type - Current	Avg Condition Before	Avg Condition After	Stop Gap Funded	Preventive Funded	Global Funded	Major Under Critical Funded	Total
Keesler	RDFIFTHST	05	2023	ROADWAY	P	Preventive	AC	97.54	97.83	$0.00	$124.20	$0.00	$0.00	$124.20
Keesler	RDFIFTHST	06	2023	ROADWAY	P	Preventive + Global MR	AC	79.54	83.62	$0.00	$197.48	$1,704.61	$0.00	$1,902.09
Keesler	RDFIRST	01	2023	ROADWAY	P	Major Below Critical	AC	45.14	100.00	$0.00	$0.00	$0.00	$190,283.40	$190,283.40
Keesler	RDFIRST	02	2023	ROADWAY	P	Major Below Critical	AC	51.24	100.00	$0.00	$0.00	$0.00	$39,667.24	$39,667.24
Keesler	RDFIRST	03	2023	ROADWAY	P	Major Below Critical	AC	47.44	100.00	$0.00	$0.00	$0.00	$62,236.49	$62,236.49
Keesler	RDFISHER	01	2023	ROADWAY	P	Preventive	AC	95.04	95.33	$0.00	$144.90	$0.00	$0.00	$144.90
Keesler	RDFISHER	02	2023	ROADWAY	P	Preventive	AC	95.54	95.83	$0.00	$168.42	$0.00	$0.00	$168.42
Keesler	RDFISHER	03	2023	ROADWAY	P	Major Below Critical	AC	49.44	100.00	$0.00	$0.00	$0.00	$71,448.66	$71,448.66
Keesler	RDGENCHAPP	01	2023	ROADWAY	P	Preventive + Global MR	AC	78.84	82.92	$0.00	$722.39	$5,286.04	$0.00	$6,008.43
Keesler	RDGENCHAPP	02	2023	ROADWAY	P	Major Below Critical	AC	58.74	100.00	$0.00	$0.00	$0.00	$74,172.69	$74,172.69
Keesler	RDGENCHAPP	03	2023	ROADWAY	P	Major Below Critical	AC	52.94	100.00	$0.00	$0.00	$0.00	$96,747.59	$96,747.59
Keesler	RDHANGAR	01	2023	ROADWAY	P	Major Below Critical	AC	40.24	100.00	$0.00	$0.00	$0.00	$606,313.00	$606,313.00
Keesler	RDHSTREET	01	2023	ROADWAY	P	Major Below Critical	AC	59.74	100.00	$0.00	$0.00	$0.00	$24,277.94	$24,277.94
Keesler	RDHSTREET	02	2023	ROADWAY	P	Major Below Critical	AC	64.24	100.00	$0.00	$0.00	$0.00	$27,682.46	$27,682.46
Keesler	RDHSTREET	03	2023	ROADWAY	P	Major Below Critical	AC	38.14	100.00	$0.00	$0.00	$0.00	$105,875.24	$105,875.24
Keesler	RDHSTREET	04	2023	ROADWAY	P	Major Below Critical	AC	39.54	100.00	$0.00	$0.00	$0.00	$110,359.76	$110,359.76
Keesler	RDHSTREET	05	2023	ROADWAY	P	Major Below Critical	AC	45.04	100.00	$0.00	$0.00	$0.00	$60,890.96	$60,890.96
Keesler	RDHSTREET	06	2023	ROADWAY	P	Preventive + Global MR	AC	80.34	84.42	$0.00	$769.96	$7,663.26	$0.00	$8,433.22
Keesler	RDJSTREET	01	2023	ROADWAY	P	Major Below Critical	AC	34.84	100.00	$0.00	$0.00	$0.00	$29,773.20	$29,773.20
Keesler	RDJSTREET	02	2023	ROADWAY	P	Preventive	PCC	81.63	81.80	$0.00	$1,094.44	$0.00	$0.00	$1,094.44
Keesler	RDJSTREET	03	2023	ROADWAY	P	Preventive	AC	91.34	91.63	$0.00	$523.98	$0.00	$0.00	$523.98
Keesler	RDJSTREET	04	2023	ROADWAY	P	Preventive	AC	90.64	90.93	$0.00	$18.30	$0.00	$0.00	$18.30
Keesler	RDLARCHER	01	2023	ROADWAY	P	Preventive	AC	92.44	92.73	$0.00	$318.33	$0.00	$0.00	$318.33
Keesler	RDLARCHER	02	2023	ROADWAY	P	Preventive	AC	92.44	92.73	$0.00	$325.30	$0.00	$0.00	$325.30
Keesler	RDLARCHER	03	2023	ROADWAY	P	Preventive	AC	92.54	92.83	$0.00	$347.56	$0.00	$0.00	$347.56
Keesler	RDLARCHER	04	2023	ROADWAY	P	Preventive	AC	92.54	92.83	$0.00	$261.23	$0.00	$0.00	$261.23
Keesler	RDLARCHER	05	2023	ROADWAY	P	Preventive	AC	92.54	92.83	$0.00	$333.14	$0.00	$0.00	$333.14
Keesler	RDLARCHER	06	2023	ROADWAY	P	Preventive	AC	92.64	92.93	$0.00	$244.64	$0.00	$0.00	$244.64

A-9.4 Add Priority and Risk–Return Category Columns.

Using the prioritized requirements list in Figure A-24, modify the spreadsheet by adding columns as shown in Figure A-25.

- Add an M&R **Priority** column (paragraph 8-6.1).
- Add a **Risk-Return Category** column (paragraph 8-6.4).
- Assign a priority value to each requirement for each year of the work plan based on the branch use and section rank as described in paragraph 8-6.1 and Table 8-1.
- Sort the spreadsheet by **Work Year**, **Priority**, and **Average Condition Before**.
- Use the values in the **Priority** and **Average Condition Before** columns to define a risk - return category for each requirement in each year of the work plan, as described in paragraph 8-6.4 and Figure 8-3.

Figure A-25 Priority and Risk-Return Columns

Network ID	Branch ID	Section ID	Work Year	Branch Use	Section Rank	Risk-Return Category	Work Type	Surface Type Current	Priority	Avg Condition Before	Avg Condition After	Stop Gap Funded	Preventive Funded	Global Funded	Major Under Critical Funded	Total
Keesler	RDFIFTHST	05	2023	ROADWAY	P	A	Preventive	AC	1	97.54	97.83	$0.00	$124.20	$0.00	$0.00	$124.20
Keesler	RDFIFTHST	06	2023	ROADWAY	P	A	Preventive + Global MR	AC	1	79.54	83.62	$0.00	$197.48	$1,704.61	$0.00	$1,902.09
Keesler	RDFIRST	01	2023	ROADWAY	P	C	Major Below Critical	AC	1	45.14	100.00	$0.00	$0.00	$0.00	$190,283.40	$190,283.40
Keesler	RDFIRST	02	2023	ROADWAY	P	C	Major Below Critical	AC	1	51.24	100.00	$0.00	$0.00	$0.00	$39,667.24	$39,667.24
Keesler	RDFIRST	03	2023	ROADWAY	P	C	Major Below Critical	AC	1	47.44	100.00	$0.00	$0.00	$0.00	$62,236.49	$62,236.49
Keesler	RDFISHER	01	2023	ROADWAY	P	A	Preventive	AC	1	95.04	95.33	$0.00	$144.90	$0.00	$0.00	$144.90
Keesler	RDFISHER	02	2023	ROADWAY	P	A	Preventive	AC	1	95.54	95.83	$0.00	$168.42	$0.00	$0.00	$168.42
Keesler	RDFISHER	03	2023	ROADWAY	P	A	Major Below Critical	AC	1	49.44	100.00	$0.00	$0.00	$0.00	$71,448.66	$71,448.66
Keesler	RDGENCHAPP	01	2023	ROADWAY	P	A	Preventive + Global MR	AC	1	78.84	82.92	$0.00	$722.39	$5,286.04	$0.00	$6,008.43
Keesler	RDGENCHAPP	02	2023	ROADWAY	P	C	Major Below Critical	AC	1	58.74	100.00	$0.00	$0.00	$0.00	$74,172.69	$74,172.69
Keesler	RDGENCHAPP	03	2023	ROADWAY	P	C	Major Below Critical	AC	1	52.94	100.00	$0.00	$0.00	$0.00	$96,747.59	$96,747.59
Keesler	RDHANGAR	01	2023	ROADWAY	P	C	Major Below Critical	AC	1	40.24	100.00	$0.00	$0.00	$0.00	$606,313.00	$606,313.00
Keesler	RDHSTREET	01	2023	ROADWAY	P	C	Major Below Critical	AC	1	59.74	100.00	$0.00	$0.00	$0.00	$24,277.94	$24,277.94
Keesler	RDHSTREET	02	2023	ROADWAY	P	C	Major Below Critical	AC	1	64.24	100.00	$0.00	$0.00	$0.00	$27,682.46	$27,682.46
Keesler	RDHSTREET	03	2023	ROADWAY	P	E	Major Below Critical	AC	1	38.14	100.00	$0.00	$0.00	$0.00	$105,875.24	$105,875.24
Keesler	RDHSTREET	04	2023	ROADWAY	P	E	Major Below Critical	AC	1	39.54	100.00	$0.00	$0.00	$0.00	$110,359.76	$110,359.76
Keesler	RDHSTREET	05	2023	ROADWAY	P	C	Major Below Critical	AC	1	45.04	100.00	$0.00	$0.00	$0.00	$60,890.96	$60,890.96
Keesler	RDHSTREET	06	2023	ROADWAY	P	A	Preventive + Global MR	AC	1	80.34	84.42	$0.00	$769.96	$7,663.26	$0.00	$8,433.22
Keesler	RDJSTREET	01	2023	ROADWAY	P	E	Major Below Critical	AC	1	34.84	100.00	$0.00	$0.00	$0.00	$29,773.20	$29,773.20
Keesler	RDJSTREET	02	2023	ROADWAY	P	A	Preventive	PCC	1	81.63	81.80	$0.00	$1,094.44	$0.00	$0.00	$1,094.44
Keesler	RDJSTREET	03	2023	ROADWAY	P	A	Preventive	AC	1	91.34	91.63	$0.00	$523.98	$0.00	$0.00	$523.98
Keesler	RDJSTREET	04	2023	ROADWAY	P	A	Preventive	AC	1	90.64	90.93	$0.00	$18.30	$0.00	$0.00	$18.30
Keesler	RDLARCHER	01	2023	ROADWAY	P	A	Preventive	AC	1	92.44	92.73	$0.00	$318.33	$0.00	$0.00	$318.33
Keesler	RDLARCHER	02	2023	ROADWAY	P	A	Preventive	AC	1	92.44	92.73	$0.00	$325.30	$0.00	$0.00	$325.30
Keesler	RDLARCHER	03	2023	ROADWAY	P	A	Preventive	AC	1	92.54	92.83	$0.00	$347.56	$0.00	$0.00	$347.56
Keesler	RDLARCHER	04	2023	ROADWAY	P	A	Preventive	AC	1	92.54	92.83	$0.00	$261.23	$0.00	$0.00	$261.23
Keesler	RDLARCHER	05	2023	ROADWAY	P	A	Preventive	AC	1	92.54	92.83	$0.00	$333.14	$0.00	$0.00	$333.14
Keesler	RDLARCHER	06	2023	ROADWAY	P	A	Preventive	AC	1	92.64	92.93	$0.00	$244.64	$0.00	$0.00	$244.64

A-9.5 Defining Method of Execution.

Using the requirements list in Figure A-25, modify the spreadsheet by adding a column for **Method of Execution**, as shown in Figure A-26.

- Assign a preliminary method of execution for each requirement in each year of the work plan (paragraph 8-7.2). This example assumes the following:
  - o In-house work forces have the capability to do localized AC and PCC repairs but do not have the capability to do global preventive M&R.
  - o There is an IDIQ contract in place with the capability to do global preventive M&R as well as localized AC and PCC repairs, but it does not have the capability to major M&R such as mill and overlay.
  - o Major M&R work will be done by competitive bid or existing multiple award task order contract (MATOC).
- Review the Consequence of Localized M&R Distress Repair Details Report and consider the types and severity of distresses present when determining the method of execution.
  - o The consequence of localized M&R work plan is based on the condition of the pavement at the time of the last inspection
  - o In Figure A-26, the eliminate backlog work plan called for preventive M&R whereas the consequence of localized M&R work

plan example in Figure A-27 shows no localized M&R because all distresses are low severity.

- o Differences like this arise because the eliminate backlog work plan anticipates the condition will deteriorate and preventive M&R will be required.

- o In this example, localized preventive M&R is a good option to repair any distresses that progressed to medium severity and global M&R is a good option to address the weathering. **Note:** The work plan had projected preventive and global M&R for RDLARCHER in 2025, but could be changed to 2023 given the high priority and return on investment.

Figure A-26 Method of Execution Column

Network ID	Branch ID	Section ID	Date	Branch Use	Section Rank	Risk - Return Category	Work Type	Method of Execution	Surface Type Current	M&R Priority	Avg Condition Before	Avg Condition After	Stop Gap Funded	Preventive Funded	Global Funded	Major Under Critical Funded	Total
Keesler	RDFISHER	01	2023	ROADWAY	P	A	Preventive	In-House	AC	1	95.04	95.33	$0.00	$144.90	$0.00	$0.00	$144.90
Keesler	RDFISHER	02	2023	ROADWAY	P	A	Preventive	In-House	AC	1	95.54	95.83	$0.00	$168.42	$0.00	$0.00	$168.42
Keesler	RDFISHER	03	2023	ROADWAY	P	A	Major Below Critical	Contract	AC	1	49.44	100.00	$0.00	$0.00	$0.00	$71,448.66	$71,448.66
Keesler	RDGENCHAPP	01	2023	ROADWAY	P	A	Preventive + Global MR	IDIQ	AC	1	78.84	82.92	$0.00	$722.39	$5,286.04	$0.00	$6,008.43
Keesler	RDGENCHAPP	02	2023	ROADWAY	P	C	Major Below Critical	Contract	AC	1	58.74	100.00	$0.00	$0.00	$0.00	$74,172.69	$74,172.69
Keesler	RDGENCHAPP	03	2023	ROADWAY	P	C	Major Below Critical	Contract	AC	1	52.94	100.00	$0.00	$0.00	$0.00	$96,747.59	$96,747.59
Keesler	RDHANGAR	01	2023	ROADWAY	P	C	Major Below Critical	Contract	AC	1	40.24	100.00	$0.00	$0.00	$0.00	$606,313.00	$606,313.00
Keesler	RDHSTREET	01	2023	ROADWAY	P	C	Major Below Critical	Contract	AC	1	59.74	100.00	$0.00	$0.00	$0.00	$24,277.94	$24,277.94
Keesler	RDHSTREET	02	2023	ROADWAY	P	C	Major Below Critical	Contract	AC	1	64.24	100.00	$0.00	$0.00	$0.00	$27,682.46	$27,682.46
Keesler	RDHSTREET	03	2023	ROADWAY	P	E	Major Below Critical	Contract	AC	1	38.14	100.00	$0.00	$0.00	$0.00	$105,875.24	$105,875.24
Keesler	RDHSTREET	04	2023	ROADWAY	P	E	Major Below Critical	Contract	AC	1	39.54	100.00	$0.00	$0.00	$0.00	$110,359.76	$110,359.76
Keesler	RDHSTREET	05	2023	ROADWAY	P	C	Major Below Critical	Contract	AC	1	45.04	100.00	$0.00	$0.00	$0.00	$60,890.96	$60,890.96
Keesler	RDHSTREET	06	2023	ROADWAY	P	A	Preventive + Global MR	IDIQ	AC	1	80.34	84.42	$0.00	$769.96	$7,663.26	$0.00	$8,433.22
Keesler	RDJSTREET	01	2023	ROADWAY	P	E	Major Below Critical	Contract	AC	1	34.84	100.00	$0.00	$0.00	$0.00	$29,773.20	$29,773.20
Keesler	RDJSTREET	02	2023	ROADWAY	P	A	Preventive	In-House	PCC	1	81.63	81.80	$0.00	$1,094.44	$0.00	$0.00	$1,094.44
Keesler	RDJSTREET	03	2023	ROADWAY	P	A	Preventive	In-House	AC	1	91.34	91.63	$0.00	$523.98	$0.00	$0.00	$523.98
Keesler	RDJSTREET	04	2023	ROADWAY	P	A	Preventive	In-House	AC	1	90.64	90.93	$0.00	$18.30	$0.00	$0.00	$18.30
Keesler	RDLARCHER	01	2023	ROADWAY	P	A	Preventive	IDIQ	AC	1	92.44	92.73	$0.00	$318.33	$0.00	$0.00	$318.33
Keesler	RDLARCHER	02	2023	ROADWAY	P	A	Preventive	IDIQ	AC	1	92.44	92.73	$0.00	$325.30	$0.00	$0.00	$325.30
Keesler	RDLARCHER	03	2023	ROADWAY	P	A	Preventive	IDIQ	AC	1	92.54	92.83	$0.00	$347.56	$0.00	$0.00	$347.56
Keesler	RDLARCHER	04	2023	ROADWAY	P	A	Preventive	IDIQ	AC	1	92.54	92.83	$0.00	$261.23	$0.00	$0.00	$261.23
Keesler	RDLARCHER	05	2023	ROADWAY	P	A	Preventive	IDIQ	AC	1	92.54	92.83	$0.00	$333.14	$0.00	$0.00	$333.14
Keesler	RDLARCHER	06	2023	ROADWAY	P	A	Preventive	IDIQ	AC	1	92.64	92.93	$0.00	$244.64	$0.00	$0.00	$244.64
Keesler	RDLARCHER	07	2023	ROADWAY	P	A	Preventive	IDIQ	AC	1	92.24	92.53	$0.00	$71.99	$0.00	$0.00	$71.99
Keesler	RDLARCHER	08	2023	ROADWAY	P	A	Preventive	IDIQ	AC	1	92.44	92.73	$0.00	$277.92	$0.00	$0.00	$277.92
Keesler	RDLARCHER	09	2023	ROADWAY	P	A	Preventive	IDIQ	AC	1	92.44	92.73	$0.00	$284.11	$0.00	$0.00	$284.11

Figure A-27 Consequence of Localized M&R Example

NetworkID	BranchID	SectionID	Policy	Distress Code	Description	Severity	Distress Qty	Distress Unit	Percent Distress	Work Description
Keesler	RDLARCHER	01	FY2022_AFCEC_RD&PK_PRV	10	L & T CR	Low	60.5	Ft	.15	No Localized M & R
Keesler	RDLARCHER	01	FY2022_AFCEC_RD&PK_PRV	20	WEATHERING	Low	41,183.04	SqFt	100.	No Localized M & R
Keesler	RDLARCHER	02	FY2022_AFCEC_RD&PK_PRV	10	L & T CR	Low	86.06	Ft	.2	No Localized M & R
Keesler	RDLARCHER	02	FY2022_AFCEC_RD&PK_PRV	20	WEATHERING	Low	42,084.95	SqFt	100.	No Localized M & R
Keesler	RDLARCHER	03	FY2022_AFCEC_RD&PK_PRV	20	WEATHERING	Low	45,568.05	SqFt	100.	No Localized M & R
Keesler	RDLARCHER	03	FY2022_AFCEC_RD&PK_PRV	10	L & T CR	Low	60.76	Ft	.13	No Localized M & R
Keesler	RDLARCHER	04	FY2022_AFCEC_RD&PK_PRV	10	L & T CR	Low	23.98	Ft	.07	No Localized M & R
Keesler	RDLARCHER	04	FY2022_AFCEC_RD&PK_PRV	20	WEATHERING	Low	34,249.04	SqFt	100.	No Localized M & R
Keesler	RDLARCHER	05	FY2022_AFCEC_RD&PK_PRV	10	L & T CR	Low	29.13	Ft	.07	No Localized M & R
Keesler	RDLARCHER	05	FY2022_AFCEC_RD&PK_PRV	20	WEATHERING	Low	43,677.04	SqFt	100.	No Localized M & R
Keesler	RDLARCHER	06	FY2022_AFCEC_RD&PK_PRV	20	WEATHERING	Low	32,510.02	SqFt	100.	No Localized M & R
Keesler	RDLARCHER	07	FY2022_AFCEC_RD&PK_PRV	20	WEATHERING	Low	9,073.98	SqFt	100.	No Localized M & R
Keesler	RDLARCHER	07	FY2022_AFCEC_RD&PK_PRV	10	L & T CR	Low	20.01	Ft	.22	No Localized M & R
Keesler	RDLARCHER	08	FY2022_AFCEC_RD&PK_PRV	20	WEATHERING	Low	35,955.01	SqFt	100.	No Localized M & R
Keesler	RDLARCHER	08	FY2022_AFCEC_RD&PK_PRV	10	L & T CR	Low	57.51	Ft	.16	No Localized M & R
Keesler	RDLARCHER	09	FY2022_AFCEC_RD&PK_PRV	10	L & T CR	Low	40.42	Ft	.11	No Localized M & R
Keesler	RDLARCHER	09	FY2022_AFCEC_RD&PK_PRV	20	WEATHERING	Low	36,755.96	SqFt	100.	No Localized M & R

A-9.6 Aggregating Requirements into Executable Tasks and Projects.

Defining the requirements for an in-house task list or a project can be accomplished using different approaches. The examples in this appendix aggregate requirements into projects by doing a series of sorts on the prioritized requirement list using the **Execution Year**, **Branch ID**, **Section ID**, **Priority**, **Risk-Return Category**, and **Method of Execution** fields to look for logical opportunities to combine requirements. The term view is used to describe the hierarchy used for each sort.

A-9.6.1 Risk Category View of M&R Requirements.

Sort the requirements for the first year of the work plan by **Risk-Return Category**, **Priority**, and **Average Condition Before**, as shown in Figure A-28. This view of the M&R requirements mirrors the hierarchy shown in Figure 8-3 and Table 8-4.

- **Note:** Set the order for **Avg Condition Before** to **Largest to Smallest**.
- Identify high-risk operational (stopgap) M&R requirements in Risk-Return Categories C and E and highlight them to indicate they are a high priority based on risk, as shown in Figure A-29.

Figure A-28 Sorting by Risk Category

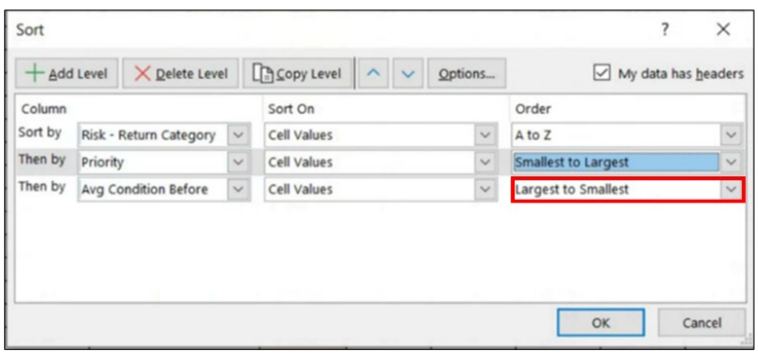


Figure A-29 Risk Category Requirements View

Network ID	Branch ID	Section ID	Work Year	Branch Use	Section Rank	Risk - Return Category	Work Type	Method of Execution	Surface Type - Current	M&R Priority	Avg Condition Before	Avg Condition After	Stop Gap Funded	Preventive Funded	Global Funded	Major Under Critical Funded	Total
Keesler	RDASTREET	01	2023	ROADWAY	S	C	Stopgap	In-House	AC	3	41.49	41.49	$4,347.32	$0.00	$0.00	$0.00	$4,347.32
Keesler	RDUNKNOWN3	01	2023	ROADWAY	S	E	Stopgap	In-House	AC	3	27.49	27.49	$4,275.51	$0.00	$0.00	$0.00	$4,275.51
Keesler	RDGALAXY	01	2023	ROADWAY	S	E	Stopgap	In-House	AC	3	12.49	12.49	$12,528.14	$0.00	$0.00	$0.00	$12,528.14
Keesler	RDFIFTHST	05	2023	ROADWAY	P	A	Preventive	IDIQ	AC	1	97.54	97.83	$0.00	$124.20	$0.00	$0.00	$124.20
Keesler	RDFISHER	02	2023	ROADWAY	P	A	Preventive	In-House	AC	1	95.54	95.83	$0.00	$168.42	$0.00	$0.00	$168.42
Keesler	RDFISHER	01	2023	ROADWAY	P	A	Preventive	In-House	AC	1	95.04	95.33	$0.00	$144.90	$0.00	$0.00	$144.90
Keesler	RDLARCHER	06	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.64	92.93	$0.00	$244.64	$0.00	$0.00	$244.64
Keesler	RDLARCHER	03	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.54	92.83	$0.00	$347.56	$0.00	$0.00	$347.56
Keesler	RDLARCHER	04	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.54	92.83	$0.00	$261.23	$0.00	$0.00	$261.23
Keesler	RDLARCHER	05	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.54	92.83	$0.00	$333.14	$0.00	$0.00	$333.14
Keesler	RDLARCHER	01	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.44	92.73	$0.00	$318.33	$0.00	$0.00	$318.33
Keesler	RDLARCHER	02	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.44	92.73	$0.00	$325.30	$0.00	$0.00	$325.30
Keesler	RDLARCHER	08	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.44	92.73	$0.00	$277.92	$0.00	$0.00	$277.92
Keesler	RDLARCHER	09	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.44	92.73	$0.00	$284.11	$0.00	$0.00	$284.11
Keesler	RDLARCHER	07	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.24	92.53	$0.00	$71.99	$0.00	$0.00	$71.99
Keesler	RDJSTREET	03	2023	ROADWAY	P	A	Preventive	In-House	AC	1	91.34	91.63	$0.00	$523.98	$0.00	$0.00	$523.98
Keesler	RDJSTREET	04	2023	ROADWAY	P	A	Preventive	In-House	AC	1	90.64	90.93	$0.00	$18.30	$0.00	$0.00	$18.30
Keesler	RDUNKNOWN4	02	2023	ROADWAY	P	A	Preventive	IDIQ	AC	1	90.64	90.93	$0.00	$29.19	$0.00	$0.00	$29.19
Keesler	RDUNKNOWN3	03	2023	ROADWAY	P	A	Preventive	IDIQ	PCC	1	88.93	89.10	$0.00	$180.90	$0.00	$0.00	$180.90
Keesler	RDTHIRDST	03	2023	ROADWAY	P	A	Preventive + Global MR	IDIQ	AC	1	87.74	91.81	$0.00	$579.63	$9,250.08	$0.00	$9,829.71
Keesler	RDZSTREET	02	2023	ROADWAY	P	A	Preventive + Global MR	IDIQ	AC	1	85.44	89.51	$0.00	$321.65	$4,322.44	$0.00	$4,644.09
Keesler	RDZSTREET	01	2023	ROADWAY	P	A	Preventive + Global MR	IDIQ	AC	1	84.34	88.41	$0.00	$705.34	$8,812.87	$0.00	$9,518.21
Keesler	RDTHIRDST	04	2023	ROADWAY	P	A	Preventive + Global MR	IDIQ	AC	1	84.14	88.22	$0.00	$250.60	$3,091.63	$0.00	$3,342.22

A-9.6.2 Adjusting Method of Execution by Branch.

Using the requirements list in Figure A-29, re-sort it to compare the method of execution for all requirements in each section for each year in the plan, as shown in Figure A-30. **Note:** The M&R priority for the branches in this example are low and work on these pavements have a low return on investment. This choice is intentional to demonstrate the same process applies to all pavements, from highest to lowest risk and return.

- Sort requirements for year one by branch and section to identify opportunities to use the same execution method (see paragraph 8-7.3) for each branch.
- Review the Consequence of Localized M&R Distress Repair Details Report and consider the types and severity of distresses present when determining changes to the method of execution
- In the example in Figure A-30, Branch PA00222 has work performed in-house and other work by IDIQ. Since the assumption is the IDIQ can handle both localized and global, update the method of execution for all to IDIQ as shown.
- Many decisions require engineering judgement. For example, Branch PA0308 in Figure A-30 has one section with execution by IDIQ and the rest in-house. Given that only one section was identified for global, postpone the global for that one section and use in-house work forces to execute all stop gap and preventive repairs for this branch.
- Repeat the process for all branches in each year of the PMP.

Figure A-30 Defining Method of Execution for a Branch

Network ID	Branch ID	Section ID	Work Year	Branch Use	Section Rank	Risk - Return Category	Work Type	Method of Execution	Surface Type - Current	M&R Priority	Avg Condition Before	Avg Condition After	Stop Gap Funded	Preventive Funded	Global Funded	Major Under Critical Funded	Total
Keesler	PA00222	01	2023	PARKING	S	D	Preventive	In-House	AC	7	92.70	92.91	$0.00	$104.21	$0.00	$0.00	$104.21
Keesler	PA00222	02	2023	PARKING	S	I	Stopgap	In-House	PCC	7	30.74	30.74	$4,235.54	$0.00	$0.00	$0.00	$4,235.54
Keesler	PA00222	03	2023	PARKING	S	D	Preventive + Global MR	IDIQ	AC	7	83.00	86.88	$0.00	$154.83	$1,782.41	$0.00	$1,937.24
Keesler	PA00223	01	2023	PARKING	S	G	Preventive	In-House	AC	7	62.60	62.80	$0.00	$3,926.17	$0.00	$0.00	$3,926.17
Keesler	PA00223	02	2023	PARKING	S	G	Preventive	In-House	AC	7	60.11	60.22	$0.00	$6,795.25	$0.00	$0.00	$6,795.25
Keesler	PA00237	01	2023	PARKING	P	B	Preventive	In-House	AC	4	91.01	91.22	$0.00	$23.74	$0.00	$0.00	$23.74
Keesler	PA00237	02	2023	PARKING	P	B	Preventive	In-House	AC	4	90.11	90.32	$0.00	$62.09	$0.00	$0.00	$62.09
Keesler	PA00237	03	2023	PARKING	P	F	Stopgap	In-House	PCC	4	47.65	47.65	$30,610.65	$0.00	$0.00	$0.00	$30,610.65
Keesler	PA00237	04	2023	PARKING	P	B	Preventive	In-House	PCC	4	83.71	84.11	$0.00	$1,458.19	$0.00	$0.00	$1,458.19
Keesler	PA00308	01	2023	PARKING	S	I	Stopgap	In-House	AC	7	31.90	31.90	$2,961.33	$0.00	$0.00	$0.00	$2,961.33
Keesler	PA00308	03	2023	PARKING	S	G	Stopgap	In-House	AC	7	49.20	49.20	$1,903.17	$0.00	$0.00	$0.00	$1,903.17
Keesler	PA00308	05	2023	PARKING	S	G	Stopgap	In-House	AC	7	53.80	53.80	$1,634.78	$0.00	$0.00	$0.00	$1,634.78
Keesler	PA00308	06	2023	PARKING	S	G	Preventive + Global MR	IDIQ	AC	7	69.40	73.28	$0.00	$1,339.40	$2,519.62	$0.00	$3,859.02
Keesler	PA00308	07	2023	PARKING	S	G	Stopgap	In-House	AC	7	50.10	50.10	$1,310.88	$0.00	$0.00	$0.00	$1,310.88
Keesler	PA00308	08	2023	PARKING	S	G	Preventive	In-House	AC	7	55.10	55.30	$0.00	$6,482.38	$0.00	$0.00	$6,482.38
Keesler	PA00308	09	2023	PARKING	S	G	Stopgap	In-House	AC	7	51.90	51.90	$1,468.86	$0.00	$0.00	$0.00	$1,468.86
Keesler	PA00404	01	2023	PARKING	S	I	Stopgap	In-House	AC	7	34.60	34.60	$7,244.38	$0.00	$0.00	$0.00	$7,244.38
Keesler	PA00408	01	2023	PARKING	S	G	Stopgap	In-House	AC	7	50.60	50.60	$758.90	$0.00	$0.00	$0.00	$758.90
Keesler	PA00408	02	2023	PARKING	S	D	Preventive	In-House	PCC	7	81.74	81.90	$0.00	$2,626.56	$0.00	$0.00	$2,626.56
Keesler	PA00412	01	2023	PARKING	S	D	Preventive	In-House	AC	7	97.90	98.10	$0.00	$15.84	$0.00	$0.00	$15.84
Keesler	PA00413	01	2023	PARKING	S	D	Preventive	In-House	PCC	7	80.94	81.10	$0.00	$249.16	$0.00	$0.00	$249.16
Keesler	PA00420	01	2023	PARKING	S	D	Preventive	In-House	AC	7	97.90	98.10	$0.00	$31.82	$0.00	$0.00	$31.82
Keesler	PA00422	01	2023	PARKING	S	G	Preventive	In-House	PCC	7	64.14	64.30	$0.00	$613.61	$0.00	$0.00	$613.61
Keesler	PA00470	01	2023	PARKING	S	D	Preventive	In-House	AC	7	91.60	91.80	$0.00	$362.74	$0.00	$0.00	$362.74

Figure A-31 Updated Method of Execution

Network ID	Branch ID	Section ID	Work Year	Branch Use	Section Rank	Risk - Return Category	Work Type	Method of Execution	Surface Type - Current	M&R Priority	Avg Condition Before	Avg Condition After	Stop Gap Funded	Preventive Funded	Global Funded	Major Under Critical Funded	Total
Keesler	PA00222	01	2023	PARKING	S	D	Preventive	IDIQ	AC	7	92.70	92.91	$0.00	$104.21	$0.00	$0.00	$104.21
Keesler	PA00222	02	2023	PARKING	S	I	Stopgap	IDIQ	PCC	7	30.74	30.74	$4,235.54	$0.00	$0.00	$0.00	$4,235.54
Keesler	PA00222	03	2023	PARKING	S	D	Preventive + Global MR	IDIQ	AC	7	83.00	86.88	$0.00	$154.83	$1,782.41	$0.00	$1,937.24
Keesler	PA00223	01	2023	PARKING	S	G	Preventive	In-House	AC	7	62.60	62.80	$0.00	$3,926.17	$0.00	$0.00	$3,926.17
Keesler	PA00223	02	2023	PARKING	S	G	Preventive	In-House	AC	7	60.11	60.22	$0.00	$6,795.25	$0.00	$0.00	$6,795.25
Keesler	PA00308	01	2023	PARKING	S	I	Stopgap	In-House	AC	7	31.90	31.90	$2,961.33	$0.00	$0.00	$0.00	$2,961.33
Keesler	PA00308	03	2023	PARKING	S	G	Stopgap	In-House	AC	7	49.20	49.20	$1,903.17	$0.00	$0.00	$0.00	$1,903.17
Keesler	PA00308	05	2023	PARKING	S	G	Stopgap	In-House	AC	7	53.80	53.80	$1,634.78	$0.00	$0.00	$0.00	$1,634.78
Keesler	PA00308	06	2023	PARKING	S	G	Preventive + Global MR	In-House	AC	7	69.40	73.28	$0.00	$1,339.40	$2,519.62	$0.00	$3,859.02
Keesler	PA00308	07	2023	PARKING	S	G	Stopgap	In-House	AC	7	50.10	50.10	$1,310.88	$0.00	$0.00	$0.00	$1,310.88
Keesler	PA00308	08	2023	PARKING	S	G	Preventive	In-House	AC	7	55.10	55.30	$0.00	$6,482.38	$0.00	$0.00	$6,482.38
Keesler	PA00308	09	2023	PARKING	S	G	Stopgap	In-House	AC	7	51.90	51.90	$1,468.86	$0.00	$0.00	$0.00	$1,468.86
Keesler	PA00404	01	2023	PARKING	S	I	Stopgap	In-House	AC	7	34.60	34.60	$7,244.38	$0.00	$0.00	$0.00	$7,244.38
Keesler	PA00408	01	2023	PARKING	S	G	Stopgap	In-House	AC	7	50.60	50.60	$758.90	$0.00	$0.00	$0.00	$758.90
Keesler	PA00408	02	2023	PARKING	S	D	Preventive	In-House	PCC	7	81.74	81.90	$0.00	$2,626.56	$0.00	$0.00	$2,626.56
Keesler	PA00412	01	2023	PARKING	S	D	Preventive	In-House	AC	7	97.90	98.10	$0.00	$15.84	$0.00	$0.00	$15.84
Keesler	PA00413	01	2023	PARKING	S	D	Preventive	In-House	PCC	7	80.94	81.10	$0.00	$249.16	$0.00	$0.00	$249.16
Keesler	PA00420	01	2023	PARKING	S	D	Preventive	In-House	AC	7	97.90	98.10	$0.00	$31.82	$0.00	$0.00	$31.82
Keesler	PA00422	01	2023	PARKING	S	G	Preventive	In-House	PCC	7	64.14	64.30	$0.00	$613.61	$0.00	$0.00	$613.61
Keesler	PA00470	01	2023	PARKING	S	D	Preventive	IDIQ	AC	7	91.60	91.80	$0.00	$362.74	$0.00	$0.00	$362.74
Keesler	PA00470	02	2023	PARKING	S	G	Preventive + Global MR	IDIQ	AC	7	66.80	70.68	$0.00	$1,384.71	$1,254.21	$0.00	$2,638.92
Keesler	PA00470	03	2023	PARKING	S	D	Preventive + Global MR	IDIQ	AC	7	83.00	86.88	$0.00	$31.11	$358.20	$0.00	$389.32
Keesler	PA00470	04	2023	PARKING	S	G	Stopgap	IDIQ	AC	7	49.20	49.20	$3,183.90	$0.00	$0.00	$0.00	$3,183.90
Keesler	PA00470	05	2023	PARKING	S	D	Preventive	IDIQ	AC	7	92.70	92.91	$0.00	$24.64	$0.00	$0.00	$24.64

A-9.6.3 Adjust Year of Execution.

Using the requirements list in Figure A-31, re-sort it to compare the year of execution for all requirements in each section for each year in the plan, as shown in Figure A-32. **Note:** The M&R priority for the branches in this example are low and work on these pavements have a low return on investment. This choice is intentional to demonstrate the same process applies to all pavements, from highest to lowest risk and return.

- Sort by branch and section and investigate opportunities to adjust the year of execution (see paragraph 8-7.3).
- In the example in Figure A-32, Major M&R is scheduled for Branch PA00308 in different years in the respective sections within the branch. It would be more cost-effective to do one M&R project for all sections in the branch.
- In this example, most sections are scheduled in 2024, so change all to 2024 and adjust the other years for each section, as required.
- Consider the types and severity of distresses present in the Consequence of Localized M&R Distress Repair Details Report to define work types and determine changes to the year of execution.
- In this example, the Consequence of Localized M&R Report indicates that there is a large quantity of medium-severity climate-related distresses, so a two-inch mill and overlay is a good repair option.
- Repeat the process for all sections in each year of the PMP.

Figure A-32 Adjust Year of Execution

Network ID	Branch ID	Section ID	Work Year	Branch Use	Section Rank	Risk - Return Category	Work Type	Method of Execution	Surface Type - Current	M&R Priority	Avg Condition Before	Avg Condition After	Stop Gap Funded	Preventive Funded	Global Funded	Major Under Critical Funded	Total
Keesler	PA00308	01	2023	PARKING	S	I	Stopgap	In-House	AC	7	31.90	31.90	$2,961.33	$0.00	$0.00	$0.00	$2,961.33
Keesler	PA00308	01	2024	PARKING	S	I	Stopgap	In-House	AC	7	30.06	30.06	$3,172.41	$0.00	$0.00	$0.00	$3,172.41
Keesler	PA00308	01	2025	PARKING	S	I	Stopgap	In-House	AC	7	28.22	28.22	$3,571.62	$0.00	$0.00	$0.00	$3,571.62
Keesler	PA00308	01	2026	PARKING	S	I	Major Below Critical	Contract	AC	7	26.38	100.00	$0.00	$0.00	$0.00	$49,565.80	$49,565.80
Keesler	PA00308	01	2027	PARKING	S	D	Preventive	In-House	AC	7	98.16	98.36	$0.00	$16.55	$0.00	$0.00	$16.55
Keesler	PA00308	03	2023	PARKING	S	G	Stopgap	In-House	AC	7	49.20	49.20	$1,903.17	$0.00	$0.00	$0.00	$1,903.17
Keesler	PA00308	03	2024	PARKING	S	G	Stopgap	In-House	AC	7	47.36	47.36	$2,024.12	$0.00	$0.00	$0.00	$2,024.12
Keesler	PA00308	03	2025	PARKING	S	G	Major Below Critical	Contract	AC	7	45.52	100.00	$0.00	$0.00	$0.00	$36,715.34	$36,715.34
Keesler	PA00308	03	2026	PARKING	S	D	Preventive	In-House	AC	7	98.16	98.36	$0.00	$20.43	$0.00	$0.00	$20.43
Keesler	PA00308	03	2027	PARKING	S	D	Preventive	In-House	AC	7	96.53	96.73	$0.00	$38.63	$0.00	$0.00	$38.63
Keesler	PA00308	05	2023	PARKING	S	G	Stopgap	In-House	AC	7	53.80	53.80	$1,634.78	$0.00	$0.00	$0.00	$1,634.78
Keesler	PA00308	05	2024	PARKING	S	G	Major Below Critical	Contract	AC	7	51.96	100.00	$0.00	$0.00	$0.00	$17,225.61	$17,225.61
Keesler	PA00308	05	2025	PARKING	S	D	Preventive	In-House	AC	7	98.16	98.36	$0.00	$20.86	$0.00	$0.00	$20.86
Keesler	PA00308	05	2026	PARKING	S	D	Preventive	In-House	AC	7	96.52	96.72	$0.00	$39.55	$0.00	$0.00	$39.55
Keesler	PA00308	05	2027	PARKING	S	D	Preventive	In-House	AC	7	94.88	95.08	$0.00	$58.14	$0.00	$0.00	$58.14
Keesler	PA00308	06	2023	PARKING	S	G	Preventive + Global MR	In-House	AC	7	69.40	73.28	$0.00	$1,339.40	$2,519.62	$0.00	$3,859.02
Keesler	PA00308	06	2024	PARKING	S	D	Preventive	In-House	AC	7	71.44	71.64	$0.00	$898.63	$0.00	$0.00	$898.63
Keesler	PA00308	06	2025	PARKING	S	G	Preventive	In-House	AC	7	69.80	70.00	$0.00	$1,117.49	$0.00	$0.00	$1,117.49
Keesler	PA00308	06	2026	PARKING	S	G	Preventive	In-House	AC	7	68.16	68.36	$0.00	$2,027.35	$0.00	$0.00	$2,027.35
Keesler	PA00308	06	2027	PARKING	S	G	Preventive	In-House	AC	7	66.52	66.72	$0.00	$2,937.10	$0.00	$0.00	$2,937.10
Keesler	PA00308	07	2023	PARKING	S	G	Stopgap	In-House	AC	7	50.10	50.10	$1,310.88	$0.00	$0.00	$0.00	$1,310.88
Keesler	PA00308	07	2024	PARKING	S	G	Major Below Critical	Contract	AC	7	48.26	100.00	$0.00	$0.00	$0.00	$17,470.96	$17,470.96
Keesler	PA00308	07	2025	PARKING	S	D	Preventive	In-House	AC	7	98.16	98.36	$0.00	$14.52	$0.00	$0.00	$14.52
Keesler	PA00308	07	2026	PARKING	S	D	Preventive	In-House	AC	7	96.52	96.72	$0.00	$27.53	$0.00	$0.00	$27.53
Keesler	PA00308	07	2027	PARKING	S	D	Preventive	In-House	AC	7	94.88	95.08	$0.00	$40.47	$0.00	$0.00	$40.47
Keesler	PA00308	08	2023	PARKING	S	G	Preventive	In-House	AC	7	55.10	55.30	$0.00	$6,482.38	$0.00	$0.00	$6,482.38
Keesler	PA00308	08	2024	PARKING	S	G	Major Below Critical	Contract	AC	7	53.46	100.00	$0.00	$0.00	$0.00	$12,192.43	$12,192.43
Keesler	PA00308	08	2025	PARKING	S	D	Preventive	In-House	AC	7	98.16	98.36	$0.00	$14.77	$0.00	$0.00	$14.77
Keesler	PA00308	08	2026	PARKING	S	D	Preventive	In-House	AC	7	96.52	96.72	$0.00	$28.00	$0.00	$0.00	$28.00
Keesler	PA00308	08	2027	PARKING	S	D	Preventive	In-House	AC	7	94.88	95.08	$0.00	$41.15	$0.00	$0.00	$41.15
Keesler	PA00308	09	2023	PARKING	S	G	Stopgap	In-House	AC	7	51.90	51.90	$1,468.86	$0.00	$0.00	$0.00	$1,468.86
Keesler	PA00308	09	2024	PARKING	S	G	Major Below Critical	Contract	AC	7	50.06	100.00	$0.00	$0.00	$0.00	$14,357.25	$14,357.25
Keesler	PA00308	09	2025	PARKING	S	D	Preventive	In-House	AC	7	98.16	98.36	$0.00	$17.39	$0.00	$0.00	$17.39
Keesler	PA00308	09	2026	PARKING	S	D	Preventive	In-House	AC	7	96.52	96.72	$0.00	$32.97	$0.00	$0.00	$32.97

A-9.6.4 Create In-House Work Plan.

Using the requirements list in Figure A-32, re-sort it to generate an in-house work plan, as shown in Figure A-33.

- Sort the list by **Work Year**, **Execution Method**, **M&R Priority**, **Risk-Return Category**, **Branch ID**, and **Section ID**.
- Move any sections with High risk and Low ROI to the top of the list. The remainder of the list is in M&R priority order, with the highest priority on localized and global preventive M&R.
- Review each section identified for in-house execution in the critical PCI work plan. Combine these M&R requirements in an in-house work plan. Review and update the plan at least annually.
- Use the Consequence of Localized M&R Distress Repair Details Report to determine the specific work types required for each section and use the optimal critical PCI work plan to make decisions about risk, return, and timing of repairs.
- For example, Figure A-34 shows the predominant distresses are load related and that PAVER has the section scheduled for Major M&R in 2024. Given the nature of the distresses, reconstruction is the likely M&R option. Is investing in full depth repairs in 2023 essential from a safety perspective when the pavement will be reconstructed in 2024 or should the Major M&R be moved to 2023?
- Execute any requirements that exceed in-house work capacity or capability with IDIQ or competitive bid contracts.

A-9.6.5 Create a Contract Project Plan.

Use the same procedure outlined above to create a contract project plan with a list of projects with execution method.

- Review each section identified for contract execution in the critical PCI work plan. Combine these M&R requirements in a contract project plan. Review and update the plan at least annually.
- Use the Consequence of Localized M&R Distress Repair Details Report to determine the specific work types required for each section and use the optimal critical PCI work plan to make decisions about risk, return, and timing of repairs.
- Repeat the process for all sections in each year of the PMP.

Figure A-33 In-House Work Plan

Network ID	Branch ID	Section ID	Work Year	Branch Use	Section Rank	Risk - Return Category	Work Type	Method of Execution	Surface Type - Current	M&R Priority	Avg Condition Before	Avg Condition After	Stop Gap Funded	Preventive Funded	Global Funded	Major Under Critical Funded	Total
Keesler	RDASTREET	01	2023	ROADWAY	S	C	Stopgap	In-House	AC	3	41.49	41.49	$4,347.32	$0.00	$0.00	$0.00	$4,347.32
Keesler	RDGALAXY	01	2023	ROADWAY	S	E	Stopgap	In-House	AC	3	12.49	12.49	$12,528.14	$0.00	$0.00	$0.00	$12,528.14
Keesler	RDUNKNOWN3	01	2023	ROADWAY	S	E	Stopgap	In-House	AC	3	27.49	27.49	$4,275.51	$0.00	$0.00	$0.00	$4,275.51
Keesler	RDFISHER	01	2023	ROADWAY	P	A	Preventive	In-House	AC	1	95.04	95.33	$0.00	$144.90	$0.00	$0.00	$144.90
Keesler	RDFISHER	02	2023	ROADWAY	P	A	Preventive	In-House	AC	1	95.54	95.83	$0.00	$168.42	$0.00	$0.00	$168.42
Keesler	RDLARCHER	01	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.44	92.73	$0.00	$318.33	$0.00	$0.00	$318.33
Keesler	RDLARCHER	02	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.44	92.73	$0.00	$325.30	$0.00	$0.00	$325.30
Keesler	RDLARCHER	03	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.54	92.83	$0.00	$347.56	$0.00	$0.00	$347.56
Keesler	RDLARCHER	04	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.54	92.83	$0.00	$261.23	$0.00	$0.00	$261.23
Keesler	RDLARCHER	05	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.54	92.83	$0.00	$333.14	$0.00	$0.00	$333.14
Keesler	RDLARCHER	06	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.64	92.93	$0.00	$244.64	$0.00	$0.00	$244.64
Keesler	RDLARCHER	07	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.24	92.53	$0.00	$71.99	$0.00	$0.00	$71.99
Keesler	RDLARCHER	08	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.44	92.73	$0.00	$277.92	$0.00	$0.00	$277.92
Keesler	RDLARCHER	09	2023	ROADWAY	P	A	Preventive	In-House	AC	1	92.44	92.73	$0.00	$284.11	$0.00	$0.00	$284.11
Keesler	RD5022	01	2023	ROADWAY	S	C	Preventive	In-House	PCC	3	68.52	68.64	$0.00	$961.09	$0.00	$0.00	$961.09
Keesler	RDBAUGHMAN	01	2023	ROADWAY	S	C	Preventive	In-House	AC	3	59.59	59.76	$0.00	$2,663.40	$0.00	$0.00	$2,663.40
Keesler	RDBAUGHMAN	02	2023	ROADWAY	S	A	Preventive	In-House	AC	3	92.89	93.06	$0.00	$44.83	$0.00	$0.00	$44.83
Keesler	RDPARADELN	01	2023	ROADWAY	S	A	Preventive	In-House	AC	3	92.89	93.06	$0.00	$354.95	$0.00	$0.00	$354.95
Keesler	RDTINGLE	01	2023	ROADWAY	S	A	Preventive	In-House	AC	3	92.79	92.96	$0.00	$139.34	$0.00	$0.00	$139.34
Keesler	RDTSTREET	01	2023	ROADWAY	S	C	Preventive	In-House	AC	3	55.89	56.05	$0.00	$12,432.39	$0.00	$0.00	$12,432.39
Keesler	PA00237	01	2023	PARKING	P	B	Preventive	In-House	AC	4	91.01	91.22	$0.00	$23.74	$0.00	$0.00	$23.74
Keesler	PA00237	02	2023	PARKING	P	B	Preventive	In-House	AC	4	90.11	90.32	$0.00	$62.09	$0.00	$0.00	$62.09
Keesler	PA00237	03	2023	PARKING	P	F	Stopgap	In-House	PCC	4	47.65	47.65	$30,610.65	$0.00	$0.00	$0.00	$30,610.65
Keesler	PA00237	04	2023	PARKING	P	B	Preventive	In-House	PCC	4	83.71	84.11	$0.00	$1,458.19	$0.00	$0.00	$1,458.19

Figure A-34 In-House Work Determination

Network ID	Branch ID	Section ID	Policy	Distress Code	Description	Severity	Distress Qty	Distress Unit	Percent Distress	Work Description	Work Qty	Work Unit	Unit Cost	Work Cost
Keesler	RDGALAXY	01	FY2022_AFCEC_RD&PK_STP	1	ALLIGATOR CR	Medium	9,552.11	SqFt	97.5	No Localized M & R	0.		$0.00	$0.00
Keesler	RDGALAXY	01	FY2022_AFCEC_RD&PK_STP	20	WEATHERING	High	9,796.99	SqFt	100.	No Localized M & R	0.		$0.00	$0.00
Keesler	RDGALAXY	01	FY2022_AFCEC_RD&PK_STP	1	ALLIGATOR CR	High	244.88	SqFt	2.5	Patching - AC Deep	312.2	SqFt	$15.30	$4,772.30

Network ID	Branch ID	Section ID	Avg Of Condition Before	Avg Of Condition After	Work Year	Stop Gap Funded	Preventive Funded	Global Funded	Major Under Critical Funded
Keesler	RDGALAXY	01	12.49	12.49	2023	$12,528.14	$0.00	$0.00	$0.00
Keesler	RDGALAXY	01	10.82	100.00	2024	$0.00	$0.00	$0.00	$55,056.25
Keesler	RDGALAXY	01	98.33	98.49	2025	$0.00	$16.75	$0.00	$0.00
Keesler	RDGALAXY	01	96.82	96.98	2026	$0.00	$31.86	$0.00	$0.00
Keesler	RDGALAXY	01	95.31	95.47	2027	$0.00	$46.96	$0.00	$0.00

A-9.7 Using PAVER Required Work to Develop a PMP.

The previous sections demonstrated how to export work plans to Excel and use them to develop a PMP consisting of an in-house work plan and contract project plan. The PAVER Project Formulation Wizard or Required Projects tool can be used to identify required Global and Major M&R work and incorporate these projects into the prioritized critical PCI work plan.

A-9.7.1 Required Projects Tool.

This tool builds projects that include localized, global, or major M&R using a step-by-step process.

- Create a project.
- Define the sections in the project.
- Define the project-level work required.
- Define any section-level work required.
- Review work items.

A-9.7.2 Project Formulation Wizard.

This tool builds global and major M&R projects using a step-by-step process similar to the Required Projects tool but handles localized M&R differently and breaks out the steps in the process in a more sequential manner than the Required Projects tool.

- Create a project.
- Define the project-level work required.
- Define Pre-Application Localized M&R Policy.
- Define the sections in the project.
- Refine section selection set engineering field parameters.
- Define section selection set age and condition parameters.
- Define distress ranges.
- Review and refine sections using the map or query tool.
- Verify selected sections.
- Review work items.

A-9.7.3 Required Projects Tool Example.

The Required Projects tool example in the following sections uses the information in the modified critical PCI work plan and consequence of localized M&R work plan developed in previous sections as a starting place. Use the tool to filter down to the specific sections identified in the work plan, then use the consequence of localized M&R work plan to identify the specific work types to include in the project.

A-9.7.3.1 Selecting Sections in The Project.

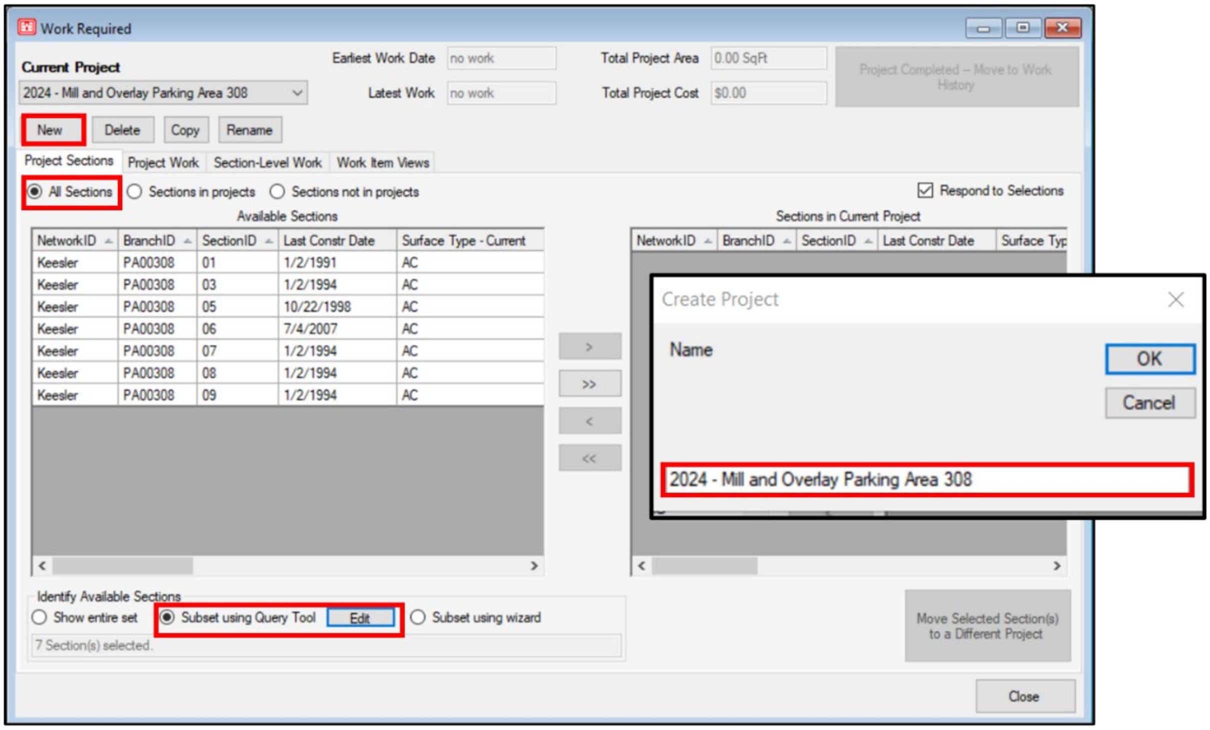
From the PAVER **Work** drop-down menu, select **Required Projects**. This opens the **Work Required** form shown in Figure A-36.

- There are several options to select sections for a project. The user can filter sections in a manner similar to the work plan sorting procedures described or select specific branches and sections based on the critical PCI work plan.
- This example demonstrates how to build a project for a specific branch. It is based on the 2024 Major M&R project in the critical PCI work plan for the Building 308 parking area from Figure A-32 and shown in Figure A-35.
- Select **New** to create a new project. Provide a descriptive name with the year of execution. For this example, use "2024 – Mill and Overlay Parking Area 308," as shown in Figure A-36.
- Select the **All Sections** option then select **Subset using Query Tool**.
- Select **Branches** on the **Query Tool** form then select **Branch ID** from the field drop-down menu, equal to "PA00308" from the **Comparison** drop-down menu.
- This filters the list down to all sections in the PA00308 branch, as shown in the left grid in Figure A-36.
- Select the double arrows **>>** to move all sections to the **Sections in Current Project** grid on the right side of the form.
- Section 06 only requires preventive M&R and is not included in the mill and overlay project. Remove it from the **Sections in Current Project** grid by highlighting it and selecting the **<** arrow to move it back to the **Available Sections** grid.

Figure A-35 PA00308 Major M&R Project

Network ID	Branch ID	Section ID	Work Year	Branch Use	Section Rank	Risk - Return Category	Work Type	Method of Execution	Surface Type - Current	M&R Priority	Avg Condition Before	Avg Condition After	Stop Gap Funded	Preventive Funded	Global Funded	Major Under Critical Funded	Total
Keesler	PA00308	01	2024	PARKING	S	I	Major Below Critical	Contract	AC	7	26.38	100.00	$0.00	$0.00	$0.00	$49,565.80	$49,565.80
Keesler	PA00308	03	2024	PARKING	S	G	Major Below Critical	Contract	AC	7	45.52	100.00	$0.00	$0.00	$0.00	$36,715.34	$36,715.34
Keesler	PA00308	05	2024	PARKING	S	G	Major Below Critical	Contract	AC	7	51.96	100.00	$0.00	$0.00	$0.00	$17,225.61	$17,225.61
Keesler	PA00308	07	2024	PARKING	S	G	Major Below Critical	Contract	AC	7	48.26	100.00	$0.00	$0.00	$0.00	$17,470.96	$17,470.96
Keesler	PA00308	08	2024	PARKING	S	G	Major Below Critical	Contract	AC	7	53.46	100.00	$0.00	$0.00	$0.00	$12,192.43	$12,192.43
Keesler	PA00308	09	2024	PARKING	S	G	Major Below Critical	Contract	AC	7	50.06	100.00	$0.00	$0.00	$0.00	$14,357.25	$14,357.25

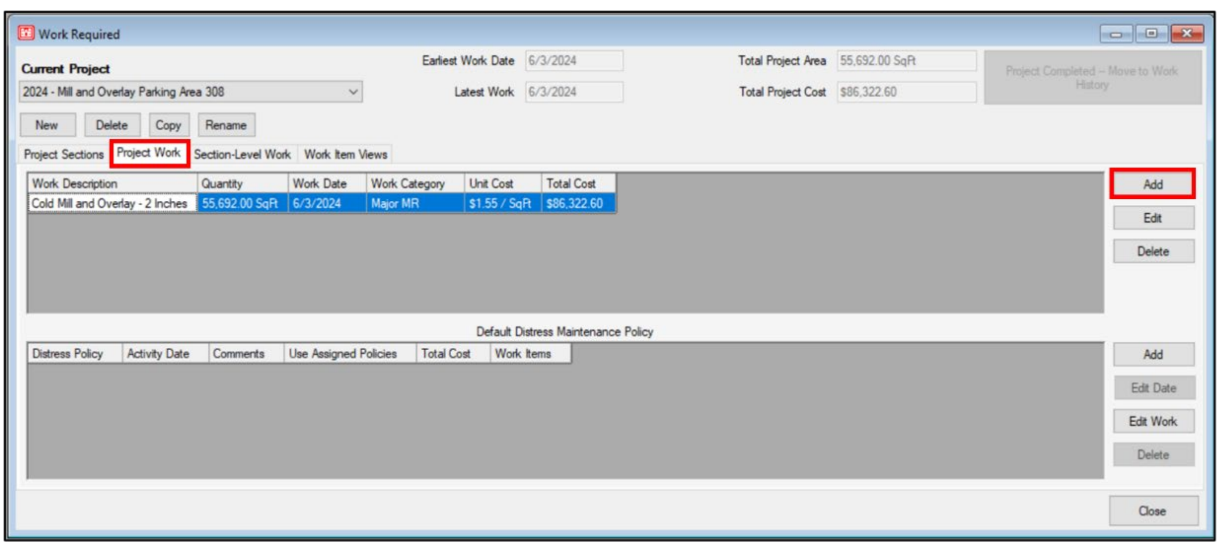
Figure A-36 Select Sections Example



A-9.7.3.2 Project Work.

After reviewing the condition and distresses in the consequence of localized work plan, a two-inch mill and overlay was selected as the best M&R option. Add this work type by selecting the **Project Work** tab, shown in Figure A-37.

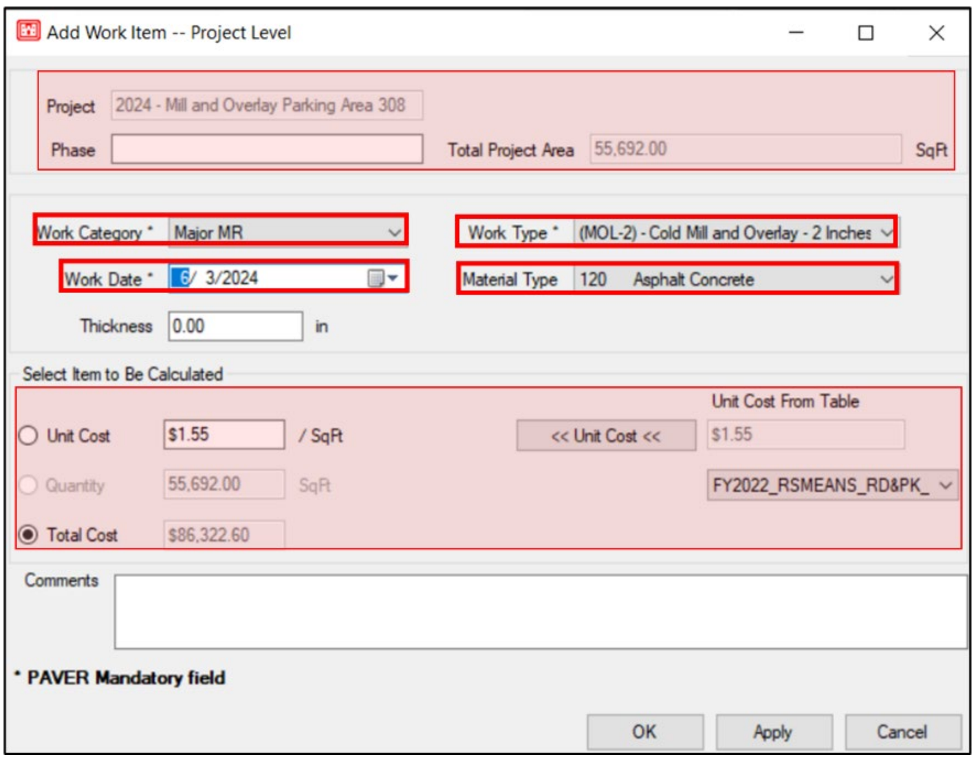
Figure A-37 Project Work Tab



- Select the **Add** button on the **Work Required** form above to open the **Add Work Item – Project Level** form shown in Figure A-38.

- The area highlighted at the top of the **Add Work Item – Project Level** form shows the **Project** name is already populated, the **Phase** field is optional, and the **Total Project Area** is populated and is the sum of the area of all sections in the project.
- Select the **Work Category** from the drop-down, then select the **Work Type**, the **Work Date** (projected date of execution), and **Material Type**.
- In this case, leave **Thickness** set to 0.00 since 2 inches of asphalt is milled and 2 inches is replaced.
- The lower portion of the form highlighted in red is for the project cost. The user can pull the unit cost from the cost by work type table for Major M&R, enter a unit cost manually, or enter the total cost of the project. In this example, the cost is coming from the FY2022_RSMEANS_RD&PK_Major cost by work type for table Major M&R.

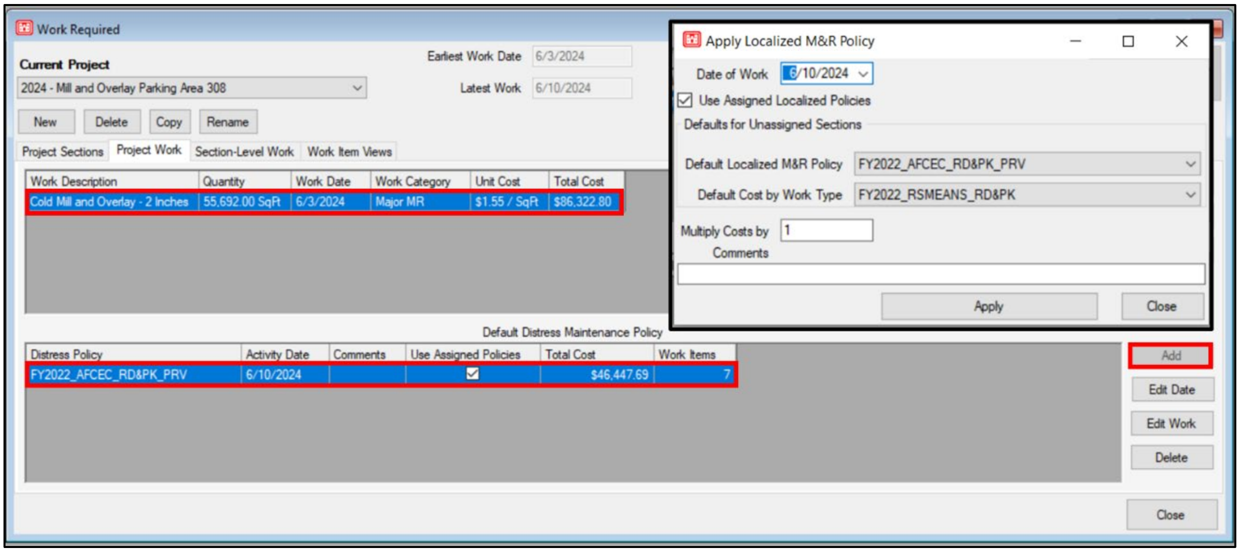
Figure A-38 Add Work Item – Project Level Form



- Select **OK** at the bottom of the **Add Work Item – Project Level** form above to close the form. The project is added to the **Project Work** tab shown in Figure A-39.
- The lower portion of the **Project Work** tab in Figure A-39 allows the user to apply localized M&R policies to the project. This is typically used when planning localized preventive or operational repair projects or when including localized work as part of a Major or global M&R project. In this case, some crack sealing and full-depth patching is appropriate after milling and prior to the overlay.

- Select **Add** to open the **Apply Localized M&R Policy** form. All sections have assigned localized M&R policies, so just select a **Date of Work** after the project start and select **Apply** to add the localized M&R work to the project, as shown in Figure A-39.

Figure A-39 Add Distress M&R Policy – Project Work Tab Cost



- **Note:** The cost of the project in Figure A-35 was higher than the estimated cost in the **Project Work** tab form in Figure A-39. The cost in Figure A-35 was based on the cost by condition tables and not associated with a specific work type. The cost in Figure A-39 was based on cost by work type. There will also be instances when the cost by condition estimates are lower than the cost by work type averages.
- Select the **Section-Level Work** tab.

A-9.7.3.3 Section-Level Work.

The **Section-Level Work** tab allows the user to review, add, edit, or delete any work item in the project on a section-by-section basis.

- The example in Figure A-40 includes Section 06. Based on the critical PCI work plan and the consequence of localized work plan, this section does not require an overlay, just crack sealing.
- Select the **Cold Mill and Overlay – 2 Inches** line item in the **Work Items for Sections** field and select **Delete**.
- Field work indicates that a patch/utility cut that was identified as low severity in the last inspection has deteriorated and will require replacement in 2024.
- Select the **Add** button to open the **Add Work Item** form and add a new work item, as shown in Figure A-41.
    - o Work Category: Localized MR

- o Work Date: 6/10/2024
- o Thickness: 0.00 in.
- o Work Type: Patching – AC Deep
- o Material Type: Asphalt Concrete
- o Use the unit cost from Localized Cost by Work Type table.
- o Enter the quantity.
- o Select **OK**.

Figure A-40 Section Work Types and Quantities

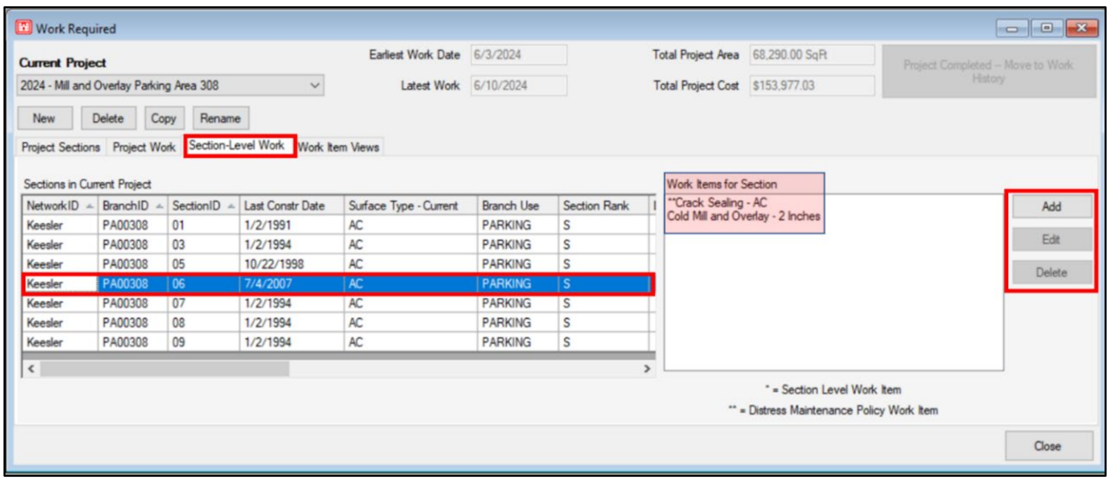
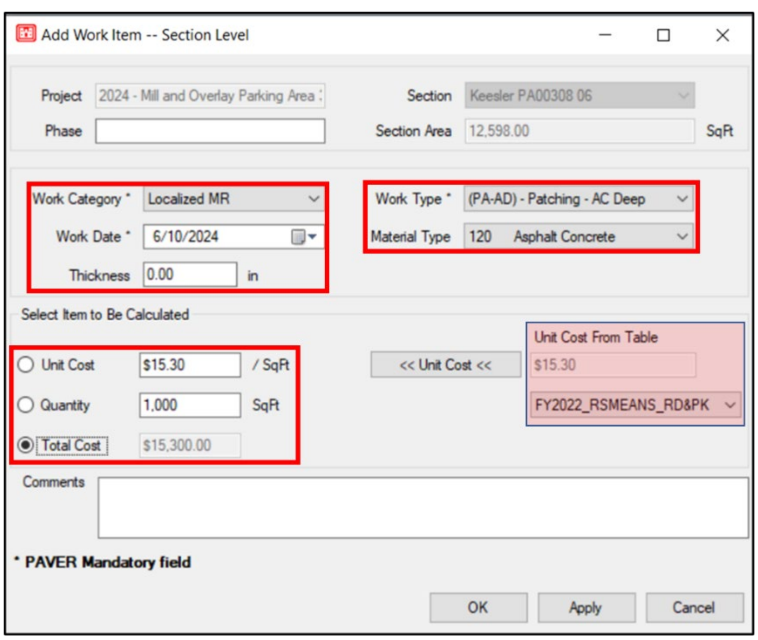


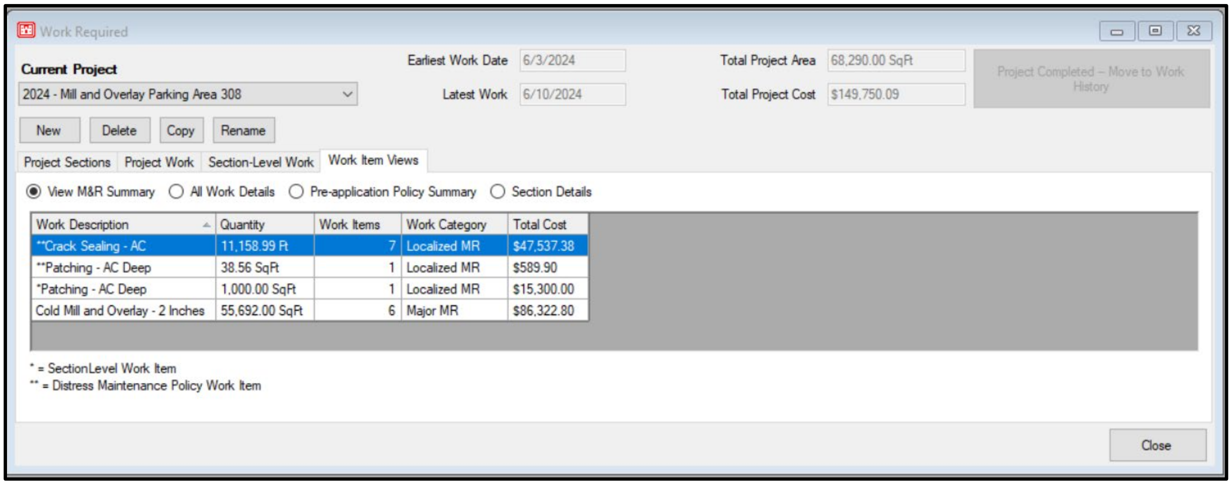
Figure A-41 Section Work Types and Quantities



A-9.7.3.4 Work Item Views.

The **Work Item Views** tab provides summary and detail-level views of the work items in the project, describing the sections included in the project, work types, quantities, and costs.

Figure A-42 View Project and Section Item Summary



A-9.7.4 Project Formulation Wizard Example.

The Required Projects Tool example in the following sections uses the information in the modified critical PCI work plan and consequence of localized M&R work plan developed in previous sections as a starting place. Use the tool to filter down to the specific sections identified in the work plan, then use the consequence of localized M&R work plan to identify the specific work types to include in the project.

A-9.7.4.1 Define Project-Level Work.

Select the **Project Formulation Wizard** icon on the tool bar. This opens the **Project Formulation Wizard** form shown in Figure A-43.

- Enter the **Project Name**. This example is a 2023 global M&R project for roads.
- Select **Add Work** to open the **Add Work Item** form shown in Figure A-44.
  - o Work Category: Global MR
  - o Work Date: 8/1/2023
  - o Thickness: 0.50 in.
  - o Work Type: Surface Treatment – Cape Seal
  - o The Global M&R cost table did not have a cost for cape seals but based local costs are $0.31 per square foot.

- o Select **OK** to add the work item.

Figure A-43 Global M&R Example

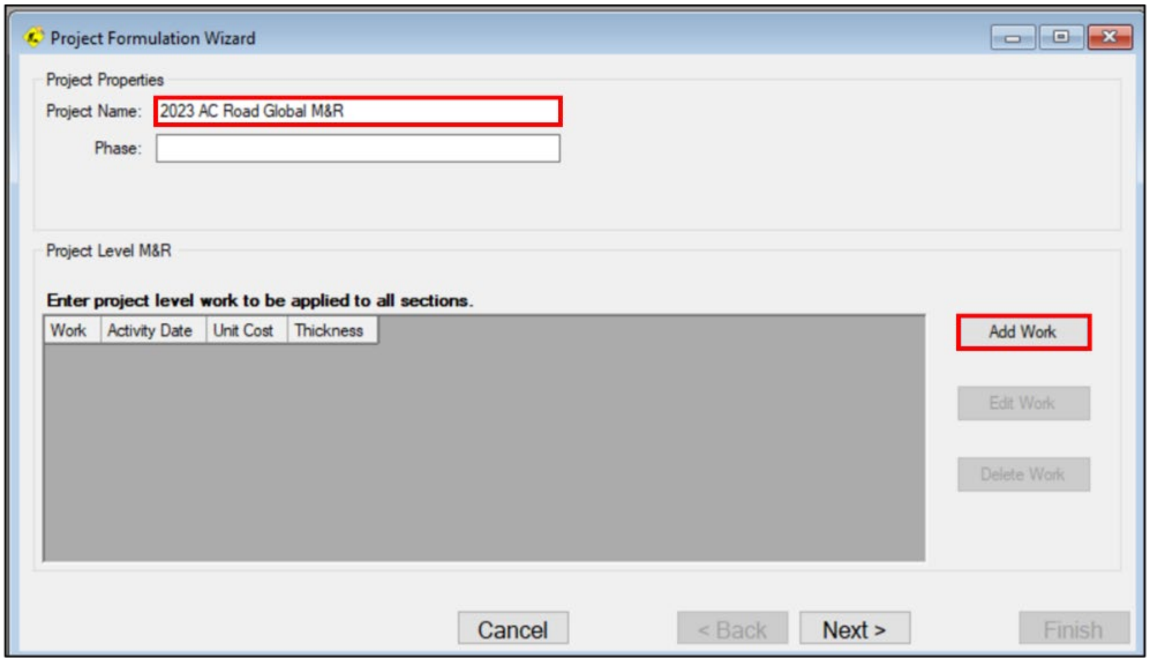
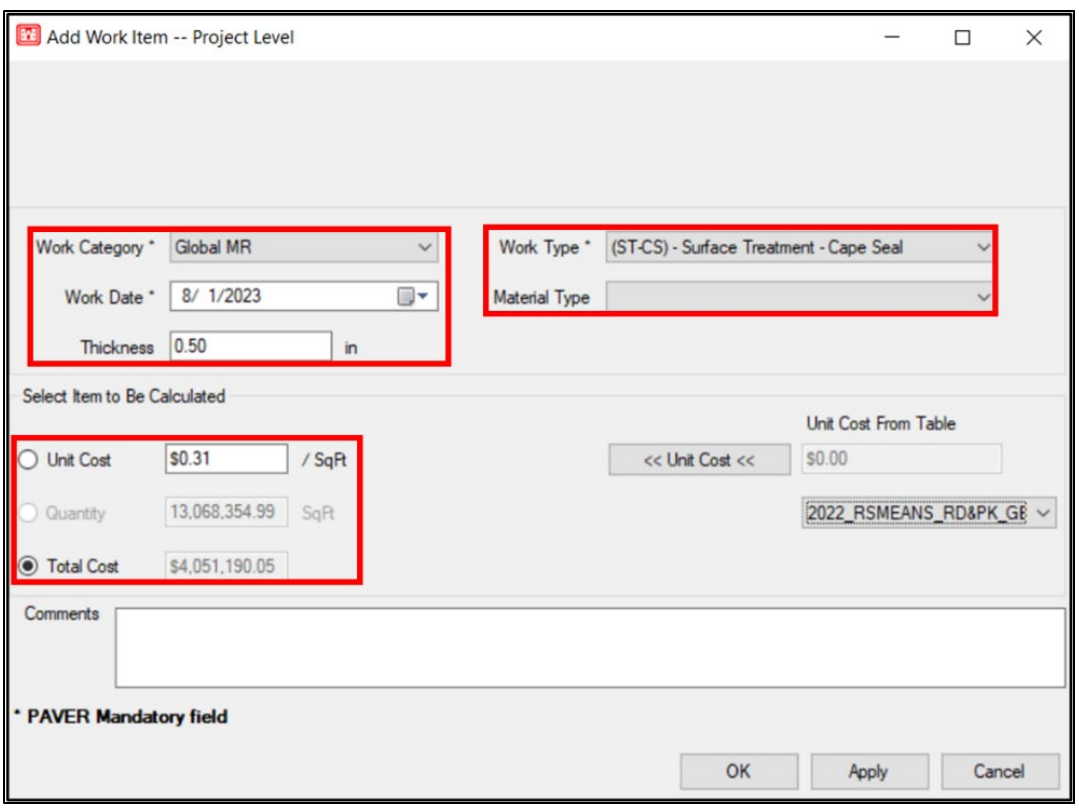


Figure A-44 Define Project-Level Work

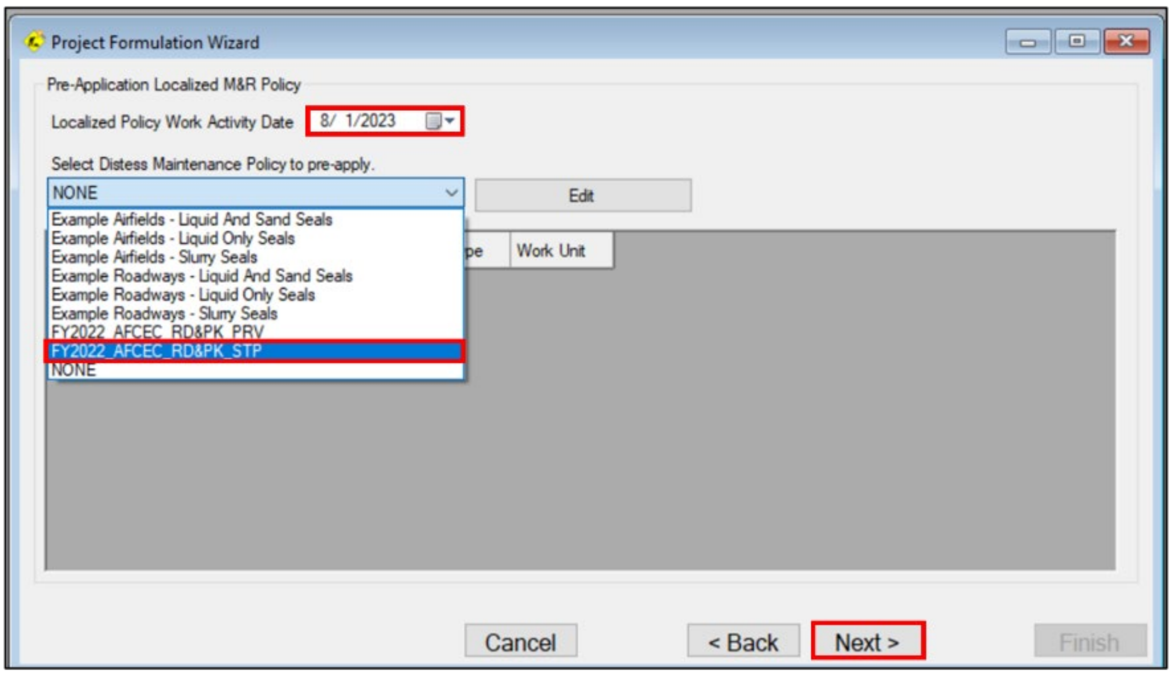


A-9.7.4.2 Pre-Application Localized M&R Policy.

Prior to applying the cape seal in this example, localized repairs are required to address some distresses.

- Select **Next >** on the **Project Formulation Wizard** form shown in Figure A-43 to open the form shown in Figure A-45.
- The **Localized Policy Work Activity Date** is the same as the project date.
- PAVER provides example policies that can be used, but for this example, select the stopgap M&R policy to repair any high-severity distresses before placing the cape seal. Review and edit the policy if required for this particular application.
- Select **Next >**.

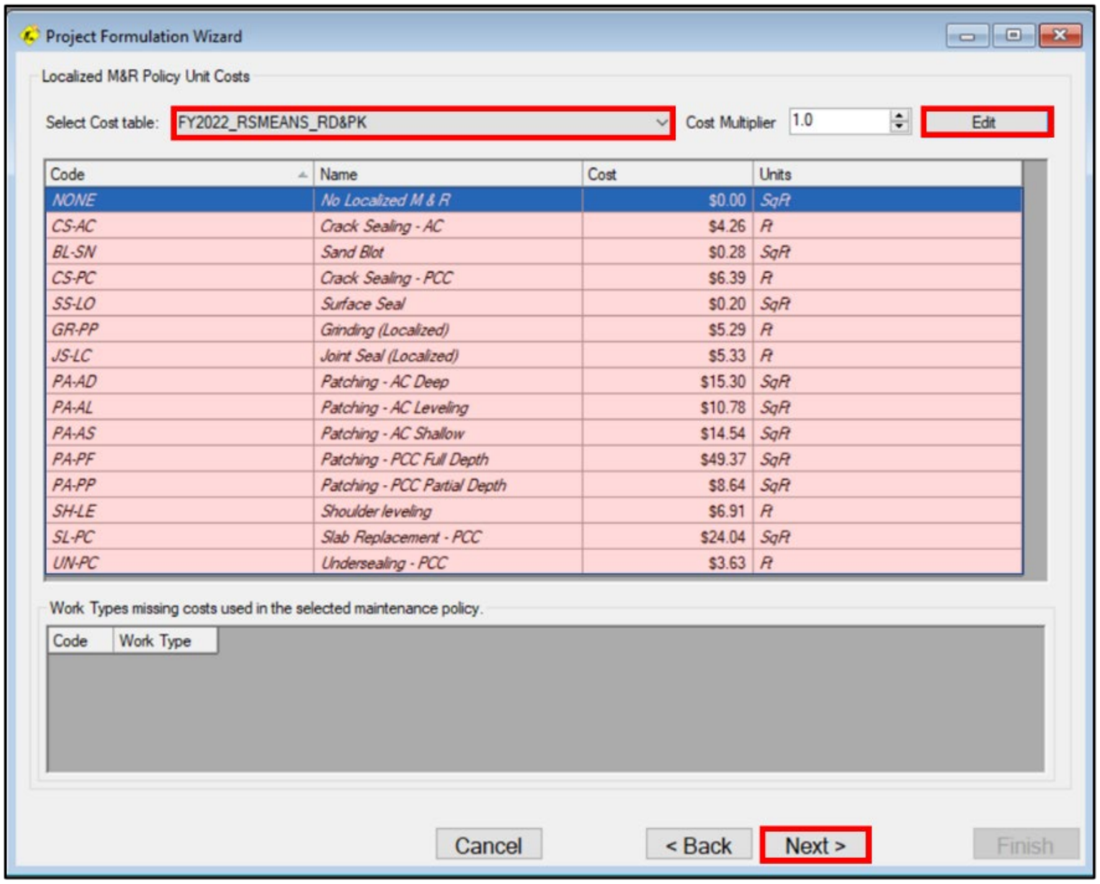
Figure A-45 Pre-Application Localized M&R Policy



A-9.7.4.3 Pre-Application Localized M&R Policy Unit Costs.

- Use the Localized M&R Policy Unit costs defined for the Localized M&R Family.
- PAVER will display any work types missing unit cost in the lower window of the form in Figure A-46. Select **Edit** to update unit costs, if required.
- Select **Next >**.

Figure A-46 Add Work Item – Project Level Form

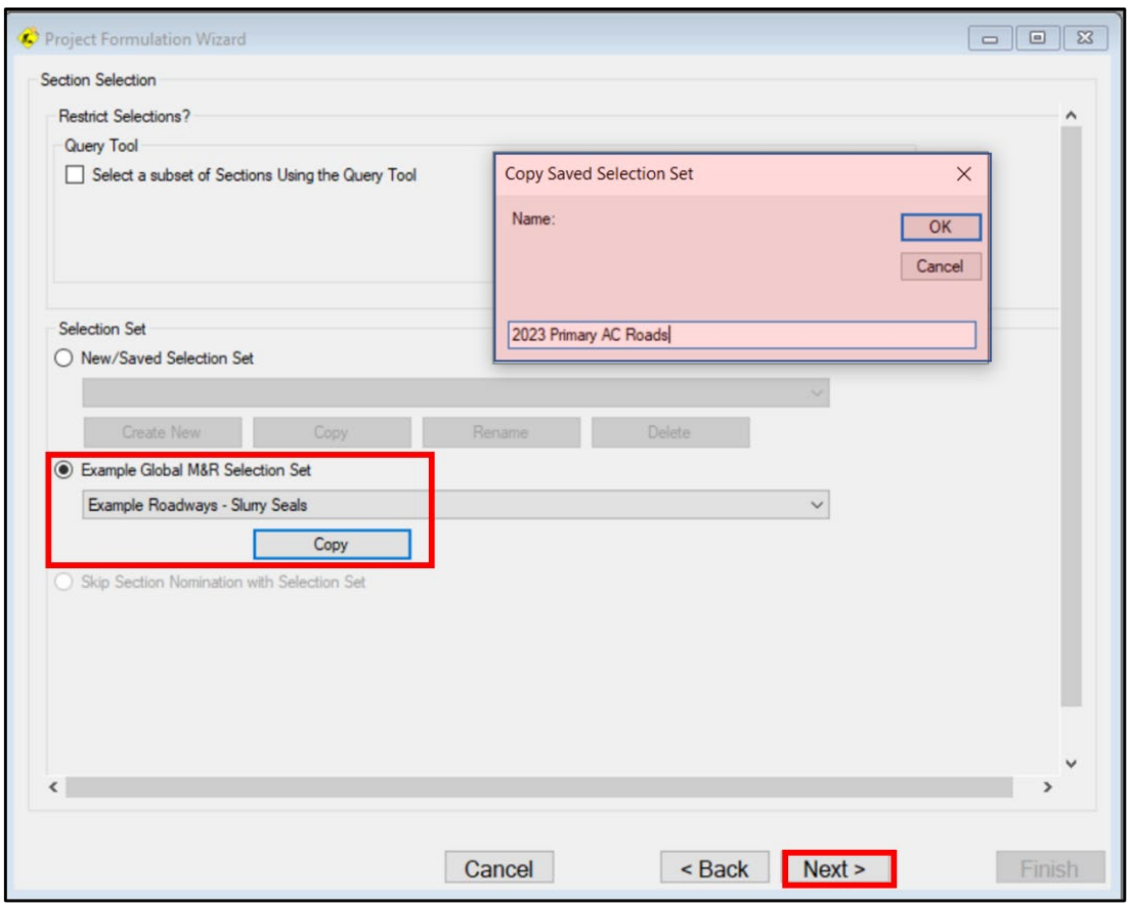


A-9.7.4.4 Define Sections in the Project.

The **Project Formulation Wizard** gives the user several options to determine the section included in a project, including the query tool used in the Required Work example, defining a new selection set, or using an example global M&R selection set to define a new selection set, which is the approach used in this example.

- Highlight the **Example Global M&R Selection Set** radio button and select **Example Roadways – Slurry Seals** from the drop-down, then select **Copy** as shown in Figure A-47.
- Give the copy of the example a new name: 2023 Primary AC Roads.
- Select **Next >**.

Figure A-47 Add Distress M&R Policy – Project Work Tab Cost

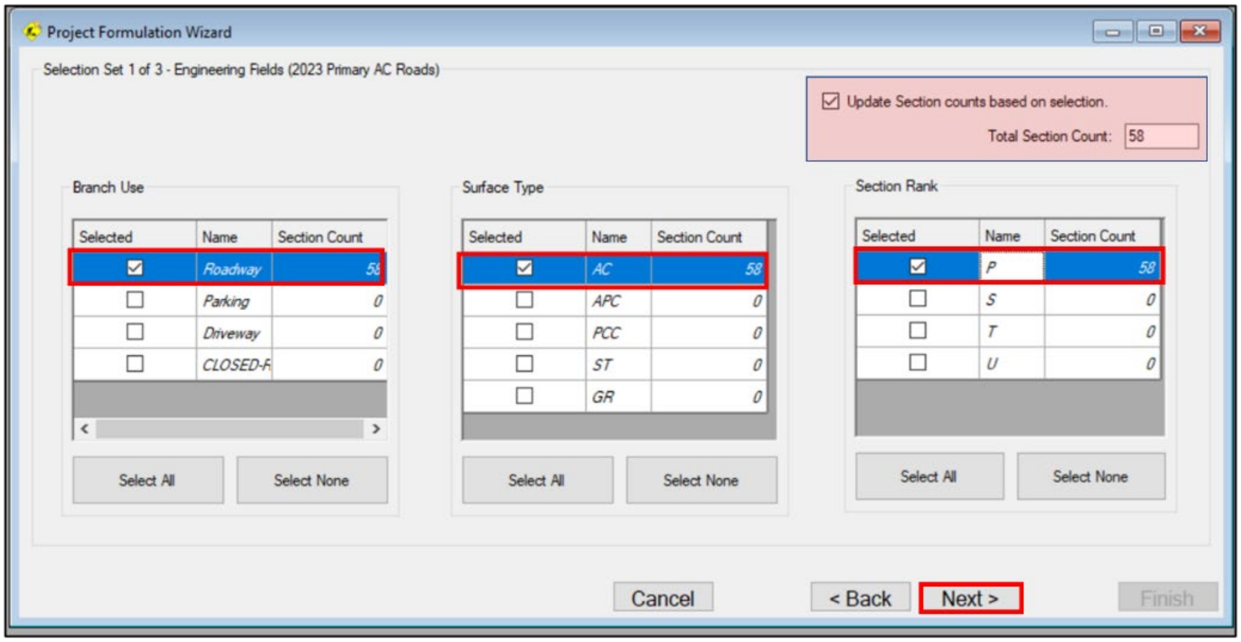


A-9.7.4.5 Selection Set - Engineering Field Parameters.

Filter the sections included in the project by checking the appropriate box for the Engineering Fields parameters, as shown in Figure A-48.

- Check the boxes for **Branch Use**: **Roadway**, **Surface Type**: **AC**, and **Section Rank**: **P**.
- The number of sections is shown in the upper-right corner of the form.
- Select **Next >**.

Figure A-48 Selection Set Engineering Field Parameters Example

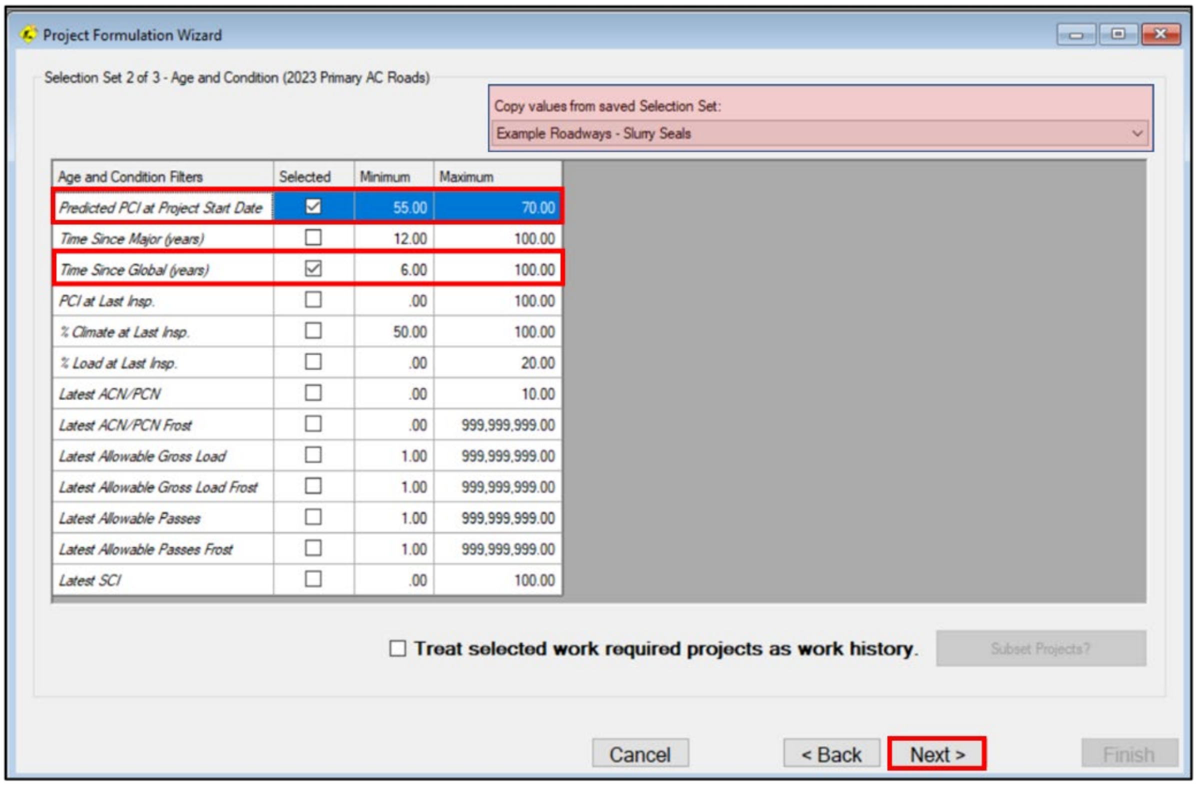


A-9.7.4.6 Selection Set – Age and Condition Parameters.

The **Selection Set - Age and Condition** parameters form opens with a standard list of parameters. The user selects the parameters for the project by checking the boxes and then setting the minimum and maximum values, as shown in Figure A-49.

- This example includes sections with a predicted PCI between 70 and 55 that have not had a global M&R application within the last six years.
- Users can save selection sets at the end of the process and reuse the parameters in future projects, as shown in the upper-right corner of the form in Figure A-49.
- Select **Next >**.

Figure A-49 Selection Set Age and Condition Parameters Example

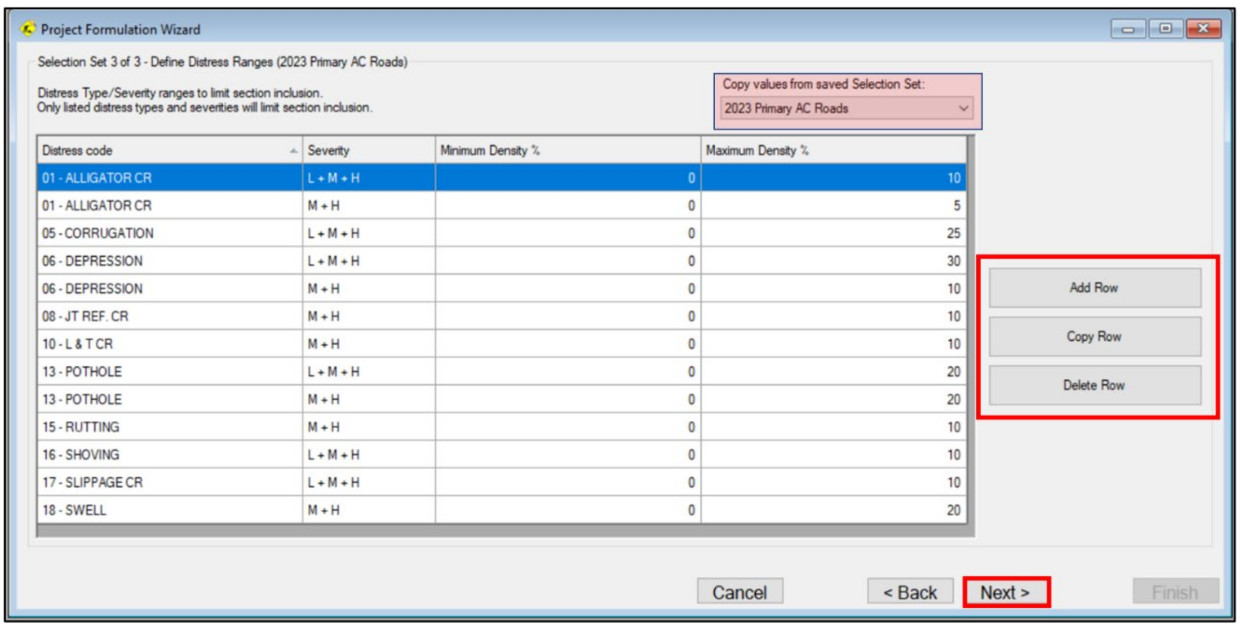


A-9.7.4.7 Selection Set – Distress Ranges.

The **Selection Set** - **Define Distress Ranges** form opens with the standard list of parameters shown in Figure A-50. The user defines the density ranges by editing the minimum and maximum density values. For example, when a section has high-severity alligator distress density above 5 percent, it would not be a good candidate for a surface treatment.

- Select **Add Row**, **Copy Row**, or **Delete Row** to tailor the parameters.
- Users can save selection sets at the end of the process and reuse the parameters in future projects, as shown in the upper-right corner of the form in Figure A-50.
- Select **Next >**.
- At the prompt to **Save Changes**, select **Yes**.

Figure A-50 View Project and Section Item Summary

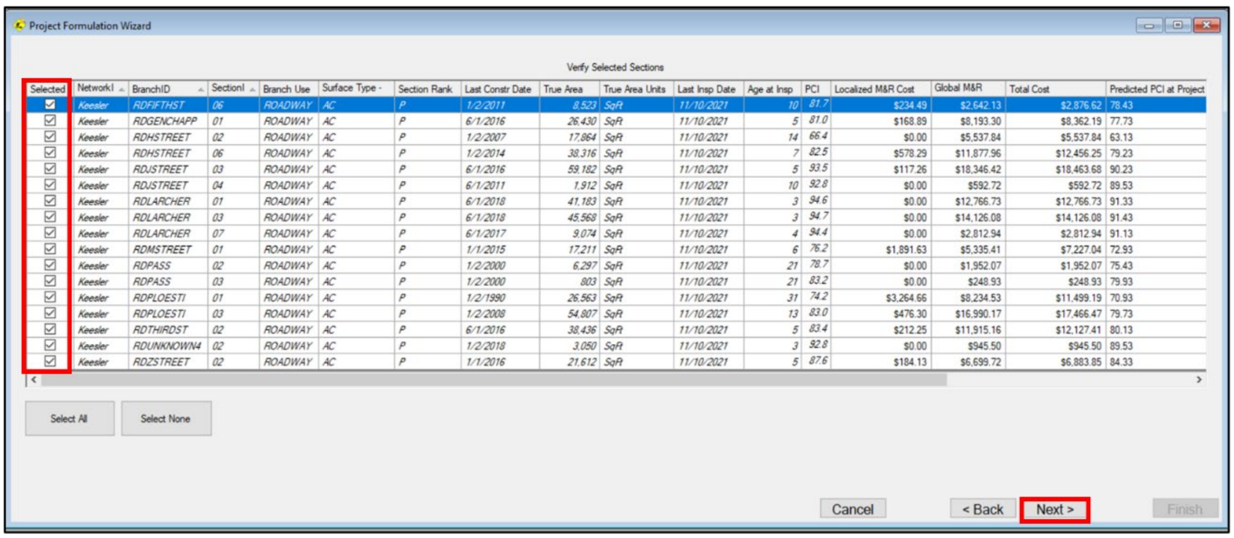


A-9.7.4.8 Review and Refine Sections in Project.

The preceding steps performed the same function, selecting sections for the project as the query tool did in the Required Projects tool example.

- PAVER generates a map view of the sections based on the selection set parameters. The user can deselect a section or add a section by clicking on it in the map.
- Select **Next >**.
- PAVER generates a list view of the sections, as shown in Figure A-51, that meet the selection set parameters. Remove sections from the project by unchecking the boxes in the left-hand column.
- Select **Next >**.

Figure A-51 Project Formulation Wizard - Verify Selected Sections



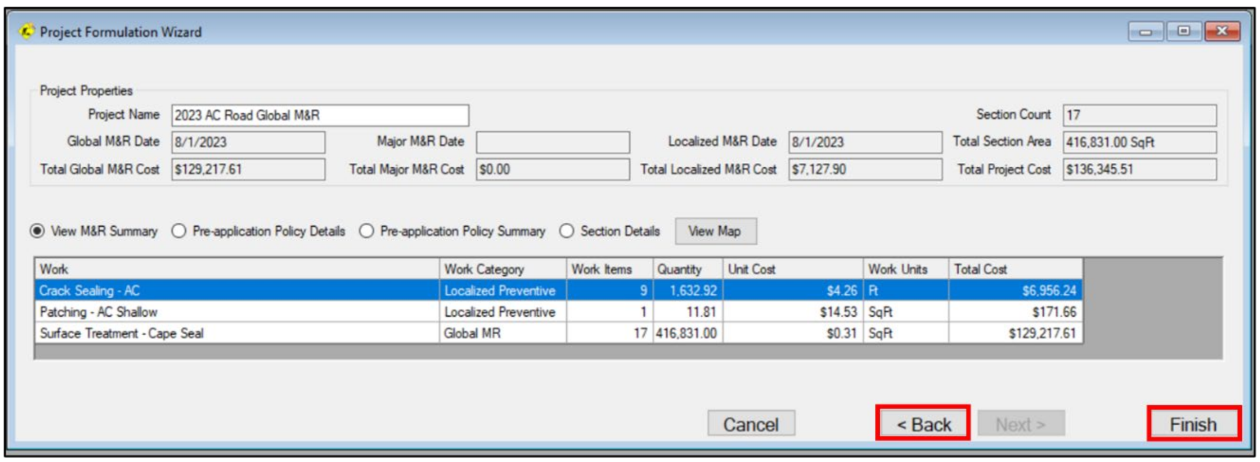
Selected	NetworkI	BranchID	SectionI	Branch Use	Surface Type	Section Rank	Last Constr Date	True Area	True Area Units	Last Insp Date	Age at Insp	PCI	Localized M&R Cost	Global M&R	Total Cost	Predicted PCI at Project
☑	Keesler	RDFIFTHST	06	ROADWAY	AC	P	1/2/2011	8,523	SqFt	11/10/2021	10	81.7	$234.49	$2,642.13	$2,876.62	78.43
☑	Keesler	RDGENCHAPP	01	ROADWAY	AC	P	6/1/2016	26,430	SqFt	11/10/2021	5	81.0	$168.89	$8,193.30	$8,362.19	77.73
☑	Keesler	RDHSTREET	02	ROADWAY	AC	P	1/2/2007	17,864	SqFt	11/10/2021	14	66.4	$0.00	$5,537.84	$5,537.84	63.13
☑	Keesler	RDHSTREET	06	ROADWAY	AC	P	1/2/2014	38,316	SqFt	11/10/2021	7	82.5	$578.29	$11,877.96	$12,456.25	79.23
☑	Keesler	RDJSTREET	03	ROADWAY	AC	P	6/1/2016	59,182	SqFt	11/10/2021	5	93.5	$117.26	$18,346.42	$18,463.68	90.23
☑	Keesler	RDJSTREET	04	ROADWAY	AC	P	6/1/2011	1,912	SqFt	11/10/2021	10	92.8	$0.00	$592.72	$592.72	89.53
☑	Keesler	RDLARCHER	01	ROADWAY	AC	P	6/1/2018	41,183	SqFt	11/10/2021	3	94.6	$0.00	$12,766.73	$12,766.73	91.33
☑	Keesler	RDLARCHER	03	ROADWAY	AC	P	6/1/2018	45,568	SqFt	11/10/2021	3	94.7	$0.00	$14,126.08	$14,126.08	91.43
☑	Keesler	RDLARCHER	07	ROADWAY	AC	P	6/1/2017	9,074	SqFt	11/10/2021	4	94.4	$0.00	$2,812.94	$2,812.94	91.13
☑	Keesler	RDMSTREET	01	ROADWAY	AC	P	1/1/2015	17,211	SqFt	11/10/2021	6	76.2	$1,891.63	$5,335.41	$7,227.04	72.93
☑	Keesler	RDPASS	02	ROADWAY	AC	P	1/2/2000	6,297	SqFt	11/10/2021	21	78.7	$0.00	$1,952.07	$1,952.07	75.43
☑	Keesler	RDPASS	03	ROADWAY	AC	P	1/2/2000	803	SqFt	11/10/2021	21	83.2	$0.00	$248.93	$248.93	79.93
☑	Keesler	RDPLOESTI	01	ROADWAY	AC	P	1/2/1990	26,563	SqFt	11/10/2021	31	74.2	$3,264.66	$8,234.53	$11,499.19	70.93
☑	Keesler	RDPLOESTI	03	ROADWAY	AC	P	1/2/2008	54,807	SqFt	11/10/2021	13	83.0	$476.30	$16,990.17	$17,466.47	79.73
☑	Keesler	RDTHIRDST	02	ROADWAY	AC	P	6/1/2016	38,436	SqFt	11/10/2021	5	83.4	$212.25	$11,915.16	$12,127.41	80.13
☑	Keesler	RDUNKNOWN4	02	ROADWAY	AC	P	1/2/2018	3,050	SqFt	11/10/2021	3	92.8	$0.00	$945.50	$945.50	89.53
☑	Keesler	RDZSTREET	02	ROADWAY	AC	P	1/1/2016	21,612	SqFt	11/10/2021	5	87.6	$184.13	$6,699.72	$6,883.85	84.33

A-9.7.4.9 Review Project Information.

The final step in the **Project Formulation Wizard** process is reviewing the project information.

- This tab provides summary and detail-level views of the work items in the project describing the sections included in the project, work types, quantities, and costs.
- Select the **< Back** button to review or revise project parameters.
- Select the **Finish** button to complete the project creation.
- The user receives a message that the required project was created.
- The user can select the button to create another project or select **Close**.

Figure A-52 Project Formulation Wizard – Project Properties

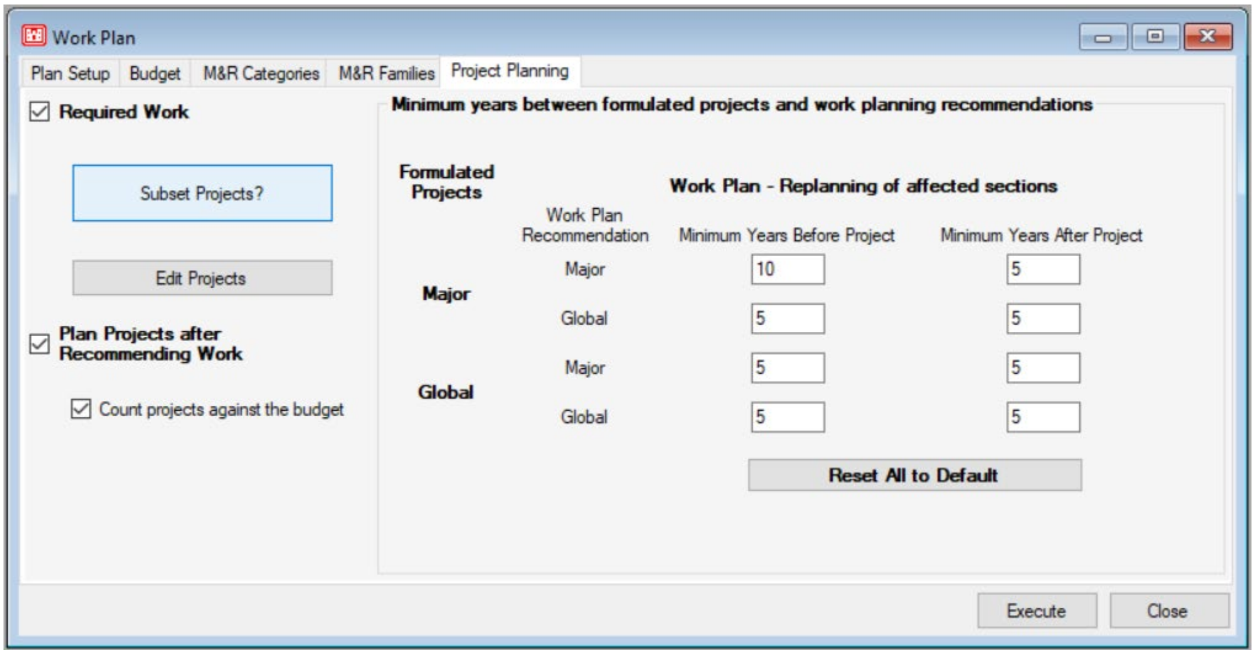


A-9.8 Project Planning.

Once the projects are generated, rerun the work plan. This can be an iterative process, run work plan, plan projects, rerun work plan, plan projects, etc.

- When rerunning the work plan, go to the **Project Planning** tab and select the checkboxes for **Required Work**, **Plan Projects after Recommending Work**, and **Count projects against the budget**, as shown in Figure A-53.
- The window for **Minimum years between formulated projects and work planning recommendations** sets the parameters PAVER uses to determine new work requirements after Major or Global M&R is performed.
- The default settings are generally acceptable but can vary based on environment. For example, the Global period is shorter for an installation that has a significant snow removal requirement.

Figure A-53 Project Planning Tab



A-9.9 Pavement Management Plan Example.

The minimum PMP is an approved list of in-house pavement M&R tasks and contract projects using the processes described in previous sections. As stated previously, the Services can augment this guidance with requirements for the specific PMP content, format, or approval process.

While the approved list of in-house pavement M&R tasks and contract projects is the core requirement, incorporating additional PMP documentation provides needed information to the approval authority and those who will implement and update the PMP.

A-9.9.3 PMP Outline.

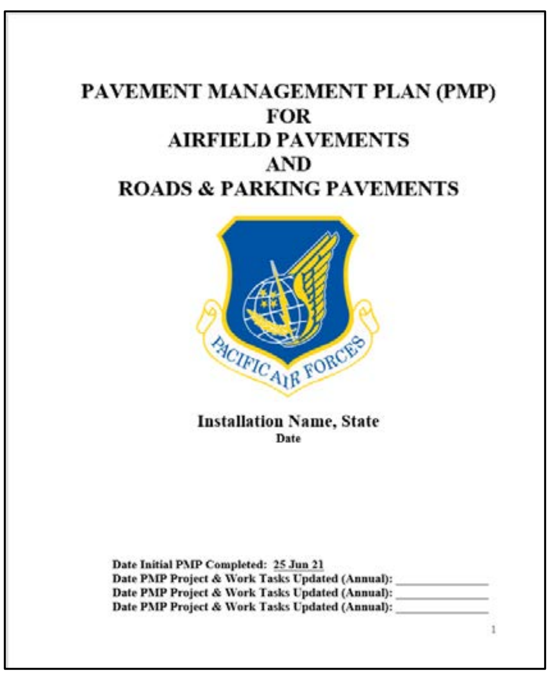
Following is a recommended PMP outline.

- Cover sheet
- Preface
- Executive Summary
- Development team members
- Development process and deliverables
- Assumptions and limiting factors
- Prioritized Work Plan for in-house execution
- Prioritized Contract Project Plan for contract execution by year

A-9.9.4 Cover Sheet.

Include the name of the installation and whether it is an airfield or roads and parking PMP. List the initial development date and the dates of all annual updates. Service policy may also require a distribution statement, as shown in the example in Figure A-54.

Figure A-54 PMP Cover Sheet Example



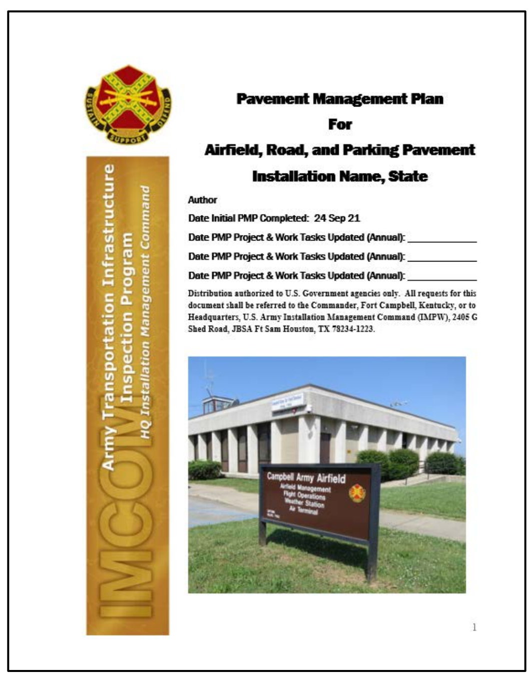
PAVEMENT MANAGEMENT PLAN (PMP)
FOR
AIRFIELD PAVEMENTS
AND
ROADS & PARKING PAVEMENTS

PACIFIC AIR FORCES

Installation Name, State
Date

Date Initial PMP Completed: 25 Jun 21
Date PMP Project & Work Tasks Updated (Annual): ____________
Date PMP Project & Work Tasks Updated (Annual): ____________
Date PMP Project & Work Tasks Updated (Annual): ____________

1



IMCOM Army Transportation Infrastructure Inspection Program
HQ Installation Management Command

Pavement Management Plan
For
Airfield, Road, and Parking Pavement
Installation Name, State

Author
Date Initial PMP Completed: 24 Sep 21
Date PMP Project & Work Tasks Updated (Annual): ____________
Date PMP Project & Work Tasks Updated (Annual): ____________
Date PMP Project & Work Tasks Updated (Annual): ____________

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A-9.9.5 Preface.

The Preface is typically a single page that provides background information on the sources of pavement evaluation data, initial PMP development, and subsequent updates, as well as information on the DoD and Service guidance the PMP implements.

Figure A-55 Preface Example

1. PREFACE

This Pavement Management Plan (PMP) documents a [Month Year] coordinated team effort between [ERDC/Contractor, Public Works, and Airfield Management when applicable] representatives to establish an Initial PMP for the airfield pavements network and the roads and parking pavements network at [Installation Name, State]. This PMP document provides information for:

- Planning and programming for pavement maintenance, repairs, and rehabilitation
- Prioritization of pavement facilities for maintenance, repair, and rehabilitation and construction projects
- Allocation of funds for annual maintenance and repair (M&R)

Army Regulation (AR) 420-1 Army Facilities Management, Department of Army Pamphlet (DA PAM) 420-1-3 Transportation Infrastructure and Dams, UFC 3-270-08 Pavement Management, and Tri-Service Pavements Working Group (TSPWG) Manual 3-270-08.14-03 outline requirements for bases to develop pavement management plans (PMP) in support of asset management.

IMCOM participated the development of an Airfield Pavement Category Intelligence Report (CIR) conducted by the Air Force. This report recommended installations develop PMPs to capitalize on efficiencies. SAF/MG approved efforts as a "go do" for the Air Force and IMCOM concurs with this recommendation for Army Installations as outlined below.

A-9.9.6 Executive Summary.

The Executive Summary outlines the purpose of the PMP and any critical issues the approval authority should be aware of. Include a summary of the annual work requirements, as shown in the example in Figure A-56. Provide a summary of the annual costs, as shown in the example in Figure A-57, and include a graphic representation of the impact of the investment in terms of condition, as shown in Figure A-58. Each of these graphics will include a brief description. The figures below are examples generated in PAVER but can also be generated using other tools.

Figure A-56 Requirements Map

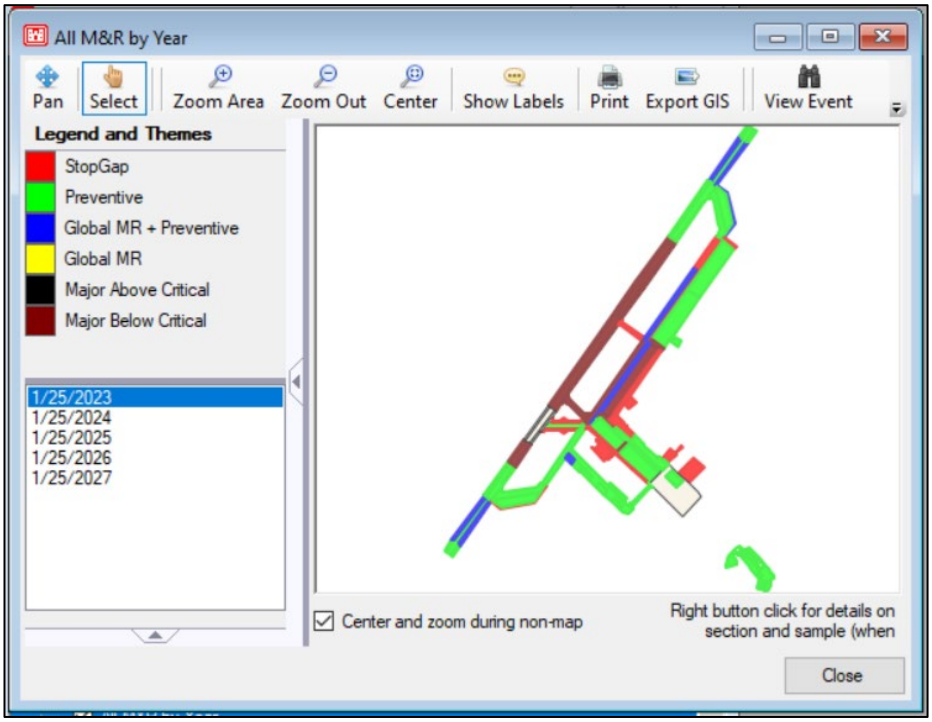


Figure A-57 Annual Funding Requirement

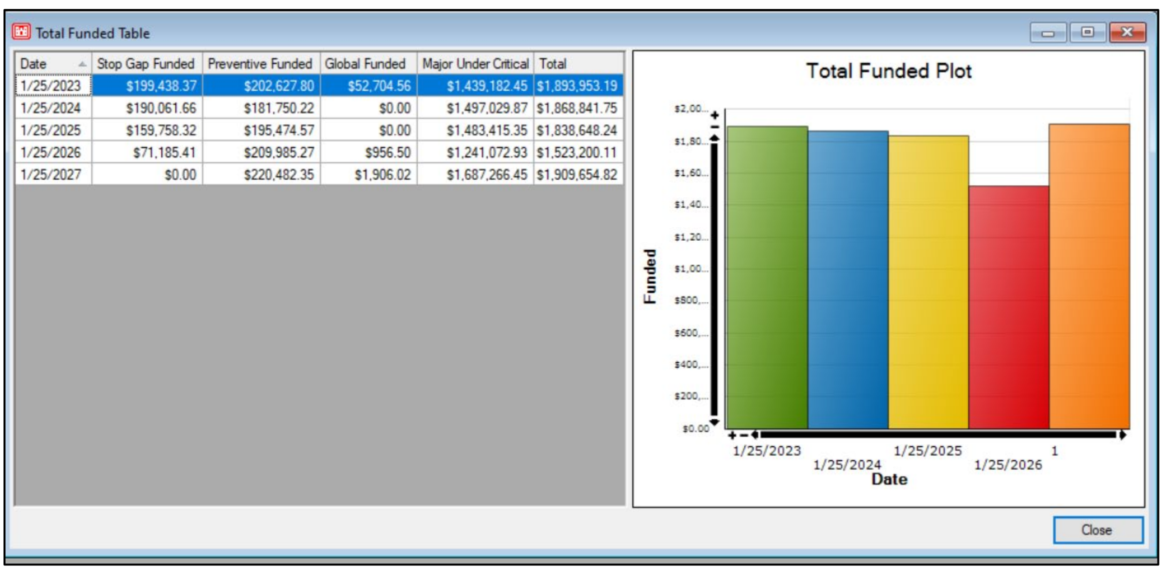
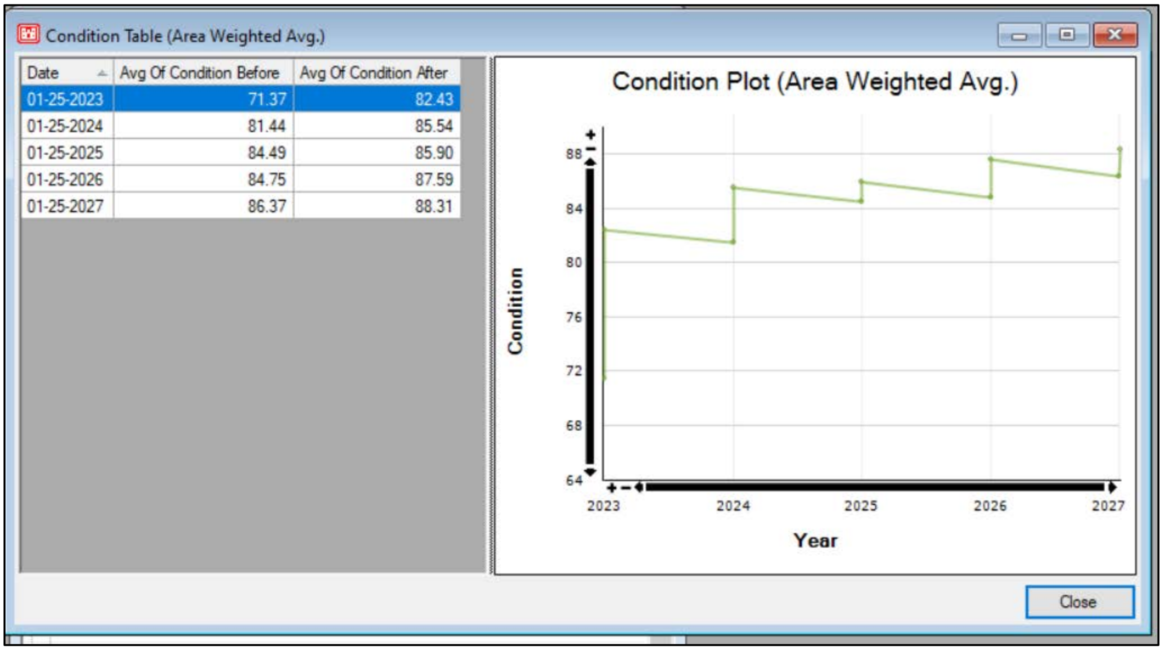


Figure A-58 Condition Table



A-9.9.7 Development Team Members.

This is a list of the members of the development team members and their contact information. The list is updated annually when the team finalizes the PMP updates.

A-9.9.8 Development Process and Deliverables.

This section expands on the information provided in the Preface and Executive Summary and should include the following.

A-9.9.8.1 Pavement Management Objective.

Perform localized and global preventive maintenance to extend pavement life and perform Major M&R at the right time with the right repair method rather than letting the pavement deteriorate to poor or failed condition before taking any repair actions. This approach optimizes the lifecycle cost of maintaining the pavement.

A-9.9.8.2 Development Process.

Include a discussion of the following items to describe the development process.

- Generate work plans with M&R requirements using the most recent PCI inspection.
- Prioritize requirements, with an emphasis on localized and global M&R to maximize pavement life. Include a discussion of the prioritization process and other key performance indicators, e.g., FOD potential and structural index.

- Aggregate requirements into executable in-house work tasks and contract projects for each year of the PMP. Discuss project scoping and any other factors addressed when aggregating requirements, e.g., waivers, construction cycle, other projects, etc.
- Verify/validate method of execution, repair types, quantities, and costs for all M&R types, including a description of the field work performed to validate repair types and quantities.
- Finalize PMP and submit for approval.

A-9.9.9 Limiting Factors and Assumptions.

Limiting factors can include, but are not limited to, constraints on in-house capabilities, funding, operations tempo, and access to pavement surfaces. Describe any assumptions made with regard to limiting or other factors.

A-9.9.10 Prioritized In-House Execution Work Plan.

This section has the products generated from PAVER work plan spreadsheets as outlined in paragraph A-7.6 or generated using the PAVER Project Formulation Wizard as outlined in paragraph A-9.7. Embedding these products in the PMP Word document as an Excel spreadsheet is a best practice. This is especially useful on large installations when the in-house execution work plan can be quite extensive. Figure A-59 provides an example of an in-house execution work plan generated by one Service.

Figure A-59 In-House Execution Work Plan

FY	Execution Method	PMP Zone	Branch	Section	Distress	Severity	Quantity		Work Description	Work Quantity		PCI	Unit Cost	Work Cost	Pre-Work Site Visit Performed (mm/dd/y	Date Work Completed (mm/dd/y	Comment
20	IN-HOUSE	BLUE	Arm/Dearm Apron TW A	A32B	CORNER SPALL	Medium	1	Slabs	Patching - PCC Partial Depth	2	SqFt	81	$12.24	$33		08/30/20	Completed
20	IN-HOUSE	BLUE	Arm/Dearm Apron TW A	A32B	JOINT SPALL	Low	7	Slabs	Crack Sealing - PCC	11	Ft	81	$4.90	$56		08/30/20	Completed
20	IN-HOUSE	BLUE	Arm/Dearm Apron TW A	A32B	JOINT SPALL	Medium	5	Slabs	Patching - PCC Partial Depth	32	SqFt	81	$12.24	$395		08/30/20	Completed
20	IN-HOUSE	BLUE	Arm/Dearm Apron TW A	A32B	JT SEAL DMG	Medium	36	Slabs	Joint Seal (Localized)	1,228	Ft	81	$4.08	$5,016		08/30/20	Completed
20	IN-HOUSE	BLUE	Arm/Dearm Apron TW A	A32B	LINEAR CR	Medium	3	Slabs	Crack Sealing - PCC	68	Ft	81	$4.90	$331		08/30/20	Completed
21	IN-HOUSE	RED	Runway 14/32	R01A	JOINT SPALL	Low	24	Slabs	Crack Sealing - PCC	39	Ft	92	$4.90	$193			
21	IN-HOUSE	RED	Runway 14/32	R01A	JOINT SPALL	Medium	9	Slabs	Patching - PCC Partial Depth	55	SqFt	92	$12.24	$677			
21	IN-HOUSE	RED	Runway 14/32	R01A	LINEAR CR	Medium	5	Slabs	Crack Sealing - PCC	99	Ft	92	$4.90	$488			
21	IN-HOUSE	RED	Runway 14/32	R05C	JOINT SPALL	High	4	Slabs	Patching - PCC Partial Depth	33	SqFt	96	$12.24	$405			
21	IN-HOUSE	RED	Runway 14/32	R05C	JOINT SPALL	Low	90	Slabs	Crack Sealing - PCC	148	Ft	96	$4.90	$724			
21	IN-HOUSE	RED	Runway 14/32	R05C	JOINT SPALL	Medium	25	Slabs	Patching - PCC Partial Depth	158	SqFt	96	$12.24	$1,942			
21	IN-HOUSE	RED	Runway 14/32	R05C	LINEAR CR	Medium	4	Slabs	Crack Sealing - PCC	79	Ft	96	$4.90	$389			
21	IN-HOUSE	RED	Runway 14/32	R08A	CORNER BREAK	Low	2	Slabs	Crack Sealing - PCC	15	Ft	94	$4.90	$73			
21	IN-HOUSE	RED	Runway 14/32	R08A	CORNER SPALL	Low	16	Slabs	Crack Sealing - PCC	27	Ft	94	$4.90	$131			
21	IN-HOUSE	RED	Runway 14/32	R08A	JOINT SPALL	High	2	Slabs	Patching - PCC Partial Depth	15	SqFt	94	$12.24	$179			
21	IN-HOUSE	RED	Runway 14/32	R08A	JOINT SPALL	Low	13	Slabs	Crack Sealing - PCC	21	Ft	94	$4.90	$102			
21	IN-HOUSE	RED	Runway 14/32	R08A	JOINT SPALL	Medium	2	Slabs	Patching - PCC Partial Depth	12	SqFt	94	$12.24	$143			
21	IN-HOUSE	RED & BLUE	Loop Taxiway	T37A	L & T CR	Medium	449	Ft	Crack Sealing - AC	449	Ft	73	$1.37	$613			
21	IN-HOUSE	RED & BLUE	Loop Taxiway	T39A	L & T CR	Medium	28	Ft	Crack Sealing - AC	28	Ft	74	$1.37	$38			
21	IN-HOUSE	RED	Loop Taxiway	T40A	L & T CR	Medium	510	Ft	Crack Sealing - AC	510	Ft	75	$1.37	$696			

A-9.9.11 Prioritized Contract Project Plan.

This section has the products generated from PAVER work plan spreadsheets as outlined in paragraph A-7.6 or generated using the PAVER Project Formulation Wizard as outlined in paragraph A-9.7. Embedding these products in the PMP Word document as an Excel spreadsheet is a best practice.

Figure A-60 Contract Project Plan Example

Rqmt FY	Opportunity Number	Name	Execution Method	ZONE	Branch Name	Section	Rank	PCI	Work Type	AREA (SF)	Work Description	Project Cost	Program
2022			Contract	BLUE	Oscar Row Apron	A11B	P	43	AC	203,500	Structural Repair an Mill and Overlay	$708,178	EXPLAN
2022			Contract	RED	P/Q/R/S Tanker Row Apron	A06B	P	53	AC	148,915	Mill and Overlay	$265,492	EXPLAN
2022			Contract	RED	P/Q/R/S Tanker Row Apron	A04B	P	34	AC	105,239	Mill and Overlay	$1,094,488	EXPLAN
2022			Contract	RED	Loop Taxiway	T39A	P	66	AC	117,065	TBD	TBD	BCAMP
2023			Contract	RED	Taxiway A	T01A	P	63	AC	314,060	Mill and Overlay	$555,886	
2023			Contract	BLUE	Taxiway A	T28A	P	54	AC	46,572	Structural Repair an Mill and Overlay	$162,071	
2023		Twy A and Twy F North	Contract	RED	Taxiway F	T02A	P	55.8	AC	97,646	Structural Repair an Mill and Overlay	$339,807	BCAMP
2023			Contract	RED	Taxiway F	T03A	P	56.8	AC	221,177	Mill and Overlay	$391,483	
2023			Contract	RED	Taxiway F	T04A	P	65.8	AC	36,229	Mill and Overlay	$64,126	
2024			Contract	RED	Arm/Dearm Apron TW E	A31B	P	59.65	PCC	16,250	20% Slab Replacement	$96,688	EXPLAN
2024			Contract	RED	Runway 14/32	R02A	P	59.4	AC	180,272	Mill and Overlay	$319,081	
2024			Contract	RED	Runway 14/32	R03A	P	66.4	AC	156,849	Mill and Overlay	$277,623	
2024			Contract	RED	Runway 14/32	R04C	P	64.4	AC	438,172	Mill and Overlay	$775,564	
2024			Contract	RED	Runway 14/32	R06C	P	68.4	AC	1,128,398	Mill and Overlay	$1,997,264	
2024			Contract	RED	Runway 14/32	R07C	P	66.4	AC	409,912	Mill and Overlay	$725,544	
2024			Contract	RED	Runway 14/32	R09A	P	63.4	AC	211,204	Mill and Overlay	$373,831	
2024		Runway Mill and Overlay	Contract	RED	Runway 14/32	R10A	P	73.4	AC	11,700	Mill and Overlay	$20,709	BCAMP
2024			Contract	RED	Runway 14/32	R11C	P	58.4	AC	7,500	Mill and Overlay	$13,275	
2024			Contract	RED	Runway 14/32	R12C	P	50.4	AC	101,877	Mill and Overlay	$180,322	
2024			Contract	RED	Runway 14/32	R13C	P	59.4	AC	125,300	Mill and Overlay	$221,781	
2024			Contract	RED	Runway 14/32	R14A	P	68.4	AC	25,951	Mill and Overlay	$45,933	
2024			Contract	RED	Runway 14/32	R15A	P	68	AC	20,761	Mill and Overlay	$36,747	

A-10 RISK (RETURN ON INVESTMENT) ANALYSIS PROCEDURES.

This section outlines a risk analysis procedure for determining the consequence of not performing localized PM and global PM. Risk is defined as a decrease in pavement life (and thus increased M&R cost) as a result of not performing the appropriate PM at the proper time.

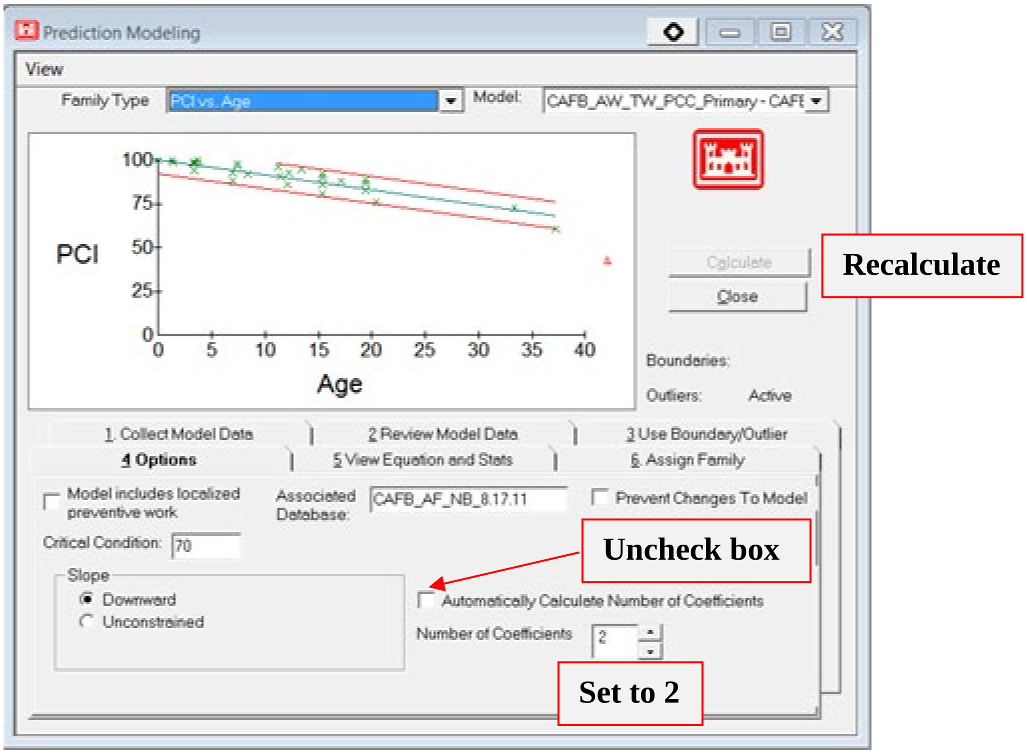
A-10.1 Risk Analysis – Localized Preventive Maintenance (PM).

A-10.1.3 Family Rate of Deterioration.

Calculate the pavement family rate of deterioration assuming localized PM has been performed in the past (R_W) and compute the rate of deterioration if localized PM is not performed (R_{WO}).

Using the steps outlined in Chapter 5 and assuming that localized PM has been performed in the past, create a family model. On tab 4, **Options**, uncheck the **Automatically Calculate Number of Coefficients** button, set the number of coefficients to 2, and press the **Calculate** button (Figure A-61). Select tab 5, **View Equation and Stats**. The second coefficient in the equation (e.g., 100 – 0.8512 X^1) is the straight-line deterioration rate (R_W = 0.85 points per year). The next step is to calculate the age (T_W) to critical PCI (PCI_C), assuming localized PM is performed.

Figure A-61 Review Model Data Tab



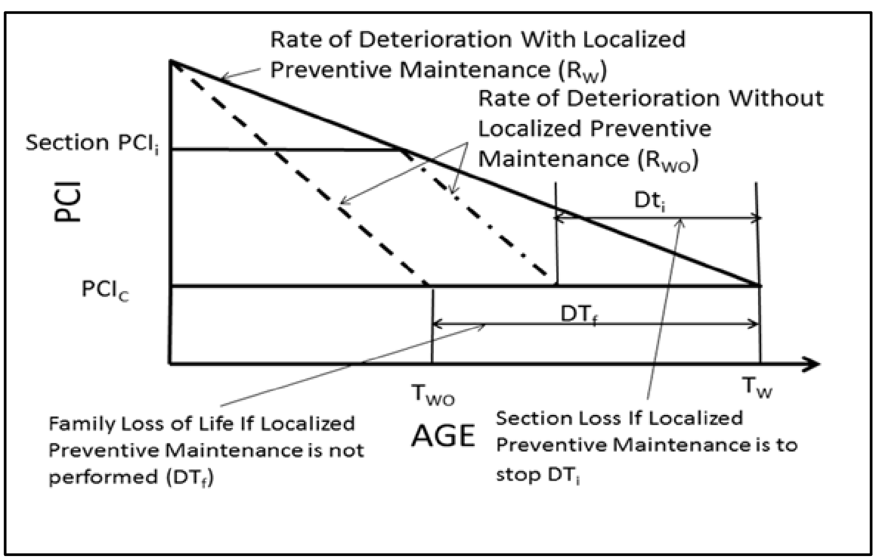
A-10.1.4 Age to Critical PCI.

The age (T_W) to critical PCI (PCI_C) is computed using the equation below.

$$T_W = (100 - PCI_C) / R_W$$

In the Figure A-62 example, assume a PCI_C = 70, T_W = (100 – 70) / 0.85 = 35.29 years.

Figure A-62 Section Deterioration



A-10.1.5 Expected Loss in Pavement Life.

Estimate the expected loss in pavement life (DT_f) caused by not performing localized PM. Loss of pavement life will depend on several factors, including pavement life with localized PM (T_W), pavement type (e.g., asphalt vs. concrete), climate, and traffic. Table A-29 provides recommended DT_f values when T_w is 20 years.

Table A-29 Recommended DTf Values

Climate	DT_{f20}, years
Dry/no freeze	5
Wet/no freeze-dry/freeze	7.5
Wet/freeze	10

The DT_f values for any other T_w can be calculated as follows:

$$DT_{fTw} = DT_{f20} * (.3691\, T_w - .0009\, {T_W}^2)/7.13$$

For example, if T_w = 35.29 years, then DT_f for dry/no freeze is calculated as:

$$5 * (.3691 * 35.29 - .0009 * (35.292))/7.13 = 8.35\, years$$

A-10.1.6 Age to Critical PCI Assuming No Localized PM.

Calculate the age to critical PCI (PCI_C), assuming localized PM is not performed (T_{WO}) using the equation below:

$$T_{WO} = T_W - DT_f$$

In the example above, assuming DT_f = 8.35 years:

$$T_{WO} = 35.29 - 8.35 = 26.94\, years$$

A-10.1.5 Rate of Deterioration Assuming No Localized PM.

Determine the pavement family rate of deterioration (R_{WO}), assuming localized PM is not performed:

$$R_{WO} = (100 - PCI_C) / T_{WO}$$

In the example above,

$$R_{WO} = (100 - 70) / 26.94 = 1.11\, PCI\ points\ per\ year$$

A-10.1.6 Expected Loss of Pavement Life with No Localized PM.

Determine the expected loss in life (DT_i) for each pavement section if localized PM is not performed:

For any pavement section (i) from the same family, DT_i can be computed if its current condition (PCI_i) is known. For this example, assume the section currently has a (PCI_i) of 85.

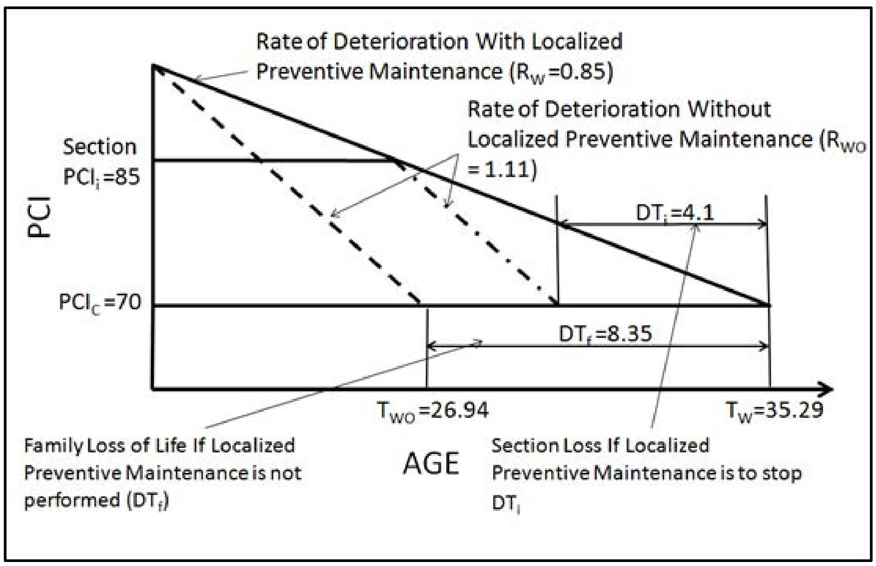
$$DT_i = (PCI_i - PCI_C) * (R_{WO} - R_W) / (R_{WO} * R_W)$$

In the above example, for a section (i) with a PCI_i = 85:

$$DT_i = (85 - 70) * (1.11 - 0.85) / (1.11 * 0.85) = 4.1\, years$$

See Figure A-63 for a depiction of the section deterioration example above.

Figure A-63 Section Deterioration Example



A-10.2 Cost of Pavement Life Loss with No Localized PM.

The procedure is based on the equivalent uniform annual cost (EUAC) economic analysis method. This method calculates the average annual cost with and without annual PM and compares the two to determine the annual cost due to loss of pavement life. The simplest form of this procedure is presented below, in which interest and inflation rates are not considered. The costs are intended to be used for comparative analysis only and not intended to represent actual project cost.

A-10.2.1 Calculate Equivalent Uniform Annual Cost (EUAC).

Determine the annual major M&R cost ($\$_{Annual\ Major\ Alt1}$) by dividing the major M&R cost at critical PCI ($\$_{Major\text{-}critical}$) by the life of the alternative T_W. $\$_{Major\ critical}$ can be estimated as one-third the cost of reconstruction for asphalt pavements and one-fourth the cost of reconstruction for concrete pavements.

In the concrete apron example above, assuming a reconstruction cost of $20.00/SF (use PACES or other estimating methods to determine estimated reconstruction costs), then $\$_{\text{Major-critical}}$ is estimated at $20/4 = $5.0/SF.

$$\$_{Annual\ Major\ Alt1} = \$5.0/35.29 = \$0.1417\ SF/Yr$$

A-10.2.2 Calculate Average Annual Cost with Localized PM.

Determine the average annual localized PM cost over the life of the alternative ($\$_{\text{Annual-Preventive}}$). This can be obtained by summing the total annual localized preventive cost over the life of the alternative (the cost will vary annually as a function of the PCI) then dividing the sum by the life (T_W). Based on unit costs in the PAVER system, this can be approximated as $0.0232/SF/YR for concrete pavements and $0.0096/SF/YR for asphalt pavements. This is a nominal average cost that can be used as constant on all analyses.

$EUAC_{Alt1}$ is determined as the sum of the $\$_{\text{Annual-Major-Alt1}}$ and $\$_{\text{Annual-Preventive}}$ costs as shown in the equation below.

$$EUAC_{Alt1} = \$_{Annual\ Major\ Alt1} + \$_{AnnualPreventive}$$

For the example above:

$$EUAC_{Alt1} = 0.1417 + 0.0232 = \$0.1649/SF/YR$$

A-10.2.3 Calculate Average Annual Cost without Localized PM.

Calculate the annual cost for the same alternative, except without a localized PM alternative ($EUAC_{Alt2}$):

Determine the annual major M&R cost ($\$_{\text{Annual Major Alt2}}$) by dividing the major M&R cost at critical PCI ($\$_{\text{Major critical}}$) by the life of the alternative (T_{WO}). $\$_{\text{Major critical}}$ can be estimated as one-third the cost of reconstruction for asphalt pavements and one-fourth the cost of reconstruction for concrete pavements.

In the example above:

$$\$_{Annual\ Major\ Alt2} = \$5.0/25.29 = \$.1977/SF/YR$$

Determine the average annual operational maintenance over the life of the alternative ($\$_{\text{Annual operational}}$). The annual operational maintenance actions are only measures taken to keep the pavement operationally safe. This can be obtained by summing the total annual operational cost over the life of the alternative (the cost will vary annually as a function of the PCI) then divide the sum by the life (T_{WO}). Based on unit costs in the PAVER system, this can be approximated as $0.0040/SF/YR for concrete pavements and $0.0004/SF/YR for asphalt pavements. This is a nominal average cost that can be used as constant on all analyses.

$EUAC_{Alt2}$ is determined as the sum of the $\$_{Annual\ Major\ Alt2}$ and $\$_{Annual\ Operational}$ costs as shown in the equation below.

$$EUAC_{\ Alt2} = \$_{Annual\ Major\ Alt2} + \$_{Annual\ Operational}$$

For the example above:

$$EUAC_{Alt2} = 0.1977 + 0.0040 = \$\,0.2017/SF/YR$$

A-10.2.4 Annual Cost Due to Loss in Pavement Life.

Calculate the annual cost due to loss in pavement life ($EUAC_{LOSS}$):

$$EUAC_{LOSS} = EUAC_{Alt2} - EUAC_{Alt1}$$

For the example above:

$$EUAC_{LOSS} = 0.2017 - 0.1649 = \$\,0.0368\ /SF/YR$$

This number is then multiplied by the losses in years from paragraph A-10.1.5, which is 4.1 years in this example, i.e., 0.0368*4.1 = $0.151/SF or approximately $1.358/SY. The section risk cost is simply the $EUAC_{LOSS}$ multiplied by the area of the section.

A-10.3 Compute Project Risk Cost.

Performing localized PM typically includes more than one pavement section. The risk for a project is simply the sum of the risk associated with every section. Set the risk cost to zero when the PCI is less than critical. The project cost is best calculated in an Excel sheet as shown in Figure A-64. The Excel sheet shown in this example was initiated in PAVER using the user-defined reports feature. The generated Excel sheet from PAVER included section area and PCI. The rest of the information in the sheet was calculated in Excel as follows.

A-10.4 Compute Risk Cost for Each Section.

Compute DT_i for each section using the equation in paragraph A-10.1.6. In the example used throughout this appendix, R_W = 0.85 and R_{WO} = 1.11

Compute the risk cost for each section as follows:

$$Section\ Risk\ Cost = DT_i * EUAC_{LOSS}$$

In this example, $EUAC_{LOSS}$ was calculated in paragraph A-10.2.4 as $0.0368/SF/YR

The project risk cost is the sum of all the section costs, which is $356,768.

Figure A-64 Project Risk Cost Table Example

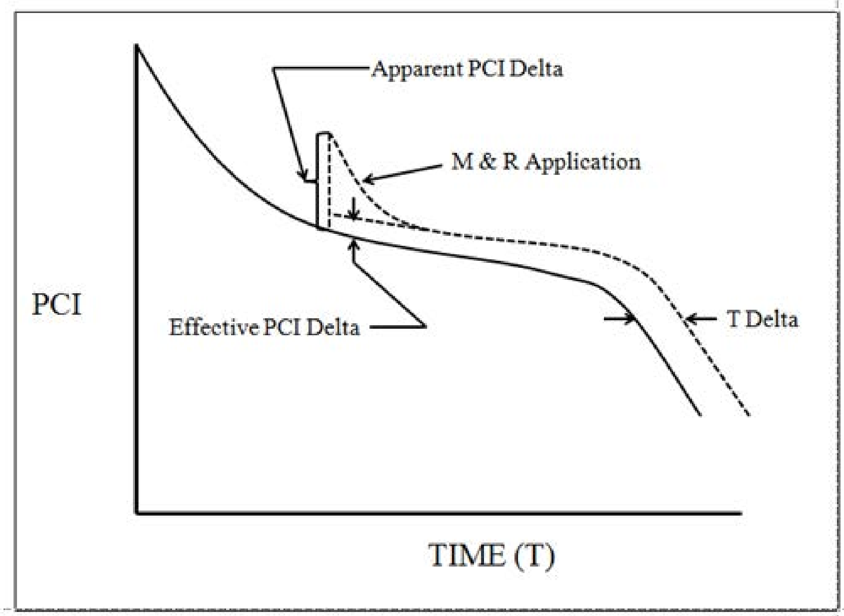
Section	Use	Rank	Surface	Area	2010 PCI	PCI Critical AFCESA	Det. Rate with SRM Rw	Pav. Life with SRM (Year) Tw	Assum. Pav. Loss Life (Year) DTf	Det. Rate without SRM Rwo	Section Loss Life (Year) Dti	Annual Preventive cost $/SF/YR	Alt1 $Annual with Major SRM Cri $/SF/YR	EUAC Alt 1 Cells: (R+S) $/SF/YR	$Annual Saftey $/SF/YR	Alt2 $Annual w/o Major SRM Cri $/SF/YR	EUAC Alt 2 Cells: (U+V) $/SF/YR	EUAC Loss Alt2- Alt1 $/SF/YR	EUACi Cells: X*Dti $/SF	Risk Cost = EUACi*Area
T32A	TAXIWAY	P	PCC	10,201	100	70	0.70	43.09	9.98	0.91	9.98	$0.0232	$0.116	$0.1392	$0.004	$0.151	$0.155	$0.016	$0.158	$1,607
T30A	TAXIWAY	P	PCC	103,119	100	70	0.70	43.09	9.98	0.91	9.98	$0.0232	$0.116	$0.1392	$0.004	$0.151	$0.155	$0.016	$0.158	$16,244
T24A	TAXIWAY	P	PCC	155,411	93	70	0.70	43.09	9.98	0.91	7.65	$0.0232	$0.116	$0.1392	$0.004	$0.151	$0.155	$0.016	$0.121	$18,769
T03A	TAXIWAY	S	PCC	7,565	92	70	0.70	43.09	9.98	0.91	7.32	$0.0232	$0.116	$0.1392	$0.004	$0.151	$0.155	$0.016	$0.116	$874
T02A	TAXIWAY	S	PCC	45,000	90	70	0.70	43.09	9.98	0.91	6.65	$0.0232	$0.116	$0.1392	$0.004	$0.151	$0.155	$0.016	$0.105	$4,726
T15A	TAXIWAY	S	PCC	117,307	83	70	0.70	43.09	9.98	0.91	4.33	$0.0232	$0.116	$0.1392	$0.004	$0.151	$0.155	$0.016	$0.068	$8,007
T20A	TAXIWAY	S	PCC	82,911	76	70	0.70	43.09	9.98	0.91	2.00	$0.0232	$0.116	$0.1392	$0.004	$0.151	$0.155	$0.016	$0.032	$2,612
T05A	TAXIWAY	S	PCC	65,585	72	70	0.70	43.09	9.98	0.91	0.67	$0.0232	$0.116	$0.1392	$0.004	$0.151	$0.155	$0.016	$0.011	$689
R06C	RUNWAY	P	PCC	153,750	100	70	0.58	51.98	11.75	0.75	11.75	$0.0232	$0.096	$0.1194	$0.004	$0.124	$0.128	$0.009	$0.104	$16,064
R07A	RUNWAY	P	PCC	129,375	100	70	0.58	51.98	11.75	0.75	11.75	$0.0232	$0.096	$0.1194	$0.004	$0.124	$0.128	$0.009	$0.104	$13,517
R03C	RUNWAY	P	PCC	858,351	93	70	0.58	51.98	11.75	0.75	9.01	$0.0232	$0.096	$0.1194	$0.004	$0.124	$0.128	$0.009	$0.080	$68,754
R01A	RUNWAY	S	PCC	30,000	90	70	0.58	51.98	11.75	0.75	7.83	$0.0232	$0.096	$0.1194	$0.004	$0.124	$0.128	$0.009	$0.070	$2,090
R06A	RUNWAY	S	PCC	30,000	85	70	0.58	51.98	11.75	0.75	5.87	$0.0232	$0.096	$0.1194	$0.004	$0.124	$0.128	$0.009	$0.052	$1,567
R04A	RUNWAY	S	PCC	45,000	80	70	0.58	51.98	11.75	0.75	3.92	$0.0232	$0.096	$0.1194	$0.004	$0.124	$0.128	$0.009	$0.035	$1,567
R09C	RUNWAY	P	PCC	153,750	75	70	0.58	51.98	11.75	0.75	1.96	$0.0232	$0.096	$0.1194	$0.004	$0.124	$0.128	$0.009	$0.017	$2,677
R10A	RUNWAY	P	PCC	170,625	70	70	0.58	51.98	11.75	0.75	0.00	$0.0232	$0.096	$0.1194	$0.004	$0.124	$0.128	$0.009	$0.000	$0
R04A	RUNWAY	S	PCC	30,000	68	70	0.58	51.98	11.75	0.75	-0.78	$0.0232	$0.096	$0.1194	$0.004	$0.124	$0.128	$0.009	-$0.007	$0
A54B	APRON	P	PCC	130,673	100	70	0.74	40.48	9.44	0.97	9.44	$0.0232	$0.124	$0.1467	$0.004	$0.161	$0.165	$0.018	$0.174	$22,684
A51C	APRON	S	PCC	236,146	100	70	0.74	40.48	9.44	0.97	9.44	$0.0232	$0.124	$0.1467	$0.004	$0.161	$0.165	$0.018	$0.174	$40,994
A48B	APRON	S	PCC	88,800	97	70	0.74	40.48	9.44	0.97	8.50	$0.0232	$0.124	$0.1467	$0.004	$0.161	$0.165	$0.018	$0.156	$13,874
A05B	APRON	S	PCC	171,402	94	70	0.74	40.48	9.44	0.97	7.55	$0.0232	$0.124	$0.1467	$0.004	$0.161	$0.165	$0.018	$0.139	$23,804
A07B	APRON	S	PCC	95,867	93	70	0.74	40.48	9.44	0.97	7.24	$0.0232	$0.124	$0.1467	$0.004	$0.161	$0.165	$0.018	$0.133	$12,759
A08B	APRON	S	PCC	363,925	92	70	0.74	40.48	9.44	0.97	6.93	$0.0232	$0.124	$0.1467	$0.004	$0.161	$0.165	$0.018	$0.127	$46,329
A26B	APRON	S	PCC	50,940	87	70	0.74	40.48	9.44	0.97	5.35	$0.0232	$0.124	$0.1467	$0.004	$0.161	$0.165	$0.018	$0.098	$5,011
A05B	APRON	S	PCC	348,676	78	70	0.74	40.48	9.44	0.97	2.52	$0.0232	$0.124	$0.1467	$0.004	$0.161	$0.165	$0.018	$0.046	$16,141
A03B	APRON	P	PCC	887,730	73	70	0.74	40.48	9.44	0.97	0.94	$0.0232	$0.124	$0.1467	$0.004	$0.161	$0.165	$0.018	$0.017	$15,411
A01B	APRON	T	PCC	516,205	70	70	0.74	40.48	9.44	0.97	0.00	$0.0232	$0.124	$0.1467	$0.004	$0.161	$0.165	$0.018	$0.000	$0
A38B	APRON	S	PCC	196,478	68	70	0.74	40.48	9.44	0.97	-0.63	$0.0232	$0.124	$0.1467	$0.004	$0.161	$0.165	$0.018	-$0.012	$0
																				$356,768

A-10.5 Risk Analysis – Global Preventive Maintenance (PM).

Typically, global PM is applied for pavements above the critical PCI at an appropriate frequency throughout the life of the pavement. Currently, global PM is limited to the application of seal coats to asphalt surfaces. In this UFC, seal coats are divided into three general applications: fog seals, rejuvenators, and slurry seals. The procedure presented below is for determining the risk for a single application. Note that in the following procedure the rate of deterioration without global PM (R_{WO_G}) is used in this analysis because the Services have not historically used global PM on airfields. If global PM has been performed in the past, use the localized preventive procedure outlined in paragraphs A-10.1 thru A-10.4.

Figure A-65 shows the general effect of applying global PM on pavement life. Pavement life is defined as the age in years from original construction or the last major M&R to the time the pavement reaches its critical PCI.

Figure A-65 Effect of Global Maintenance on PCI



A-10.5.1 Family Rate of Deterioration Without Global Preventive Maintenance (PM).

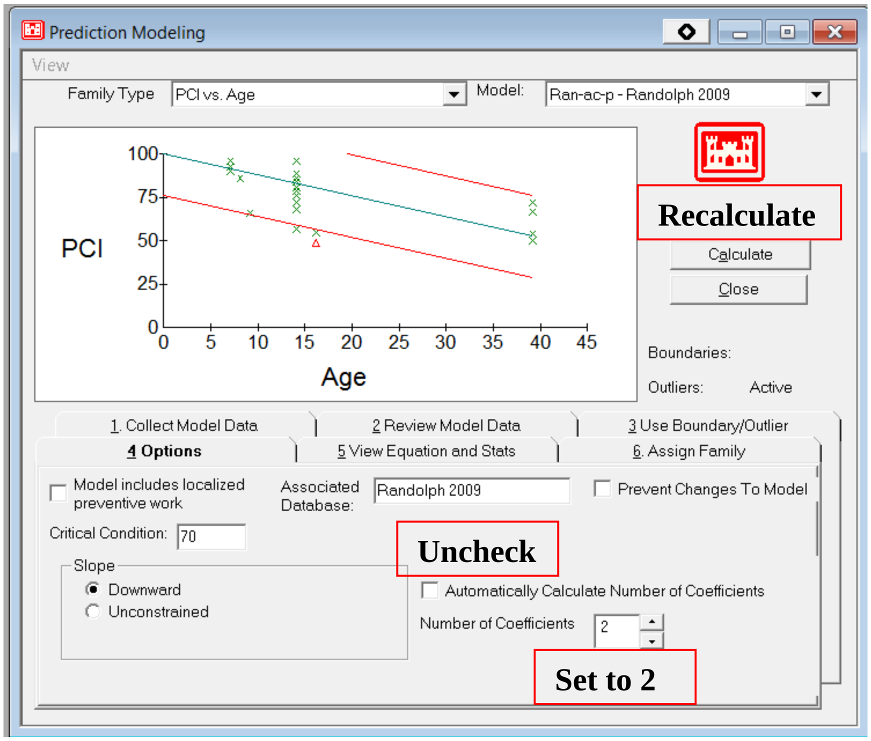
a. For each pavement section, calculate the pavement family rate of deterioration with and without performing global PM.

b. Determine the pavement family rate of deterioration (R_{WO_G}) assuming global PM has not been performed in the past.

c. Create a family curve in PAVER that includes the pavement section(s) under consideration. Figure A-66 shows an example family curve that was created for primary asphalt taxiways at an Air Force base.

d. On tab 4, **Options**, uncheck the **Automatically Calculate Number of Coefficients** button then set the number of coefficients to 2 and press the **Calculate** button as shown in Figure A-66.

Figure A-66 Effect of Global Maintenance on PCI



e. Select tab 5, **View Equation and Stats**. The second coefficient in the equation (e.g., 100 – 1.20653 X^1) is the straight-line deterioration rate (Rwo_G = 1.21 points per year). The next step is to calculate the age (T_{WO_G}) to critical PCI (PCI_C), assuming localized PM has not been performed.

A-10.5.2 Age to Critical PCI Without Global Preventive Maintenance (PM).

a. Calculate age to critical PCI (PCI_C), assuming global PM has not been performed (T_{WO_G}).

$$T_{WO\_G} = (100 - PCI_C) / R_{WO\_G}$$

b. In the example above, assuming a PCI_C = 70:

$$T_{WO\_G} = (100 - 70) / 1.21 = 24.8 \text{ years}$$

c. Delta T (DT) is the estimated effective increase in pavement life due to application of the global treatment. The value of DT is a function of a variety of factors, including pavement condition, climatic condition, and the type of treatment being applied. It normally ranges from two to six years, depending on treatment type. DT is less than the frequency at which the treatment is applied. For example, if a rubberized slurry seal is applied on a six-year cycle, the expected DT cannot be equal to or greater than six years. Table A-30 provides a range of recommended DT values for fog seals, rejuvenators, and slurry seals. Use the midpoint of the range unless local experience and conditions indicate other values within the range are more appropriate.

Table A-30 Recommended DTf Values

Type of Seal Coat	DT, years
Fog seal	2–3 years
Rejuvenator	3–5 years
Slurry seal	4–6 years

d. Calculate the age to critical PCI (PCI_C), assuming global PM is performed (T_{W_G}):

$$T_{W\_G} = T_{WO\_G} + DT$$

e. In the example above, assuming DT = 5 years:

$$T_{W\_G} = 24.8 + 5 = 29.8\ years$$

A-10.5.3 Estimate Cost Due to Loss in Pavement Section Life.

Performing global maintenance will increase pavement life, but a risk analysis must determine the consequences of not performing an action. This section determines the cost of not performing global maintenance (i.e., the loss in pavement life by not performing global maintenance). The procedure is based on the EUAC economic analysis method. This method calculates the average annual cost with and without global PM and compares the two to determine the annual cost due to loss of pavement life. The simplest form of this procedure is presented below, in which interest and inflation rates are not considered. The costs are intended to be used for comparative analysis only and not intended to represent actual project cost.

A-10.5.4 Calculate EUAC With Global Preventive Maintenance (PM).

a. Use the following procedure to calculate the EUAC for the global PM alternative ($EUAC_{Alt1}$).

b. Determine the annual major M&R cost ($\$_{Annual-Major-Alt1}$) by dividing the major M&R cost at critical PCI ($\$_{Major-critical}$) by the life of the alternative (T_{W_G}). $\$_{Major-critical}$ can be estimated as one-third the cost of reconstruction for asphalt pavements and one-fourth the cost of reconstruction for concrete pavements.

c. In the example above, assuming a reconstruction cost of $6.00/SF then $\$_{Major-critical}$ is estimated at $6/3 = $2.0/SF.

$$\$_{Annual\ Major\ Alt1} = \$2.0/29.8 = \$0.0671\ SF/Yr$$

d. Determine the annualized cost of the global treatment being applied ($\$_{Global}$).

$$\$_{Global} = Treatment\ unit\ cost/T_{W\_G}$$

e. For the example above, assuming the treatment unit cost is $0.30/SF:

$$\$_{Global} = \$0.30/29.8 = \$0.0100\ SF/YR$$

f. $EUAC_{Alt1}$ is determined as the sum of costs from $\$_{Major\text{-}critical}$ and $\$_{Global}$ above, as shown in the equation below:

$$EUAC_{Alt1} = \$_{Annual\ Major\ Alt1} + \$_{Global}$$

g. For the example above:

$$EUAC_{Alt1} = 0.0671 + 0.0100 = \$0.0771/SF/YR$$

A-10.5.5 Calculate EUAC Without Global Preventive Maintenance (PM).

Calculate annual cost for the same alternative, except without global PM alternative ($EUAC_{Alt2}$):

Determine the annual major M&R cost ($\$_{Annual\ Major\ Alt2}$) by dividing the major M&R cost at critical PCI ($\$_{Major\ critical}$) by the life of the alternative (T_{WO_G}). $\$_{Major\ critical}$ can be estimated as one-third the cost of reconstruction for asphalt pavements and one-fourth the cost of reconstruction for concrete pavements.

In the example above:

$$\$_{Annual\ Major\ Alt2} = \$2.0/24.8 = \$\,0.0806\ /SF/YR$$

A-10.5.6 Calculate Annual Cost Due to Loss of Pavement Life.

Calculate the annual cost due to loss of pavement life ($EUAC_{LOSS}$):

$$EUAC_{LOSS} = EUAC_{Alt2} - EUAC_{Alt1}$$

For the example above:

$$EUAC_{LOSS} = \$0.0806 - \$0.0771 = \$\,0.0035/SF/YR$$

This number is then multiplied by DT, which is five years in this example, i.e., 0.0035*5 = $0.0175/SF or approximately $0.1575/SY.

A-10.6 Compute Project Risk Cost.

Performing globalized PM typically includes more than one pavement section. The risk for the project is simply the sum of the risk associated with every section. Set the risk cost to zero when the PCI is less than critical. The project cost is best calculated in an Excel sheet as shown in Figure A-67. The Excel sheet in this example was initiated in PAVER using the user-defined reports feature. The generated Excel sheet from PAVER included section area and PCI. The rest of the information in the sheet was calculated in

Excel as shown above. Note that negative costs or costs shown in red/parentheses indicate these applications may not be justified based on the assumptions.

Figure A-67 Sample Table - Global

Branch	Section	Use	Rank	Surface	Area	2010 PCI	PCI Critical AFCESA	Det. Rate with SRM Rwo_G	Pav. Life without Global (Year) Two_G	Assum. Pav. Increase in Life (Year) DT	Pav. Life with Global (Year) Tw_G	Alt1 $Annual with Major SRM $/SF/YR	$Annual Global $/SF/YR	EUAC Alt 1 Cells: (M+N) $/SF/YR	Alt2 $Annual with Major SRM and w/o Global $/SF/YR	EUAC Loss Alt2- Alt1 $/SF/YR	EUACI Cells: (Q*K) $/SF	Risk Cost = EUACI*Area
TWBMAIN	T32A	TAXIWAY	P	AC	10,201	100	70	1.21	24.79	6.00	30.79	$0.065	$0.010	$0.075	$0.081	0.01	0.04	365.72
TWCMAIN	T30A	TAXIWAY	P	AC	103,119	100	70	1.21	24.79	6.00	30.79	$0.065	$0.010	$0.075	$0.081	0.01	0.04	3697.01
TWGMAIN	T05A	TAXIWAY	P	AC	155,411	93	70	1.21	24.79	6.00	30.79	$0.065	$0.010	$0.075	$0.081	0.01	0.04	5571.77
TWASOUTH	T03A	TAXIWAY	S	AC	7,565	92	70	1.21	24.79	6.00	30.79	$0.065	$0.010	$0.075	$0.081	0.01	0.04	271.22
TWBNORTH	T02A	TAXIWAY	S	AC	45,000	90	70	1.21	24.79	6.00	30.79	$0.065	$0.010	$0.075	$0.081	0.01	0.04	1613.33
TWRAMP5	T15A	TAXIWAY	S	AC	117,307	83	70	1.21	24.79	5.00	29.79	$0.067	$0.010	$0.077	$0.081	0.00	0.02	2034.30
TWPAD18	T20A	TAXIWAY	S	AC	82,911	76	70	1.21	24.79	5.00	29.79	$0.067	$0.010	$0.077	$0.081	0.00	0.02	1437.81
TWNORTH	T05A	TAXIWAY	S	AC	65,585	72	70	1.21	24.79	5.00	29.79	$0.067	$0.010	$0.077	$0.081	0.00	0.02	1137.35
TW422MAIN	T06C	TAXIWAY	P	AC	153,750	100	70	1.42	21.13	5.00	26.13	$0.077	$0.011	$0.088	$0.095	0.01	0.03	5100.13
TW422MAIN	T07A	TAXIWAY	P	AC	129,375	100	70	1.42	21.13	4.00	25.13	$0.080	$0.012	$0.092	$0.095	0.00	0.01	1620.18
TW422MAIN	T03C	TAXIWAY	P	AC	858,351	93	70	1.42	21.13	4.00	25.13	$0.080	$0.012	$0.092	$0.095	0.00	0.01	10749.27
TW624NORTH	T01A	TAXIWAY	S	AC	30,000	90	70	1.42	21.13	4.00	25.13	$0.080	$0.012	$0.092	$0.095	0.00	0.01	375.70
TW624NORTH	T06A	TAXIWAY	S	AC	30,000	85	70	1.42	21.13	3.00	24.13	$0.083	$0.012	$0.095	$0.095	(0.00)	(0.00)	(59.68)
TW624NORTH	T04A	TAXIWAY	S	AC	45,000	80	70	1.10	27.27	3.00	30.27	$0.066	$0.010	$0.076	$0.073	(0.00)	(0.01)	(356.76)
TW422MAIN	T09C	TAXIWAY	P	AC	153,750	75	70	1.10	27.27	2.00	29.27	$0.068	$0.010	$0.079	$0.073	(0.01)	(0.01)	(1610.71)
TW422MAIN	T10A	TAXIWAY	P	AC	170,625	70	70	1.10	27.27	2.00	29.27	$0.068	$0.010	$0.079	$0.073	(0.01)	(0.01)	0.00
TW624SOUTH	T04A	TAXIWAY	S	AC	30,000	68	70	1.10	27.27	2.00	29.27	$0.068	$0.010	$0.079	$0.073	(0.01)	(0.01)	0.00
																		$31,947

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APPENDIX B GLOSSARY

B-1 ACRONYMS.

AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt Concrete
ACN	Aircraft Classification Number
AMC	Air Mobility Command
ASTM	American Society for Testing and Materials
CATCODE	Category Code
CBR	California Bearing Ratio
CFME	Continuous Friction Measuring Equipment
CI	Condition Index
CIP	Common Installation Picture
CPE	Corrugated Polyethylene
DCP	Dynamic Cone Penetrometer
DoD	Department of Defense
EA	Engineering Assessment
EO	Executive Order
EUAC	Equivalent Uniform Annual Cost
FAA	Federal Aviation Administration
FAC	Facility Analysis Code
FARP	Forward Arming and Refueling Point
FCI	Facility Condition Index
FLIP	Flight Information Publications
FOD	Foreign Object Damage / Debris
FWD	Falling Weight Deflectometer
GIS	Geographic Information System

GPR	Ground-Penetrating Radar
GPS	Global Positioning System
HMA	Hot Mix Asphalt
HWD	Heavy Weight Deflectometer
ICAO	International Civil Aviation Organization
IDIQ	Indefinite Delivery / Indefinite Quantity
iNFADS	Navy Facility Assets Data Store
IRI	International Roughness Index
ISM	Impulse Stiffness Modulus
K	Modulus of Subgrade Reaction
km/h	Kilometers per Hour
LCD	Last Construction Date
m	Meter
M&R	Maintenance and Repair
mm	Millimeter
mph	Miles per Hour
O&M	Operations and Maintenance
OSD	Office of the Secretary of Defense
PCC	Portland Cement Concrete
PCI	Pavement Condition Index
PCN	Pavement Classification Number
PM	Preventive Maintenance
PMP	Pavement Management Plan
POC	Point of Contact
POL	Petroleum, Oil, Lubricants
PPD	Physical Property Data

PRV	Plant Replacement Value
ROI	Return on Investment
RPAD	Real Property Asset Database
RPSUID	Real Property Site Unique ID
RPUID	Real Property Site Unique ID
SCI	Structural Condition Index
SDDCTEA	Military Surface Deployment and Distribution Command Transportation Engineering Agency
SDSFIE	Spatial Data Standards for Facilities, Infrastructure, and Environment
SI	Structural Index
UFC	Unified Facilities Criteria
WBDG	Whole Building Design Guide

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APPENDIX C REFERENCES

FEDERAL

Executive Order (EO) 13327, *Federal Real Property Asset Management*, https://www.fedcenter.gov/Bookmarks/index.cfm?id=56&pge_prg_id=0&pge_id=0

DEPARTMENT OF DEFENSE (DOD)

https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc

UFC 3-201-01, *Civil Engineering*

UFC 3-250-01, *Pavement Design for Roads and Parking Areas*

UFC 3-250-03, *Standard Practice Manual for Flexible Pavements*

UFC 3-250-04, *Standard Practice for Concrete Pavements*

UFC 3-250-07, *Standard Practice for Pavement Recycling*

UFC 3-250-08FA, *Standard Practice for Sealing Joints and Cracks in Rigid and Flexible Pavements*

UFC 3-260-01, *Airfield and Heliport Planning and Design*

UFC 3-260-02, *Pavement Design for Airfields*

UFC 3-260-03, *Airfield Pavement Evaluation*

UFC 3-260-16, *O&M Manual: Standard Practice for Airfield Pavement Condition Surveys*

UFC 3-270-01, *O&M Manual: Asphalt and Concrete Pavement Maintenance and Repair*

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

UFGS 32 12 17.19, *Fuel-Resistant Asphalt Paving for Airfields – Surface Course*, https://www.wbdg.org/ffc/dod/unified-facilities-guide-specifications-ufgs

DoD Guide for Segmenting Types of Linear Structures, https://www.acq.osd.mil/eie/Downloads/BSI/Linear%20Segmentation%20Requirement.pdf

TSPWGM 3-260-00.NS7210, *Standards for NATO Deployed Air Operations*, https://www.wbdg.org/ffc/dod/supplemental-technical-documents

GENERAL SERVICES ADMINISTRATION (GSA)

GSA *Guidance for Real Property Inventory Reporting*, https://www.gsa.gov/policy-regulations/policy/real-property-policy/asset-management/federal-real-property-council-frpc/frpc-guidance-library

ARMY

SDDCTEA Pamphlet 55-17, *Better Military Traffic Engineering*, https://www.sddc.army.mil/sites/TEA/Functions/SpecialAssistant/TrafficEngineeringBranch/Pages/pamphlets.aspx

TM 3-34.48-2, *Theater of Operations: Roads, Airfields, and Heliports – Airfield and Heliport Design*, https://armypubs.army.mil/ProductMaps/PubForm/Details.aspx?PUB_ID=106072

NATO

https://nso.nato.int/nso/home/main/home

NATO STANDARD AEP-46, *ACN/PCN*

NATO STANAG 3634, *Runway Friction and Braking Conditions*

NATO Standard AATMP-13, *Runway Friction and Braking Conditions*

NATO STANAG 7131, *Aircraft Classification Number (ACN)/Pavement Classification Number (PCN)*

NATO STANAG 7181, *Standard Method for Airfield Pavement Condition Index (PCI) Surveys*

NATO Standard AEP-56, *Standard Method for Airfield Pavement Condition Index (PCI) Surveys*

FEDERAL AVIATION ADMINISTRATION (FAA)

https://www.faa.gov/regulations_policies/advisory_circulars/

AC 150/5320-12C, *Measurement, Construction, and Maintenance of Skid Resistant Airport Pavement Surfaces*

AC 150/5380-9, *Guidelines and Procedures for Measuring Airfield Pavement Roughness*

AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS (AASHTO)

https://store.transportation.org/

AASHTO *Roadside Design Guide*

AASHTO *Guidelines for Geometric Design of Low-Volume Roads*

AASHTO *A Policy on Geometric Design of Highways and Streets*

AASHTO R 43, *Standard Practice for Quantifying Roughness of Pavements*

INTERNATIONAL CIVIL AVIATION ORGANIZATION (ICAO)

Aerodrome Design Manual, Part 3, Pavements, https://www.icao.int/

ASTM INTERNATIONAL

ASTM E1926, *Standard Practice for Computing International Roughness Index of Roads from Longitudinal Profile Measurements*, https://www.astm.org/

ASPHALT INSTITUTE (AI)

http://www.asphaltinstitute.org/

MS-4, *The Asphalt Handbook*

MS-17, *Asphalt Overlays for Highway and Street Rehabilitation*

UFC 3-301-01
11 April 2023
Change 4, 3 June 2025

UNIFIED FACILITIES CRITERIA (UFC)

STRUCTURAL ENGINEERING

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

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UFC 3-301-01
11 April 2023
Change 4, 3 June 2025

UNIFIED FACILITIES CRITERIA (UFC)

STRUCTURAL ENGINEERING

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING SYSTEMS COMMAND (Preparing Activity)

AIR FORCE CIVIL ENGINEER CENTER

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

Change No.	Date	Location
1	Oct 2, 2023	See change summary
2	Sept 4, 2024	See change summary
3	Feb 3, 2025	See change summary
4	June 3, 2025	See change summary

This UFC supersedes UFC 3-301-01, dated 1 October 2019.

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FOREWORD

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

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

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

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

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

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UNIFIED FACILITIES CRITERIA (UFC)
REVISION SUMMARY SHEET

Document: UFC 3-301-01, Change 1, Dated October 2, 2023
Superseding: UFC 3-301-01, Dated April 11, 2023

\1
Description of changes:
This update to UFC 3-301-01 incorporates a change to Tsunami design provisions wherein “other utilities”, which would generally refer to elements of secondary or tertiary importance, may be designed for a reduced risk category where approved by the AHJ. Additionally, an existing prohibition against the use of fabric hangar doors in windborne debris regions has been changed to include fabric covered buildings in general in windborne debris regions.

Reason for changes:
Regarding tsunami design change: In some cases it may be infeasible to harden all elements of a utility system against tsunami effects, particularly less critical distributions systems. Accordingly, it was decided that the Authority Having Jurisdiction (AHJ) can approve the reduction of tsunami risk category for “other utilities”, which can have the effect of reducing or eliminating tsunami design requirements for secondary and/or tertiary systems.

Regarding fabric covered buildings in windborne debris regions: It became apparent that there was an omission in DoD structural criteria, wherein an existing prohibition against the use of fabric covered hangar doors existed, while there was no such prohibition against using fabric covered buildings in general, which are vulnerable to the same failure mode. Moreover, this omission would result in a prohibition against the use of a fabric door on a fabric covered building, which would prove illogical. Awareness of this omission occurred as a result of a recent emphasis on the utilization of fabric covered buildings across the Department of Defense. Fabric, unlike other construction materials is uniquely vulnerable to tearing and tear propagation do to windborne debris. Past experience with Hurricane Michael at Tyndall Air Force Base has demonstrated this vulnerability.

Impact: There are both costs and benefits to these changes

Tsunami design changes: This change will result in substantial cost savings to the Department of Defense over time, where the department is impacted by tsunami.

Fabric covered structures: A direct increase in cost will be negligible for this change, as the life cycle cost for a fabric covered building, compared to a metal clad building, will not vary significantly for windborne debris regions. Ultimately however, it is expected that this prohibition will result in considerable savings to DoD, by reducing facility loss and facility content loss due to damage caused by major hurricanes and typhoons.
/1/

Document: UFC 3-301-01, Change 2, Dated September 4, 2024
Superseding: UFC 3-301-01, Change 1, Dated October 2, 2023

\2
Description of changes (seismic coefficients):
Seismic design values for OCONUS installations have been updated (effective Sept 4, 2024). This will affect existing OCONUS RFP's and designs according to UFC 1-200-01 (Chapter 1-3.1).

Reason for changes:
Seismic acceleration coefficients (earthquake loading) for OCONUS installations have not been fully updated since the 1990's. At that time, they were prepared based on less reliable information. In 2010, the Global Earthquake Model (GEM), a non-profit foundation, began a multi-year effort to construct a global earthquake hazard model using high quality site hazard data available from governments, academia, and industry resources. This Model is continuously refined and improved. In 2021, the Department of Defense (DoD), in partnership with the Department of State (DoS), contracted with GEM to develop new seismic design values for all OCONUS DoD installations and DoS facilities using the GEM model. Results from this effort have recently become available and have been incorporated into DoD design criteria (effective Sept 4, 2024).

Impact:
There may be a significant cost increase for some locations. Because prior values were based on less reliable information, this update has resulted in numerous changes. In most cases changes are mild to moderate. However, in a few locations, values have increased markedly. For this reason, this change has the potential to result in a significant cost increase for some locations.
/2/

\2
Description of changes (fall protection):
Two separate sections referencing fall protection were consolidated and simplified.

Reason for changes:
Fall protection requirements noted within the UFC were confusing as written, redundant to the IBC and ASCE 7 and, in some cases, were not relevant to the building structure.

Impact:
There is no significant impact associated with this change.
/2/

\2
Description of changes (Roof Diaphragms Resisting Wind Loads in High-wind Regions):
An exception was added to this provision to prevent it from being applied to new buildings.

Reason for changes:
As written, the provision could be incorrectly applied to new buildings.

Impact:
There is no significant impact associated with this change.
/2/

Document: UFC 3-301-01, Change 3, Dated February 3, 2025
Superseding: UFC 3-301-01, Change 2, Dated September 4, 2024

\3
Description of changes:
-Adoption of the 2024 I-codes

-Adoption of ASCE 7-22, Minimum Design Loads and Associated Criteria for Buildings and Other Structures

-Frost depth, for the purpose of foundation design, is now to be determined by project geotechnical engineer

Reason for changes:
Maintain concurrence with model building codes and alignment with DoD building code (1-200-01).

Impact:
Typical of the code update cycle.
/3/

Document: UFC 3-301-01, Change 4, Dated June 3, 2025
Superseding: UFC 3-301-01, Change 3, Dated February 3, 2025

\4
Description of changes:
Includes sundry changes and clarifications but also a significant change to the risk category table (Table 2-2).

Reason for change:

- There is a conflict originating in the IBC, where public utilities are designated as both risk category III and IV. This has been corrected by deletion of the risk category III option for public utilities. It is not intended that this change affect current projects in any stage of design.

- The application of Risk Category V in the context of missile defense has gradually expanded beyond its original intent, which was to protect nationally critical defensive assets. The current revision realigns the category's use with its initial purpose—focusing on missile defense and other highly critical assets whose loss could result in catastrophic national consequences, rather than merely regional or local impact.

Impact: This change will result in substantial cost savings

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FIGURES

TABLES

CHAPTER 1 INTRODUCTION

1-1 BACKGROUND.

UFC 1-200-01 implements and supplements 2024 IBC as the building code for DoD. Chapter 2 of this UFC further modifies the IBC for structural-specific design requirements and is organized by the chapter of the IBC that each section modifies. Apply any section in the 2024 IBC, that is not specifically referenced, as it is written in the 2024 IBC. Chapter 3 of this UFC further modifies ASCE 7-22 for structural-specific design requirements and is organized by the chapter of ASCE 7 that each section modifies. Apply any section in ASCE 7-22, that is referenced by the 2024 IBC but is not modified in Chapter 3 of this UFC, as it is written in ASCE 7-22.

The 2024 IBC and ASCE 7-22 section modifications are one of four actions, according to the following legend:

[Addition] – Add new section, including new section number, not shown in 2024 IBC or ASCE 7-22.

[Deletion] – Delete referenced 2024 IBC or ASCE 7-22 section or noted portion of a section.

[Replacement] – Delete referenced 2024 IBC or ASCE 7-22 section or noted portion and replace it with the narrative shown.

[Supplement] – Add narrative shown as a supplement to the narrative shown in the referenced section of 2024 IBC or ASCE 7-22.

1-2 REISSUE AND CANCELS.

This edition of UFC 3-301-01 cancels UFC 3-301-01 dated 1 October 2019.

1-3 PURPOSE AND SCOPE.

This Unified Facilities Criteria (UFC) provides requirements for structures designed and constructed for the Department of Defense (DoD). These technical requirements are based on the 2024 *International Building Code* (2024 IBC), as modified by UFC 1-200-01, *DoD Building Code*, and the structural standard referenced by the 2024 IBC: ASCE/SEI 7-22 *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* (hereinafter referred to simply as ASCE 7-22). The criteria further provides limited technical guidance for seismic evaluation and strengthening of existing buildings, and references ICSSC RP 10, *Standards of Seismic Safety for Existing Federally Owned and Leased Buildings* (RP 10) as well as ASCE/SEI 41-17, *Seismic Evaluation and Retrofit of Existing Buildings* (hereinafter referred to simply as ASCE 41-17). Additionally, for nonseismic retrofit of existing buildings, the criteria references the 2024 edition of the *International Existing Building Code* (2024 IEBC). This information is for use by structural engineers to develop design calculations, specifications, plans, and design-build Requests for Proposal (RFPs), and it is meant to serve as the minimum design requirement for DoD buildings.

1-4 APPLICABILITY.

This UFC follows the same applicability as UFC 1-200-01, paragraph 1-3, with no exceptions.

1-5 CONFLICTS AND MODIFICATIONS.

The 2024 IBC provisions are directed toward public health, safety, and general welfare, presenting minimum standards that must be met by the private sector construction industry. The use of industry standards for DoD projects promotes communication in the marketplace, improves competition, and results in cost savings. However, the military sometimes requires higher standards to achieve unique building performance, or to construct types of facilities that are not used in the private sector. In addition, the construction of military facilities outside the United States can introduce requirements that are not addressed in national model building codes. Modifications to the 2024 IBC and ASCE 7-22 provisions contained herein are intended to fulfill those unique military requirements. Where conflicts between the 2024 IBC or ASCE 7-22 and this UFC arise, this UFC prevails.

In addition, for construction outside the United States, conflicts between host nation building codes and the UFC may arise. In those instances, the more stringent design provisions prevail.

1-6 OVERVIEW OF THIS UFC.

Brief descriptions of the various chapters and appendices of this UFC follow.

- Chapter 2 – MODIFICATIONS TO IBC. Chapter 2 provides supplemental requirements for applying the 2024 IBC structural provisions to conventional DoD building design by listing required modifications for specific 2024 IBC sections. The 2024 IBC sections that are not referenced in Chapter 2 or otherwise modified by provisions of Chapter 6 and Appendix B apply as they are written in the 2024 IBC.

- Chapter 3 – MODIFICATIONS TO ASCE 7. Chapter 3 provides supplemental requirements for applying the ASCE 7-22 structural and nonstructural component provisions to conventional DoD building design by listing required modifications for specific ASCE 7-22 sections. The ASCE 7-22 sections that are adopted by the 2024 IBC but are not referenced in Chapter 3 or otherwise modified by provisions of Chapter 7 and Appendix B apply as they are written in ASCE 7-22.

- CHAPTER 4 - EVALUATION AND RETROFIT OF EXISTING BUILDINGS. This chapter contains provisions for the *repair*, *alteration*, change of occupancy, acquisition, *addition* to, and relocation of existing buildings. For seismic evaluation of existing buildings, this chapter adopts by reference the provisions of

ICSSC RP 10, as well as those of ASCE/SEI 41-17. This chapter also makes revisions to specific sections in RP 10. Additionally, this chapter contains modifications to the 2024 IEBC including the scope, and the prescriptive compliance method for nonseismic evaluation of existing buildings.

- CHAPTER 5 – NONBUILDING STRUCTURES. This chapter lists the names of various standards and other guidelines to be followed for the design of highway bridges, railroad bridges, tanks for liquid storage, tanks for petroleum storage, environmental engineering concrete structures, prestressed concrete tanks, water treatment facility structures, transmission towers and poles, antenna towers, and pedestrian bridges.

- CHAPTER 6 – MODIFICATIONS TO THE IBC FOR CRITICAL HEALTHCARE FACILITIES. This chapter contains a number of additional requirements for certain critical healthcare facilities identified in the chapter. The requirements are presented in the form of modifications to Chapters 16, 18, 19, 20, 21, and 22 of the IBC.

- CHAPTER 7 – MODIFICATIONS TO ASCE 7 FOR CRITICAL HEALTHCARE FACILITIES. This chapter contains a number of additional requirements for the same healthcare facilities within the scope of Chapter 6. The requirements are presented in the form of modifications to Chapters 11, 12, and 13 of ASCE 7.

- Appendix A – BEST PRACTICES. This appendix provides useful recommendations and guidance on a number of important topics such as building drift limits, impact resistant glazing, wind and seismic loads on photovoltaic arrays, etc.

- Appendix B – ALTERNATE DESIGN PROCEDURE FOR BUILDINGS AND OTHER STRUCTURES IN RISK CATEGORY IV. For buildings assigned to Risk Category IV, those that are “essential” because of their military function or post-earthquake recovery role, the 2024 IBC/ASCE 7-22 requires higher design lateral loads and more stringent structural detailing procedures than those for buildings assigned to Risk Category I, II, or III. Applying nonlinear analysis procedures may result in more economical or better-performing Risk Category IV buildings than linear elastic procedures can provide. While the 2024 IBC/ASCE 7-22 permits nonlinear static analysis procedures, it provides little guidance on how to perform them. Appendix B presents optional nonlinear static analysis procedures that may be used for Risk Category IV buildings. Apply the optional nonlinear procedures outlined in Appendix B only with the approval of the Authority Having Jurisdiction.

- Appendix C – GUIDANCE FOR SEISMIC DESIGN OF NONSTRUCTURAL COMPONENTS. Appendix C provides guidance for seismic design of nonstructural components. Requirements for design of nonstructural components in this UFC are supplemented by guidance provided in this appendix.

- Appendix D – MECHANICAL AND ELECTRICAL COMPONENT CERTIFICATION. Appendix D provides guidance in addition to what is available in ASCE 7-22 Section 13.2.2 on certification of mechanical and electrical components.

- Appendix E – MINIMUM UNIFORMLY DISTRIBUTED LIVE LOADS, L_O, AND MINIMUM CONCENTRATED LIVE LOADS. This appendix contains Table E-1, which replaces Table 1607.1 of the 2024 IBC and includes additional occupancy or use classification for military facilities that are shown in bold italics.

- Appendix F - GUIDANCE FOR COMPOSITE TECHNOLOGIES FOR BRIDGE APPLICATIONS. The fiber reinforced polymer (FRP) technologies covered in this Appendix include carbon FRP composite prestressing systems, FRP composite external strengthening and repair systems, and FRP composite elements including bridge piles and bridge decks. This appendix also includes information on thermoplastic materials for replacement of timber bridges including thermoplastic lumber, thermoplastic piles, and thermoplastic I-beams.

- Appendix G – GLASS FIBER-REINFORCED POLYMER (GFRP) BARS FOR CONCRETE STRUCTURES. This appendix provides design resources to structural engineers interested in using glass fiber-reinforced polymer (GFRP) reinforcement in concrete structures. New standards developed by ASTM and ACI for GFRP bars are discussed along with other supporting guides and reports. This appendix identifies the limits on the use of GFRP reinforcement in concrete structures and key design considerations.

- Appendix H – GLOSSARY. This appendix lists all the abbreviated terms used in this UFC.

- Appendix I – REFERENCES. The UFC has an extensive list of referenced public documents. The primary references for this UFC are the 2024 IBC and ASCE 7-22.

1-7 COMMENTARY.

Limited commentary has been provided in the chapters. Section designations for such commentary are preceded by a “[C]”, and the commentary narrative is shaded.

1-8 OTHER CRITERIA.

Military criteria other than those listed in this document may be applicable to specific types of structures. Such structures must meet the additional requirements of the applicable military criteria.

1-8.1 General Building Requirements.

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

1-8.2 Progressive Collapse Analysis and Design.

When required, apply UFC 4-023-03, *Design of Buildings to Resist Progressive Collapse*.

1-8.3 Design of Risk Category V Structures.

A risk category not included in the 2024 IBC/ASCE 7-22, Risk Category V, has been added to address national strategic military assets. Structures in this risk category are designed to remain elastic during the MCE_R. Refer to Table 2-2 of this UFC for the list of structures that must be assigned to RC V. Refer to UFC 3-301-02 for the design of all RC V structures.

1-8.4 Cybersecurity.

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

1-9 REFERENCES.

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

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CHAPTER 2 MODIFICATIONS TO IBC

2-1 IBC CHAPTER 1 - SCOPE AND ADMINISTRATION.

2-1.1 Section 101 – GENERAL.

101.4.7 – Existing Buildings [Replacement]

For seismic evaluation and retrofit of existing buildings, the provisions of Chapter 4 of this UFC apply to all matters governing the *repair*, *alteration*, *change of occupancy*, acquisition, *addition* and relocation.

For nonseismic evaluation and retrofit of existing buildings, the provisions of the *International Existing Building Code*, as modified by Chapter 4 of this UFC, shall apply to matters governing the *repair*, *alteration*, *change of occupancy*, *addition* to and relocation of *existing buildings*.

[C] 101.4.7 – Existing Buildings [Replacement]

The purpose of this [Replacement] is to direct users to specific provisions for seismic evaluation and retrofit of existing buildings. Chapter 4 of this UFC cites a federal recommended practice document (ICSSC RP 10) and a national standard (ASCE 41-17) for seismic evaluation and retrofit of existing buildings. The chapter provides some modifications and clarifications to the requirements of RP 10 and ASCE 41-17.

Additionally, nonseismic retrofit provisions included in Chapter 4 of this UFC are also referenced here.

2-1.2 Section 116 - UNSAFE STRUCTURES AND EQUIPMENT.

116.5 – Restoration or Abatement [Replacement]

Where the structure or equipment determined to be unsafe by the AHJ is restored to a safe condition, the owner, the owner’s authorized agent, operator or occupant of the structure, premises or equipment deemed unsafe must abate or cause to be abated or corrected such unsafe conditions by repair, rehabilitation, demolition or other approved corrective action. To the extent that *repairs*, *alterations* or *additions* are made or a change of occupancy occurs during the restoration of the structure, such *repairs*, *alterations*, *additions* or *change of occupancy* must comply with the requirements of Sections 101.4.7 of this UFC.

2-2 IBC CHAPTER 2 – DEFINITIONS.

2-2.1 Section 202 – DEFINITIONS.

STRUCTURAL ENGINEER OF RECORD (SER) [Addition]

The Structural Engineer of Record (SER) is a registered design professional who performs, supervises, or approves the analysis, design, and document preparation for the building structural system. The SER is responsible for the design of the structural system, which is the completed combination of elements that serves to support the building's self-weight, superimposed dead loads, applicable live loads, and environmental loads such as wind, seismic, and thermal.

2-3 IBC CHAPTER 4 – SPECIAL DETAILED REQUIREMENTS BASED ON OCCUPANCY AND USE.

2-3.1 Section 423 – STORM SHELTERS.

423.4 – Critical Emergency Operations [Supplement]

The requirements of this section shall also apply to hurricane-prone regions (see ASCE 7 Section 26.2) and to facilities housing critical national defense functions that must be manned continuously and for which there is no redundant capability at a different location.

423.5 – Group E occupancies. [Supplement]

Delete Exception 1. Renumber Exceptions 2 and 3 as Exceptions 1 and 2 respectively.

Group E day care facilities shall include Child Development Centers (CDCs), even if classified as Group I-4, as defined by the army, the navy, the air force, the marine corps, and other branches of the military for their respective purposes.

2-4 IBC CHAPTER 16 – STRUCTURAL DESIGN.

2-4.1 Section 1603 – CONSTRUCTION DOCUMENTS.

1603.1.5 – Earthquake Design Data Item 3. [Replacement]

3. Spectral response acceleration parameters, S_s and S_1. If the data are based on site-specific response analysis, this must be noted. Site-specific source data must also include whether response spectrum or time-history analyses were performed.

1603.1.10 – Systems/Components Requiring Special Inspection for Seismic Resistance [Addition]

Construction documents and specifications must be prepared for those systems and components requiring special inspection for seismic resistance, as specified in 2024 IBC Section 1705.13 as modified by the appropriate special inspection section in UFC 1-200-01 and by the SER. Reference to seismic standards in lieu of detailed drawings is acceptable.

1603.2 – Delegated Engineered Systems [Addition]

The SER for a structure may delegate responsibility for the design of systems or components of the structure to a qualified registered professional engineer. Both the SER for the structure and the engineer receiving such delegation must comply with the requirements of this UFC.

Exception: The SER must design and detail all lateral force-resisting system connections for wind and seismic forces, including steel connections. This provision does not preclude a pre-engineered building engineer from designing primary lateral force-resisting connections where said engineer is the building SER. This would be the case with pre-engineered metal buildings and pre-engineered parking garages for example.

The following are some examples of optional delegated designs:

a. Pre-fabricated wood components (e.g. pre-engineered trusses)
b. Cast-in-place post-tensioned concrete structural systems
c. Precast, prestressed concrete components
d. Open web steel joists and joist girders
e. Specialty foundation systems
f. Simple (shear only) steel connections (lateral force-resisting system connections must be designed by SER)
g. Cold-formed steel joist/stud/truss framing and pre-fabricated components
h. Seismic design and anchorage of nonstructural components
i. Proprietary track for under-hung cranes and monorails
j. Cross-laminated timber connections (lateral force-resisting system connections must be designed by SER)

The engineer to whom design responsibility has been delegated must sign and seal all work they design. The SER must review all submittals that have been signed and sealed by the delegated engineer to verify compliance with the design intent and the specified design criteria and to ensure coordination with the contract documents and other shop drawings. All submittals from the engineer to whom design responsibility has been delegated must be approved by the SER prior to the start of fabrication of the system or component and prior to any field construction that may be affected by the system or component.

2-4.2 Section 1604 - GENERAL DESIGN REQUIREMENTS.

1604.3 - Serviceability [Supplement]

The SER must ensure that the maximum allowable frame drift is suitable for the proposed structure considering occupancy, use/function, and all details of construction. See ASCE 7-22 Appendix C “Serviceability Considerations” including commentary, and Section A-1.1 of UFC 3-301-01 for additional guidance.

1604.3.1 - Deflections [Replacement]

Deflections of structural members must not exceed the most restrictive of the limitations of: (1) Sections 1604.3.2 through 1604.3.5, (2) those permitted by Table 1604.3, or (3) those permitted by Table 2-1 of UFC 3-301-01.

Table 2-1 \4\ /4/ Wind Induced Deflection Limits for Framing Supporting Exterior Wall Finishes [a,b]

Brick veneer	*L*/600
Exterior Insulation Finish Systems	*L*/240
Cement board	*L*/360
Stone Masonry	VERIFY WITH STONE SUPPLIER
Plywood and Wood-Based Structural-Use Panels	*L*/240
Gypsum sheathing	*L*/240
Metal or vinyl siding and insulated metal panel	*L*/120

\4\ /4/

a. The wind load is permitted to be taken as 0.42 times the “component and cladding” wind loads for the purpose of determining the deflection limits herein.

b. L must be calculated as $L = kl$, where k is the theoretical effective length factor, and l is length of the member between supports.

Table 1604.5 [Replacement]

Replace Table 1604.5 of the IBC with Table 2-2 of this UFC. All references in the IBC to Table 1604.5 must be interpreted as a reference to Table 2-2 of this UFC. Items that are different from those in 2024 IBC Table 1604.5 are shown in italics.

Table 2-2 Risk Category of Buildings and Other Structures

Risk Category	Nature of Occupancy	*Seismic Factor I_e*			*Tsunami Factor I_{TSU}*	*DoD Sea Level Rise (SLR) Scenario* [f]
I	**Buildings and other structures that represent a low hazard to human life in the event of failure, including, but not limited to:** • Agricultural facilities • Certain temporary facilities • Minor storage facilities	*1.00*			*N/A* *Tsunami design not required*	*N/A*
II	**Buildings and other structures except those listed in Risk Categories I, III, IV *and V***	*1.00*			*1.00*	*Low (2065)*
III	**Buildings and other structures that represent a substantial hazard to human life *or represent significant economic loss* in the event of failure, including, but not limited to:** • Buildings and other structures whose primary occupancy is public assembly with an occupant load greater than 300.[d] • Buildings and other structures containing one or more public assembly spaces, each having an occupant load greater than 300 and a cumulative occupant load of these public assembly spaces of greater than 2,500.[d] • Buildings and other structures containing *elementary school, secondary school, or daycare facilities* with an occupant load greater than 250.[d] • Buildings and other structures containing *adult education facilities, such as colleges and universities,* with an occupant load greater than 500.[d] • Group I-3 Condition 1 occupancies • Any other occupancy with an occupant load greater than 5,000.[a,d] • **\4\ /4/** • Buildings and other structures not included in Risk Categories IV *and V* containing quantities of toxic, *flammable,* or explosive materials that: Exceed maximum allowable quantities per control area as given in Table 307.1(1) or 307.1(2) or per outdoor control area in accordance with *NFPA 1: Fire Code*; and are sufficient to pose a	*1.25*			*1.25*	*Medium (2065)*

Risk Category	Nature of Occupancy	*Seismic Factor I_e*			*Tsunami Factor I_{TSU}*	*DoD Sea Level Rise (SLR) Scenario* [f]
	threat to the public if released.[b] • *Facilities protecting high-value equipment (including aircraft maintenance hangars)* [d]					
IV	**Buildings and other structures designed as essential facilities and buildings where loss of function represents a substantial hazard to occupants or users, including, but not limited to:** • Group I-2, Condition 2 occupancies.[e] • Ambulatory care facilities having emergency surgery or emergency treatment facilities.[e] • Group I-3 occupancies other than Condition 1. • Fire, rescue, ambulance, and police stations, and emergency vehicle garages.[e] • Designated earthquake, hurricane, or other emergency shelters.[e] • Designated emergency preparedness, communications, and operations centers, and other facilities required for emergency response.[e] • Public utility facilities providing power generation, potable water treatment, or wastewater treatment. • *Power-***\4** *generation and other utility functions providing* **/4/** *emergency backup to Risk Category IV structures.*[e] • Buildings and other structures containing quantities of highly toxic materials that: Exceed maximum allowable quantities per control area as given in *IBC* Table 307.1(2) or per outdoor control area in accordance with *NFPA 1, Fire Code*; and are sufficient to pose a threat to the public if released.[b] • Air traffic control towers (ATCTs), *Radar Approach Control Facility (RACF)* and air traffic control centers *unless the facility is classified as a non-essential facility and is not required for post-disaster operations (i.e., minor facility, where an alternate temporary control facility is available, or auxiliary outlying field, etc.)*. • *Emergency aircraft hangars that house aircraft required for post-disaster emergency response; if no suitable back-up facilities exist* • Buildings and other structures *not included in Risk Category V,* having *DoD mission-essential command, control, primary communications, data handling, and intelligence functions that are not duplicated at geographically separate locations.*[e]	*1.50*			*1.25*	*High (2065)* [g]

Risk Category	Nature of Occupancy	*Seismic Factor* I_e			*Tsunami Factor* I_{TSU}	*DoD Sea Level Rise (SLR) Scenario* [f]
	• Water storage facilities and pump structures required to maintain water pressure for fire suppression.					
V [c]	***Facilities designed as national strategic military defensive assets, including, but not limited to:*** • **\4** *Defense Critical Assets (DCA)* [h] • *Facilities directly supporting operational nuclear armed missile defense.* **/4/** • *Emergency backup powergeneration for Risk Category V occupancy* • *Power-generating stations* **\4** *providing* **/4/** *primary power for Risk Category V occupancy, if emergency backup power generation is not available* • *Facilities involved in storage, handling, or processing of nuclear, chemical, biological, or radiological materials, where structural failure could have widespread catastrophic consequences.*	*1.0*			*1.25*	*Highest (2065)* [g]

Notes to Table 2-2, "Risk Category of Buildings and Other Structures"

a. For purposes of occupant load calculations, occupancies required by *IBC* Table 1004.5 to use gross floor area calculations shall be permitted to use net floor areas to determine the total occupant load. The floor area for vehicular drive aisles shall be permitted to be excluded in the determination of net floor area in parking garages.

b. Where approved by the *AHJ*, the classification of buildings and other structures as Risk Category III or IV based on their quantities of toxic, highly toxic or explosive materials is permitted to be reduced to Risk Category II, provided that it can be demonstrated by a hazard assessment in accordance with ASCE 7 Section 1.5.3 that a release of the toxic, highly toxic or explosive material is not sufficient to pose a threat to the public.

c. Risk Category V has been added to address national strategic military assets. Structures in this risk category are designed to remain elastic during the MCE_R*. Refer to UFC 3-301-02 for the design of all RC V structures.*

d. These facilities may be designed for Tsunami Risk Category I or II as approved by the AHJ.

e. These facilities may be designed for Tsunami Risk Category I, II or III as designated by the AHJ if adequate equivalent facilities are available *outside of the tsunami inundation zone or if adequate equivalent facilities within the inundation zone have been designed for the effects of tsunami.*

f. *Use the site-specific value from the DoD Regional Sea Level (DRSL) database corresponding to the designated scenario (low/medium/high/highest) for the year 2065. The DRSL database is available at https://sealevelscenarios.serdp-estcp.org*

g. *Subject to approval by the AHJ, a DoD 2065 sea level rise scenario of Medium may be used for Risk Category IV and V structures when designing for a combination of tsunami and sea level rise. Reference Section 3-3.1 within this UFC for specific limitations and requirements.*

h. **\4** *Defense Critical Assets must be explicitly listed in the OSD approved Mission Assurance tracking system. See DODI 3020.40 and 3020.45. The list of specific DCA's must follow the appropriate classification guidance.* **/4/**

1604.12 - Expansion Joints [Addition]

See guidance in *"Design of Concrete Floor Slabs-on-Ground for DoD Facilities"* posted under Related Materials for this UFC on the WBDG.

2-4.3 Section 1605 – LOAD COMBINATIONS.

1605.1.2 – Structural Members Sensitive to Vertical Ground Motion [Addition]

Where the design earthquake spectral response acceleration parameter at short periods, S_{DS}, is greater than 0.6g, the components of building and nonbuilding structures listed below must be designed for additional load combinations given in Sections 2.3.6 and 2.4.5 in Chapter 3 of this UFC for Strength Design and Allowable Stress Design, respectively.

Building Structures:

- horizontal or nearly horizontal structural members spanning 65 ft or more
- horizontal or nearly horizontal cantilever components longer than 16 ft
- horizontal or nearly horizontal prestressed components
- building components, excluding foundations, in which demands due to gravity loads exceed 80% of the nominal strength of the component
- horizontal structural elements supporting discontinuous vertical elements of the gravity load-resisting system
- base-isolated structures

Nonbuilding Structures:

- long-span roof structures (e.g., stadiums or aircraft maintenance hangar header truss)
- electric power generation facilities

Exception: Nonbuilding structures addressed by ASCE 7-22 Section 15.1.4 are not required to comply with this section.

[C] 1605.1.2 Structural Members Sensitive to Vertical Ground Motion [Addition]

The effects of vertical earthquake ground motion on buildings have traditionally been given much less attention than the effects of horizontal ground motion. This is largely due to the belief that the peak vertical ground acceleration is considerably smaller than the peak horizontal ground acceleration. A fairly large safety factor against static vertical loads also exists in engineered buildings. As a result, it is generally considered adequate to include the effects of vertical ground motions in the simplified form of $0.2S_{DS}D$, as done in the IBC and the ASCE 722 standard for many years. However, certain structural members are particularly vulnerable to vertical ground motions and require more explicit consideration of such ground motions in their design. This [Addition] addresses those specific members by incorporating additional provisions for design considering vertical ground motions.

The threshold value of S_{DS} > 0.6g was derived from a similar requirement in the 2004 edition of Eurocode 8, which specified the peak vertical ground acceleration, a_{vg}, to be greater than 0.25g for its special provisions related to vertical ground motions to apply. The derivation is as shown below:

1. From the vertical ground motion response spectrum given in ASCE 7-22 Section 11.9.2, the ratio of the peak vertical ground acceleration (spectral acceleration at $T_v = 0$) and the maximum vertical spectral acceleration (flat top portion of the response spectrum) is0.65/1.05 = 0.62.
2. The maximum vertical spectral acceleration has been traditionally assumed to be $2/3S_{DS}$.
3. So, the peak vertical ground acceleration can be expressed in terms of S_{DS} as: $a_{vg} = 0.62×(2/3S_{DS}) = 0.41S_{DS}$
4. So, a_{vg} > 0.25g => S_{DS} > 0.6g

1605.2 – Alternative Allowable Stress Design Load Combinations [Deletion]

Delete this section in its entirety.

2-4.4 Section 1607 - LIVE LOADS.

1607.1 - General [Replacement]

Live loads are those loads defined in Section 1607.1. Table E-1 of this UFC defines minimum uniformly distributed live loads and minimum concentrated live loads for the design of structures. Table E-1 is IBC Table 1607.1 with additional Occupancy or Use classifications for military facilities. The classifications that have been added to IBC Table 1607.1 are shown in bold italics within Table E-1.

Table 1607.1 [Replacement]

Replace Table 1607.1 of the IBC with Table E-1 of this UFC. (All references in the IBC to Table 1607.1 must be interpreted as references to Table E-1 of this UFC.)

1607.8.1 - Loads [Replacement]

Where a structure does not restrict access for vehicles that exceed a 10,000 pound (4536 kg) gross vehicle weight rating, those portions of said structure subject to such loading must be designed using the vehicular live loads, including consideration of impact and fatigue, in accordance with the AASHTO Bridge Design Specification.

1607.12.4 – Fall arrest and lifeline, and rope descent system anchorages [Replacement]

The applied 3100-pound load is a live load to be used with either the load combinations for allowable stress design or the load combinations for strength design.

To protect personnel during occupancy and maintenance phases, consider fall hazards at the planning and design phase of a project and eliminate them to the maximum extent possible. Also consider safe access to work location at heights.

When elimination or prevention of fall hazards is not feasible, include in design certified and labeled anchorages that are conveniently located to perform the work safely.

Where fall protection is required near weight-handling equipment, prevent conflicts between the weight-handling equipment and fall protection measures.

1607.12.5 - Hangars [Addition]

In hangars, where horizontal lifelines are used as the fall protection solution for aircraft maintenance, make sure that there will be no interference between the crane envelope inside the hangar and the horizontal lifeline system.

\4\ 1607.14 – Bridge Crane Support Structure [Addition]

Reference AISC Design Guide 7, Section 18 for design of crane supporting structure, including crane support beams (runway beams).

For seismic design categories C-F see 3-7.6 13.6.14 **/4/**

2-4.5 Section 1608 - SNOW LOADS.

1608.2 - Ground Snow Loads [Replacement]

Ground snow loads at DoD installations within the United States and its territories and possessions must be determined using the ASCE Hazard Tool hosted at

https://ascehazardtool.online

Snow loads are zero for Hawaii, except in mountainous regions as approved by the AHJ.

At locations where the ground snow load is not provided by the ASCE Hazard Tool, consult the AHJ.

1608.2.2 - Specific Locations Outside of the United States [Addition]

Ground snow loads at specific locations outside of the United States and its territories and possessions are identified using a spreadsheet that can be found on the Whole Building Design Guide Structural Engineering UFC Page as a related item for download

At locations where the ground snow load is not provided, use the best locally available information.

1608.2.3 - Snow Load Case Studies [Addition]

Snow load case studies may be done to clarify and refine snow loadings at site-specific locations with the approval of the AHJ. Where required by the AHJ, a site-specific study must be conducted. The ground snow load is to be determined based on an RC II structure for this purpose. The methodology used to conduct snow load case studies at site-specific locations is presented in the Cold Regions Research and Engineering Laboratory (CRREL) report “Database and Methodology for Conducting Site Specific Snow Load Case Studies for the United States.” by Tobiasson and Greatorex and “Site-Specific Case Studies for Determining Ground Snow Loads in the United States” by Buska, Greatorex, and Tobiasson.

2-4.6 Section 1609 - WIND LOADS.

1609.1.1 – Determination of Wind Loads [Supplement]

Add the following to the list of exceptions:

8. For winds parallel to the ridge of open buildings, the wind load delivered to the main wind force resisting system from the bare frames or partially clad end walls must be determined in accordance with the provisions of ASCE 7-22 Section 28.3.7.

1609.1.2 – Aircraft Hangar Wind Loads [Addition]

Wind load on the main wind force resisting system **\4** and components and cladding **/4/** of aircraft hangars must be determined based on the following conditions:

- Hangar doors closed for winds at the maximum design velocity. Calculate the structural forces based upon the assumption of a “partially enclosed building.” It is permissible to use the large volume reduction factor of ASCE 7 in determining the design wind pressures. Assume that a 1-inch (25-mm) strip around the perimeter of all hangar door panels is an opening and combine this with the area of all unshielded fenestration.

- Hangar doors open to the maximum extent possible with a design wind velocity of 60 mph (97 km/h). Calculate the structural forces upon the assumption of a “partially enclosed building.” Use the total open-door area in the large volume reduction factor calculation.

1609.2.3 – Vertical Lift Fabric Hangar Doors (VLFD) [Addition]

Vertical Lift Fabric Doors are prohibited within windborne debris regions.

Additionally, VLFD’s are prohibited for use in aircraft maintenance hangars where 700-year-MRI wind speeds (IBC Figure 1609.3(2), ASCE 7 Figure 26.5-1B) equal or exceed wind speeds defining a windborne debris region, namely, 130 mph (58 m/s) within one mile of the coastal mean high-water line where an Exposure D condition exists upwind of the waterline or 140 mph (63.6 m/s) anywhere else.

[C] 1609.2.3 – Vertical Lift Fabric Hangar Doors (VLFD) [Addition]

VLFD’s are currently prohibited for use in windborne debris regions defined in the IBC due to failures experienced during hurricane Michael. These failures were predominately caused by wind driven debris.

Additionally, DoD has prohibited VLFD use in locations where the 700-year-MRI wind speed exceeds the threshold wind speed for windborne debris regions. This is because the risk of damage caused by windborne debris is the same in these areas as in windborne debris regions. In essence, this has served to slightly expand windborne debris regions as defined in the IBC.

1609.2.4 – Roll Up Doors and Sectional Doors in Hurricane Prone Regions [Addition]

In hurricane prone regions, warehouse and/or garage roll up doors or sectional doors must be pressure tested for components and cladding design wind pressure and shown to pass in accordance with ANSI/DASMA 108, *Standard Method for Testing Sectional Garage Doors and Rolling Doors*. This requirement must be noted on the construction drawings in addition to the project specifications. The SER must specify the components and cladding design wind pressure for garage/sectional doors on the construction drawings.

1609.3.1 - Wind Speed Conversion [Replacement]

When required, the basic wind speed can be converted to an allowable stress design wind speed, V_{asd}, using Equation 16-18a.

$$V_{asd}=\sqrt{0.6}V \qquad \text{(Equation 16-18a)}$$

When required, the basic wind speed can be converted to a fastest-mile wind speed, V_{fm}, using Equation 16-18b.

$$V_{fm}=(\sqrt{0.6}V\text{-}10.5)/1.05 \qquad \text{(Equation 16-18b)}$$

1609.3 - Basic Wind Speed [Replacement]

Basic wind speeds at DoD installations within the United States and its territories and possessions must be determined using the ASCE Hazard Tool hosted at:

https://ascehazardtool.org

At locations where the basic wind speed is not provided by the ASCE Hazard Tool, consult the AHJ. The basic wind speeds, *V*, determined by the AHJ must be in accordance with Chapter 26 of ASCE 7.

1609.3.2 - Specific Locations Outside of the United States [Addition]

Basic wind speeds at specific locations outside of the United States and its territories and possessions can be identified using a spreadsheet that can be found on the Whole Building Design Guide Structural Engineering UFC Page as a related item for download

At locations where the basic wind speed is not provided, use the best locally available information.

1609.3.3 – Design Wind Speed for Non-permanent Structures [Addition]

For **Non-permanent** Structures, as defined in UFC 1-201-01, it is permissible to multiply the basic wind speed, *V*, as identified in UFC 3-301-01, by a reduction factor of 0.78.

This section supersedes Section 3-2.1.5 of UFC 1-201-01 and IBC Section 3103.6.1.2.

[C] 1609.3.3 – Design Wind Speed for Non-permanent Structures [Addition]

For the purpose of determining design wind speeds for non-permanent structures with design life of 5 years or less, UFC 1-201-01, 4 March 2022, Change 4, 8 August 2023, permits application of a 0.78 reduction factor to the design wind speeds determined in accordance with UFC 3-301-01 for regular structures. However, that allowance is restricted to non-hurricane prone regions only. This [Addition] revises that provision to expand the applicability of the 0.78 factor to hurricane prone regions as well.

The revision was based on a study that looked at design wind speeds at a large number of locations across the United States using a “uniform hazard” approach. For a given risk category of a non-permanent structure, wind speeds were determined for the same probability of exceedance in 5 years as that used in ASCE 7 for a 50-year design life of regular structures. For example, in ASCE 7, the design wind speed values for RC II structures are based on a return period of 700 years, which translates to about 7% probability of exceedance in 50 years. Assuming the same level of wind hazard is acceptable for a non-permanent structure over its 5-yr design life, i.e., a 7% probability of exceedance in 5 years, wind speeds for non-permanent structures assigned to Risk Category II should be determined based on 70-yr wind events. Similarly, design wind speeds for non-permanent structures assigned to Risk Category I, III, and IV need to be determined based on 30, 170 and 300-yr return period wind events, respectively. These can be determined through interpolation using the 300-yr wind speeds given in ASCE 7 Chapter 26 and 25-, 50-, and 100-yr wind speeds given in ASCE 7 Appendix CC, where the return periods are expressed on a log scale.

It was found that, wind speeds determined as described above for a total of 342 locations in the United States matched very closely with the wind speeds determined by simply reducing the ASCE 7 values by a factor of 0.78 as permitted in UFC 1-201-01. And this was seen to be as true for hurricane prone regions as it was for non-hurricane prone regions. As a result, the 0.78 factor is retained for the sake of simplicity, but its applicability is expanded to hurricane prone regions.

For a more detailed discussion on this change, please refer to the report produced by S. K. Ghosh Associates LLC titled "An Evaluation of the Wind and Seismic Provisions of UFC 1-201-01 for Temporary Structures".

The 2024 IBC has introduced a new Section 3103.6.1.2 for determining the basic wind speeds for non-permanent structures. This section in the UFC supersedes that IBC section.

2-4.7 Section 1613 - EARTHQUAKE LOADS.

1613.1 – Scope [Supplement]

For all structures, wherever ASCE 7-22 Table 12.2-1 is referenced, it must be replaced by Table 3-1 of this UFC.

[C] 1613.1 – Scope [Supplement]

Although Chapter 14 of ASCE 7-22 is not adopted by the 2024 IBC, occasional references to ASCE 7-22 Chapter 14 sections are made in this UFC.

1613.1.1 - Seismic Ground Motion Values [Replacement]

Seismic multi-period response spectra at DoD installations within the United States and its territories and possessions must be determined using the ASCE Hazard Tool hosted at

https://ascehazardtool.org

At locations where the seismic parameters are not provided by the ASCE Hazard Tool, consult the AHJ.

1613.1.1.1 - Specific Locations Outside of the United States [Addition]

Seismic ground motion parameters at specific locations outside of the United States and its territories and possessions can be identified using a load spreadsheet posted for download on the Whole Building Design Guide Structural Engineering UFC page (UFC 3-301-01)

For locations not shown, contract the Structural Criteria Working Group member for your service branch.

1613.1.1.2 – Site Specific Seismicity Study Process [Addition]

The site-specific ground motion procedures in Chapter 21 of ASCE 7 may be used to determine ground motions for any structure.

1613.1.1.3 – Ground Motion Parameters for Non-Permanent Structures [Addition]

For Non-permanent Structures, as defined in UFC 1-201-01, it is permissible to use the BSE-1E level response spectra obtained from the ASCE Hazard Tool, which correspond to a seismic hazard of 20% probability of exceedance in 50 years. The link to ASCE Hazard Tool is provided below:

https://ascehazardtool.org

The rest of the seismic design, including determination of Seismic Design Category, is to be performed as required by the IBC and ASCE 7 and as modified by this UFC, based on these reduced ground motion values.

This section supersedes Section 3-2.1.6 of UFC 1-201-01 and IBC Section 3103.6.1.4.

[C] 1613.2.1.4 – Ground Motion Parameters for Non-Permanent Structures [Addition]

For the purpose of determining design seismic loads for non-permanent structures with design life of 5 years or less, UFC 1-201-01, 4 March 2022, Change 4, 8 August 2023, permits application of a 0.6 reduction factor to the design seismic loads determined in accordance with UFC 3-301-01 for regular structures. In addition, that allowance is restricted to regions of low seismicity only. This [Addition] revises that provision based on a “uniform hazard” approach that applies to all locations, and that is more consistent with the way all seismic requirements are specified for regular structures.

Ground motion spectral response values that form the basis of seismic design of regular structures (50-yr design life) in this UFC correspond to a seismic hazard of 2% probability of exceedance in 50 years. In other words, it is deemed adequate to design a structure for a seismic hazard that has a 2% probability of exceedance in the structure’s design life. The same criterion could be applied to non-permanent structures as well where it should be adequate to design the structure for a reduced seismic hazard of 2% probability of exceedance in 5 years. In 50-yr term, a 2%-in-5-yr hazard translates to a 20%-in-50-yr hazard.

This [Addition] also allows the use of the same reduced hazard ground motion parameters for the purpose of all seismic design requirements, including determination of Seismic Design Category, for non-permanent structures. As a result, the adoption of a reduced hazard not only reduces the seismic forces, but also leads to less stringent seismic design and detailing requirements for non-permanent structures.

Note that in ASCE 7-10 a switch was made from uniform hazard MCE ground motion to risk-targeted MCE_R ground motion as the basis of design. However, the magnitudes of the two at a particular location are not sufficiently different to warrant a change in the recommendation to use of 20%-in-50-yr ground motion for non-permanent structures.

For a more detailed discussion on this change, please refer to the report produced by S. K. Ghosh Associates LLC titled “An Evaluation of the Wind and Seismic Provisions of UFC 1-201-01 for Temporary Structures”.

The 2024 IBC has introduced a new Section 3103.6.1.4 for determining the ground motion values for non-permanent structures. This section in the UFC supersedes that IBC section.

1613.4 – Ballasted Photovoltaic Panel Systems [Replacement]

Ballasted photovoltaic panel systems are not permitted.

[C] 1613.4 – Ballasted Photovoltaic Panel Systems [Replacement]

Ballasted systems are specifically disallowed by UFC 3-110-03, *Roofing*.

1613.7 - Procedure for Determining MCE_R and Design Spectral Response Accelerations [Addition]

Ground motion accelerations, represented by response spectra, must be determined in accordance with the procedure of ASCE 7-22 Sections 11.4.2-11.4.6, as modified by Chapter 3 of this UFC, or the site-specific procedure required by ASCE 7-22 Section 11.4.8 as modified by Section 3-5.3 of this UFC.

Subject to approval by the AHJ, a site-specific response analysis using the procedure of ASCE 7-22 Chapter 21 may be used in determining ground motions for any structure. Such analysis needs to include justification for its use in lieu of the ground motion data provided by ASCE 7.

A site response analysis using the procedures of ASCE 7 Section 21.1 must be used for structures on sites classified as Site Class F (see ASCE 7 Section 20.2.1), unless at least one of the following conditions is applicable:

1. The structure is exempted from site response analysis requirement in accordance with ASCE 7 Section 20.2.1.

2. The Risk-Targeted Maximum Considered Earthquake (MCE_R) spectral response acceleration at short periods, S_s, and the mapped MCE_R spectral response acceleration at 1-second period, S_1, as determined in accordance with UFC 3-301-01, are less than or equal to 0.25 and 0.10, respectively.

S_s and S_1 must be determined for installations within the United States from Section1613.1.1, added by this UFC. For installations located outside the United

States, S_s and S_1 must be determined from Section 1613.1.1.1, added by this UFC.

2-4.8 Section 1615 – TSUNAMI LOADS.

1615.1 – General [Replacement]

The design and construction of buildings and structures located in a Tsunami Design Zone, as defined by the Tsunami Design Geodatabase or by DoD tsunami mapping for at risk OCONUS installations, must be in accordance with Chapter 6 of ASCE 7, as modified by Section 3-3 of this UFC.

For at risk Pacific and Pacific Rim OCONUS installations, see the following link to access tsunami inundation and flow maps:

https://www.wbdg.org/dod/ufc/tsunami-inundation-mapping

Maps are formatted as KMZ files, which can be downloaded and opened with Google Earth, ARCGIS, or an equivalent KMZ compatible geo map application.

2-4.9 Section 1616 – STRUCTURAL INTEGRITY [Deletion].

Delete this section in its entirety.

2-5 IBC CHAPTER 17 - SPECIAL INSPECTIONS AND TESTS.

2-5.1 Section 1701 – GENERAL.

1701.1 - Scope [Supplement]

Add the following paragraph:

Contractual relationships and the composition of the architect / engineer / construction (AEC) team differ from those contemplated by the language of the IBC, when doing DoD construction. When performing design or construction using typical methods for in-house design, AE design, and contracting for construction, IBC/ASCE 7 terms of Authority Having Jurisdiction and Building Official must be as defined in MIL STD 3007

Unless noted otherwise, apply the following substitutions for implementing the IBC:

- “Building official” - defined as “Authority Having Jurisdiction” as referenced in MIL STD 3007).
- “Owner” - defined as “Authority Having Jurisdiction”
- “Permit applicant” - defined as “contractor”

[C] 1701.1 - Scope [Supplement]

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

2-5.2 Section 1703 – APPROVALS.

1703.4 - Performance [Replacement]

New, unusual, or innovative materials, systems or methods previously untried may be incorporated into designs when evidence shows that such use is in the best interest of the Government from the standpoint of economy, lower life-cycle costs, and quality of construction. Supporting data, where necessary to assist in the approval of materials or assemblies not specifically provided for in the code, must consist of valid evaluation reports from International Code Council – Evaluation Service (ICC-ES), or other qualified testing and evaluation service with the prior approval of the AHJ.

1703.4.1 - Research and Investigation [Deletion]

Delete this section in its entirety.

1703.4.2 - Research Reports [Deletion]

Delete this section in its entirety.

2-5.3 Section 1704 – SPECIAL INSPECTIONS AND TESTS, CONTRACTOR RESPONSIBILITY, AND STRUCTURAL OBSERVATIONS.

1704.2.3 Statement of special inspections. [Replacement]

Replace the first paragraph with the following:

The SER must submit a Statement of Special Inspections in accordance with Section 107.1. This statement must be in accordance with Section 1704.3. A template ‘Statement of Special Inspections’ and a template ‘Schedule of Special Inspections’ may be downloaded from the Structural Engineering UFC (3-301-01) page on the Whole Building Design Guide.

1704.6 – Structural Observations [Replacement]

Replace the first two sentences with the following:

Where required by the provisions of Section 1704.6.1, structural observations must be performed by the SER or their designated representative who must be a Registered Design Professional. Structural observation does not include or waive the responsibility for the inspections in Section 110 or the special inspections in Section 1705 or other sections of this code.

1704.6.1 – Structural Observations for Structures [Replacement]

Replace Item 1 with the following:

1 - The structure is classified as Risk Category III or IV in accordance with Table 2-2 of this UFC.

Replace Item 4 with the following:

4 – Such observation is required by the SER.

1704.7 – Special Inspector of Record [Addition]

When the provisions of Section 1704.6.1 apply, the services of a Special Inspector of Record (SIOR) must be retained by the Contractor as a third-party quality assurance agent (see UFC 1-200-01). The SIOR must be a licensed professional engineer in a state acceptable to the AHJ. The SIOR must submit qualifications to, and be approved by, the AHJ.

1704.7.1 – Duties of the Special Inspector of Record (SIOR) [Addition]

The duties of the SIOR are defined in the following UFGS specification:

Section 01 45 35

1704.7.2 – Final Inspection Report [Addition]

When the work requiring Special Inspections is completed and all nonconforming items are resolved to the satisfaction of the SER, the Contractor needs to notify the SIOR to submit a Final Special Inspection Report to the Contracting Officer, the SER, and the Contractor. The Final Special Inspection Report must attest that Special Inspection was performed on all work requiring Special Inspection and that all nonconforming work and corrections of all discrepancies noted in the daily reports was resolved to the satisfaction of the SER and the Contracting Officer. The Final Special Inspection Report must be signed, dated, and must bear the seal of the SIOR.

2-5.4 Section 1705 – REQUIRED SPECIAL INSPECTIONS AND TESTS.

1705.3.3 – Adhesive Anchors [Addition]

The SER is required to determine the proof load (see ACI 318-19 Section 26.7.1(k)) to be used for field-testing and to indicate in the construction documents which anchors are considered critical for testing.

1705.13.6 – Plumbing, Mechanical and Electrical Components [Supplement]

Add the following before the existing text:

Special inspection and verification are required for Designated Seismic Systems and must be performed as required by the Statement of Special Inspections, and the Schedule of Special Inspections, which must be prepared for each project. Templates for these documents may be downloaded from the Structural Engineering UFC (3-301-01) page on the Whole Building Design Guide.

The SER must prepare a Statement of Special Inspections in accordance with Section 1704 for the Designated Seismic Systems. The Statement of Special Inspections must define the periodic walk-down inspections that must be performed to ensure that the nonstructural elements satisfy life safety mounting requirements. The walk-down inspections must be performed by design professionals who are familiar with the construction and installation of mechanical and electrical components, and their vulnerabilities to earthquakes. The selection of the design professional is subject to the approval of the SER.

Designated Seismic Systems require a final walk-down inspection by the SER. The final review must be documented in a report. The final report prepared by the SER must include the following:

1. Record/observations of final site visit
2. Documentation that all required inspections were performed in accordance with the Statement of Special Inspections.
3. Documentation that the Designated Seismic Systems were installed in accordance with the construction documents and inspected in accordance with the requirements of Chapter 17, as modified by this section.

2-6 IBC CHAPTER 18 - SOILS AND FOUNDATIONS.

2-6.1 Section 1808 – FOUNDATIONS.

1808.4 - Vibratory Loads. [Supplement]

Add the following to the end of the paragraph:

Design foundations in accordance with ACI 351.3R or ACI 351.4R, as applicable, and UFC 3-220-01.

1808.8.2.1 – Reinforcement. [Addition]

For footings over three feet (914 mm) thick, the minimum ratio of reinforcement area to gross concrete area in each direction must be 0.0015, with not less than one-half nor more than two-thirds of the total reinforcement required placed near any one face. Use a bar size no smaller than No. 4 (#13M) with a maximum spacing of 12 inches (305 mm). [See 13.3.4.4 of ACI CODE-318-19].

2-6.2 Section 1809 - SHALLOW FOUNDATIONS.

1809.5.2 - Frost Line Depth. [Addition]

Frost line depth for foundation construction must be specified by the project geotechnical engineer.

1809.5.3 – Footing Depth Considering Frost. [Addition]

Frost line depth for foundation construction must be specified by the project geotechnical engineer.

2-7 IBC CHAPTER 19 – CONCRETE.

2-7.1 Section 1901 – GENERAL.

1901.8 - Construction Joints [Addition]

Provide construction, contraction, and expansion joints in structures in accordance with ACI 224.3R and ACI CODE-318-19, Section 26.5.6.

1901.9 – Lightweight Concrete Water Content [Addition]

All coarse lightweight aggregate used in a concrete mixture must be saturated surface dry prior to mixing. The total allowable water in the concrete mixture must account for the water in the aggregate and admixtures. The water-to-cementitious materials ratio must not exceed 0.50.

1901.10 – Glass Fiber Reinforced Polymer (GFRP) Reinforcement [Addition]

Design and construct structural concrete which utilizes glass fiber reinforced polymer (GFRP) reinforcement in accordance with ACI CODE-440.11-22, *Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars--Code and Commentary*. The use of GFRP reinforcement is preferred where corrosion is a durability concern. GFRP does not corrode making it an economical solution for the structures that require regular repair due to exposure to salts and seawater. GFRP is also 1/4 of the weight of steel reinforcement, making it easier to transport, handle, and place.

GFRP reinforcement has limitations to consider before useing Fire ratings for GFRP in structures are not standardized and are low. For this reason, GFRP reinforcement is:

- Not permitted in structures that have a fire rating above zero. Also not permitted in structures that may not have a fire rating but could collapse due to fire and threaten life safety (for example, GFRP reinforcing not allowed for upper deck of double-deck piers, and comparable structures similarly affected by heat zones).

- Allowed for use in architectural precast concrete; however, all connections must use steel.

Other limitations on the use of GFRP according to ACI CODE-440.11-22:

- Do not use in seismic force-resisting systems of structures assigned to Seismic Design Categories B, C, D, E, and F.

- GFRP is permitted in structural members not part of the seismic force-resisting systems of structures assigned to Seismic Design Categories A, B, and C.

- Not recommended for lightweight concrete due to insufficient research data.

- Prestressed concrete systems are not currently covered.

The limitations on seismic force-resisting systems are because GFRP reinforcement is elastic until failure. The current seismic force-resisting systems are designed to yield in certain regions to dissipate the energy generated by seismic excitation. GFRP reinforcement will be permitted if the reinforcement is designed to remain fully elastic.

Appendix G provides guidance in the design and construction of GFRP in concrete structures.

2-7.2 Section 1903 – SPECIFICATIONS FOR TESTS AND MATERIALS.

1903.4 – Additively Constructed Concrete (3D Printed Concrete) [Addition]

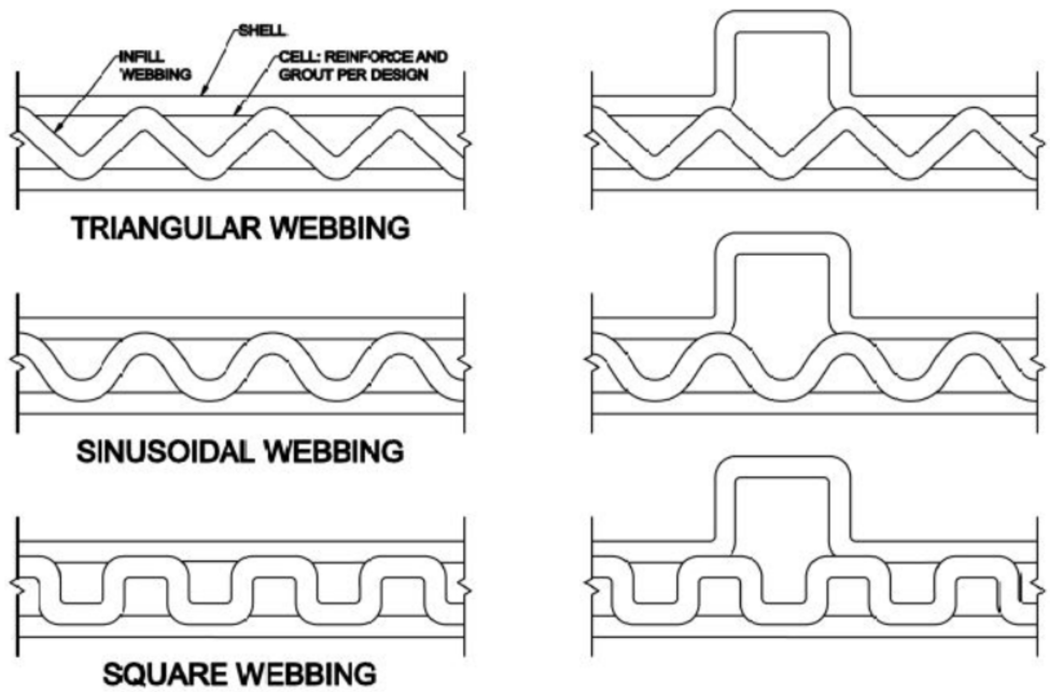
Pursuant to UFC 1-200-01 Section 104.11, concrete produced using additive construction, hereafter referred to as Additively Constructed Concrete (ACC), is allowed as alternative material, design and method of construction when complying with the following requirements and when approved in writing by the

AHJ.

ACC structures are limited to one-story, Risk Category I or II structures in Seismic Design Categories A and B only. Additionally, the following general requirements or limitations apply:

- Unreinforced concrete construction is not allowed
- ACC elements are not allowed as part of the Lateral Force-resisting System (LRFS) in Seismic Design Category B unless LFRS assemblies have been shake table tested with relevant loading or wind loads can be demonstrated to govern over seismic loads using an *R*-factor of 1.0.
- Provide a full description of concrete mixes, including how mixes will differ from region to region as applicable. Include admixtures in description, where utilized.
- Provide a narrative description of Quality Assurance and Quality Control procedures for concrete placement, including hot and cold weather placement constraints for ACC elements. if applicable
- Maintain minimum cover over reinforcement per ACI 318. Cover shall not consist of printed materials unless demonstrated through testing that ACI 318 development length requirements can be met using applicable load factors.
- Cast-in-place or post-installed anchors must not depend on printed material for shear or tensile strength unless site tested to 150% of design load.
- Diaphragm to wall connections must be shown by calculation or testing to resist in plane and out of plane forces with applicable load factors. Anchorage may not be solely dependent on printed shell material.
- Provide complete design drawings, including connection detailing sufficient to adequately depict continuous vertical and lateral load path to foundation.
- Provide mathematical demand and capacity calculations based on ACI 318 for all applicable ASCE 7 loads and affected elements. Calculations must demonstrate a complete vertical and lateral load path and may not rely on printed shell elements to resist loads except for pure compression. Alternatively, webbing may be employed with shell elements as indicated in the Figure 2-1, but only with third-party load testing validation of composite assemblies for all relevant loading. Load capacity values must be published as part of a third-party testing report and tested assemblies must be applicable to constructed assemblies.

Figure 2-1 Webbing in Shell Elements



- Design must be peer reviewed by the government a minimum of 90 days prior to construction start and will include review by subject matter experts at United States Army Corps of Engineers (USACE) Construction Engineering Research Laboratory (CERL). All comments and concerns must be resolved to the government's satisfaction.

Allowable ACC Elements and Limitations

- ACC is limited to reinforced walls no taller than ten feet, reinforced embedded wall pilasters and non-participating stay-in-place formwork for simple reinforced continuous wall footings.
- Suspended elements, including but not limited to beams, girders, or floor and roof diaphragm elements are not approved for ACC.
- ACC wall elements must consist of two printed concrete face shells acting as stay-in-place forms with a minimum interior core width of four inches and a maximum core width of twelve inches. Provide print stabilizers spanning between face shells to occur at no greater than twelve inches on center horizontally and six inches on center vertically. Provide corner stabilizers spanning from interior wall corners to exterior face shell in both directions (e.g., either side of interior corner). Larger print stabilizer spacing requires print-stability testing.
- Embedded pilasters must consist of printed shells and interior monolithic,

reinforced, cast-in-place concrete cores that are six to eight inches by six to eight inches. Larger sections require print-stability testing.

- Wall cavities adjacent to pilasters that are without webbing or monolithic cast-in-place concrete shall not be permitted unless this portion is considered to be non-structural.

Third Party Independent Testing Requirements

ACC structures must conform to the requirements noted in this section and ICC AC509 - *3D Automated Construction Technology for 3D Concrete Walls*. If AC 509 is in conflict, this UFC supersedes. Compliance to this section must be demonstrated by obtaining an ICC ES evaluation report (or equivalent) that conforms to both ICC-AC509 and the following modifications to ICC-AC509

ICC AC509 4.2.1 [Replacement] Cast specimens for compressive testing shall be tested in accordance with ASTM C31 for monolithically cast portions of wall. Cast specimens following ASTM C31 or ASTM C109 shall be permitted for printable material mixture development only. Prior to construction, conduct compressive strength testing in accordance with ASTM C109 with specimens extracted by saw cutting in accordance with ASTM C42 and prepared to meet planeness requirements according to ASTM C109. Specimens shall capture at least one interface and shall be tested for compression in the directions parallel to print direction, perpendicular to print direction, and transverse to print direction.

ICC AC509 4.2.2 [Replacement] Prior to specimen creation, the flow of the printable material shall be tested in accordance with ASTM C230. For materials that exhibit slump prior to entering the printer, the mix may be tested in accordance with ASTM C143 or C1611. Printable materials shall be tested in accordance to ASTM C230 prior to placement and within 5 minutes after leaving the printer.

ICC AC509 4.2.4 [Replacement] Unconfined compression Strength (UCS) Testing: Shall be performed in accordance with ASTM D2166, with cylindrical specimen sizes representative of the bead geometry, where the diameter or height of the specimen must be at least 5 times the maximum particle size. Prior to construction, the UCS shall be performed at 0, 15, 30, 45, 60, 90, and 120 minutes after mixing and the elastic limit at each age shall be determined. This shall be used to report the time to next layer limit based on weight of successive layers expected. Printable materials shall be tested in accordance with this test method prior to placement during printing and within 5 minutes of leaving the printer.

ICC AC509 4.3.3 [Supplement] Freeze-Thaw specimens of printed materials shall be extracted from printed components through saw cutting in accordance with ASTM C666. Specimen sizes shall be as described in ASTM C666 to include specimens with at least 1 interface on each side parallel to the length of the specimen and specimens with at least 3 layers perpendicular to the length of the specimen. For regions where freeze-thaw is not a concern this test may be forgone.

ICC AC509 4.4.1 [Replacement] Perform tests on 3D printed specimens in accordance with ASTM C341. Length change specimens of printed materials shall be extracted from printed components. Specimens shall have at least 1 interface on each side parallel to the length of the specimen. Components that will be in contact with soils with high sulfate content or exposed to salts must be tested according to ASTM C1012.

ICC AC509 4.6.2 [Addition] Tensile bond strength shall be in accordance with ASTM C496 or ASTM C1583. Shear bond strength shall be tested as described below.

4.6.2.1 Tensile bond strength tested in accordance with ASTM C496 shall use prismatic specimens consisting of at least two layers with a single interface loaded along the interface. Specimens shall be tested transverse to the print with the height being equal to a single shell width, and the height being equal to two times a single shell width, and the length being equal to at least 3 times a single shell width.

4.6.2.2 Specimens for direct shear testing shall be loaded in single or double shear using prismatic specimens consisting of at least two layers for single shear and three layers for double shear. Specimens shall have dimensions that are representative of the wall shell dimensions and a length of at least 3 times the shell width. Loading rate shall in accordance to ASTM C496.

4.6.2.3 Specimens for interface testing shall be extracted by saw cutting in accordance with ASTM C42 and prepared to meet planeness requirements in ASTM C109.

ICC AC509 4.8 [Addition] For construction geometries, a print stability test must be performed, which consists of a print mock-up representative of the wall geometry used in construction, to ensure that there are no stability issues prior to construction. Time between layers and construction shall be representative of field conditions. This is permitted to be done as part of the development of structural test samples.

ICC AC509 4.9 [Addition] Dynamic Testing

4.9.1 Testing for blast overpressure, where applicable, must be in accordance with ASTM F2247 or ASTM F2927 for door locations and ASTM F1642 or GSA TS01 for windows locations. Ballistics testing must be in accordance with MIL STD 662.

4.9.2 Wind and seismic testing shall be performed in accordance with

ASTM E2126 procedure for in-plane shear or out-of-plane bending. Where structures must meet seismic categories higher than C, shake table testing shall be performed to meet design requirements.

4.9.3 Impact testing shall be performed in accordance with ASTM E1886 for windborne debris and ASTM E695 for impact loading.

ICC AC509 5.5 [Replacement] Special Inspections shall be performed in accordance with this UFC. Quality control testing shall be performed by obtaining samples cured following ASTM C31 for compression testing and interface testing shall be performed according to Sections 4.2 and 4.6. Fresh material testing shall be performed in accordance with ASTM C31, with testing performed in accordance with Sections 4.2.2 and 4.2.4 in place of the slump test.

5.5.1 Representative components for sample extraction shall be printed at the same time as construction of the printed components to be placed in service. Each representative component shall be large enough to extract samples for compliance with Sections 4.2.1, 4.4.1, and 4.6.2.

5.5.2 Data on printing conditions and process shall be documented and reported to include: start times, print time for each layer, delay times (includes waiting between layers), reasons for delays, times at which delays occurred, and hourly temperature and humidity. If delay occurs in the middle of printing a layer, the time prior to delay and following delay should be recorded, in addition to the delay.

2-7.3 Section 1904 - DURABILITY REQUIREMENTS.

1904.3 – Environmental Severity Classification and Concrete Cover [Addition]

Conform to ACI 357.3R Table 5.5.4 for minimum concrete cover for exterior exposed concrete at project locations with an Environmental Severity Classification (ESC) C3 through C5. See UFC 1-200-01 for determination of ESC for project locations. Exposed concrete is any concrete that is not enclosed within a building envelope. In addition, concrete with a minimum of two coats of exterior grade paint is not considered exposed where properly maintained. Corrosion inhibitor coatings/additives would not qualify as a paint coating. This requirement does not apply to galvanized, stainless or epoxy coated reinforcement. Refer to ACI 318 cover requirements in these cases.

2-7.4 Section 1907 -SLABS-ON-GROUND.

1907.3 – Thickness. [Supplement]

Reference guidance in *“Design of Concrete Floor Slabs-on-Ground for DoD Facilities”* under Related Materials for this UFC (WBDG page for 3-301-01).

1907.5 – Slab-on-Ground Design. [Addition]

Slabs-on-ground supporting warehouses must have minimum reinforcement according to UFC 4-440-01.

1907.6 – Slab-on-Ground Over Permafrost. [Addition]

Design and construction of slabs-on-ground over permafrost must be in accordance with UFC 3-130-01.

1907.7 – Post-Tensioned Slab-on-Ground. [Addition]

The design of post-tensioned slabs-on-ground must be in accordance with PTI DC10.1.

2-8 IBC CHAPTER 21 – MASONRY.

2-8.1 Section 2101 – GENERAL.

Renumber Section 2101.2.1 as 2101.2.6.

2101.2.1 - Allowable Stress Design [Addition]

Masonry must be designed as reinforced unless the element is isolated from the structure so that vertical and lateral forces are not imparted to the element.

2101.2.2 - Strength Design [Addition]

Masonry must be designed as reinforced unless the element is isolated from the structure so that vertical and lateral forces are not imparted to the element.

2101.2.3 - Empirical Design [Addition]

Do not design masonry according to the empirical method.

2101.4 - Shear Wall Construction [Addition]

Shear walls must be of running bond construction only; stack bond construction is not permitted.

2101.5 - Prohibition [Addition]

The following material is not permitted:

> Celersap (common European in place clay tile forming system for concrete floors)

2-8.2 Section 2104 – CONSTRUCTION.

Renumber Sections 2104.1.1 and 2104.1.2 as 2104.1.4 and 2104.1.5, respectively.

2104.1.1 - Placing Mortar and Units [Addition]

Masonry walls below grade and elevator shaft walls must be grouted solid.

2104.1.2 - Installation of Wall Ties [Addition]

Use of corrugated metal brick ties is not permitted.

2104.1.3 - Joint Reinforcement [Addition]

Horizontal wall reinforcement must be continuous around wall corners and through wall intersections, unless the intersecting walls are separated. Reinforcement that is spliced in accordance with the applicable provisions of TMS 402-22 is permitted to be considered continuous.

2104.1.6 - Concrete Masonry Control Joints [Addition]

Spacing and placement of control joints must be in accordance with NCMA TEK 10-2C or 10-3.

2104.1.7 - Vertical Brick Expansion Joints [Addition]

Spacing, placement, and size of vertical brick expansion joints must be in accordance with BIA Technical Notes 18 and 18A.

2-8.3 Section 2106 - SEISMIC DESIGN.

2106.2 - Additional Requirements for Masonry Systems [Addition]

2106.2.1 - Minimum Reinforcement for Special or Intermediate Masonry Walls, SDC B-F [Addition]

In addition to the minimum reinforcement requirements of Sections 7.3.2.5 and 7.3.2.4 of TMS 402-22, the following applies:

> Only horizontal reinforcement that is continuous in the wall or element is permitted to be included in computing the area of horizontal reinforcement. Intermediate bond beam steel properly designed at control joints is permitted be considered continuous.

2106.2.2 - Joints in Structures assigned to SDC B or Higher [Addition]

Where concrete abuts structural masonry and the joint between the materials is not designed as a separation joint, the concrete must be roughened so that the average height of aggregate exposure is 1/8 in. (3 mm) and must be bonded to the masonry in accordance with these requirements as if it were masonry. Vertical joints not intended to act as separation joints are required to be crossed by horizontal reinforcement as required by Section 5.2.3 of TMS 402-22.

2106.2.3 - Coupling Beams in Structures Assigned to SDC D or Higher [Addition]

Structural members that provide coupling between shear walls must be designed to reach their moment or shear nominal strength before either shear wall reaches its moment or shear nominal strength. Analysis of coupled shear walls must comply with accepted principles of mechanics.

The design shear strength, ϕV_n, of the coupling beams is required to satisfy the following criterion:

$$\varphi V_n \geq \frac{1.25\left(M_{n1} + M_{n2}\right)}{L_c} + 1.4V_g$$

Where:

M_{n1} and M_{n2} = nominal moment strengths at the ends of the beam
L_c = length of the beam between the shear walls
V_g = unfactored shear force due to gravity loads

The calculation of the nominal moment strength needs to include the reinforcement in reinforced concrete roof and floor systems. The width of the reinforced concrete slab used for inclusion of reinforcement must be six times the floor or roof slab thickness.

2106.2.4 - Anchoring to Masonry [Addition]

Anchors in masonry must be designed in accordance with TMS 402-22. Additionally, at least one of the following must be satisfied for structures assigned to SDC C or higher.

a. Anchors in tension are designed to be governed by the tensile strength of a ductile steel element.
b. Anchors are designed for the maximum load that can be transmitted to the anchors from a ductile attachment, considering both material overstrength and strain hardening of the attachment.

c. Anchors are designed for the maximum load that can be transmitted to the anchors by a non-yielding attachment.

d. Anchors are designed for the maximum load obtained from design load combinations that include E, where the effect of horizontal ground motion, Q_E, is multiplied by Ω_o.

[C] 2106.2.4 - Anchoring to Masonry [Addition]

This [Addition] harmonizes design of anchors embedded in masonry with that of anchors embedded in concrete. These provisions are intended to prevent brittle failure in the connections. ACI 318-19 Chapter 17 includes similar provisions to prevent brittle failure of anchors embedded in concrete. These requirements are simplified versions of those in ACI 318-19. Note Option a is available only for anchors in tension, and not for anchors in shear. Also, Item d requires that the anchor design forces produced by the horizontal ground motions only (Q_E) be multiplied by the overstrength factor Ω_o. Anchor design forces produced by the vertical earthquake ground motions (E_V) do not need to be amplified.

2-8.4 Section 2109 - EMPIRICAL DESIGN OF ADOBE MASONRY [Deletion].

Delete this section in its entirety.

2-9 IBC CHAPTER 22 – STEEL.

2-9.1 Section 2201 – GENERAL.

2201.4 – Connections [Supplement]

Add the following to the end of the paragraph:

Compressible-washer-type direct tension indicators or twist-off-type tension-control bolts conforming to Research Council on Structural Connections (RCSC) *Specification for Structural Joints Using High-Strength Bolts* must be provided at all high-strength bolted connections.

2-9.2 Section 2202 - STRUCTURAL STEEL AND COMPOSITE STRUCTURAL STEEL AND CONCRETE.

2202.1 – General [Supplement]

Add the following to the end of the paragraph:

Design structural steel floor framing systems for vibration serviceability in accordance with AISC Design Guide 11.

2202.3 – Steel Structures in Corrosive Environments [Addition]

Protect exposed steel in corrosion prone environments with hot- dipped galvanizing or use stainless alloy. See UFC 1-200-01, section 4-1.3 for definition of corrosion prone environments. Coatings may be used alone in other environments. Select the appropriate system or material to suit the anticipated exposure. For exposed exterior steel deck and cold-formed steel members, provide ASTM A653/A653M G90 galvanizing and connect with corrosion-resistant fasteners. See Section A-5.4 of UFC 3-301-01 for additional guidance.

2-9.3 Section 2204 - COLD-FORMED STEEL.

2208.1 – Steel Roof Deck [Supplement]

Add the following to the end of the paragraph:

Steel roof deck is not permitted to be thinner than 22-gauge.

2-9.4 Section 2206 - COLD-FORMED STEEL LIGHT-FRAME CONSTRUCTION.

2206.1.1 - Seismic Requirements for Cold-Formed Steel Structural Systems [Replacement]

Design cold-formed steel light-frame construction to resist seismic forces in accordance with the provisions of Section 2206.1.1.1, and Section 2206.1.1.2 or Section 2206.1.1.3.

Renumber Sections 2206.1.1.1 and 2206.1.1.2 as 2206.1.1.2 and 2206.1.1.3, respectively.

2206.1.1.1 – Diagonal Bracing Material [Addition]

For diagonal bracing, use ASTM A653/A653M steel without rerolling.

[C] 2206.1.1.1 - Diagonal Bracing Material [Addition]

Rerolling induces strain hardening and reduces the elongation of the material and is therefore not desirable for performance under seismic loading.

2206.4 – Floor Vibrations [Addition]

Design cold-formed steel framing systems for vibration serviceability in accordance with the proposed design procedure in *Floor Vibration Design Criterion for Cold-Formed C-Shaped Supported Residential Floor Systems* by Kraus. The proposed design procedure is based on residential construction but is suitable for most applications of cold-formed steel floor construction.

2206.5 – Brick Veneer/Steel Stud Walls [Addition]

Follow the recommendations of BIA Technical Note 28B for the Design of steel stud backup for brick veneer. In particular, follow recommendations for minimum stud gage, minimum galvanization, minimum anchorage of studs to track, welding of studs, use of deflection track, allowable stud deflection, wall sheathing, and water-resistant barriers.

2206.6 – Cold-Formed Steel Connections [Addition]

Interconnect cold-formed steel members with screw fasteners or by welding. The use of pneumatic nailing is permitted only for the connection of cold-formed steel members to members made of other materials.

2206.7 – Galvanized Cold-Formed Framing [Addition]

Cold-formed steel members exposed to spray from salt, salt water, brackish water, or seawater must be galvanized with ASTM A653/A653M G90 galvanizing and all fasteners must be hot-dipped galvanized or made of stainless steel.

2-10 IBC CHAPTER 23 – WOOD.

2-10.1 Section 2308 – CONVENTIONAL LIGHT-FRAME CONSTRUCTION.

2308.2.6 – Risk category limitation [Replacement]

The use of the provisions for *conventional light-frame construction* in this section is not permitted for RC IV buildings assigned to *Seismic Design Category* C, D, E, or F, as determined per 2024 IBC Section 1613.2.

2-11 IBC CHAPTER 31 – SPECIAL CONSTRUCTION.

2-11.1 Section 3102 – MEMBRANE STRUCTURES.

3102.1 – Membrane Structures [Addition]

Structures with fabric envelopes or cladding, including but not limited to frame-supported, air-supported, cable net supported, grid shell supported, and geodesic dome supported are prohibited within windborne debris regions for Risk Categories II-V. Additionally, this prohibition applies where 1700-year-MRI wind speeds (IBC Figure 1609.3(2), ASCE 7 Figure 26.5-1C) equal or exceed wind speeds defining a windborne debris region, namely, 130 mph (58 m/s) within one mile of the coastal mean high-water line or 140 mph (63.6 m/s) anywhere else.

[C] 3102.1 – Membrane Structures [Addition]

Structures with fabric envelopes or cladding are prohibited for use in windborne debris regions due to the fabric's vulnerability to sharp flying debris. While a supporting frame may be designed to remain stable even with the loss of the fabric, risk to life and/or high value content remains. This prohibition is supported by lessons learned during recent hurricane and typhoon events.

Additionally, DoD also prohibits Structures with fabric envelopes or cladding for use in all locations where the 1700-year-MRI wind speed exceeds the threshold wind speed for windborne debris regions. This is because the risk of windborne debris damage is the same in these areas as in areas defined by the IBC as windborne debris regions. This additional requirement slightly expands IBC windborne debris regions.

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CHAPTER 3 MODIFICATIONS TO ASCE 7

3-1 ASCE 7-22 CHAPTER 1 – GENERAL.

3-1.1 Section 1.3 - BASIC REQUIREMENTS.

1.3.1 – Strength and Stiffness [Supplement]

Add to the end of Item c.: During the design concept stage of development, documentation must be submitted to the AHJ for approval of the performance-based design approach.

1.3.1.3 – Performance-Based Procedures [Replacement]

Structural and nonstructural components and their connections must be demonstrated by a combination of analysis and testing to provide a reliability not less than that expected for similar components designed in accordance with the Strength Procedures of Section 1.3.1.1 when subject to the influence of dead, live, environmental, and other loads. Consideration must be given to uncertainties in loading and resistance.

1.3.1.3.3 – Documentation [Replacement]

Submit reports for approval to the AHJ and to an independent peer reviewer (where required), which document compliance with this section and the results of analysis and testing.

3-1.2 Section 1.5 - CLASSIFICATION OF BUILDINGS AND OTHER STRUCTURES.

Tables 1.5-1 and 1.5-2 [Replacement]

Replace Tables 1.5-1 and 1.5-2 of ASCE 7 with Table 2-2 of this UFC. All references in ASCE 7 to Tables 1.5-1 and 1.5-2 must be interpreted as a reference to Table 2-2 of this UFC. Items that are different from those in 2024 IBC Table 1604.5 are shown in italics.

3-2 ASCE 7-22 CHAPTER 2 – COMBINATIONS OF LOADS.

3-2.1 Section 2.3 - LOAD COMBINATIONS FOR STRENGTH DESIGN.

2.3.4 – Load Combinations Including Self-Straining Forces and Effects [Supplement]

Add to the end of the paragraph: The effect of load T needs to be taken into consideration on a structure. For further information see ASCE 7 Section C2.3.4.

[C] 2.3.4 - Load Combinations Including Self-Straining Forces and Effects [Supplement]

ASCE 7-22 Section 2.3.4 does not provide specific load factors to use with T. Commentary Section C.2.3.4 contains such load factors. The entire text of the commentary should be read and understood before using the load combinations in the commentary. The impact of T on serviceability and long-term performance of the facility may also need to be evaluated.

2.3.6 – Basic Combinations with Seismic Load Effects [Supplement]

Add before EXCEPTION: The following additional load combinations with seismic load effects must be considered for elements of buildings and nonbuilding structures specified in Section 1605.1.2 in Chapter 2 of this UFC. Provisions in the EXCEPTION that apply to combination 6 and 7 also apply to combinations 8 and 9, respectively.

Where the prescribed seismic load effect, E = f(E_v, E_h), defined in ASCE 7 Section 12.4.2 or 12.14.3.1, is combined with the effects of other loads, the following seismic load combinations apply:

8. $1.2D + 1.0E_{v0} + 0.3E_h + L + 0.2S$
9. $0.9D - 1.0E_{v0} + 0.3E_h$

Where the seismic load effect with overstrength, E_m = f(E_v, E_{mh}), defined in ASCE 7 Section 12.4.3, is combined with the effects of other loads, the following seismic load combinations apply:

8. $1.2D + 1.0E_{v0} + 0.3E_{mh} + L + 0.2S$
9. $0.9D - 1.0E_{v0} + 0.3E_{mh}$

The effect of vertical ground motion, E_{v0}, can be determined from one of the following:

- $E_{v0} = 0.67S_{DS}D$
- E_{v0} is determined directly from the design vertical response spectrum given in ASCE 7 Section 11.9.

[C] 2.3.6 – Basic Combinations with Seismic Load Effects [Supplement]

The additional load combinations were derived using the 100+30 rule of combining the effects from orthogonal seismic loads. The code-specified vertical ground motion effect ($0.2S_{DS}D$) can be derived by first assuming peak vertical ground motion component to be $^{2}/_{3}{}^{rd}$ of the corresponding peak horizontal component, and then combining 30% of that ($0.3 \times 0.67 S_{DS} = 0.2 S_{DS}$) with 100% of the horizontal seismic load effects. This section simply adds two more load combinations where 100% of the vertical seismic load effect is combined with 30% of the horizontal seismic load effect.

3-2.2 Section 2.4 – LOAD COMBINATIONS FOR ALLOWABLE STRESS DESIGN.

2.4.4 – Load Combinations Including Self-Straining Forces and Effects [Supplement]

Add to the end of the paragraph: The effect of load *T* needs to be taken into consideration on a structure. For further information, see ASCE 7 Section C2.4.4.

[C] 2.4.4 - Load Combinations Including Self-Straining Forces and Effects [Supplement]

ASCE 7-22 Section 2.4.4 does not provide specific load factors to use with *T*. Commentary Section C.2.4.4 contains such load factors. The entire text of the commentary should be read and understood before using the load combinations in the commentary. The impact of *T* on serviceability and long-term performance of the facility may also need to be evaluated.

2.4.5 – Basic Combinations with Seismic Load Effects [Supplement]

Add before EXCEPTIONS: The following additional load combinations with seismic load effects are to be considered for elements of buildings and nonbuilding structures specified in Section 1605.1.2 in Chapter 2 of this UFC. Provisions in the EXCEPTIONS that apply to combination 8, 9 and 10 also apply to combinations 11, 12 and 13, respectively.

Where the prescribed seismic load effect, $E = f(E_v, E_h)$, defined in ASCE 7 Section 12.4.2 or 12.14.3.1, is combined with the effects of other loads, the following seismic load combinations apply:

11. $1.0D + 0.7E_{v0} + 0.21E_h$
12. $1.0D + 0.525E_{v0} + 0.1575E_h + 0.75L + 0.75S$
13. $0.6D – 0.7E_{v0} + 0.21E_h$

Where the seismic load effect with overstrength, $E_m = f(E_v, E_{mh})$, defined in ASCE 7 Section 12.4.3, is combined with the effects of other loads, the following seismic load combinations apply:

11. $1.0D + 0.7E_{v0} + 0.21E_{mh}$

12. $1.0D + 0.525E_{v0} + 0.1575E_{mh} + 0.75L + 0.75S$

13. $0.6D – 0.7E_{v0} + 0.21E_{mh}$

The effect of vertical ground motion, E_{v0}, can be determined from one of the following:

- $E_{v0} = 0.67S_{DS}D$
- E_{v0} is determined directly from the design vertical response spectrum given in ASCE 7 Section 11.9.

[C] 2.4.5 – Basic Combinations with Seismic Load Effects [Supplement]

See the commentary to Section 2.3.6 above for some background on how the additional load combinations were derived.

3-2.3 Section 2.5 - LOAD COMBINATIONS FOR EXTRAORDINARY EVENTS.

2.5.1 – Applicability [Replacement]

When required, strength and stability must be checked to ensure that structures are capable of resisting the effects of progressive collapse according to UFC 4-023-03.

2.5.2 – Load Combinations [Deletion]

Delete this section in its entirety.

2.5.3 – Stability Requirements [Deletion]

Delete this section in its entirety.

3-3 ASCE 7-22 CHAPTER 6 – TSUNAMI LOADS.

3-3.1 Section 6.5 - ANALYSIS OF DESIGN INUNDATION DEPTH AND FLOW VELOCITY

6.5.3 – Sea Level Change [Supplement]

Subject to approval by the AHJ, a medium 2065 DoD Regional Sea Level Rise (DRSL) target may be utilized for Risk Category IV and V structures in tsunami prone regions when designing for a combination of tsunami and sea level rise. Design must incorporate future construction adaptation to either the High 2065 or Highest 2065 DRSL scenarios according to Table 2-2 for RC IV and V structures. Cost and risk must be considered when selecting adaptive design features. The adaptive design features must be included in the design analysis and in the design drawings and should be labeled, “Not in Contract (NIC)”, to permit future construction as needed with negligible additional design cost or effort. The DRSL database is available at:

https://sealevelscenarios.serdp-estcp.org

3-3.2 Section 6.14 - TSUNAMI VERTICAL EVACUATION REFUGE STRUCTURES

6.14.1 - Minimum Inundation Elevation and Depth [Supplement]

Where a 1.3 factor is required, it is not cumulative to the Tsunami factor in Table 2-2, but rather supplants the tsunami factor in Table 2-2.

3-3.3 Section 6.15 - DESIGNATED NONSTRUCTURAL COMPONENTS AND SYSTEMS

6.15.1 – Performance Requirements [Supplement]

Design mission critical systems according to the requirements of Section 6.15.1. In addition to projected sea level rise (see Table 2-2), mission critical systems must be situated above maximum inundation elevation factored up by 1.3, unless designed directly for tsunami effects and if inundation would not inhibit critical function during and after a tsunami.

3-4 ASCE 7-22 CHAPTER 7 – SNOW LOADS.

3-4.1 Section 7.4 – Sloped Roof Snow Loads, p_s [Supplement].

Add to the end of the paragraph: Where obstructions occur on the roof from equipment such as photovoltaic panels, lightning cable systems, etc., the potential for snow buildup around the obstructions needs to be considered.

3-5 ASCE 7-22 CHAPTER 11 – SEISMIC DESIGN CRITERIA.

3-5.1 Section 11.1 – GENERAL.

11.1.2 – Scope [Supplement]

The design and detailing of the components of the seismic force-resisting system must comply with the applicable provisions of ASCE 7-22 Section 11.7 and ASCE 7-22 Chapter 12, as modified by this UFC, in addition to the nonseismic requirements of the 2024 IBC.

11.1.3 – Applicability [Supplement]

Add the following at the end of the section: Buildings or structures that are not routinely occupied, but whose primary purpose is to support human activities, such as training towers, are not to be classified as non-building structures unless specifically approved by the AHJ.

3-5.2 Section 11.2 – DEFINITIONS.

DESIGNATED SEISMIC SYSTEMS [Replacement]

The designated seismic system of a structure consists of those nonstructural components that require design in accordance with Chapter 13 and for which the component importance factor, I_p, is greater than 1.0. This designation applies to systems that are required to be operational following the design earthquake. Designated seismic systems will be identified by Owner and will have an importance factor, $I_p = 1.5$.

FRAME:

Moment Frame [Replacement]

A frame in which members and joints resist lateral forces by flexure as well as along the axis of the members. Moment frames are categorized as intermediate moment frames (IMF), ordinary moment frames (OMF), and special moment frames (SMF). Every joint must be restrained against rotation.

3-5.3 Section 11.5 - IMPORTANCE FACTOR AND RISK CATEGORY.

11.5.1 - Importance Factor [Replacement]

A seismic importance factor, I_e, must be assigned to each structure in accordance with Table 2-2 of this UFC.

3-6 ASCE 7-22 CHAPTER 12 – SEISMIC DESIGN REQUIREMENTS FOR BUILDING STRUCTURES.

3-6.1 Section 12.2 – STRUCTURAL SYSTEM SELECTION.

12.2.1 - Selection and Limitations [Supplement]

Table 3-1, Replacement for ASCE 7-22 Table 12.2-1, must be used in lieu of ASCE 7-22 Table 12.2-1.

3-6.2 Section 12.6 - ANALYSIS PROCEDURE SELECTION [Supplement].

Add at the end of the section:

For RC IV structures designed using the alternate procedure of Appendix B of this UFC, only nonlinear static or nonlinear response history procedure in accordance with the provisions of Appendix B is permitted.

**Table 3-1 Replacement for ASCE 7-22 Table 12.2-1,
Design Coefficients and Factors for Basic Seismic Force-Resisting Systems**

BASIC SEISMIC FORCE-RESISTING SYSTEM	*DETAILING REFERENCE SECTION*	RESPONSE MODIFICATION COEFFICIENT R^a	OVERSTRENGTH FACTOR, Ω_0^b	DEFLECTION AMPLIFICATION FACTOR, C_d^c	STRUCTURAL SYSTEM LIMITATIONS INCLUDING STRUCTURAL HEIGHT, h_n, (FEET) LIMITS BY SEISMIC DESIGN CATEGORY[d]				
					B	C	D[e]	E[e]	F[f]
A. Bearing Wall Systems									
1. Special reinforced concrete shear walls[g,h]	***(18.2.1.6)[t]***	5	2-1/2	5	NL	NL	160	160	100
2. Reinforced concrete ductile coupled walls[q]	***(18.10.9)[t]***	8	2-1/2	8	NL	NL	160	160	100
3. Ordinary reinforced concrete shear walls[g]	***(18.2.1.6)[t]***	4	2-1/2	4	NL	NL	NP	NP	NP
4. Detailed plain concrete shear walls[g]	***(1905.5)[v]***	2	2-1/2	2	NL	NP	NP	NP	NP
5. Ordinary plain concrete shear walls[g]	***(Chapter 14)[t]***	1-1/2	2-1/2	1-1/2	NL	NP	NP	NP	NP
6. Intermediate precast shear walls[g]	***(18.2.1.6)[s], (1905.3)[v]***	4	2-1/2	4	NL	NL	40[i]	40[i]	40[i]
7. Ordinary precast shear walls[g]	***(Chapter 11)[t]***	3	2-1/2	3	NL	NP	NP	NP	NP
8. Special reinforced masonry shear walls	***(7.3.2.5)[u]***	5	2-1/2	3-1/2	NL	NL	160	160	100
9. Intermediate reinforced masonry shear walls	***(7.3.2.4)[u]***	3-1/2	2-1/2	2-1/4	NL	NL	NP	NP	NP
10. Ordinary reinforced masonry shear walls	***(7.3.2.3)[u]***	2	2-1/2	1-3/4	NL	160	NP	NP	NP
11. Detailed plain masonry shear walls	This system is not permitted by UFC, but is permitted by ASCE 7-22 for SDC B								
12. Ordinary plain masonry shear walls	This system is not permitted by UFC, but is permitted by ASCE 7-22 for SDC B								

Table 3-1 Replacement for ASCE 7-22 Table 12.2-1, Design Coefficients and Factors for Basic Seismic Force-Resisting Systems

BASIC SEISMIC FORCE-RESISTING SYSTEM	*DETAILING REFERENCE SECTION*	RESPONSE MODIFICATION COEFFICIENT R^a	OVERSTRENGTH FACTOR, Ω_0^b	DEFLECTION AMPLIFICATION FACTOR, C_d^c	STRUCTURAL SYSTEM LIMITATIONS INCLUDING STRUCTURAL HEIGHT, h_n, (FEET) LIMITS BY SEISMIC DESIGN CATEGORY[d]				
					B	C	D[e]	E[e]	F[f]
13. Prestressed masonry shear walls	***(7.3.2.9, 7.3.2.10, 7.3.2.11)[u]***	1-1/2	2-1/2	1-3/4	NL	NP	NP	NP	NP
14. Ordinary reinforced AAC masonry shear walls	***(7.3.2.9)[t]***	2	2-1/2	2	NL	35	NP	NP	NP
15. Ordinary plain AAC masonry shear walls	***(7.3.2.7)[t]***	1-1/2	2-1/2	1-1/2	NL	NP	NP	NP	NP
16. Light-frame (wood) walls sheathed with wood structural panels rated for shear resistance	***(2301-2307)[v]***	6-1/2	3	4	NL	NL	65	65	65
17. Light-frame (cold-formed steel) walls sheathed with wood structural panels rated for shear resistance or ***with*** steel sheets	***(2206, 2301-2307)[v]***	6-1/2	3	4	NL	NL	65	65	65
18. Light-frame walls with shear panels of all other materials	***(2206, 2301-2307)[v]***	2	2-1/2	2	NL	NL	35	NP	NP
19. Light-frame (cold-form steel) wall systems using flat strap bracing	***(2206, 2301-2307)[v]***	4	2	3-1/2	NL	NL	65	65	65
20. Cross-laminated timber shear walls	***4.6[w]***	3	3	3	65	65	65	65	65
21. Cross-laminated timber shear walls with shear resistance provided by high-aspect-ratio panels only	***4.6[w]***	4	3	4	65	65	65	65	65

Table 3-1 Replacement for ASCE 7-22 Table 12.2-1
Design Coefficients and Factors for Basic Seismic Force-Resisting Systems

BASIC SEISMIC FORCE-RESISTING SYSTEM	DETAILING REFERENCE SECTION	RESPONSE MODIFICATION COEFFICIENT R^a	SYSTEM OVER-STRENGTH FACTOR, Ω_0^b	DEFLECTION AMPLIFICATION FACTOR, C_d^c	STRUCTURAL SYSTEM LIMITATIONS INCLUDING STRUCTURAL HEIGHT, h_n, (FEET) LIMITS BY SEISMIC DESIGN CATEGORY[d]				
					B	C	D[e]	E[e]	F[f]
B. Building Frame Systems									
1. Steel eccentrically braced frames	***(F3)***[s]	8	2	4	NL	NL	160	160	100
2. Steel special concentrically braced frames	***(F2)***[s]	6	2	5	NL	NL	160	160	100
3. Steel ordinary concentrically braced frames	***(F1)***[s]	3-1/4	2	3-1/4	NL	NL	35[j]	35[j]	NP[j]
4. Special reinforced concrete shear walls[g,h]	***(18.2.1.6)***[t]	6	2-1/2	5	NL	NL	160	160	100
5. Reinforced concrete ductile coupled walls[q]	***(18.10.9)***[t]	8	2-1/2	8	NL	NL	160	160	100
6. Ordinary reinforced concrete shear walls[g]	***(18.2.1.6)***[t]	5	2-1/2	4-1/2	NL	NL	NP	NP	NP
7. Detailed plain concrete shear walls[g]	***(1905.5)***[v]	2	2-1/2	2	NL	NP	NP	NP	NP
8. Ordinary plain concrete shear walls[g]	***(Chapter 14)***[t]	1-1/2	2-1/2	1-1/2	NL	NP	NP	NP	NP
9. Intermediate precast shear walls[g]	***(18.2.1.6)***[t]***, (1905. 3)***[v]	5	2-1/2	4-1/2	NL	NL	40[i]	40[i]	40[i]
10. Ordinary precast shear walls[g]	***(Chapter 11)***[t]	4	2-1/2	4	NL	NP	NP	NP	NP
11. Steel and concrete composite eccentrically braced frames	***(H3)***[s]	8	2-1/2	4	NL	NL	160	160	100
12. Steel and concrete composite special concentrically braced frames	***(H2)***[s]	5	2	4-1/2	NL	NL	160	160	100
13. Steel and concrete composite ordinary braced frames	***(H1)***[s]	3	2	3	NL	NL	NP	NP	NP

Table 3-1 Replacement for ASCE 7-22 Table 12.2-1
Design Coefficients and Factors for Basic Seismic Force-Resisting Systems

BASIC SEISMIC FORCE-RESISTING SYSTEM	DETAILING REFERENCE SECTION	RESPONSE MODIFICATION COEFFICIENT R^a	SYSTEM OVER-STRENGTH FACTOR, Ω_0^b	DEFLECTION AMPLIFICATION FACTOR, C_d^c	STRUCTURAL SYSTEM LIMITATIONS INCLUDING STRUCTURAL HEIGHT, h_n, (FEET) LIMITS BY SEISMIC DESIGN CATEGORY[d]				
					B	C	D[e]	E[e]	F[f]
14. Steel and concrete composite plate shear walls	***(H6)***[s]	6-1/2	2-1/2	5-1/2	NL	NL	160	160	100
15. Steel and concrete composite special shear walls	***(H5)***[s]	6	2-1/2	5	NL	NL	160	160	100
16. Steel and concrete composite ordinary shear walls	***(H4)***[s]	5	2-1/2	4-1/2	NL	NL	NP	NP	NP
17. Special reinforced masonry shear walls	***(7.3.2.5)***[u]	5-1/2	2-1/2	4	NL	NL	160	160	100
18. Intermediate reinforced masonry shear walls	***(7.3.2.4)***[u]	4	2-1/2	4	NL	NL	NP	NP	NP
19. Ordinary reinforced masonry shear walls	***(7.3.2.3)***[u]	2	2-1/2	2	NL	160	NP	NP	NP
20. Detailed plain masonry shear walls	This system is not permitted by UFC, but is permitted by ASCE 7-22 for SDC B								
21. Ordinary plain masonry shear walls	This system is not permitted by UFC, but is permitted by ASCE 7-22 for SDC B								
22. Prestressed masonry shear walls	***(7.3.2.9, 7.3.2.10, 7.3.2.11)***[u]	1-1/2	2-1/2	1-3/4	NL	NP	NP	NP	NP
23. Light-frame (wood) walls sheathed with wood structural panels rated for shear resistance	***(2301-2307)***[v]	7	2-1/2	4-1/2	NL	NL	65	65	65
24. Light-frame (cold-formed steel) walls sheathed with wood structural panels rated for shear resistance or ***with*** steel sheets	***(2206, 2301-2307)***[v]	7	2-1/2	4-1/2	NL	NL	65	65	65
25. Light-framed walls with shear panels of all other materials	***(2206, 2301-2307)***[v]	2-1/2	2-1/2	2-1/2	NL	NL	35	NP	NP

Table 3-1 Replacement for ASCE 7-22 Table 12.2-1
Design Coefficients and Factors for Basic Seismic Force-Resisting Systems

BASIC SEISMIC FORCE-RESISTING SYSTEM	DETAILING REFERENCE SECTION	RESPONSE MODIFICATION COEFFICIENT R^a	SYSTEM OVER-STRENGTH FACTOR, $\Omega_0{}^b$	DEFLECTION AMPLIFICATION FACTOR, $C_d{}^c$	STRUCTURAL SYSTEM LIMITATIONS INCLUDING STRUCTURAL HEIGHT, h_n, (FEET) LIMITS BY SEISMIC DESIGN CATEGORY[d]				
					B	C	D[e]	E[e]	F[f]
26. Steel buckling-restrained braced frames	***(F4)***[s]	8	2-1/2	5	NL	NL	160	160	100
27. Steel special plate shear walls	***(F5)***[s]	7	2	6	NL	NL	160	160	100
28. Steel and concrete coupled composite plate shear walls	***(H8)***[s]	8	2-1/2	5-1/2	NL	NL	160	160	100
C. Moment-Resisting Frame Systems									
1. Steel special moment frames	***(E3)***[s]	8	3	5-1/2	NL	NL	NL	NL	NL
2. Steel special truss moment frames	***(E4)***[s]	7	3	5-1/2	NL	NL	160	100	NP
3. Steel intermediate moment frames	***(E2)***[s]	4-1/2	3	4	NL	NL	35[k]	NP[k]	NP[k]
4. Steel ordinary moment frames	***(E1)***[s]	3-1/2	3	3	NL	NL	NP[l,r]	NP[l,r]	NP[l,r]
5. Special reinforced concrete moment frames[m]	***(18.2.1.6)***[t]	8	3	5-1/2	NL	NL	NL	NL	NL
6. Intermediate reinforced concrete moment frames	***(18.2.1.6)***[t]	5	3	4-1/2	NL	NL	NP	NP	NP
7. Ordinary reinforced concrete moment frames	***(18.2.1.6)***[t]	3	3	2-1/2	NL	NP	NP	NP	NP
8. Steel and concrete composite special moment frames	***(G3)***[s]	8	3	5-1/2	NL	NL	NL	NL	NL
9. Steel and concrete composite intermediate moment frames	***(G2)***[s]	5	3	4-1/2	NL	NL	NP	NP	NP
10. Steel and concrete composite partially restrained moment frames	***(G4)***[s]	6	3	5-1/2	160	160	100	NP	NP
11. Steel and concrete composite ordinary moment frames	***(G1)***[s]	3	3	2-1/2	NL	NP	NP	NP	NP

Table 3-1 Replacement for ASCE 7-22 Table 12.2-1 Design Coefficients and Factors for Basic Seismic Force-Resisting Systems

BASIC SEISMIC FORCE-RESISTING SYSTEM	DETAILING REFERENCE SECTION	RESPONSE MODIFICATION COEFFICIENT R^a	SYSTEM OVER-STRENGTH FACTOR, $\Omega_0{}^b$	DEFLECTION AMPLIFICATION FACTOR, $C_d{}^c$	STRUCTURAL SYSTEM LIMITATIONS INCLUDING STRUCTURAL HEIGHT, h_n, (FEET) LIMITS BY SEISMIC DESIGN CATEGORY[d]				
					B	C	D[e]	E[e]	F[f]
12. Cold-formed steel—special bolted moment frame[n]	***(2204)[v]***	3-1/2	3[o]	3-1/2	35	35	35	35	35
D. Dual Systems with Special Moment Frames Capable of Resisting at Least 25% of Prescribed Seismic Forces [ASCE 7-22 12.2.5.1]									
1. Steel eccentrically braced frames	***(F3)[s]***	8	2-1/2	4	NL	NL	NL	NL	NL
2. Steel special concentrically braced frames	***(F2)[s]***	7	2-1/2	5-1/2	NL	NL	NL	NL	NL
3. Special reinforced concrete shear walls[g,h]	***(18.2.1.6)[t]***	7	2-1/2	5-1/2	NL	NL	NL	NL	NL
4. Reinforced concrete ductile coupled walls[q]	***(18.10.9)[t]***	8	2-1/2	8	NL	NL	NL	NL	NL
5. Ordinary reinforced concrete shear walls[g]	***(18.2.1.6)[t]***	6	2-1/2	5	NL	NL	NP	NP	NP
6. Steel and concrete composite eccentrically braced frames	***(H3)[s]***	8	2-1/2	4	NL	NL	NL	NL	NL
7. Steel and concrete composite special concentrically braced frames	***(H2)[s]***	6	2-1/2	5	NL	NL	NL	NL	NL
8. Steel and concrete composite plate shear walls	***(H6)[s]***	7-1/2	2-1/2	6	NL	NL	NL	NL	NL
9. Steel and concrete composite special shear walls	***(H5)[s]***	7	2-1/2	6	NL	NL	NL	NL	NL
10. Steel and concrete composite ordinary shear walls	***(H4)[s]***	6	2-1/2	5	NL	NL	NP	NP	NP
11. Special reinforced masonry shear walls	***(7.3.2.5)[u]***	5-1/2	3	5	NL	NL	NL	NL	NL

Table 3-1 Replacement for ASCE 7-22 Table 12.2-1
Design Coefficients and Factors for Basic Seismic Force-Resisting Systems

BASIC SEISMIC FORCE-RESISTING SYSTEM	DETAILING REFERENCE SECTION	RESPONSE MODIFICATION COEFFICIENT R[a]	SYSTEM OVERSTRENGTH FACTOR, Ω_0[b]	DEFLECTION AMPLIFICATION FACTOR, C_d[c]	STRUCTURAL SYSTEM LIMITATIONS INCLUDING STRUCTURAL HEIGHT, h_n, (FEET) LIMITS BY SEISMIC DESIGN CATEGORY[d]				
					B	C	D[e]	E[e]	F[f]
12. Intermediate reinforced masonry shear walls	***(7.3.2.4)***[u]	4	3	3-1/2	NL	NL	NP	NP	NP
13. Steel buckling-restrained braced frames	***(F4)***[s]	8	2-1/2	5	NL	NL	NL	NL	NL
14. Steel special plate shear walls	***(F5)***[s]	8	2-1/2	6-1/2	NL	NL	NL	NL	NL
15. Steel and concrete coupled composite plate shear walls	***(H8)***[s]	8	2-1/2	5-1/2	NL	NL	NL	NL	NL
E. Dual Systems with Intermediate Moment Frames Capable of Resisting at Least 25% of Prescribed Seismic Forces [ASCE 7-22 12.2.5.1]									
1. Steel special concentrically braced frames[p]	***(F2)***[s]	6	2-1/2	5	NL	NL	35	NP	NP
2. Special reinforced concrete shear walls[g,h]	***(18.2.1.6)***[t]	6-1/2	2-1/2	5	NL	NL	160	100	100
3. Ordinary reinforced masonry shear walls	***(7.3.2.3)***[u]	3	3	2-1/2	NL	160	NP	NP	NP
4. Intermediate reinforced masonry shear walls	***(7.3.2.4)***[u]	3-1/2	3	3	NL	NL	NP	NP	NP
5. Steel and concrete composite special concentrically braced frames	***(H2)***[s]	5-1/2	2-1/2	4-1/2	NL	NL	160	100	NP
6. Steel and concrete composite ordinary braced frames	***(H1)***[s]	3-1/2	2-1/2	3	NL	NL	NP	NP	NP
7. Steel and concrete composite ordinary shear walls	***(H4)***[s]	5	3	4-1/2	NL	NL	NP	NP	NP
8. Ordinary reinforced concrete shear walls[g]	***(18.2.1.6)***[t]	5-1/2	2-1/2	4-1/2	NL	NL	NP	NP	NP

Table 3-1 Replacement for ASCE 7-22 Table 12.2-1
Design Coefficients and Factors for Basic Seismic Force-Resisting Systems

BASIC SEISMIC FORCE-RESISTING SYSTEM	DETAILING REFERENCE SECTION	RESPONSE MODIFICATION COEFFICIENT R^a	SYSTEM OVERSTRENGTH FACTOR, Ω_0^b	DEFLECTION AMPLIFICATION FACTOR, C_d^c	STRUCTURAL SYSTEM LIMITATIONS INCLUDING STRUCTURAL HEIGHT, h_n, (FEET) LIMITS BY SEISMIC DESIGN CATEGORY[d]				
					B	C	D[e]	E[e]	F[f]
F. Shear Wall-Frame Interactive System with Ordinary Reinforced Concrete Moment Frames and Ordinary Reinforced Concrete Shear Walls[g]	***(18.2.1.6)[t]***	4-1/2	2-1/2	4	NL	NP	NP	NP	NP
G. Cantilevered column systems detailed to conform to the requirements for [ASCE 7-22 12.2.5.2]:									
1. Steel special cantilever column systems	***(E6)[s]***	2-1/2	2-1/2	2-1/2	35	35	35	35	35
2. Steel ordinary cantilever column systems	***(E5)[s]***	1-1/4	1-1/4	1-1/4	35	35	NP[l]	NP[l]	NP[l]
3. Special reinforced concrete moment frames[m]	***(18.2.1.6)[t]***	2-1/2	2-1/2	2-1/2	35	35	35	35	35
4. Intermediate reinforced concrete moment frames	***(18.2.1.6)[t]***	1-1/2	1-1/2	1-1/2	35	35	NP	NP	NP
5. Ordinary reinforced concrete moment frames	***(18.2.1.6)[t]***	1	1-1/4	1	35	NP	NP	NP	NP
6. Timber frames	***(2301 – 2307)[v]***	1-1/2	1-1/2	1-1/2	35	35	35	NP	NP
H. Steel Systems Not Specifically Detailed for Seismic Resistance, Excluding Cantilevered Column Systems	***AISC 360-22, AISI S100, AISI S240, ASCE 8***	3	3	3	NL	NL	NP	NP	NP

FOR SI: 1 foot (ft) = 304.8 mm, 1 pound per square foot (psf) = 0.0479 kN/m²

a. Response modification coefficient, R, for use throughout. Note R reduces forces to a strength level, not an allowable stress level.

b. Where the tabulated value of the overstrength factor, Ω_o, is greater than or equal to 2½, Ω_o is permitted to be reduced by subtracting the value of ½ for structures with flexible diaphragms.

c. Deflection amplification factor, C_d, for use in ***ASCE 7-22*** Sections 12.8.6, 12.8.7, 12.9.1.2, ***12.12.2, 12.12.3, and 12.12.4***.

d. NL= Not limited and NP = Not permitted. For metric units, use ***30*** m for 100 ft and ***50*** m for 160 ft.

e. See ***ASCE 7-22*** Section 12.2.5.4 for a description of seismic force-resisting systems limited to buildings with a structural height, h_n, of 240 feet (***75*** m) or less.

f. See ***ASCE 7-22*** Section 12.2.5.4 for seismic force-resisting systems limited to buildings with a structural height, h_n, of 160 feet (***50*** m) or less.

g. In Section 2.3 of ACI 318-19, a shear wall is defined as a structural wall.

h. In Section 2.3 of ACI 318-19, the definition of "special structural wall" includes precast and cast-in-place construction.

i. An increase in structural height, h_n, to 45 ft (***14*** m) is permitted for single story storage warehouse facilities.

j. Steel ordinary concentrically braced frames ***(OCBFs)*** are permitted in single-story buildings up to a structural height, h_n, of 60 ft (***18*** m) where the dead load of the roof does not exceed 20 psf (***1.0*** kN/m^2) and in penthouse structures.

k. See ***ASCE 7-22*** Section 12.2.5.7 for limitations in structures assigned to Seismic Design Categories D, E, or F.

l. See ***ASCE 7-22*** Section 12.2.5.6 for limitations in structures assigned to Seismic Design Categories D, E, or F.

m. In Section 2.3 of ACI 318-19, the definition of "special moment frame" includes precast and cast-in-place construction.

n. Cold-formed steel – special bolted moment frames must be limited to one-story in height in accordance with ANSI/AISI S400-20.

o. Alternately, the seismic load effect with overstrength, E_{mh}, is permitted to be based on the expected strength determined in accordance with ANSI/AISI S400-20.

p. Ordinary moment frame is permitted to be used in lieu of intermediate moment frame for Seismic Design Category B or C.

q. Structural height, h_n, shall not be less than 60 ft (18.3 m)

r. Ordinary Moment Frames are permitted to be used as part of the structural system that transfers forces between isolator units.

s. ANSI/AISC 341-22 section number.

t. ACI 318-19, Section 18.2.1.6 cites appropriate sections in ACI 318-19.

u. TMS 402-22 section number.

v. 2024 IBC section number.

w. 2021 Special Design Provisions for Wind and Seismic with Commentary (SDPWS) section number.

3-6.3 Section 12.10 - DIAPHRAGMS, CHORDS, AND COLLECTORS.

12.10.2.1 - Collector Elements Requiring Load Combinations with Overstrength Factor for Seismic Design Categories C through F

Item (c) [Replacement]. Forces calculated using the load combinations of Section 2.3.6 without overstrength factor, with seismic forces determined by Eq. (12.10-2).

EXCEPTION [Replacement]:
In structures or portions thereof braced entirely by wood light-frame shear walls, collector elements and their connections, including connections to vertical elements, need only be designed to resist forces using the load combinations of Section 2.3.6 without overstrength factor, with seismic forces determined in accordance with Section 12.10.1.1.

[C] 12.10.2.1 - Collector Elements Requiring Load Combinations with Overstrength Factor for Seismic Design Categories C through F

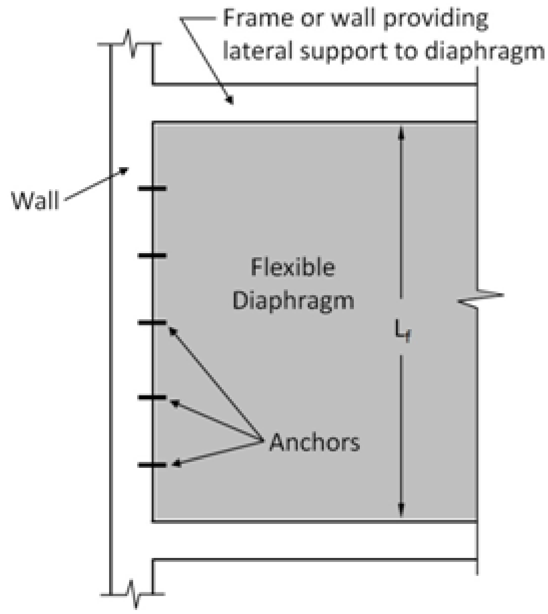
The two [Replacement] added under this section are intended to clarify that the load combinations to be used with these two provisions are the ones that do not include the overstrength factor. The text in ASCE 7-22 simply refers to the load combinations in Section 2.3.6. However, ASCE 7-22 Section 2.3.6 contains two sets of seismic load combinations – regular load combinations involving seismic load effects not amplified by the overstrength factor of the structure, and load combinations where the seismic load effects are amplified by the overstrength factor.

3-6.4 Section 12.11 - STRUCTURAL WALLS AND THEIR ANCHORAGE.

12.11.2.1 - Wall Anchorage Forces [Supplement]

Refer to Figure 3-1 for determination of the span of flexible diaphragm, L_f.

Figure 3-1 Anchorage of Walls to Flexible Diaphragm



3-7 ASCE 7-22 CHAPTER 13 – SEISMIC DESIGN REQUIREMENTS FOR NON-STRUCTURAL COMPONENTS.

3-7.1 Section 13.1 – GENERAL.

13.1.1 - Scope [Supplement]

Add as the last paragraph:

Appendix C of this UFC provides supplementary guidance on architectural, mechanical, and electrical component design requirements. Section C-2 provides guidance on architectural component design, including interior and exterior wall elements. Section C-3 provides guidance on electrical and mechanical systems design. To the extent that is practicable, subsections of Appendix C reference relevant sections of ASCE 7-22.

3-7.2 Section 13.2 - GENERAL DESIGN REQUIREMENTS.

13.2.3 - Special Certification Requirements for Designated Seismic Systems [Supplement]

Appendix D of this UFC provides verification and certification guidance.

When shake table testing is performed, the Required Response Spectra (RRS) must be either derived using ICC-ES AC156 or developed from a study based on site-specific in-structure response time history. In the case of the latter, the RRS for each axis must be generated from the time histories defined in Section 2-15.2

of UFC 3-301-02, and be peak broadened by 15%. The in-structure response spectra per Section 2-17.4.4 of UFC 3-301-02 must be used to determine demand if the Nonstructural Component is not supported at grade.

Testing must be performed in accordance with nationally recognized testing procedures such as:

1. The requirements of the International Code Council Evaluations Service (ICC-ES), *Acceptance Criteria for Seismic Qualification by Shake-Table Testing of Nonstructural Components*, ICC-ES AC156, November 2020.

2. The *CERL Equipment Fragility and Protection Procedure (CEFAPP)*, USACERL Technical Report 97/58, Wilcoski, J., Gambill, J.B., and Smith, S.J., March 1997. The test motions, test plan, and results of this method require peer review.

3. For power substation equipment only, Institute of Electrical and Electronics Engineers (IEEE), *Recommended Practices for Seismic Design of Substations*, IEEE 693-2018.

Shake table tests must include triaxial motion components that result in the largest response spectral amplitudes at the natural frequencies of the equipment for each of the three axes of motion. The Test Response Spectrum (TRS) test motions, demand RRS, test plan, and test results must be reviewed independently by a team of Registered Design Professionals. The design professionals must have documented experience in the appropriate disciplines, seismic analysis, and seismic testing. The independent review must include, but need not be limited to, the following:

1. Review of site-specific seismic criteria, including the development of site-specific spectra and ground motion histories, and all other project-specific criteria;

2. Review of seismic designs and analyses for both the equipment and all supporting systems, including the generation of in-structure motions;

3. Review of all testing requirements and results; and,

4. Review of all equipment quality control, quality assurance, maintenance, and inspection requirements.

13.2.3.1 - Component Certification and Operations & Maintenance (O&M) Manual [Addition]

For any electrical or mechanical component required by ASCE 7-22 Section 13.2.3 to be certified, evidence demonstrating compliance with the requirement must be maintained in a file identified as “Equipment Seismic Certification Documentation.” This file must be a part of the Operations & Maintenance (O&M)

Manual that is turned over to the AHJ. The project specifications must require the O&M Manual to state that replaced or modified components need to be certified per the original certification criteria.

13.2.3.2 - Component Identification Nameplate [Addition]

Any electrical or mechanical component required by ASCE 7-22 Section 13.2.3 to be certified is required to bear permanent marking or nameplates constructed of a durable heat- and water-resistant material. Nameplates must be mechanically attached to such nonstructural components and placed on each component for clear identification. The nameplate cannot be less than 5 in. x 7 in. with red letters 1 in. in height on a white background, stating “Certified Equipment.” The following statement is required to be on the nameplate: “This equipment/component is seismically certified. Modification or replacement must be approved in advance by a qualified professional engineer and documented in the “Equipment Seismic Certification Documentation” file within the O&M manuals. The nameplate needs to also contain the component identification number in accordance with the drawings/specifications and the O&M manuals.

3-7.3 Section 13.3 - SEISMIC DEMANDS ON NONSTRUCTURAL COMPONENTS.

13.3.2 - Seismic Relative Displacements [Supplement]

Egress stairways and ramps must be detailed in accordance with ASCE 7-22 Section 13.5.10.

3-7.4 Section 13.4 - NONSTRUCTURAL COMPONENT ANCHORAGE AND ATTACHMENT.

13.4.2.2 - Anchors in Masonry [Replacement]

Anchors in masonry must be designed in accordance with TMS 402-22. Additionally, at least one of the following must be satisfied in structures assigned to SDC C or higher.

a. Anchors in tension are designed to be governed by the tensile strength of a ductile steel element.

b. Anchors are designed for the maximum load that can be transmitted to the anchors from a ductile attachment, considering both material overstrength and strain hardening of the attachment.

c. Anchors are designed for the maximum load that can be transmitted to the anchors by a non-yielding attachment.

d. Anchors are designed for the maximum load obtained from design load combinations that include *E*, where the effect of horizontal ground motion, Q_E, is multiplied by Ω_{op} as given in ASCE 7-22 Tables 13.5-1 and 13.6-1.

[C] 13.4.2.2 - Anchors in Masonry [Replacement]

This [Replacement] harmonizes design of anchors embedded in concrete and masonry. ASCE 7-22 Section 13.4.2.2 includes provisions to prevent brittle failure of anchors in masonry attaching nonstructural components. This [Replacement] simply makes the requirements consistent with those of ACI 318-19. Note Option a is available only for anchors in tension, and not for those in shear. This [Replacement] also exempts anchors in SDC A and B structures from these ductility/overstrength requirements, which is consistent with what is required for anchors in concrete.

13.4.2.3 - Post-Installed Anchors in Concrete and Masonry [Replacement]

In structures assigned to SDC C or higher, post-installed mechanical anchors in concrete are required to be prequalified for seismic applications in accordance with ACI 355.2 or other approved qualification procedures. Post-installed adhesive anchors in concrete in structures assigned to SDC C, D, E, or F are required to be prequalified for seismic applications in accordance with ACI 355.4 or other approved qualification procedures. In structures assigned to SDC C or higher, post-installed anchors in masonry are required to be prequalified for seismic applications in accordance with approved qualification procedures.

[C] 13.4.2.3 - Post-Installed Anchors in Concrete and Masonry [Replacement]

This [Replacement] specifies that ACI 355.2 is for prequalification of post-installed mechanical anchors only and adds a reference to ACI 355.4 for prequalification of post-installed adhesive anchors, which is not referenced in ASCE 7-22.

3-7.5 Section 13.5 - ARCHITECTURAL COMPONENTS.

13.5.6 - Suspended Ceilings [Supplement]

For buildings assigned to RC IV, suspended ceilings must be designed to resist seismic effects using a rigid bracing system, where the braces are capable of resisting tension and compression forces, or diagonal splay wires, where the wires are installed taut. Particular attention should be paid in walk-down inspections (see Section 1705.13.6 in Chapter 2 of this UFC) to ensure splay wires are taut. Positive attachment must be provided to prevent vertical movement of ceiling elements. Vertical support elements need to be capable of resisting both compressive and tensile forces. Vertical supports and braces designed for compression must have a slenderness ratio, Kl/r, of less than 200. Additional guidance on suspended ceiling design is provided in Section C-2.2.8 of this UFC.

13.5.7 – Access Floors [Supplement]

Installed access floor components that have importance factors, I_p, greater than 1.0 must meet the requirements of Special Access Floors (ASCE 7-22 Section 13.5.7.2). Note: Equipment that requires certification (see Section 13.2.3 in this UFC) needs to account for the motion amplification that occurs because of any supporting access flooring.

3-7.6 Section 13.6 - MECHANICAL AND ELECTRICAL COMPONENTS.

13.6.1 - General [Supplement]

Stacks attached to or supported by buildings must be designed to meet the force and displacement provisions of ASCE 7-22 Sections 13.3.1 and 13.3.2. They must further be designed in accordance with the requirements of ASCE 7-22 Chapter 15 and the special requirements of ASCE 7-22 Section 15.6.2. Guidance on stack design may be found in Section C-3.2.

13.6.2 - Mechanical Components [Supplement]

Guidance on the design of piping supports and attachments is found in Section C-3.1.3 of this UFC.

13.6.3 - Electrical Components [Supplement]

Guidance on the design of electrical equipment supports, attachments, and certification is found in Appendices C and D of this UFC.

13.6.4 - Component Support [Supplement]

For buildings that are assigned to RC IV, guidance on the design of lighting fixtures is found in Section C-3.4 of this UFC.

13.6.11.3 - Seismic Controls for Elevators [Supplement]

For buildings that are assigned to RC IV or to SDC E or F, the trigger level for seismic switches must be set to 50% of the acceleration of gravity along both orthogonal horizontal axes. Elevator systems (equipment, supports, etc.) in RC IV or SDC E or F buildings will have an I_p = 1.5 and must be designed to ensure elevator operability at accelerations below 50% of the acceleration of gravity along both orthogonal horizontal axes. Additional guidance on the design of elevator systems is found in Section C-3.3 of this UFC.

[C] 13.6.11.3 - Seismic Switches [Supplement]

Note that the 0.50*g* is consistent with Article 3137, *Seismic Requirements for Elevators, Escalators and Moving Walks*, Subchapter 6, Elevator Safety Orders, California Code of Regulations, Title 8 (https://www.dir.ca.gov/title8/3137.html).

13.6.12 - Rooftop Solar Panels [Deletion]

Delete the exception to this section in its entirety.

[C] 13.6.12 - Rooftop Solar Panels [Deletion]

The exception addresses ballasted solar panels without positive direct attachment to the roof structure. Ballasted systems are specifically disallowed by UFC 3-110-03, *Roofing*.

13.6.14 - Bridges, Cranes, and Monorails [Addition]

Structural supports for those crane systems that are located in buildings and other structures assigned to SDC C with I_p greater than 1.0, or assigned to SDC D, E, or F, must be designed to meet the force and displacement provisions of ASCE 7-22 Section 13.3. Seismic forces, F_p, must be calculated using C_{AR}/R_{po} = 1, except that crane rail connections must be designed for the forces resulting from C_{AR}/R_{po} = 1.15 in all directions. When designing for forces in either horizontal direction, the weight of crane components, W_p, need not include any live loads, lifted loads, or loads from crane components below the bottom of the crane cable. If the crane is not in a locked position, the lateral force parallel to the crane rails can be limited by the friction forces that can be applied through the brake wheels to the rails. In this case, the full rated live load of the crane plus the weight of the crane must be used to determine the gravity load that is carried by each wheel. Guidance on the design of these systems is found in Section C-3.5 of this UFC.

[C] 13.6.14 - Bridges, Cranes, and Monorails [Addition]

The parameters a_p and R_p are not used in ASCE 7-22. However, there is no direct correspondence between these and the new parameters in ASCE 7-22: the Component Resonance Ductility Factor, C_{AR}, and the Component Strength Factor, R_{po}. The ratio C_{AR}/R_{po} = 1.0 preserves the previous a_p/R_p = 1.0.

Since crane rail connections are not listed in Table 13.6-1, R_{po} for those connections is taken as 1.3 which is the lowest R_{po} value in the entire Table 13.6-1. Cranes and Monorails fall under Other mechanical components and are assigned an R_{po} of 1.5. Thus, C_{AR}/R_{po} ratio is raised by a factor of 1.5/1.3 = 1.15.

13.6.14.1 - Bridges, Cranes, and Monorails for RC IV Buildings [Addition]

In addition to the requirements of Section 13.6.14 of this UFC, for bridges, cranes, and monorails for all RC IV buildings, vertical earthquake-induced motions corresponding to the MCE_R event must be considered. When a site-specific vertical spectrum is not used, the vertical response spectrum may be developed following the provisions of ASCE 7-22 Section 11.9.2.

3-8 ASCE 7 CHAPTER 15 – SEISMIC DESIGN REQUIREMENTS FOR NONBUILDING STRUCTURES.

3-8.1 Section 15.4 - STRUCTURAL DESIGN REQUIREMENTS.

15.4.5 – Drift Limit [Replacement]

Nonbuilding structures similar to buildings are required to comply with lateral drift limitations specified for buildings in ASCE 7-22 Chapter 12.

EXCEPTION: The drift limitations of ASCE 7-22 Section 12.12.1 need not apply to nonbuilding structures if a rational analysis acceptable to the AHJ indicates they can be exceeded without adversely affecting structural stability of attached or interconnected components and elements such as walkways and piping. *P*-delta effects need to be considered where critical to the function or stability of the structure.

15.4.9.2 - Anchors in Masonry [Replacement]

Anchors in masonry must be designed in accordance with TMS 402-22. Additionally, for non-building structures assigned to SDC C, D, E, or F, at least one of the following must be satisfied.

a. Anchors in tension are designed to be governed by the tensile strength of a ductile steel element.

b. Anchors are designed for the maximum load that can be transmitted to the anchors from a ductile attachment, considering both material overstrength and strain hardening of the attachment.

c. Anchors are designed for the maximum load that can be transmitted to the anchors by a non-yielding attachment.

d. Anchors are designed for the maximum load obtained from design load combinations that include E, where the effect of horizontal ground motion, Q_E, is multiplied by Ω_o as given in ASCE 7-22 Tables 13.5-1 and 13.6-1.

[C] 15.4.9.2 - Anchors in Masonry [Replacement]

This [Replacement] harmonizes design of anchors embedded in concrete and masonry. ASCE 7-22 Section 15.4.9.2 includes provisions to prevent brittle failure of anchors in masonry in nonbuilding structures. This [Replacement] simply makes the requirements consistent with those of ACI 318-19. Note Option ‘a’ is available only for anchors in tension, not shear.

15.4.9.3 - Post-Installed Anchors in Concrete and Masonry [Replacement]

Post-installed mechanical anchors in concrete in non-building structures assigned to SDC C, D, E, or F are required to be prequalified for seismic applications in accordance with ACI 355.2 or other approved qualification procedures. Post-installed adhesive anchors in concrete in non-building structures assigned to SDC C, D, E, or F are required to be prequalified for seismic applications in accordance with ACI 355.4 or other approved qualification procedures. Post-installed anchors in masonry non-building structures assigned to SDC C, D, E, or F are required to be prequalified for seismic applications in accordance with approved qualification procedures.

[C] 15.4.9.3 - Post-Installed Anchors in Concrete and Masonry [Replacement]

This [Replacement] specifies that ACI 355.2 is for prequalification of post-installed mechanical anchors only and adds a reference to ACI 355.4 for prequalification of post-installed adhesive anchors, which is not referenced in ASCE 7-22.

3-8.2 Section 15.5 - NONBUILDING STRUCTURES SIMILAR TO BUILDINGS.

15.5.6.1 - General [Supplement]

UFC 4-152-01, *Design: Piers and Wharves*, governs the seismic design of piers and wharves for the DoD.

15.5.6.2 - Design Basis [Deletion]

Delete this section in its entirety.

3-8.3 Section 15.7 - TANKS AND VESSELS.

15.7.5 – Anchorage

Item (c) [Replacement]

Post-installed anchors are permitted to be used in accordance with Section 15.4.9.3 of this UFC, provided the anchor embedment into the concrete is sufficient to develop the steel strength of the anchor rod in tension.

15.7.11.7 – Supports and Attachments for Boilers and Pressure Vessels

Item (b) [Replacement]

Anchorage must be in accordance with Chapter 17 of ACI 318. Post-installed anchors are permitted to be used in accordance with Section 15.4.9.3 of this UFC, provided the anchor embedment into the concrete is sufficient to develop the steel strength of the anchor rod in tension. For anchors in tension, where the special seismic provisions of ACI 318 Section 17.10.5.2 apply, the requirements of ACI 318 Section 17.10.5.3(a) must be satisfied.

3-9 ASCE 7 CHAPTER 26 – WIND LOADS: GENERAL REQUIREMENTS.

3-9.1 Section 26.12 - ENCLOSURE CLASSIFICATION.

26.12.1 - General. [Supplement]
Design all fire station garage bays as partially enclosed structures, with the assumption that garage bay doors have failed. The remainder of the fire station, if isolated from garage bay internal pressure, may be designed according to standard code provisions.

[C] 26.12.1 - General [Supplement]

Damage experienced during Hurricane Michael in 2018 included multiple instances of roof diaphragm loss due to exterior roll-up and sectional door failures, including a fire station where bay doors failed, followed by a total loss of roof diaphragm.

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CHAPTER 4 EVALUATION AND RETROFIT OF EXISTING BUILDINGS

4-1 GENERAL.

For evaluation and retrofit of existing buildings, the provisions of this chapter apply to all matters governing the *repair*, *alteration*, change of occupancy, acquisition, *addition*, and relocation. For seismic evaluation and retrofit, the following document is hereby adopted:

> ICSSC RP 10, *Standards of Seismic Safety for Existing Federally Owned and Leased Buildings*, cited herein as RP 10, is applicable to all existing DoD owned and leased buildings at all locations worldwide.

For nonseismic evaluation and retrofit of existing buildings relating to all matters governing the *repair*, *alteration*, change of occupancy, acquisition, *addition*, and relocation, the following document is hereby adopted:

> International Code Council, *2024 International Existing Building Codes*, cited herein as IEBC.

Modifications are made to specific sections of RP 10 as well as IEBC. It is expected that designers may highlight or otherwise mark those paragraphs of RP 10, and IEBC that are modified by this chapter. The required RP 10, and IEBC section modifications are one of three actions, according to the following legend:

> **[Addition] –** New section added, includes new section number not shown in RP 10 or the 2024 IEBC.
>
> **[Replacement] –** Delete referenced RP 10 or 2024 IEBC section and replace it with the provisions shown.
>
> **[Supplement] –** Add provisions shown as a supplement to the provisions shown in the referenced section of RP 10 or the 2024 IEBC.

[C] 4-1 General

RP 10, *Standards of Seismic Safety for Existing Federally Owned and Leased Buildings*, gives exemptions, triggers, scope, and criteria applicable to repair, alteration, change of occupancy, acquisition, addition to and relocation of existing buildings. RP 10 uses the national standard ASCE 41-17 as the source of its criteria for seismic evaluation and retrofit.

This Chapter clarifies certain terms used in RP 10 and the application of RP 10 to various risk categories. RP 10's exemptions and benchmarking provisions are also modified by this chapter.

The IEBC, *International Existing Building Code*, establishes minimum requirements for existing buildings using prescriptive and performance-related provisions. It is founded on broad-based principles intended to encourage the use and reuse of existing buildings while requiring reasonable updates and improvements.

This Chapter contains modifications to the 2024 IEBC including the scope, and the prescriptive compliance method for nonseismic evaluation of existing buildings.

4-2 MODIFICATIONS TO RP 10.

Apply the following modifications to RP 10.

4-2.1 Circumstances Initiating Evaluation and Mitigation (Triggers).

RP10 Section 1.0 [Supplement]. Wherever RP10 cites 2021 IBC and 2021 IEBC, the corresponding section or provision of 2024 IBC and 2024 IEBC is to be used instead. Wherever RP10 cites ASCE 7-16, the corresponding section or provision of ASCE 7-22 is to be used instead.

RP 10 Section 1.2.1 Item c [Replacement]. An *addition*, *alteration*, or *repair* to a building assigned to Seismic Design Category (SDC) C, where the project construction cost is more than 50 percent of the current pre-construction replacement cost of the building (not including tenant supplied operational service equipment and fit-outs or seismic mitigation efforts).

RP 10 Section 1.2.1 Item d [Replacement]. An *addition*, *alteration*, or *repair* to a building assigned to Seismic Design Category (SDC) D, E or F, where the project construction cost is more than 30 percent of the current pre-construction replacement cost of the building (not including tenant supplied operational service equipment and fit-outs or seismic mitigation efforts).

4-2.2 Performance Objectives for Evaluation and Retrofit using ASCE 41-17.

RP 10 Section 2.0 [Supplement]. Tables 4-1(a) and 4-1(b) of this chapter must be used for structural and nonstructural components, respectively, in lieu of RP 10 Tables 2-1, 2-2, and 2-3 for determining the required performance objectives for evaluation and retrofit based on the risk category of building and the circumstance that triggered the requirement for evaluation and retrofit. At the AHJ's discretion, the nonstructural scope may be waived in areas of the building not affected by the project and not affecting DoD operations, safety, or post-earthquake occupancy.

[C] RP 10 Section 2.0 [Supplement]. Tables 4-1(a) and 4-1(b) do not revise the requirements contained in RP 10 Tables 2-1, 2-2 and 2-3, but are meant to present the same requirements with more clarity. One exception is Item i in Table 4-1(a), Unacceptable Risk Exposure (URE) trigger, where RP 10 does not provide any clear evaluation criteria but leaves it to the discretion of each agency to decide which buildings they choose to assign to the URE designation. However, NIST wanted agencies to be more proactive about retrofitting at least their URMs and similar buildings. Thus, Item i in Table 4-1(a) was developed with a focus on URMs. A fairly low threshold of Collapse Prevention in BSE-1E is used for the evaluation of these buildings in all risk categories, because these buildings are not expected to pass any higher evaluation threshold. The retrofit requirements are the same as those for other project types that require basic performance objective for existing buildings (BPOE). If attaining the retrofit performance objectives becomes a challenge for URM buildings in higher risk categories, an effective solution would be to relocate the activities housed in those buildings.

RP10 Section 2.1 [Supplement]. For definition of enhanced performance objective greater than that specified in Table 2-1 in RP10, refer to ASCE 41-17 Section 2.2.2.

Seismic multi-period response spectra for BSE-1E, BSE-2E, BSE-1N, and BSE-2N earthquakes at DoD installations within the United States and its territories and possessions can be determined using the ASCE Hazard Tool (https://ascehazardtool.org/).

For locations not included in the ASCE Hazard Tool, consult the AHJ.

[C] RP10 Section 2.1 [Supplement]. RP 10 references four seismic hazard levels – BSE-2N (2% probability of exceedance in 50 years), BSE-1N ($^2/_3$ of BSE-2N), BSE-2E (5% probability of exceedance in 50 years) and BSE-1E (20% probability of exceedance in 50 years). The ASCE Hazard Tool (https://ascehazardtool.org/) provides seismic multi-period response spectra for all four hazard levels for any location within the conterminous United States.

Table 4-1(a) Structural Performance Objectives[1,2]

Trigger	Trigger Description	Risk Category I or II		Risk Category III		Risk Category IV	
		Evaluation	Retrofit	Evaluation[4]	Retrofit	Evaluation[5]	Retrofit
RP 10 Section 1.2.1 Items (Mandatory Process)							
a	Change of Occupancy or use Change in Effective Seismic Weight	CP in BSE-2N[3]	LS in BSE-1N CP in BSE-2N	LmS in BSE-2N[3]	DC in BSE-1N LmS in BSE-2N	IO in BSE-1N LS in BSE-2N	IO in BSE-1N LS in BSE-2N
b	Addition	CP in BSE-2N[3]	LS in BSE-1N CP in BSE-2N	LmS in BSE-2N[3]	DC in BSE-1N LmS in BSE-2N	IO in BSE-1N LS in BSE-2N	IO in BSE-1N LS in BSE-2N
	Alteration	CP in BSE-2E[3]	LS in BSE-1E CP in BSE-2E	LmS in BSE-2E[3]	DC in BSE-1E LmS in BSE-2E	IO in BSE-1E LS in BSE-2E	IO in BSE-1E LS in BSE-2E
c	SDC C, Project Cost > 50% of Replacement Cost for Addition	CP in BSE-2N[3]	LS in BSE-1N CP in BSE-2N	LmS in BSE-2N[3]	DC in BSE-1N LmS in BSE-2N	IO in BSE-1N LS in BSE-2N	IO in BSE-1N LS in BSE-2N
	SDC C, Project Cost > 50% of Replacement Cost for Alteration and Repair	CP in BSE-2E[3]	LS in BSE-1E CP in BSE-2E	LmS in BSE-2E[3]	DC in BSE-1E LmS in BSE-2E	IO in BSE-1E LS in BSE-2E	IO in BSE-1E LS in BSE-2E
d	SDC D – F, Project Cost > 30% of Replacement Cost for Addition	CP in BSE-2N[3]	LS in BSE-1N CP in BSE-2N	LmS in BSE-2N[3]	DC in BSE-1N LmS in BSE-2N	IO in BSE-1N LS in BSE-2N	IO in BSE-1N LS in BSE-2N
	SDC D – F, Project Cost > 30% of Replacement Cost for Alteration and Repair	CP in BSE-2E[3]	LS in BSE-1E CP in BSE-2E	LmS in BSE-2E[3]	DC in BSE-1E LmS in BSE-2E	IO in BSE-1E LS in BSE-2E	IO in BSE-1E LS in BSE-2E
e	Repair of substantial structural damage	CP in BSE-2E[3]	LS in BSE-1E CP in BSE-2E	LmS in BSE-2E[3]	DC in BSE-1E LmS in BSE-2E	IO in BSE-1E LS in BSE-2E	IO in BSE-1E LS in BSE-2E
f	Acquisition by purchase or donation	CP in BSE-2E[3]	LS in BSE-1E CP in BSE-2E	LmS in BSE-2E[3]	DC in BSE-1E LmS in BSE-2E	IO in BSE-1E LS in BSE-2E	IO in BSE-1E LS in BSE-2E
g	Lease or lease renewal	CP in BSE-2E[3]	LS in BSE-1E CP in BSE-2E	LmS in BSE-2E[3]	DC in BSE-1E LmS in BSE-2E	IO in BSE-1E LS in BSE-2E	IO in BSE-1E LS in BSE-2E
h	Relocation	CP in BSE-2N[3]	LS in BSE-1N CP in BSE-2N	LmS in BSE-2N[3]	DC in BSE-1N LmS in BSE-2N	IO in BSE-1N LS in BSE-2N	IO in BSE-1N LS in BSE-2N
i	Unacceptable risk exposure	CP in BSE-1E	LS in BSE-1E CP in BSE-2E	CP in BSE-1E	DC in BSE-1E LmS in BSE-2E	CP in BSE-1E	IO in BSE-1E LS in BSE-2E
RP 10 Section 1.2.2 Items (Screening Process)		CP in BSE-2E[3]	LS in BSE-1E CP in BSE-2E	LmS in BSE-2E[3]	DC in BSE-1E LmS in BSE-2E	IO in BSE-1E LS in BSE-2E	IO in BSE-1E LS in BSE-2E

[1] CP = Collapse Prevention; LmS = Limited Safety; LS = Life Safety; DC = Damage Control; IO = Immediate Occupancy

[2] See [C] RP10 Section 2.1 [Supplement] of this UFC for definitions of BSE-1E, BSE-2E, BSE-1N, and BSE-2N

[3] At the AHJ's discretion, Tier 3 evaluation at BSE-1 hazard level may also be required, for performance levels required for corresponding retrofit.

[4] For Risk Category III, Tier 1 screening or Tier 2 evaluation at the Limited Safety level are to use the Tier 1 checklists and Tier 2 procedures for Collapse Prevention performance, but M_s-factors and other quantitative limits are to be taken as the average of Life Safety and Collapse Prevention values.

[5] For Risk Category IV, Tier 1 screening or Tier 2 evaluation at the Life Safety level are to use the Tier 1 checklists and Tier 2 procedures for Collapse Prevention performance, but M_s-factors and other quantitative limits are to be taken as Life Safety values.

Table 4-1(b) Nonstructural Performance Objectives[1,2,3]

Trigger	Trigger Description	Risk Category I or II		Risk Category III		Risk Category IV	
		Evaluation	Retrofit	Evaluation	Retrofit	Evaluation	Retrofit
RP 10 Section 1.2.1 Items (Mandatory Process)							
a	Change of Occupancy or Use	PR in BSE-1N[4] HR in BSE-2N	PR in BSE-1N[4] HR in BSE-2N	PR in BSE-1N HR in BSE-2N	PR in BSE-1N HR in BSE-2N	OP in BSE-1N HR in BSE-2N	OP in BSE-1N HR in BSE-2N
b	Addition	PR in BSE-1N[4] HR in BSE-2N	PR in BSE-1N[4] HR in BSE-2N	PR in BSE-1N HR in BSE-2N	PR in BSE-1N HR in BSE-2N	OP in BSE-1N HR in BSE-2N	OP in BSE-1N HR in BSE-2N
	Alteration	LS in BSE-1E HR in BSE-2E	LS in BSE-1E HR in BSE-2E	PR in BSE-1E HR in BSE-2E	PR in BSE-1E HR in BSE-2E	PR in BSE-1E HR in BSE-2E	PR in BSE-1E HR in BSE-2E
c	SDC C, Project Cost > 50% of Replacement Cost for Addition	PR in BSE-1N[4] HR in BSE-2N	PR in BSE-1N[4] HR in BSE-2N	PR in BSE-1N HR in BSE-2N	PR in BSE-1N HR in BSE-2N	OP in BSE-1N HR in BSE-2N	OP in BSE-1N HR in BSE-2N
	SDC C, Project Cost > 50% of Replacement Cost for Alteration and Repair	LS in BSE-1E HR in BSE-2E	LS in BSE-1E HR in BSE-2E	PR in BSE-1E HR in BSE-2E	PR in BSE-1E HR in BSE-2E	PR in BSE-1E HR in BSE-2E	PR in BSE-1E HR in BSE-2E
d	SDC D – F, Project Cost > 30% of Replacement Cost for Addition	PR in BSE-1N[4] HR in BSE-2N	PR in BSE-1N[4] HR in BSE-2N	PR in BSE-1N HR in BSE-2N	PR in BSE-1N HR in BSE-2N	OP in BSE-1N HR in BSE-2N	OP in BSE-1N HR in BSE-2N
	SDC D – F, Project Cost > 30% of Replacement Cost for Alteration and Repair	LS in BSE-1E HR in BSE-2E	LS in BSE-1E HR in BSE-2E	PR in BSE-1E HR in BSE-2E	PR in BSE-1E HR in BSE-2E	PR in BSE-1E HR in BSE-2E	PR in BSE-1E HR in BSE-2E
e	Repair of substantial structural damage	LS in BSE-1E HR in BSE-2E	LS in BSE-1E HR in BSE-2E	PR in BSE-1E HR in BSE-2E	PR in BSE-1E HR in BSE-2E	PR in BSE-1E HR in BSE-2E	PR in BSE-1E HR in BSE-2E
f	Acquisition by purchase or donation	LS in BSE-1E HR in BSE-2E	LS in BSE-1E HR in BSE-2E	PR in BSE-1E HR in BSE-2E	PR in BSE-1E HR in BSE-2E	PR in BSE-1E HR in BSE-2E	PR in BSE-1E HR in BSE-2E
g	Lease or lease renewal	LS in BSE-1E HR in BSE-2E	LS in BSE-1E HR in BSE-2E	PR in BSE-1E HR in BSE-2E	PR in BSE-1E HR in BSE-2E	PR in BSE-1E HR in BSE-2E	PR in BSE-1E HR in BSE-2E
h	Relocation	PR in BSE-1N[4] HR in BSE-2N	PR in BSE-1N[4] HR in BSE-2N	PR in BSE-1N HR in BSE-2N	PR in BSE-1N HR in BSE-2N	OP in BSE-1N HR in BSE-2N	OP in BSE-1N HR in BSE-2N
i	Unacceptable risk exposure	Not required	Not required	Not required	Not required	Not required	Not required
RP 10 Section 1.2.2 Items (Screening Process)		LS in BSE-1E HR in BSE-2E	LS in BSE-1E HR in BSE-2E	PR in BSE-1E HR in BSE-2E	PR in BSE-1E HR in BSE-2E	PR in BSE-1E HR in BSE-2E	PR in BSE-1E HR in BSE-2E

[1] LS = Life Safety; PR = Position Retention; OP = Operational; HR = Hazard Reduced

[2] See [C] RP10 Section 2.1 [Supplement] of his UFC for definitions of BSE-1E, BSE-2E, BSE-1N, and BSE-2N

[3] If initial evaluation indicates that damage to nonstructural components would pose an unacceptable risk exposure to the occupants or to the agency's mission, the agency may supplement the initial scope with evaluation considering the 'LS' performance level at the BSE-2E or BSE-2N seismic hazard level

[4] For buildings assigned to Risk Category I or II, a nonstructural component need only be evaluated for the 'LS' performance level if evaluation for the 'PR' performance level would, in the judgment of the federal agency, disproportionately affect project feasibility.

4-2.3 Exemptions and Benchmark Buildings.

4-2.3.1 Exemptions.

Where applied to projects involving change of occupancy, exemptions in RP 10 Section 1.3 based on occupancy or use apply to the new or intended occupancy.

RP 10 Section 1.3, Item e [Replacement]. Risk Category I or II building structures intended for incidental human occupancy not exceeding two persons per 100 ft^2 of space for a total of less than 2 hours a day.

4-2.3.2 Benchmark Buildings.

RP 10 Section 1.4 [Supplement]. Where the Benchmark Building provisions of ASCE 41-17 apply, Table 4-2 of this chapter is to replace ASCE 41-17 Table 3-2, Benchmark Building Codes and Standards for Life Safety Structural Performance at BSE-1E and Table 3-3, Benchmark Building Codes and Standards for Immediate Occupancy Structural Performance at BSE-1E.

4-3 ADDITIONAL REQUIREMENTS.

4-3.1 Combined Projects.

Alteration work performed in conjunction with an addition project must comply with the provisions for alteration projects. Repair work performed in conjunction with an addition project must comply with the provisions for repair projects.

[C] 4-3.1 Combined Projects

In general, RP 10 makes provisions based on the intended project type. This added section addresses cases where multiple project types, one of which is an addition, are undertaken. The provision is primarily a pointer to the requirements in this chapter.

4-3.2 Existing Structural Elements Carrying Lateral Load.

Where an addition is structurally independent of the existing structure, existing seismic force-resisting structural elements are permitted to remain unaltered. Where the addition is not structurally independent of the existing structure, the existing structure and its *addition* acting together as a single structure must be shown to meet the requirements of 2024 IBC Sections 1609 and 1613. For the purposes of this section, compliance with ASCE 41-17, using a Tier 3 procedure and the retrofit performance objective given in Table 4-1(a) of this chapter is to be deemed to meet the requirements of Section 1613.

Exception**:** Any existing seismic force-resisting structural element whose demand-capacity ratio with the addition considered is no more than 10 percent greater than its demand-capacity ratio with the addition ignored is permitted to remain unaltered provided the addition neither creates new structural irregularities, as defined in ASCE 7-22 Section 12.3.2, nor makes existing structural irregularities more severe. For purposes of calculating demand-capacity ratios, the demand must consider applicable load combinations that include wind or earthquake load effects. For purposes of this exception, comparisons of demand-capacity ratios and calculation of design lateral loads, forces and capacities must account for the cumulative effects of additions and alterations since original construction.

4-3.2.1 Alterations

If no alterations are made to an existing structure that receives a new structurally independent addition, then seismic evaluation of the existing structure is not required. If alterations are made to an existing structure that receives a new structurally independent addition, the requirements of RP 10 must be met for the existing structure.

4-3.2.2 Repairs

If no repairs are made to an existing structure that receives a new structurally independent addition, then seismic evaluation of the existing structure is not required. If repairs are made to an existing structure that receives a new structurally independent addition, the requirements of RP 10 must be met for the existing structure.

Table 4-2 Replacement for ASCE/SEI 41-17 Tables 3-2 and 3-3 for Benchmark Buildings

Building Type[1,2,3]	Building Seismic Design Provisions					Seismic Evaluation or Retrofit Provisions			*Tri-Services Criteria[8]*		
	NBC[LS]	SBC[LS]	UBC[LS]	IBC[LS]	NEHRP[LS]	FEMA 178[LS]	FEMA 310/ ASCE 31[LS4, IO5]	FEMA 356/ ASCE 41[LS6, IO7]	*Original Design*		*Evaluation or Retrofit*
									LS	*IO*	*LS, IO*
Wood Frame, Wood Shear Panels (Types W1 & W2)	1993	1994	1976	2000	1985	NBM	1998	2000	***1982***	***1986***	***1999***
Wood Frame, Wood Shear Panels (Type W1A)	NBM	NBM	1997	2000	1997	NBM	1998	2000	***1998***	***1998***	***1999***
Steel Moment-Resisting Frame (Types S1 & S1A)	NBM	NBM	1994[9]	2000	1997	NBM	1998	2000	***1998***	***1998***	***1999***
Steel Concentrically Braced Frame (Types S2 & S2A)	NBM	NBM	1997	2000	NBM	NBM	1998	2000	***1992***	***1992***	***1999***
Steel Eccentrically Braced Frame (Types S2 & S2A)	NBM	NBM	1988[9]	2000	1997	NBM	NBM	2000	***1992***	***1992***	***1999***
Buckling-Restrained Braced Frame (Types S2 & S2A)	NBM	NBM	NBM	2006	NBM	NBM	NBM	2000	***1992***	***1992***	***1999***
Metal Building Frames (Type S3)	NBM	NBM	NBM	2000	NBM	1992	1998	2000	***1992[10]***	***1998[10]***	***1999***
Steel Frame w/Concrete Shear Walls (Type S4)	1993	1994	1994	2000	1985	NBM	1998	2000	***1982***	***1986***	***1999***

Building Type[1,2,3]	Building Seismic Design Provisions					Seismic Evaluation or Retrofit Provisions			*Tri-Services Criteria[8]*		
	NBC[LS]	SBC[LS]	UBC[LS]	IBC[LS]	NEHRP[LS]	FEMA 178[LS]	FEMA 310/ ASCE 31[LS4, IO5]	FEMA 356/ ASCE 41[LS6, IO7]	*Original Design*		*Evaluation or Retrofit*
									LS	*IO*	*LS, IO*
Steel Frame with URM Infill (Types S5 & S5A)	NBM	NBM	NBM	2000	NBM	NBM	1998	2000	***NBM***	***NP***	***1999***
Steel Plate Shear Wall (Type S6)	NBM	NBM	NBM	2006	NBM	NBM	NBM	2000	***NBM***	***NBM***	***NBM***
Cold-Formed Steel Light-Frame Construction – shear wall system (Type CFS1)	NBM	NBM	1997[11]	2000	1997[11]	NBM	NBM	2000[11] (LS only)	***NBM***	***NBM***	***NBM***
Cold-Formed Steel Light-Frame Construction – Strap-Braced Wall System (Type CFS2)	NBM	NBM	NBM	2003	2003	NBM	NBM	NBM	***NBM***	***NBM***	***NBM***
Reinforced Concrete Moment-Resisting Frame (Type C1)[12]	1993	1994	1994	2000	1997	NBM	1998	2000	***1982***	***1986***	***1999***
Reinforced Concrete Shear Walls (Types C2 & C2A)	1993	1994	1994	2000	1985	NBM	1998	2000	***1982***	***1986***	***1999***
Concrete Frame with URM Infill (Types C3 & C3A)	NBM	NBM	NBM	2000	NBM	NBM	1998	2000	***NBM***	***NP***	***1999***
Tilt-up Concrete (Types PC1 & PC1A)	NBM	NBM	1997	2000	NBM	NBM	1998	2000	***1998***	***1998***	***1999***

Building Type[1,2,3]	Building Seismic Design Provisions					Seismic Evaluation or Retrofit Provisions			***Tri-Services Criteria[8]***		
	NBC[LS]	SBC[LS]	UBC[LS]	IBC[LS]	NEHRP[LS]	FEMA 178[LS]	FEMA 310/ ASCE 31[LS4, IO5]	FEMA 356/ ASCE 41[LS6, IO7]	***Original Design***		***Evaluation or Retrofit***
									LS	***IO***	***LS, IO***
Precast Concrete Frame (Types PC2 & PC2A)	NBM	NBM	NBM	2000	NBM	1992	1998	2000	***1998***	***1998***	***1999***
Reinforced Masonry ***Bearing Walls w/Flexible Diaphragms*** (Type RM1)	NBM	NBM	1997	2000	NBM	NBM	1998	2000	***1998***	***1998***	***1999***
Reinforced Masonry ***Bearing Walls w/Stiff Diaphragms*** (Type RM2)	1993	1994	1994	2000	1985	NBM	1998	2000	***1982***	***1986***	***1999***
Unreinforced Masonry ***Bearing Walls w/Flexible Diaphragms*** (Type URM)	NBM	NBM	1991	2000	NBM	NBM	1998NBM	2000	***NBM***	***NP***	***1999 (LS only)***
Unreinforced Masonry ***Bearing Walls w/Stiff Diaphragms*** (Type URMA)	NBM	NBM	NBM	2000	NBM	NBM	1998	2000	***NBM***	***NP***	***1999***
Seismic Isolation or Passive Dissipation	NBM	NBM	1991	2000	NBM	NBM	NBM	2000	***NBM***	***NBM***	***NBM***
Load-Bearing Cold-Formed Steel Framing (Not listed in ASCE/SEI 41-17)	***N/A***	***N/A***	***N/A***	***N/A***	***N/A***	***N/A***	***N/A***	2000	***1998[13]***	***1998[13]***	***1999***

[LS] Only buildings designed and constructed or evaluated in accordance with these documents and being evaluated to the Life-Safety Performance Level may be considered Benchmark Buildings.

[IO] Buildings designed and constructed or evaluated in accordance with these documents and being evaluated to the Immediate Occupancy Performance Level may be considered Benchmark Buildings.

NBM - No benchmark year; buildings need to be evaluated.

NP – Not Permitted. Tri-Services guidance does not permit the use of URM.

[1] Building Type refers to one of the Common Building Types defined in ***ASCE 41-17*** Table 3-1.

[2] Buildings on hillside sites must not be considered Benchmark Buildings.

[3] For buildings in areas of Very Low Seismicity, the benchmark provisions are to be limited to the IBC, FEMA 310/ASCE 31, and FEMA 356/ASCE 41.

[4] Life Safety Structural Performance Level for the seismic hazard as defined by those provisions.

[5] Immediate Occupancy Structural Performance Level for the seismic hazard as defined by those provisions.

[6] Life Safety Structural Performance Level for BSE-1 seismic hazard as defined by those provisions.

[7] Immediate Occupancy Structural Performance Level for BSE-1 seismic hazard as defined by those provisions.

[8] The Tri-Services Criteria Benchmark Year provisions apply only to the structural aspects of the evaluation; older retrofits designed using Tri-Services Criteria need to be evaluated for compliance with the new standards. Nonstructural and foundation elements are required to have a minimum Tier 1 evaluation, in accordance with ASCE 41-17, except under the following circumstances:

a. ***The building was designed and constructed in accordance with TI 809-04 or later Tri-Services criteria; or,***

b. ***The building was evaluated in accordance with TI 809-05 or later Tri-Services criteria, and the building evaluation and rehabilitation included structural, nonstructural, geotechnical, and foundation measures.***

[9] Steel moment-resisting frames and eccentrically braced frames with links adjacent to columns must comply with the 1994 UBC Emergency Provisions, published September/October 1994, or subsequent requirements.

[10] Pre-engineered metal buildings designed in accordance with 1992 criteria using ASCE 7 loading may be considered as Benchmark Buildings for Life Safety Performance Objective, only if all other applicable restrictions are met. Pre-engineered metal buildings designed in accordance with 1998 criteria, including TI 809-30, Metal Building Systems, may be considered as Benchmark Buildings for both the Life Safety and Immediate Occupancy Performance Objectives, only if all other applicable restrictions are met.

[11] Cold-formed steel shear walls with wood structural panels only.

[12] Flat slab concrete moment frames must not be considered Benchmark Buildings.

[13] ***This benchmark year is based in the initial publication of TI 809-07, Design of Cold-Formed Load-Bearing Steel System and Masonry Veneer Steel Stud Walls, 1998.***

NBC – Building Code Officials and Code Administrators International (BOCA), *National Building Code*, 1993.

SBC – Southern Building Code Congress International (SBCC), *Standard Building Code*, 1994.

UBC – International Conference of Building Officials (ICBO), *Uniform Building Code*, ***year as shown in table***.

GSREB – ICBO, *Guidelines for Seismic Retrofit of Existing Buildings*, 2001.

IBC – International Code Council, *International Building Code*, 2000.

NEHRP – Federal Emergency Management Agency (FEMA), *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings*. ***Years shown in table refer to editions of document.***

FEMA 178 – FEMA, *NEHRP Handbook for the Seismic Evaluation of Existing Buildings*, 1992.

FEMA 310 – FEMA, *Handbook for the Seismic Evaluation of Buildings – A Prestandard*, 1998. ***FEMA 310 was superseded by ASCE 31-03, which in turn has been superseded by ASCE 41-13 and ASCE 41-17.***

FEMA 356 - FEMA, *Prestandard and Commentary for the Seismic Rehabilitation of Existing Buildings* - ***FEMA 356 was superseded by ASCE 41-06, which in turn has been superseded by ASCE 41-13 and ASCE 41-17.***

ASCE 31 – ASCE, *Seismic Evaluation of Existing Buildings*, 2003

ASCE 41 – ASCE, *Seismic Rehabilitation of Existing Buildings*, 2006

Tri-Services Criteria:

1982 – TM 5-809-10; NAVFAC P-355; AFM 88-3, Ch 13, Seismic Design for Buildings, 1982.

1986 – TM 5-809-10-1; NAVFAC P-355.1; AFM 88-3, Ch 13, Sec A, Seismic Design Guidelines for Essential Buildings, 1986.

1988 – TM 5-809-10-2; NAVFAC P-355.2; AFM 88-3, Ch 13, Sec B, Seismic Design Guidelines for Upgrading Existing Buildings, 1988.

1992 – TM 5-809-10; NAVFAC P-355; AFM 88-3, Ch 13, Seismic Design for Buildings, 1992.

4-4 MODIFICATIONS TO IEBC.

4-4.1 IEBC Part 1 – scope and application.

101.2 – Scope [Supplement]

ASCE 7-22 Chapter 6, Tsunami Loads and Effects, does not apply to Repairs, Alterations, and Changes of Occupancy of Existing Buildings and Other Structures as defined by the 2024 International Existing Building Code (IEBC).

[C] 101.2 - Scope [Supplement]
The IEBC does not currently incorporate Tsunami requirements. Accordingly, this [Supplement] is provided as clarification. This may change with future editions of the IEBC.

4-4.2 IEBC Chapter 5 – prescriptive compliance method.

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

When a building alteration or repair is performed where the basic wind speed for RC II structures is greater than 130 mph (58 m/s) or where it is a special wind region in accordance with this UFC, roof diaphragms, diaphragm connections to roof framing members, and diaphragm-to-wall connections must be evaluated for wind loads specified in this UFC, provided at least one of the following conditions occurs and this provision has not been invoked in the previous 25 years:

1. The cost of the alteration or repair exceeds 50% of replacement value for the building.
2. Reroofing a Risk Category III or IV building involves removal of more than 50 percent of roofing material.

If the diaphragm and/or diaphragm connections are found incapable of resisting 75 percent of the current UFC design wind loads, they must be replaced or strengthened in accordance with current design wind loads specified in this UFC.

Exception: The following building types are exempt from this requirement:

- Reinforced concrete buildings with concrete diaphragms
- Reinforced concrete masonry unit buildings with concrete diaphragms.
- Detached one- and two-family dwellings
- Multiple single-family dwellings (townhouses) with less than eight attached dwelling units not more than three stories above grade.

- Risk Category I buildings

[C] 503.12 – Roof Diaphragms Resisting Wind Loads in High-wind Regions [Replacement]

High-Wind regions are defined in the 2024 IEBC as areas where the basic wind speed equals or exceeds 130 mph (58 m/s).

4-4.3 IEBC Chapter 7 – alterations - level one.

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

Apply section 503.12 of this UFC.

CHAPTER 5 NONBUILDING STRUCTURES

5-1 HIGHWAY BRIDGE DESIGN.

Design of highway bridges is required to be in accordance with *AASHTO* LRFD Bridge Design Specifications. Design examples are available in the PCI Bridge Design Manual and the following links

- *LRFD Design Examples* (https://www.fhwa.dot.gov/bridge/lrfd/examples.cfm)
- *Reference Manual* (https://www.fhwa.dot.gov/bridge/pubs/nhi15047.pdf)

5-2 RAILROAD BRIDGE DESIGN.

Design of railroad bridges is required to be in accordance with the AREMA Manual for Railway Engineering.

5-3 TANKS FOR LIQUID STORAGE.

Design of tanks for liquid storage is required to be in accordance with NFPA 22, AWWA D100, AWWA D103, AWWA D107, AWWA D115, AWWA D110 and AWWA D120 as applicable.

5-4 TANKS FOR PETROLEUM STORAGE.

Design of tanks for petroleum storage is required to be in accordance with UFC 3-460-01.

5-5 ENVIRONMENTAL ENGINEERING CONCRETE STRUCTURES.

Design of environmental engineering concrete structures is required to be in accordance with ACI CODE-350.

5-6 PRESTRESSED CONCRETE TANKS.

Design of prestressed concrete tanks is required to be in accordance with ACI 372R.

5-7 WATER TREATMENT FACILITIES.

Design of water treatment facilities is required to be in accordance with the Water Environment Federation (WEF) Manual of Practice (MOP) 8.

5-8 TRANSMISSION TOWERS AND POLES.

Design of transmission towers is required to be in accordance with ASCE 10. Design of transmission poles is required to be in accordance with IEEE Standards Association's National Electric Safety Code.

5-9 ANTENNA TOWERS.

Design of antenna towers is required to be in accordance with ANSI/TIA-222-H.

5-10 PEDESTRIAN BRIDGES.

Design of pedestrian bridges is required to be in accordance with the AASHTO LRFD Guide Specifications for Design of Pedestrian Bridges.

CHAPTER 6 MODIFICATIONS TO THE IBC FOR CRITICAL HEALTHCARE FACILITIES

This Chapter adopts some of the modifications made by the 'A' chapters of the 2022 California Building Code for DoD's critical healthcare facilities. The 2022 CBC is based on the 2021 IBC. The 2025 CBC, based on the 2024 IBC, was not available when this Chapter was finalized. So, any reference to IBC in this Chapter is to the 2021 IBC and its referenced standards: ASCE 7-16, ACI 318-19, TMS 402-16, AISC 360-16, and AISC 341-16. This Chapter will need to be updated once the 2025 CBC is published.

6-1 IBC CHAPTER 1 – SCOPE AND ADMINISTRATION.

6-1.1 Section 101 – GENERAL.

101.2 – Scope. [Supplement]

For the seismic design of the facilities listed below assigned to SDC D, E, or F, the modifications to 2021 IBC Chapters 16, 18, 19, 21, and 22 included in this chapter apply in addition to those in Chapter 2 of this UFC. Where the provisions of this chapter and those in the 2021 IBC or in Chapter 2 of this UFC are in conflict, the provisions of this chapter govern.

- Group I-2, Condition 2 occupancies, as defined in 2021 IBC Section 308.3, having emergency surgery or emergency treatment facilities.
- Ambulatory care facilities having emergency surgery or emergency treatment facilities.

6-2 IBC CHAPTER 16 – STRUCTURAL DESIGN.

6-2.1 Section 1603 – CONSTRUCTION DOCUMENTS.

1603.1.5 – Earthquake Design Data. [Supplement]

Add the following three items to the list:

12. Applicable horizontal structural irregularities.
13. Applicable vertical structural irregularities.
14. Location of base as defined in ASCE 7-16 Section 11.2.

6-3 IBC CHAPTER 18 – SOILS AND FOUNDATIONS.

6-3.1 Section 1807 – FOUNDATION WALLS, RETAINING WALLS AND EMBEDDED POSTS AND POLES.

1807.1.1 – Design Lateral Soil Loads. [Replacement]

Foundation walls must be designed for the lateral soil loads determined by a geotechnical investigation, in accordance with Section 1803.

1807.1.3 – Rubble Stone Foundation Walls. [Replacement]

Rubble stone foundation walls are not permitted.

1807.1.4 – Permanent Wood Foundation Systems. [Replacement]

Permanent wood foundation systems are not permitted.

1807.2.2 – Design Lateral Soil Loads [Replacement]

Retaining walls shall be designed for the lateral soil loads determined by a geotechnical investigation in accordance with Section 1803 and shall not be less than eighty percent of the lateral soil loads determined in accordance with Section 1610. For use with the load combinations, lateral soil loads due to gravity loads surcharge shall be considered gravity loads and seismic earth pressure increases due to earthquake shall be considered as seismic loads. For structures assigned to Seismic Design Category D, E, or F, the design of retaining walls supporting more than 6 feet (1829 mm) of backfill height shall incorporate the additional seismic lateral earth pressure in accordance with the geotechnical investigation where required in Section 1803.2.

6-4 IBC CHAPTER 19 – CONCRETE.

6-4.1 Section 1901 – GENERAL.

1901.5 – Construction Documents [Supplement]

Add the following item to the list:

12. Detailing of openings larger than 12 inches (305 mm) in any dimension.

6-4.2 Section 1903 – SPECIFICATIONS FOR TESTS AND MATERIALS.

1903.4 – Flat Wall Insulating Concrete Form (ICF) Systems. [Replacement]

Insulating concrete form material used for forming flat concrete walls shall not be permitted for hospitals or correctional treatment centers; they shall conform to ASTM E2634 for skilled nursing and intermediate care facilities and clinics.

1903.5 – Aggregates – Modify ACI 318 Section 26.4.1.2.1(a).(1) as follows: **[Addition]**

(1) Normal weight aggregate: Aggregate shall be nonreactive as determined by one of the methods in ASTM C33 Appendix XI: Methods for Evaluating Potential

for Deleterious Expansion Due to Alkali Reactivity of an Aggregate. Aggregates deemed to be deleterious or potentially deleterious may be used with the addition of a material that has been shown to prevent harmful expansion in accordance with Appendix XI of ASTM C33, when approved by the Authority Having Jurisdiction.

1903.6 – Limits on Cementitious Materials. [Addition]

For hospitals and correctional treatment centers, modify ACI 318 Section 26.4.2.2(b) as follows:

The maximum percentage of pozzolans, including fly ash and silica fume, and slag cement in concrete assigned to all exposure categories shall be in accordance with Table 26.4.2.2(b) and Section 26.4.2.2(b) Items (1) and (2).

Where pozzolans are used as cementitious materials, duration for minimum specified compressive strength of concrete (f_c') that exceeds 28 days shall be considered an alternative system.

1903.7 – Steel Fiber Reinforcement [Addition]

Steel fiber reinforcement is not permitted.

6-4.3 Section 1905 – MODIFICATIONS TO ACI 318.

Retain Section 1905.1.8, renumbered as 1905.1.4, and replace the other modifications to ACI 318-19 made in the 2021 IBC Section 1905 with the following modifications.

1905.1.1 – ACI 318, Section 9.6.1.3. [ACI 318 Modification]

Modify ACI 318, Section 9.6.1.3 by adding the following:

This section shall not be used for members that resist seismic loads, except for the following condition:

Foundation members designed for seismic load combinations including the overstrength factor in hospitals and correctional treatment centers.

The A_s provided shall not be less than that required by 1.2 times the cracking load based upon f_r defined in Section 19.2.3.

1905.1.2 – ACI 318, Section 11.2.4.1. [ACI 318 Replacement]

Replace ACI 318, Section 11.2.4.1 as follows:

11.2.4.1 – Walls shall be anchored to intersecting elements such as floors or roofs; or to columns, pilasters, buttresses, of intersecting walls and footings with reinforcement at least equivalent to No. 4 bars at 12 inches (305 mm) on center for each layer of reinforcement.

1905.1.3 – ACI 318, Section 12.7.3 [ACI 318 Addition]

Add Section 12.7.3.4 to ACI 318 as follows:

12.7.3.4 - At least two No. 5 bars in diaphragms having two layers of reinforcement in both directions and one No. 5 bar in diaphragms having a single layer of reinforcement in both directions must be provided around openings larger than 12 inches in any dimension in addition to the minimum reinforcement required by Section 12.6. Extend bars beyond the opening sufficient to develop their capacity.

1905.1.5 – ACI 318, Section 18.12.6 [ACI 318 Addition]

Add Section 18.12.6.2 to ACI 318 as follows:

18.12.6.2 – Collector and boundary elements in topping slabs placed over precast floor and roof elements shall not be less than 3 inches (76 mm) or $6d_b$ thick, where d_b is the diameter of the largest reinforcement in the topping slab.

1905.1.6 – ACI 318, Section 26.12.2.1(a). [ACI 318 Replacement]

Replace ACI 318 Section 26.12.2.1(a) by the following:

26.12.2.1(a) Samples for strength tests of each class of concrete placed each day shall be taken not less than once a day, or not less than once for each 50 cubic yards (345 m^3) of concrete, or not less than once for each 2,000 square feet (186 m^2) of surface area for slabs or walls. Additional samples for 7-day compressive strength tests shall be taken for each class of concrete at the beginning of the concrete work or whenever the mix or aggregate is changed.

6-5 IBC CHAPTER 21 – MASONRY.

6-5.1 Section 2101 – GENERAL.

2101.1.1 – Prohibition [Addition]

The following design methods, systems, and materials in TMS 402-16 are not permitted:

1 Unreinforced masonry

2 Autoclaved aerated concrete (AAC) masonry

3 Empirical design of masonry

4 Adobe construction

5 Ordinary reinforced masonry shear walls

6 Intermediate reinforced masonry shear walls

7 Prestressed masonry shear walls

8 Simplified Direct Design procedure for masonry

6-5.2 Section 2106 – SEISMIC DESIGN.

2106.1.1 – TMS 402-16, Sections 5.3.1.4(a) and 5.3.1.4(b) [IBC Addition, TMS Replacement]

Replace TMS 402-16, Sections 5.3.1.4(a) and 5.3.1.4(b) as follows:

a. Ties must be at least 3/8 inch (10 mm) in diameter and must be embedded in grout. Top tie must be within 2 inches (51 mm) of the top of the column or of the bottom of the horizontal bar in the supported beam.

b. The spacing of column ties must be as follows: not greater than 8 bar diameters, 24 tie diameters, or one half the least dimension of the column, or 8 inches (203 mm) for the full column height.

2106.1.2 – TMS 402-16, Chapter 5 [IBC Addition, TMS Addition]

Add TMS 402-16, Section 5.6 as follows:

5.6 – Lateral Support of Members

5.6.1 – Lateral support of masonry may be provided by cross walls, columns, plasters, counterforts or buttresses where spanning horizontally, or by floors, beams, girts or roofs where spanning vertically. Where walls are supported laterally by vertical elements, the stiffness of each vertical element shall exceed that of the tributary area of the wall.

2106.1.3 – TMS 402-16, Sections 7.4.4.1 and 7.4.5.1. [IBC Addition, TMS Replacement, Deletion]

Replace TMS 402-16, Section 7.4.4.1 as follows and delete Section 7.4.5.1:

7.4.4.1 – Minimum Reinforcement Requirements for Masonry Walls.

The total area of reinforcement in reinforced masonry walls must not be less than 0.003 times the sectional area of the wall. Neither the horizontal nor the vertical reinforcement is permitted to be less than one third of the total. Horizontal and vertical reinforcement must be spaced at not more than 24 inches (610 mm) center to center. Where stack bond is used in reinforced hollow-unit masonry, the open-end type of unit shall be used with vertical reinforcement spaced a maximum of 16 inches (406 mm) on center.

7.4.4.1.1 The smallest bar diameter permitted is No. 4, except that No. 3 bars may be used for ties and stirrups. Vertical wall reinforcement needs to have dowels of equal size and equal matched spacing in all footings. Reinforcement must be continuous around wall corners and through intersections. Only reinforcement that is continuous in the wall is permitted in computing the minimum area of reinforcement. Reinforcement with splices conforming to TMS 402-16 can be considered as continuous reinforcement.

7.4.4.1.2 Horizontal reinforcing bars in bond beams must be provided at the top of footings, at the top of wall openings, at roof and floor levels, and at the top of parapet walls. For walls 12 inches (nominal) (305 mm) or more in thickness, horizontal and vertical reinforcement must be equally divided into two layers, except where designed as retaining walls. Where reinforcement is added above the minimum requirements, such additional reinforcement need not be so divided.

7.4.4.1.3 Provide trim bars around openings in reinforced masonry walls of not less than one number 5 bar (or two number 4 bars) for all openings greater than 24 inches (406mm) in any direction. Extend said trim bars 24 inches or 48 bar diameters beyond the corners of the opening, whichever is greater. Trim bars noted in this requirement are in addition to minimum reinforcement elsewhere.

7.4.4.1.4 When reinforcement in bearing walls is designed, placed, and anchored in position as for columns, the allowable stresses must be as for columns.

7.4.4.1.5 Joint reinforcement is not permitted to be used as principal reinforcement in masonry.

6-5.3 Section 2107 - ALLOWABLE STRESS DESIGN.

2107.4 – TMS 402-16, Section 8.3.4.4 Walls [IBC Addition, TMS Supplement]

Modify TMS 402-16, Section 8.3.4.4 as follows by adding:

8.3.4.4.1 The minimum thickness of walls is given in Section 8.3.4.4.2. Stresses must be determined on the basis of the net thickness of the masonry, with consideration for reduction, such as raked joints.

8.3.4.4.2 The thickness of masonry walls must be designed so that allowable maximum stresses specified in Chapter 8 of TMS 402-16 are not exceeded. Also, masonry walls are not permitted to exceed the height or length-to-thickness ratio nor be less than the minimum thickness as specified in Chapter 8 of TMS 402-16 and as set forth in Table 6-1.

8.3.4.4.3 Every pier or wall section with a width less than three times its thickness shall be designed and constructed as required for columns if such pier is a structural member. Every pier or wall section with a width between three and five times its thickness or less than one half the height of adjacent openings shall have all horizontal steel in the form of ties except that in walls 12 inches (305 mm) or less in thickness such steel may be in the form of hairpins.

2107.5 – Masonry Compressive Strength [IBC Addition]

The specified compressive strength of structural masonry must be equal to or exceed 1,500 psi (10.34 MPa). The value of specified compressive strength used to determine nominal strength value in Chapter 8 of TMS 402-16 must not exceed 3,000 psi (20.7 MPa) for concrete masonry and must not exceed 4,500 psi (31.03 MPa) for clay masonry.

6-5.4 Section 2108 – STRENGTH DESIGN OF MASONRY.

2108.4 – TMS 402, Section 9.1.9.1.1.[IBC Addition, TMS Modification]

Modify TMS 402, Section 9.1.9.1.1 as follows:

9.1.9.1.1 – Masonry Compressive Strength. The specified compressive strength of structural masonry must be equal to or exceed 1,500 psi (10.34 MPa). The value of specified compressive strength used to determine nominal strength value in chapter 9 of TMS 402-16 must not exceed 3,000 psi (20.7 MPa) for concrete masonry and must not exceed 4,500 psi (31.03 MPa) for clay masonry.

6-6 IBC CHAPTER 22 – STEEL.

6-6.1 Section 2204 – CONNECTIONS.

2204.1.1 – Restrained Welded Connections. [Addition]

In hospitals and correctional treatment centers, welded structural steel connections having a medium or high level of restraint, as defined by AWS D1.1 Annex H, shall have a minimum pre-heat temperature of not less than 150° F (66° C). Welded structural steel connections with welds to flange, web, wall or plate having a high level of restraint shall maintain a post-heat temperature of 300° F (149° C) for a minimum of 1 hour after completion of welding

2204.4 – Column Base Plate. [Addition]

When shear and/or tensile forces are intended to be transferred between column base plates and anchor bolts, provisions shall be made in the design to eliminate the effects of oversized holes permitted in base plates by AISC 360 by use of shear lugs into the reinforced concrete foundation element and/or welded shear transfer plates or other means acceptable to the Authority Having Jurisdiction, when the oversized holes are larger than the anchor bolt by more than 1/8 inch (3.2 mm). When welded shear transfer plates and shear lugs or other means acceptable to the Authority Having Jurisdiction are not used, the anchor bolts shall be checked for the induced bending stresses in combination with the shear stresses.

6-6.2 Section 2207 – STEEL JOISTS.

2207.6 – Joist Chord Bracing. [Addition]

The chords of all joists shall be laterally supported at all points where the chords change direction.

6-6.3 Section 2210 – COLD-FORMED STEEL.

2210.1.1.2 – Steel Roof Deck [Supplement]

Add the following to the end of the paragraph:

In hospitals and correctional treatment centers, steel roof deck is not permitted to be thinner than 20-gauge.

6-6.4 Section 2211 – COLD-FORMED STEEL LIGHT-FRAMED CONSTRUCTION.

2211.1.2 – Prescriptive Framing [Replacement]

Prescriptive framing systems are not permitted within the seismic force-resisting system of a building.

Table 6-1 Minimum Thickness of Masonry Walls[1,2]

Type of Masonry	Maximum Ratio of Unsupported Height or Length to Thickness[2,3]	Nominal Minimum Thickness (Inches)
Bearing or Shear Walls:		
1. Stone masonry	14	16
2. Reinforced grouted masonry	25	6
3. Reinforced hollow unit masonry	25	6
Nonbearing Walls:		
4. Exterior reinforced walls	30	6
5. Interior reinforced partitions	36	4

1. For varying thickness, use the least thickness when determining the height or length to thickness ratio.
2. In determining the height or length-to-thickness ratio of a cantilevered wall, use a dimension that is twice the dimension of the end of the wall from the lateral support.
3. Cantilevered walls not part of a building and not carrying applied vertical loads need not meet these minimum requirements but their design must comply with stress and overturning requirements.

CHAPTER 7 MODIFICATIONS TO ASCE 7-16 FOR CRITICAL HEALTHCARE FACILITIES

This Chapter adopts some of the modifications made by Section 1617A of the 2022 California Building Code to ASCE 7-16 for DoD's critical healthcare facilities. The 2022 CBC is based on the 2021 IBC. The 2025 CBC, based on the 2024 IBC, was not available when this Chapter was finalized. So, any reference to IBC in this Chapter is to the 2021 IBC and its referenced standards: ASCE 7-16, ACI 318-19, TMS 402-16, AISC 360-16, and AISC 341-16. This Chapter will need to be updated once the 2025 CBC is published.

7-1 ASCE 7-16 CHAPTER 11 – SEISMIC DESIGN CRITERIA.

7-1.1 Section 11.1 – GENERAL.

11.1.2 – Scope [Supplement]

For the facilities listed below and assigned to SDC D, E, or F, the modifications to ASCE 7-16 included in this chapter apply in addition to those in Chapter 3 of this UFC. Where the provisions of this chapter and those in ASCE 7-16 or in Chapter 3 of this UFC are in conflict, the provisions of this chapter govern.

- Group I-2, Condition 2 occupancies, as defined in 2021 IBC Section 308.3, having emergency surgery or emergency treatment facilities.
- Ambulatory care facilities having emergency surgery or emergency treatment facilities.

7-2 ASCE 7-16 CHAPTER 12 – SEISMIC DESIGN REQUIREMENTS FOR BUILDING STRUCTURES.

7-2.1 Section 12.1 – STRUCTURAL DESIGN BASIS.

12.1.7 – Structural Configuration. [Addition]

The following configuration limitations apply to structures within the scope of this chapter.

1. Bay spacing must be essentially equal and uniform throughout.
2. Transfer beams or trusses supporting upper-level columns are not to be used unless permitted on a case by case basis by the AHJ.
3. Seismic joints must be avoided, if at all possible. When required, they need to be specifically identified in the schematic design phase of the project and approved by the AHJ, subject to the following provisions:
   a. Seismic joints must be properly detailed on the working drawings;

b. Seismic joints must be sized based on the maximum expected displacements, considering the effects of story drift, diaphragm displacements and rotations, and a realistic approximation of element section properties. For materials designed considering the ultimate limit state, such as concrete, the stiffness representative of this state must be used. Seismic separations must be at least 125% of the separation required by ASCE 7-16.

4. Adjacent structures that are not integral with an existing structure must be separated by not less than 2 inches per story.

12.1.8 – Limitations on Seismic Force-Resisting Reinforced Concrete Structural Members. [Addition]

Lightweight concrete is not permitted to be used in structural members resisting seismic forces, except in concrete floors and roof slabs used as diaphragms to distribute earthquake forces to vertical seismic force-resisting members.

12.1.9 – Limitations on Seismic Force-Resisting Steel Structural Members. [Addition]

Steel eccentrically braced systems must be subject to the additional limitation that connections of nonstructural components are not to be located in the vicinity of EBF link beams. Such connections include, but are not limited to, precast panel connections, elevator guide rail supports, staircase supports, pipe supports, etc.

7-2.2 Section 12.2 – STRUCTURAL SYSTEM SELECTION.

12.2.1 – Selection and Limitations. [Supplement]

Table 7-1, Replacement for ASCE 7-16 Table 12.2-1, must be used in lieu of ASCE 7-16 Table 12.2-1. Only the structural systems included in Table 7-1 are permitted to be used in structures within the scope of this chapter.

Unless specifically prohibited in Chapter 6 of this UFC, other structural systems that are permitted by ASCE 7-16 for SDC D, E or F, including those employing seismic isolation and seismic damping systems are permitted subject to written approval by the AHJ. Proposals to obtain written approval for other structural systems must demonstrate the equivalent performance of those systems, relative to the permitted systems, considering (a) initial construction and maintenance costs, (b) requirements for bracing nonstructural components and building contents, (c) risk of economic losses and disruption to hospital functions due to earthquakes and (d) other demonstrable benefits.

12.2.3.1 – R, C_d , and Ω_o Values for Vertical Combinations. [Replacement]

Replace ASCE 7, Section 12.2.3.1, Items 1 and 2, by the following:

The value of the response modification coefficient, *R*, used for design at any story shall not exceed the lowest value of *R* that is used in the same direction at any story above that story. Likewise, the deflection amplification factor, C_d , and the system overstrength factor, Ω_o , used for the design at any story shall not be less than the largest value of these factors that are used in the same direction at any story above that story.

12.2.3.2 – Two-Stage Analysis Procedure. [Supplement]

Modify Item a, and add Items f, and g, as follows:

a. The stiffness of the lower portion shall be at least 10 times the stiffness of the upper portion. For purposes of determining this ratio, the base shear shall be computed and distributed vertically according to ASCE 7-16 Section 12.8. Using these forces, the stiffness for each portion shall be computed as the ratio of the base shear for that portion to the elastic displacement, δ_{xe} , computed at the top of that portion, considering the portion fixed at its base. For the lower portion, the applied forces shall include the reactions from the upper portion, modified as required in Item d.

f. Where Horizontal Irregularity Type 4 or Vertical Irregularity Type 4 exists at the transition from the upper to the lower portion, the reactions from the upper portion shall be amplified in accordance with ASCE 7-16 Sections 12.3.3.3, 12.10.1.1 and 12.10.3.3 as applicable, in addition to amplification required by Item d.

g. Where design of members in the upper portion is governed by the seismic load effects with overstrength, as defined in ASCE 7-16 Section 12.4.3, the amplified loads must be considered in the design of the lower portion.

Table 7-1 Replacement for ASCE 7-22 Table 12.2-1
Design Coefficients and Factors for Basic Seismic Force-Resisting Systems

BASIC SEISMIC FORCE-RESISTING SYSTEM	*DETAILING REFERENCE SECTION*	RESPONSE MODIFICATION COEFFICIENT R^a	SYSTEM OVERSTRENGTH FACTOR, $\Omega_o{}^b$	DEFLECTION AMPLIFICATION FACTOR, $C_d{}^c$	STRUCTURAL SYSTEM LIMITATIONS INCLUDING STRUCTURAL HEIGHT, h_n, (FEET) LIMITS BY SEISMIC DESIGN CATEGORY[d]				
					B	C	D[e]	E[e]	F[f]
B. Building Frame Systems									
1. Steel eccentrically braced frames	***(F3)***[r]	8	2	4	NL	NL	160	160	100
2. Steel special concentrically braced frames	***(F2)***[r]	6	2	5	NL	NL	160	160	100
4. Special reinforced concrete shear walls[g,h]	***(18.2.1.6)***[s]	6	2-1/2	5	NL	NL	160	160	100
5. Reinforced concrete ductile coupled walls[w]	***(18.10.9)***[s]	8	2-1/2	8	NL	NL	160	160	100
17. Special reinforced masonry shear walls	***(7.3.2.5)***[t]	5-1/2	2-1/2	4	NL	NL	160	160	100
24. Light-frame (wood) walls sheathed with wood structural panels rated for shear resistance	***(2301-2307)***[u]	7	2-1/2	4-1/2	NL[v]	NL[v]	65[v]	65[v]	65[v]
25. Light-frame (cold-formed steel) walls sheathed with wood structural panels rated for shear resistance or with steel sheets	***(2206, 2301-2307)***[u]	7	2-1/2	4-1/2	NL[v]	NL[v]	65[v]	65[v]	65[v]
26. Steel buckling-restrained braced frames	***(F4)***[r]	8	2-1/2	5	NL	NL	160	160	100
C. Moment-Resisting Frame Systems									
1. Steel special moment frames	***(E3)***[r]	8	3	5-1/2	NL	NL	NL	NL	NL
5. Special reinforced concrete moment frames[m]	***(18.2.1.6)***[s]	8	3	5-1/2	NL	NL	NL	NL	NL
D. Dual Systems with Special Moment Frames Capable of Resisting at Least 25% of Prescribed Seismic Forces [ASCE 7-16 12.2.5.1]									

Table 7-1 (Continued) Replacement for ASCE 7-22 Table 12.2-1 Design Coefficients and Factors for Basic Seismic Force-Resisting Systems

BASIC SEISMIC FORCE-RESISTING SYSTEM	DETAILING REFERENCE SECTION	RESPONSE MODIFICATION COEFFICIENT R[a]	SYSTEM OVERSTRENGTH FACTOR, Ω_0[b]	DEFLECTION AMPLIFICATION FACTOR, C_d[c]	STRUCTURAL SYSTEM LIMITATIONS INCLUDING STRUCTURAL HEIGHT, h_n, (FEET) LIMITS BY SEISMIC DESIGN CATEGORY[d]				
					B	C	D[e]	E[e]	F[f]
1. Steel eccentrically braced frames	*(F3)*[r]	8	2-1/2	4	NL	NL	NL	NL	NL
2. Special reinforced concrete shear walls[g,h]	***(18.2.1.6)***[s]	7	2-1/2	5-1/2	NL	NL	NL	NL	NL
3. Reinforced concrete ductile coupled walls[w]	***(18.10.9)***[s]	8	2-1/2	8	NL	NL	NL	NL	NL
11. Special reinforced masonry shear walls	***(7.3.2.5)***[t]	5-1/2	3	5	NL	NL	NL	NL	NL
13. Steel buckling-restrained braced frames	***(F4)***[r]	8	2-1/2	5	NL	NL	NL	NL	NL

FOR SI: 1 foot (ft) = 304.8 mm, 1 pound per square foot (psf) = 0.0479 kN/m²

a. Response modification coefficient, *R*, for use throughout. Note *R* reduces forces to a strength level, not an allowable stress level.

b. Where the tabulated value of the overstrength factor, Ω_o, is greater than or equal to 2½, Ω_o is permitted to be reduced by subtracting the value of ½ for structures with flexible diaphragms.

c. Deflection amplification factor, C_d, for use in ***ASCE 7*** Sections 12.8.6, 12.8.7, 12.9.1.2, ***12.12.3, and 12.12.4***.

d. NL= Not limited and NP = Not permitted. For metric units, use ***30*** m for 100 ft and ***50*** m for 160 ft.

e. See ***ASCE 7-16*** Section 12.2.5.4 for a description of seismic force-resisting systems limited to buildings with a structural height, h_n, of 240 feet (***75*** m) or less.

f. See ***ASCE 7-16*** Section 12.2.5.4 for seismic force-resisting systems limited to buildings with a structural height, h_n, of 160 feet (***50*** m) or less.

g. In Section 2.3 of ACI 318, a shear wall is defined as a structural wall.

h. In Section 2.3 of ACI 318, the definition of “special structural wall” includes precast and cast-in-place construction.

m. In Section 2.3 of ACI 318, the definition of “special moment frame” includes precast and cast-in-place construction.

r. ANSI/AISC 341-16 section number.

s. ACI 318-19, Section 18.2.1.6 cites appropriate sections in ACI 318-19.

t. TMS 402-16 section number.

u. 2021 IBC section numbers.

v. Permitted only for structures up to two-stories

w. Structural height, h_n, shall not be less than 60 ft (18.3m).

7-2.3 Section 12.3 – DIAPHRAGM FLEXIBILITY, CONFIGURATION IRREGULARITIES, AND REDUNDANCY.

12.3.3.1 – Prohibited Horizontal and Vertical Irregularities for Seismic Design Categories D through F. [Replacement]

Structures having horizontal structural irregularity Type 1b of ASCE 7-16 Table 12.3-1 or vertical structural irregularities Type 1b, 5a or 5b of ASCE 7-16 Table 12.3-2 are not permitted.

7-2.4 Section 12.7 – MODELING CRITERIA.

12.7.3 – Additional Lateral Force [Addition]

Where buildings provide lateral support for walls retaining earth, and the exterior grades on opposite sides of the building differ by more than 6 feet (1829 mm), the seismic increment of earth pressure due to earthquake acting on the higher side, as determined by a geotechnical engineer qualified in soils engineering, plus the difference in earth pressures shall be added to the design lateral forces.

Renumber existing Sections 12.7.3 and 12.7.4 as 12.7.4 and 12.7.5, respectively.

7-2.5 Section 12.12 – DRIFT AND DEFORMATION.

12.12.3 – Structural Separation. [Replacement]

Replace ASCE 7-16 Equation 12.12-1 by the following:

$$\delta_M = C_d \delta_{max} \qquad \text{(Equation 12.12-1)}$$

7-3 ASCE 7-16 CHAPTER 13 – SEISMIC DESIGN REQUIREMENTS FOR NONSTRUCTURAL COMPONENTS.

7-3.1 Section 13.2 – GENERAL DESIGN REQUIREMENTS.

13.2.2 – Special Certification Requirements for Designated Seismic Systems [Supplement]

Special Seismic Certification must be provided in accordance with the requirements of ASCE 7-16 Section 13.2.2, except for equipment and components that are on the HCAI Special Seismic Certification Preapproval (OSP) list, issued by California’s Department of Health Care Access and Information (HCAI).

Items prequalified under the Special Seismic Certification Preapproval (OSP) program of HCAI are deemed to possess Special Seismic Certification required by ASCE 7-16 Section 13.2.2.

[C] 13.2.2 – Special Certification Requirements for Designated Seismic Systems [Supplement]
HCAI has issued a Policy Intent Notice (PIN) 55 on its Special Seismic Certification Preapproval (OSP) program. This program offers a means to obtain prequalification of product lines for special seismic certification. Lists of equipment that is pre-approved by HCAI can be found at https://hcai.ca.gov/facilities/building-safety/preapproval-programs/osp/ and https://hcai.ca.gov/facilities/building-safety/preapproval-programs/osp-by-category/. The basis of HCAI preapproval is always shake table testing in compliance with ICC-ES AC156 and satisfaction of ICC-ES AC156 post-test acceptance criteria.

7-3.2 Section 13.4 – NONSTRUCTURAL COMPONENT ANCHORAGE.

13.4.2.3 – Post-Installed Anchors in Concrete and Masonry [Replacement]

Revise section title to: **Prequalified Post-Installed Anchors and Specialty Inserts in Concrete and masonry.**

Replace text with: Post-installed anchors and specialty inserts in concrete that are prequalified for seismic applications in accordance with ACI 355.2, ACI 355.4, ICC-ES AC193, ICC-ES AC232, ICC-ES AC308 or ICC-ES AC446 are permitted. Post-installed anchors in masonry must be pre-qualified for seismic applications in accordance with ICC-ES AC01, AC58 or AC106.

Use of screw anchors is limited to dry interior conditions. Screw anchors are not permitted for use in building exterior envelopes. Re-use of screw anchors or screw anchor holes is not permitted.

7-3.3 Section 13.5 – ARCHITECTURAL COMPONENTS.

13.5.7 – Access Floors [Supplement]

In hospitals and correctional treatment centers, all access floors must be special access floors in accordance with ASCE 7-16 Section 13.5.7.2, except for raised roof or exterior floor paver systems.

7-3.4 Section 13.6 – MECHANICAL AND ELECTRICAL COMPONENTS.

13.6.11.1.1 – Elevator guide rail support. [Addition]

The design of guide rail support-bracket fastenings and the supporting structural framing must use the weight of the counterweight or maximum weight of the car plus not less than 40 percent of its rated load. The seismic forces must be assumed to be distributed one third to the top guiding members and two thirds to the bottom guiding members of cars and counterweights, unless other substantiating data are provided. In addition to the requirements of ASCE 7-16, Section 13.6.11.1, the minimum ASD-level seismic forces must be 0.5g acting in any horizontal direction.

7-4 ASCE 7-16 CHAPTER 17 – SEISMIC DESIGN REQUIREMENTS FOR SEISMICALLY ISOLATED STRUCTURES.

7-4.1 Section 17.4 – ANALYSIS PROCEDURE SELECTION.

17.4.2.3 – Linear Procedures [Addition]

Linear procedures must not be used in Seismic Design Category E or F structures.

7-5 ASCE 7-16 CHAPTER 18 – SEISMIC DESIGN REQUIREMENTS FOR STRUCTURES WITH DAMPING SYSTEMS.

18.3 – Nonlinear Response History Procedure [Supplement]

Add the following to the Exception:

For this section, the MCE_R response shall be based on the largest response due to a single ground motion and not the average response of a suite of ground motions.

APPENDIX A BEST PRACTICES

A-1 STRUCTURAL DESIGN.

A-1.1 Building Drift Limits.

The topic of serviceability is addressed in IBC Section 1604.3 which requires: “Structural systems and members thereof shall be designed to have adequate stiffness to limit deflections as indicated in Table 1604.3.” Section 1604.3.1 requires: “The deflections of structural members shall not exceed the more restrictive of the limitations of Sections 1604.3.2 through 1604.3.5 or that permitted by Table 1604.3.” Sections 1604.3.2 through 1604.3.5 refer to ACI 318 requirements for concrete, AISC 360, AISI S100, ASCE 8, SJI 100 or SJI 200 requirements for steel, TMS 402 requirements for masonry, and AA ADM requirements for Aluminum. However, the section is obviously focused on structural members, not an entire building or structure.

ASCE 7-22 Section 12.12 requires interstory drift caused by code-prescribed seismic forces to be within tolerable limits as obtained from Table 12.12-1. These are the only mandatory building drift limits of the IBC.

ASCE 7-22 Appendix C, Serviceability Considerations, which is non-mandatory, states in Section C.2.2: “Lateral deflection or drift of structures and deformation of horizontal diaphragms and bracing systems caused by wind effects must not impair the serviceability of the structure.” The extensive commentary on this appendix discusses how the above objective might be accomplished, but leaves it to engineering judgment that should be exercised in consultation with the building owner.

The establishment of acceptable drift limits and load combinations that must be considered in evaluating serviceability does require significant engineering judgment. Application of a requirement that is overly stringent can significantly impact the cost of a structure. Lax requirements, on the other hand, can lead to damage of rigidly connected components.

The *Metal Building Systems Manual* provides guidance on allowable drift due to wind loads for pre-engineered metal buildings, and serviceability recommendations for metal buildings can also be found in Chapter L of AISC 360 with additional guidance in AISC *Steel Design Guide 3*.

When separate support columns are used for top-running cranes, they should be supported so that differential movement between the crane columns and building columns, due to differences in stiffness, does not overstress either set of columns and result in local column buckling.

A-1.2 Impact Resistant Glazing.

Buildings that are subjected to tornado winds can suffer some of the same missile impact damage to the exterior façade of the building as those located in windborne debris regions. The loss of glazing on a building due to missile impact can render the facility inoperable. The loss of glazing will also cause an increase in internal pressure in the building, causing further damage. ASCE 7-22 has added a whole new Chapter 32 on design for tornado loads. Tornado-Prone Region is defined in Section 32.2 as "The area of the conterminous United States most vulnerable to tornadoes, as shown in Figure 32.1-1." Section 32.12.3 is applicable in tornado-prone regions and requires: "Glazed openings shall be protected as specified in this section for Essential Facilities and for buildings and other structures required to maintain the functionality of Essential Facilities." Protection requirements for glazed openings are given in Section 32.12.3.1. Design for tornado loads given in Chapter 32 is not required for RC I or II structures. Consideration should be given to providing impact resistant glazing on facilities that are not covered by Section 32.12.3 in tornado prone areas similar to what is required in wind-borne debris regions as specified in IBC Section 1609.2.

A-1.3 Hard Wall Buildings.

In buildings constructed of load bearing tilt-up or precast structural walls, the loss of the roof diaphragm during a high wind event can lead to total collapse of the structure.

FEMA has issued an important publication, FEMA P-1026, on the seismic design of these buildings. ASCE 7-22 has added Section 12.10.4, based on the FEMA P-1026 document.

A-1.4 Wind and Seismic Loads on Photovoltaic Arrays.

Design provisions for rooftop-mounted photovoltaic panels and their attachments are included in ASCE 7-22 Section 13.6.12 for seismic loading and in ASCE 7-22 Chapters 29 through 31 for wind loading. Additional guidance on the design wind and seismic loads for rooftop-mounted photovoltaic arrays can be found in *Wind Design for Solar Arrays* (SEAOC PV2-2017) and *Structural Seismic Requirements and Commentary for Rooftop Solar Photovoltaic Arrays* (SEAOC PV1-2012), prepared by the Structural Engineers Association of California Solar Photovoltaic Systems Committee. When designing support structures for photovoltaic arrays, review requirements in UFC 3-110-03 *Roofing* concerning roof mounted systems including the requirement that supports be permanently affixed to the structure, which means that ballasted systems are not permitted. 2024 IBC Section 1607.14.4 includes gravity load requirements for roof structures that provide support for photovoltaic panel systems. This section does not disallow ballasted systems. Seismic design of ballasted photovoltaic panel systems is in fact specifically permitted by 2024 IBC Section 1613.3.

A-1.5 Wind Loads on Buildings with Large Openings.

When determining wind loads on building containing large openings such as overhead doors in warehouses, maintenance shops, etc., it is recommended that the criteria for hangars in Section 1609.1.2 of Chapter 2 of this UFC be used.

A-2 SOILS AND FOUNDATIONS.

A-2.1 Gable Bent Footings.

Moment frame reactions from metal building gable bents have horizontal thrusts at column bases which can be resisted by several methods. For large thrust forces (40 to 50 kips (118 kN to 222 kN)), tie rods are usually cost-effective. The tie rods can be embedded in a thickened slab or can be part of a tie beam between column foundations. For smaller thrust forces, hairpin reinforcing bars may be used to transfer the thrust force from the column anchor bolts into the slab-on-ground reinforcement, which acts as the tie between the columns. However, each of these methods requires close attention to detailing of joints in the slab, isolation joints around a foundation pier and other possible interruptions in the continuous slab reinforcement between columns. Also, future renovations that might require trenching across the continuous slab reinforcement could result in the loss of the tension tie. A third method must design the foundation for an overturning moment due to the thrust force at the base of the column. Each of these methods can provide the necessary resistance to the thrust force but needs to be evaluated for each project condition. For further discussion on the design of foundations for gable bent reactions, refer to *Metal Building Systems: Design and Specification* by Alexander Newman.

A-2.2 Footings on Expansive Soils.

In the presence of expansive soils, footings must be designed to withstand expansive soil movement in order to prevent significant damage to structures. Cyclical expansive soil movement from soil water content, usually caused by a combination of inadequate drainage and seasonal wetting and drying cycles, are especially troublesome. Base the design on soil testing and recommendations by qualified geotechnical engineers. Ensure soil investigations include estimates of settlement, heave, and recommendations to mitigate effects of expansive soil movement. Ensure positive drainage away from structures that will prevent ponding close to structures. Guidance on design of foundations on expansive soils can be found in UFC 3-220-01 and PTI DC 10.5-21.

A-2.3 Footing Depth Considering Frost.

Footing depth for frost must be provided by the project geotechnical engineer

A-3 CONCRETE.

A-3.1 Slab-on-Ground Concrete Strength.

Reference guidance in *"Design of Concrete Floor Slabs-on-Ground for DoD Facilities"* under Related Materials for this UFC (WBDG page for 3-301-01).

A-3.2 Slab-on-Ground Joints.

Reference guidance in *"Design of Concrete Floor Slabs-on-Ground for DoD Facilities"* under Related Materials for this UFC (WBDG page for 3-301-01).

A-3.3 Slab-on-Ground Drying Shrinkage.

Reference guidance in "Design of Concrete Floor Slabs-on-Ground for DoD Facilities" under Related Materials for this UFC (WBDG page for 3-301-01).

A-3.4 Slab-on-Ground Vapor Retarder/Barrier.

Reference guidance in "Design of Concrete Floor Slabs-on-Ground for DoD Facilities" under Related Materials for this UFC (WBDG page for 3-301-01).

A-4 MASONRY.

A-4.1 Masonry Veneer Base Detail.

The base of masonry veneer should be placed on a foundation ledge that is lower than the base of the stud wall by at least 4 inches (102 mm). The width of this foundation ledge will include the width of the masonry veneer and the cavity. This width should not be less than two-thirds of the veneer thickness plus the minimum air space.

A-5 STEEL.

A-5.1 Shelf Angles for Masonry.

Shelf angles should be hot-dip galvanized structural steel members. Angles should be provided in segments approximately 10 feet (3 m) in length, with gaps between segments. Shelf angles should be detailed to allow enough gaps for thermal expansion and contraction of the steel in angle runs and at building corners. Corners of buildings should have corner pieces with each leg no less than 4 feet (1.2 m) in length where possible.

Limit deflection of horizontal legs of shelf angles under masonry loading to 1/16 inch (1.6 mm) at the end of the horizontal leg. Rotation of the shelf angle support should be included in the horizontal leg displacement calculation.

A-5.2 Cold-Formed Continuous Beams and Joists.

Guidance on determining the effective length of the unbraced compression flange for cold-formed continuous beams and joists can be found in AISI *Effective Lengths for Laterally Unbraced Compression Flanges of Continuous Beams Near Intermediate Supports*.

A-5.3 Masonry Veneer/Steel Stud Wall Detailing.

Recommended details for masonry veneer/steel stud wall assemblies can be found in BIA Technical Note 28B.

A-5.4 Steel Structures in Corrosive Environments.

Steel structures designed for corrosive environments should include consideration of the following corrosion protection measures:

a. Box-shaped members should be designed so that all inside surfaces may be readily inspected, cleaned, and painted, or should be closed entirely, except when hot-dip galvanized, to prevent exposure to moisture.

b. The legs of two back-to-back angle members, when not in contact, should have a minimum separation of 3/8 inch (9.5 mm) to permit air circulation.

c. Pockets or depressions in horizontal members should have drain holes to prevent water from ponding in low areas. Positive drainage should be provided away from exposed steel. Column bases should be terminated on concrete curbs or piers above grade, and tops of curbs or piers should be pitched to drain.

d. Where extremely corrosive conditions exist, consideration should be given to providing cathodic protection in addition to protective coatings for steel members exposed to saltwater moisture environments.

e. Structural members embedded in concrete and exterior railing, handrails, fences, guardrails, and anchor bolts should be galvanized or constructed of stainless steel.

f. Dissimilar metals, (e.g., aluminum and steel, stainless steel and carbon steel, zinc-coated steel and uncoated steel) should be isolated by appropriate means to avoid the creation of galvanic cells which can occur when dissimilar metals come in contact.

g. Consult a corrosion specialist certified by NACE International to recommend material protection for elements exposed to heavy industrial pollution, chemicals, or corrosive soils.

h. For increased serviceability and compatibility with fireproofing, use galvanized steel deck in accordance with ASTM A653/A653M.

i. Note that some common grades of stainless alloy such as ASTM A306 or A316 are susceptible to corrosion when immersed in salt or brackish water.

Further guidance for designing steel structures in corrosive environments can be found in ASM [formerly, American Society of Metals] *Handbook Volume 13B*.

A-5.5 Steel Structures in Arctic and Antarctic Zones.

For carbon steel, the transition from ductile to brittle behavior occurs within temperatures to be expected in Arctic and Antarctic zones. Ductility is important for structures in high seismic areas. Toughness, a characteristic also affected by cold temperatures, is important for structures which could be subjected to cyclic or impact loads. Design of structures which could be subjected to cyclic or impact loads in cold climates should include consideration of the following measures to mitigate potential fatigue and fracture problems:

a. Provide ample fillets to avoid stress risers.

b. Use bolted joints whenever possible. If welded joints are used, take precautions to eliminate gas and impurities in welds. Proper preheating and post-cooling are essential.

c. Use low-carbon steels and nickel-alloy steels that have good toughness characteristics at low temperatures.

A-5.6 Steel Column Base Plate Shear Transfer.

Shear transfer between column base plates and the concrete foundation elements can be accomplished through several load paths including shear friction between the base plate and grout, anchor rods or shear keys. The design provisions in AISC *Design Guide 1: Base Plate and Anchor Rod Design* should be followed when designing base plates for shear. Research and full-scale testing of base plates in shear, conducted at the University of California, Berkeley, provide further guidance on recommended shear friction coefficient, anchor rod bending length, and concrete capacity design of shear key bearing. Results of the testing can be found in the research report *Shear Transfer in Exposed Column Base Plates*, published by AISC.

A-5.7 Steel Joist Connections.

Connections between open web steel joists and supporting girders or joist girders and building columns are in many instances covered by typical details provided by the joist supplier, which may not provide the needed capacity for lateral or uplift loading. Each joist connection should be designed specifically for the project and take into consideration the lateral and uplift loads acting on the connection.

A-6 WOOD.

A-6.1 Connections.

When using prescriptive guidelines in building codes for nailed wood connections, careful consideration needs to be given to ensuring a complete load path from the roof to the foundation. The use of metal plate connections for roof trusses, top plates and sill plates is an effective way to provide a more robust load path.

APPENDIX B ALTERNATE DESIGN PROCEDURE FOR BUILDINGS AND OTHER STRUCTURES IN RISK CATEGORY IV

B-1 GENERAL.

B-1.1 Overview.

This Appendix may be used for the alternate design of buildings and other structures assigned to RC IV.

Buildings assigned to RC IV are either unit/installation-essential or post-disaster essential (Table 2-2). This Appendix provides an optional nonlinear static and nonlinear dynamic analysis procedure for RC IV buildings and other structures that may be used as an alternative to the procedures found in the 2024 *International Building Code* (2024 IBC). This Appendix references the 2017 edition of ASCE/SEI 41, *Seismic Evaluation and Retrofit of Existing Buildings* (herein-after referred to simply as ASCE 41-17). This procedure may provide more economical or better-performing structural designs compared to linear analysis procedures. The analysis procedures outlined in this Appendix are to be used only with the approval of the Authority Having Jurisdiction.

The nonlinear procedures outlined in this Appendix require that an RC IV building meet two general structural performance objectives:

1. A Life Safety (LS) performance level for the Risk-Targeted Maximum Considered Earthquake (MCE_R) ground motions, nominally an earthquake associated with a 1% probability of structural collapse in 50 years; and,

2. An Immediate Occupancy (IO) performance level for earthquake ground motion that is two-thirds of the MCE_R ground motion. This earthquake is termed herein as the BSE-1N earthquake, adopting the terminology used in ASCE 41-17.

The procedures in this Appendix also require that the nonstructural components in an RC IV building meet the following two performance objectives:

1. A Hazard Reduced (HR) performance level for the Risk-Targeted Maximum Considered Earthquake (MCE_R) ground motion; and,

2. An Operational (OP) performance level for earthquake ground motion that is two-thirds of the MCE_R ground motion.

Performance criteria based on tolerable levels of damage are defined to ensure that these performance objectives are met. Nonlinear strength and deformation demands are determined by performing nonlinear static or nonlinear dynamic analyses and the results compared with acceptance criteria contained in authoritative documents, such as ASCE 41-17 or FEMA P-750 or developed based on laboratory data or rational analysis.

To ensure that satisfactory nonlinear behavior is achieved, restrictions are imposed on the types of seismic force-resisting systems that can be used in conjunction with this Appendix.

This Appendix replaces the provisions of Chapter 16 of the 2024 IBC, as modified by Chapter 2 of this UFC, for use in performing the alternative analysis of RC IV buildings and other structures. All other chapters of the 2024 IBC apply as modified by Chapter 2 of this UFC.

[C] B-1.1 Overview

In ASCE 7-22, MCE_R is used in conjunction with a “Collapse Prevention” performance objective. The alternate design in this chapter is required to meet a “Life Safety” performance objective. So, from a purist point of view, the procedure in this Appendix should have used MCE ground motion values, which could be determined by dividing the S_S- and S_1- values of ASCE 7-22, by risk coefficients C_{RS} (ASCE 7-22 Figure 22-18) and C_{R1} (ASCE 7-22 Figure 22-19), respectively. In view of the fact that C_{RS}- and C_{R1}-values are typically within a narrow range around 1.0, a decision was made to avoid unjustifiable complications and use MCE_R ground motion in place of MCE ground motion for the alternative designs of this Appendix. The same approach is adopted in ASCE 41-17 as well.

The Life Safety (LS) and Immediate Occupancy (IO) performance levels for structural members at MCE_R and BSE-1N ground motions, respectively, are consistent with Table 4.1(a) of this UFC, RP10 Table 2.2 and ASCE 41-17 Table 2.3.

In the past, the performance levels for the nonstructural components were Life Safety (LS) and Immediate Occupancy (IO) at MCE_R and BSE-1N ground motions, respectively. In this UFC, the performance levels are changed to Hazard Reduced (HR) and Operational (OP) at MCE_R and BSE-1N ground motions, respectively, to be consistent with Table 4.1(b) of this UFC, RP10 Table 2.2 and ASCE 41-17 Table 2.3.

B-1.2 Design Review Panel.

A design review of the seismic force-resisting system design and structural analysis must be performed by an independent team of Registered Design Professionals in the appropriate disciplines and others experienced in seismic analysis methods and the theory and application of nonlinear seismic analysis and structural behavior under extreme cyclic loads. In addition to a final review, a Design Review Panel should be convened at the beginning of a design to review proposed design methodology and strategy. Membership on the Design Review Panel is subject to the approval of the Authority Having Jurisdiction. A design review needs to include, but not necessarily be limited to, the following:

1. Any site-specific seismic criteria used in the analysis, including the development of site-specific spectra and ground motion time-histories;

2. Any acceptance criteria used to demonstrate the adequacy of structural elements and systems to withstand the calculated force and deformation demands, together with any laboratory or other data used to substantiate the criteria;

3. The preliminary design, including the selection of the structural system and the configuration of structural elements; and,

4. The final design of the entire structural system and all supporting analyses.

B-2 DEFINITIONS.

B-2.1 General.

2024 IBC Section 202 and ASCE 7-22 Section 11.2 apply. In addition, the definitions listed in Section X.1 of Resource Paper 2 of FEMA P-750, *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures*, 2009 Edition, apply.

B-3 CONSTRUCTION DOCUMENTS.

B-3.1 General.

2024 IBC Section 1603, as modified by Section 2-4.1 of this UFC, applies.

Exception:

For buildings designed using this Appendix, the Seismic Importance Factor, I_e, the design base shear, seismic response coefficient, C_s, and the Response Modification Factor, R, do not apply and need not be listed in construction documents.

B-4 GENERAL DESIGN REQUIREMENTS.

B-4.1 General.

2024 IBC Section 1604 applies, except as modified herein. Table 2-2 of this UFC must replace 2024 IBC Table 1604.5. The Importance Factor for seismic loading defined in Table 2-2 does not apply and should be taken as 1.0. Importance Factors for seismic design of nonstructural components must be determined in accordance with the criteria of ASCE7-22 Chapter 13. Importance Factors for snow and ice loads are no longer used in ASCE 7-22.

B-5 LOAD COMBINATIONS.

B-5.1 General.

RC IV buildings and other structures, and portions thereof, must be designed to resist the load combinations specified in this section. For all load combinations where earthquake-generated forces are not considered, ASCE 7-22 Section 2.3 applies. Where earthquake-generated forces are considered, ASCE 7-22 Section 2.3.6 load combinations 6 and 7, must be replaced by Equations B-1 and B-2 of this UFC. ASCE 7-22 Section 2.4 and 2024 IBC Section 1605.2 do not apply; allowable stress design is not permitted for use in this Appendix. The load combinations in ASCE 7-22 Section 2.3.6 that include seismic load effect with overstrength, E_m, does not apply; for any design situation requiring the use of load combinations with overstrength factor, Equations B-1 and B-2 apply, subject to the exceptions noted in Section B-18.1.

B-5.2 Seismic Load Combinations.

When the effects of earthquake-generated forces are considered, structures are required to resist the most critical effects from the following combinations of factored loads:

When the effects of gravity and seismic loads are additive:

$1.1(D + 0.25\,L + 0.15\,S) + E$ **(Equation B-1)**

When the effects of gravity and seismic loads are counteractive:

$0.9\,D + E$ **(Equation B-2)**

Where

D = Effect of dead load

L = Effect of unreduced design live load

S = Effect of design flat roof snow load calculated in accordance with ASCE 7-22 for a Risk Category IV building.

E = The effect of horizontal and vertical earthquake forces at the BSE-1N displacement (Δ_S) or MCE_R displacement (Δ_M), determined in the nonlinear analysis, as set forth in Section B-18.1.

Exception**:** Where the design flat-roof snow load calculated in accordance with ASCE 7-22 is less than 40 psf, the effective snow load is permitted to be taken as zero.

B-6 DEAD LOADS.

B-6.1 General.

2024 IBC Section 1606 applies.

B-7 LIVE LOADS.

B-7.1 General.

2024 IBC Section 1607, as modified by Section 2-4.4 of this UFC, applies, except that wherever Table 1607.1 is referenced, it must be replaced by Table E-1 of this UFC.

B-8 SNOW LOADS.

B-8.1 General.

2024 IBC Section 1608, as modified by Section 2-4.5 of this UFC, applies.

B-9 WIND LOADS.

B-9.1 General.

2024 IBC Section 1609, as modified by Section 2-4.6 of this UFC, applies.

B-10 SOIL LOADS AND HYDROSTATIC PRESSURE.

B-10.1 General.

2024 IBC Section 1610 applies, without the exception in Section 1610.1.

B-11 RAIN LOADS.

B-11.1 General.

2024 IBC Section 1611 applies.

B-12 FLOOD LOADS.

B-12.1 General.

2024 IBC Section 1612 applies.

B-13 ICE LOADS—ATMOSPHERIC ICING.

B-13.1 General.

2024 IBC Section 1614 applies.

B-14 TSUNAMI LOADS.

B-14.1 General.

Probabilistic Tsunami Hazard Analysis (PTHA) may be performed on either the current topography or the topography adjusted for sea level rise. Use current NAVD88 [North American Vertical Datum of 1988]/MHW still water elevation for EGL (Energy Grade Line) velocity calculations regardless of topography used for PTHA.

B-15 EARTHQUAKE LOADS – GENERAL.

B-15.1 Scope.

Every structure, and portion thereof, shall as a minimum be designed and constructed to resist the effects of earthquake motions and assigned an SDC as set forth in 2024 IBC Section 1613.2.5/ASCE 7-22 Section 11.6. The use of nonlinear analysis procedures in this Appendix minimizes the need for SDC use, but the SDC is required for establishing detailing requirements.

B-16 EARTHQUAKE LOADS – SITE GROUND MOTION.

B-16.1 Determining MCE_R and BSE-1N Response Spectra and Spectral Response Accelerations.

Where an MCE_R response spectrum is required, the Multi-Period 5% damped MCE_R response spectrum from the USGS Seismic Design GeoDatabase for the applicable site class should be used.

Exceptions:

1. Where a site-specific ground motion analysis is performed in accordance with Section 11.4.7, the response spectrum shall be determined in accordance with Section 21.2.3.

2. Where values of the Multi-Period 5% damped MCE_R response spectrum are not available USGS Seismic Design GeoDatabase, the MCE_R response spectrum shall be permitted to be determined in accordance with Section 11.4.5.2, with S_{MS} and S_{M1} substituted for S_{DS} and S_{D1} respectively.

S_{MS} and S_{M1} values can be obtained directly from the USGS Seismic Design GeoDatabase or from the MCER response spectrum by looking up the ordinates corresponding to periods of 0.2 secs and 1.0 secs respectively.

The BSE-1N spectral accelerations, adjusted for site class effects, at short periods (S_{DS}) and at 1-second period (S_{D1}) must be determined as 2/3 of S_{MS} and S_{M1}, respectively. The design response spectrum for BSE-1N ground shall be obtained by multiplying the ordinates of the Multi-Period MCE_R response spectrum by 2/3.

B-16.1.1 Site Class Definition.

ASCE 7-22 Section 20.2 applies as written.

[C] B-16.1.1 – Site Class Definition.

Note that Site Class definitions have changed in ASCE 7-22. There are now nine site classes instead of six, site class BC, CD, and DE having been added to A, B, C, D, E, and F. Also the distinction among the site classes is now solely based on shear wave velocity. Standard penetration resistance or undrained shear strength can no longer be the basis of such distinction.

If S_s and S_1 values are required, they can be obtained from the MCE_R response spectrum from Site Class BC by looking up the ordinates corresponding to periods of 0.2 sec an1.0 sec respectively. Alternatively they can be obtained directly from USGS Seismic Hazard Geodatabase.

B-16.2 Site-specific Response Analysis for Determining Ground Motion Accelerations.

B-16.2.1 Site Response Analysis

ASCE 7-22 Section 21.1 applies.

B-16.2.2 MCE_R Ground Motion Hazard Analysis.

ASCE 7-22 Section 21.2 applies.

B-17 EARTHQUAKE LOADS – CRITERIA SECTION.

B-17.1 Structural Design Criteria.

Each structure must be assigned a Seismic Design Category in accordance with 2024 IBC Section 1613.2.5/ASCE 7-22 Section 11.6, for use with required structural design and construction provisions. Each structure must be provided with complete lateral and vertical force-resisting systems capable of providing adequate strength, stiffness, and energy dissipation capacity to withstand the earthquake ground motions determined in accordance with Section B-16 within the prescribed performance objectives of Section B-18. In addition, each structure must be designed to accommodate the architectural, mechanical, and electrical component requirements of Section B-22. Ground motions must be assumed to occur along any horizontal direction of a structure. A continuous load path, or paths, with adequate strength and stiffness to transfer forces induced by the earthquake ground motions from the points of application to the final point of resistance must be provided.

B-17.2 Importance Factors.

The seismic importance factor, I_e, is not used. The component seismic importance factor, I_p, used in Section B-22, must be the value specified in Sections B-22.4.4.

B-17.3 Site Limitations.

A structure assigned to RC IV must not be sited where there is a known potential for an active fault to cause rupture of the ground surface at the structure. An *active fault* is defined in ASCE 7-22 as follows: A fault determined to be active by the Authority Having Jurisdiction from properly substantiated data (e.g., most recent mapping of active faults by the US Geological Survey).

> **[C] B-16.5 – Site Limitations.**
>
> In UFC 3-301-01, Change 1, 2 October 2023 (the previous version of this UFC), an active fault was defined as a fault for which there is an average historic slip rate of 1 mm or more per year and for which there is geographic evidence of seismic activity in Holocene times (the most recent 11,000 years). This definition dates back to the 2000 IBC.

B-17.4 Building Configuration.

The requirements of ASCE 7-22 Sections 12.3.1[Diaphragm Flexibility], 12.3.2 [Irregular and Regular Classification], and 12.3.3 [Limitations and Additional Requirements for Systems with Structural Irregularities] do not apply to facilities designed using the provisions of this Chapter.

B-17.5 Analysis Procedures.

B-17.5.1 Nonlinear Analysis.

The Alternate RC IV analysis procedure of this Appendix may be used in lieu of the Equivalent Lateral Force or Modal Response Spectrum Analysis procedures that would generally be used to comply with the 2024 IBC and Chapter 2 of this UFC. For this alternate procedure, a nonlinear structural analysis must be performed. The analysis may use either the Nonlinear Static Procedure (NSP) or the Nonlinear Dynamic Procedure (NDP).

B-17.5.1.1 Nonlinear Static Procedure.

The NSP is permitted for structures not exceeding 6 stories in height and having a fundamental period, T, not greater than $3.5T_S$, where T_S is determined in accordance with ASCE 7-22 Section 11.4.6. Application of the NSP needs to comply with the requirements of *Resource Paper 2 of FEMA P-750, NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures, 2009 Edition, Part 3, Resource Papers (RP) on Special Topics in Seismic Design*, <u>subject to the modifications below</u>. In applying the NSP, the user may employ the references cited in Resource Paper 2 of FEMA P-750. Further information on NSP may be found in *FEMA P-750, NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other*

Structures, 2009 Edition, Part 2, Commentary and in NEHRP Seismic Design Technical Brief No. 4, *Nonlinear Structural Analysis for Seismic Design*, NIST GCR 10-917-5. The following should be noted:

1. To apply the FEMA P-750 NSP, the design earthquake ground motions and associated spectral accelerations must be as specified herein (MCE_R and BSE-1N), and not the design ground motions defined in FEMA P-750.
2. A target displacement must be separately determined for each of the MCE_R and BSE-1N spectra.
3. The structure as a whole and each of the elements of the lateral force-resisting system and its connections must be evaluated for their adequacy to provide Immediate Occupancy Performance at the BSE-1N target displacement and to provide Life Safety Performance at the MCE_R target displacement.
4. P-Delta effects must be included in the development of the backbone curves (see Section 2.4 of NIST GCR 10-917-5 NEHRP Seismic Design Technical Brief No 4).
5. Multidirectional and concurrent seismic effects must be included as defined in Section 7.2.5 of ASCE/SEI 41-17.
6. The following modifications must be made to Resource Paper 2 of FEMA P-750

   a. Replace references to ASCE 41-06 w/Supplement 1 with ASCE/SEI 41-17.
   b. Replace references to Section 3.3.3 of ASCE 41-06 w/Supplement 1 with Section 7.4.3 of ASCE/SEI 41-17.
   c. Replace references to Section 3.3.3.3.2 of ASCE 41-06 w/Supplement 1 with Section 7.4.3.3.2 of ASCE/SEI 41-17.
   d. Replace reference to Equation 3-16 of ASCE/SEI 41-06 w/Supplement 1 with Equation 7-32 of ASCE/SEI 41-17 and replace μ_{max} in Equation 7-32 of ASCE/SEI 41-17 with R_{max}.

B-17.5.1.2 Nonlinear Dynamic Procedure.

Application of the NDP needs to comply with the requirements of ASCE 7-22 Chapter 16.

B-17.5.2 Site Ground Motions.

Two characteristic ground motions must be required for the design of facilities using this procedure:

1. For the LS performance level, the MCE_R ground motion must be used. For the NSP, spectral response accelerations must be determined using the procedures of Section B-16.1 or Section B-16.2. For the NDP, MCE_R ground motions must be determined using procedures prescribed in ASCE 7-22 Section 16.2.

2. For the IO performance level, the BSE-1N ground motion must be used. For the NSP, spectral response accelerations must be determined using the procedures of Section B-16.1 or Section B-16.2. For the NDP, BSE-1N ground motions must be determined using procedures prescribed in ASCE 7-22 Section 16.2.

B-18 EARTHQUAKE LOADS – MINIMUM DESIGN LATERAL FORCE AND RELATED EFFECTS.

B-18.1 Seismic Load Effect, *E*.

When the NSP is used, the seismic load effect, E, for use in the load combinations of Section B-5.2 must be determined from ASCE 7-22 Section 12.4. In the application of ASCE 7-22 Section 12.4, the term S_{DS} must be interpreted as S_{MS} for the LS performance level. When the NDP is used, the seismic load effect, E, is simply the response determined from the dynamic analysis. The redundancy coefficient, ρ, must be taken as 1.0.

Exceptions:

1. Where these provisions require consideration of structural overstrength (see ASCE 7-22 Section 12.4.3), the values of member forces, Q_E, obtained from NSP analysis at the peak (maximum base shear) of the NSP pushover curve must be used in place of the quantity E_{mh}.

2. Where these provisions require consideration of structural overstrength (see ASCE 7-22 Section 12.4.3), the values of member forces, Q_E, obtained from NDP analysis at the maximum base shear found in the analysis using any of the ground motion records must be used in place of the quantity E_{mh}.

B-18.2 Redundancy.

ASCE 7-22 Section 12.3.4 does not apply to facilities designed using the provisions of this Chapter.

B-18.3 Deflection and Drift Limits.

B-18.3.1 Allowable Story Drift.

Because the Alternate Design Procedure is a nonlinear performance-based design approach, specific target drift limits are not set for designs.

B-18.3.1.1 Life Safety Performance Level.

The LS performance level must be achieved for MCE_R ground shaking. At the LS performance level, structural members may be damaged, but they retain a margin of safety of at least 1.5 against the onset of loss of gravity load carrying capacity. Some residual global structural strength and stiffness remain at the maximum lateral displacement in all stories. No out-of-plane wall failures occur. Partitions may be damaged, and the building may be beyond economical repair. Some permanent (inelastic) drift may occur. While inelastic behavior is permitted, member strength degradation needs to be limited in primary structural members (residual strength cannot be less than 80% of peak strength). Primary structural elements are those that are required to provide the building with an ability to resist collapse when ground motion-induced seismic forces are generated. For secondary structural elements (those that are not primary elements), strength degradation to levels below the nominal yield strength is permitted. Not more than 20% of the total strength or initial stiffness of a structure can be assumed to be provided by secondary elements. The LS performance objective needs to be verified by analysis - either the NSP or the NDP. The LS acceptance criteria contained in ASCE 41-17 must be used to demonstrate acceptable performance (see ASCE 41-17 Table 2-3). Alternatively, acceptance criteria can be developed by the designer and approved by the design review panel (see Section B-1.2).

B-18.3.1.2 Immediate Occupancy Performance Level.

The IO performance level must be achieved for BSE-1N ground shaking. At the IO performance level, a building remains safe to occupy, essentially retaining pre-earthquake design strength and stiffness and nonstructural elements retain position and are operational. Minor cracking of facades, ceilings, and structural elements may occur. Significant permanent (inelastic) drift does not occur. The structural system for the building remains "essentially" elastic. Any inelastic behavior does not change the basic structural response and does not present any risk of local failures. Member deformations are not permitted to exceed 125% of deformations at nominal member yield strengths. No member strength degradation is permitted, regardless of deformation. The IO performance objective needs to be verified by analysis, either the NSP or the NDP. The IO acceptance criteria contained in ASCE 41-17 must be used to demonstrate acceptable performance (see ASCE 41-17 Table 2-3). Alternatively, appropriate acceptance criteria can be developed by the designer and approved by the design review panel (see Section B-1.2).

B-18.3.2 Drift Determination and P-Delta Effects.

B-18.3.2.1 Drift and Deflection Determination for Nonlinear Static Procedure.

The design story drifts, Δ_S *and* Δ_M must be taken as the values obtained for each story at the target displacements for the BSE-1N and MCE_R, respectively.

B-18.3.2.2 Drift and Deflection Determination for Nonlinear Dynamic Procedure.

Transient as well as residual story drifts must be determined in accordance with ASCE 7-22 Sections 16.4.1.2 and 16.4.1.3, respectively.

B-18.3.2.3 P-Delta Effects for Nonlinear Static Procedure and Nonlinear Dynamic Procedure.

P-Delta (P-Δ) effects must be incorporated in all lateral load analyses.

B-18.4 Seismic Force-resisting Systems.

B-18.4.1 Permitted Seismic Force-resisting Systems.

Table B-1, Permitted Systems for RC IV Buildings Designed Using Alternate Analysis Procedure, must replace ASCE 7-22 Table 12.2-1 and Table 3-1 of this UFC. Table B-1 must be used to determine whether a seismic force-resisting system is permitted. Table B-1 also lists building height limitations for the permitted systems. Seismic force-resisting systems that are not listed in Table B-1 may be permitted if analytical and test data are submitted that establish the dynamic characteristics and demonstrate the lateral force resistance and energy dissipation capacity to be equivalent to those of the structural systems listed in the table. Such exceptions may be authorized when permission is granted by the design review panel (see Section B-1.2).

B-18.4.2 Structural Design Requirements.

B-18.4.2.1 Dual Systems.

ASCE 7-22 Section 12.2.5.1 applies.

B-18.4.2.2 Combinations of Framing Systems.

Different seismic force-resisting systems are permitted along the two orthogonal axes of a building structure, so long as both systems comply with the provisions of this Chapter.

B-18.4.2.3 Interaction Effects.

Moment-resisting frames that are enclosed or adjoined by more rigid elements that are not considered to be part of the seismic force-resisting system must be designed so that the action or failure of those rigid elements will not impair the vertical load-carrying and seismic force-resisting capability of the frame. The design needs to provide for the effect of these rigid elements on the structural system at structural deformations corresponding to the design story drift at the target displacement, as determined by analysis.

B-18.4.2.4 Deformational Compatibility.

For components that are not included in the seismic force-resisting system, ensure that ductile detailing requirements are provided such that the vertical load-carrying capacity of these components is not compromised by induced moments and shears resulting from the design story drift.

For structures assigned to Seismic Design Category D, E, or F, reinforced concrete frame members not designed as part of the seismic force-resisting system must comply with ACI 318 *Building Code Requirements for Structural Concrete,* Section 18.14.

B-18.4.3 Response Modification (*R*), System Overstrength (Ω_0), Deflection Amplification (C_d) Factors.

Because only the NDP or the NSP are permitted for the alternate design of RC IV structures the factors *R*, C_d, and Ω_o are not required.

B-18.4.4 Member Strength.

The load combination requirements of Sections B-5.1 and B-5.2 must be satisfied. Horizontal seismic load effects must be determined in accordance with Section B-18.1.

B-19 EARTHQUAKE LOADS, SOIL-STRUCTURE INTERACTION EFFECTS.

B-19.1 Analysis Procedure.

When these effects are considered, the provisions of ASCE 7-22 Chapter 19 apply.

B-20 SEISMIC DESIGN AND STRUCTURAL MEMBER LOAD EFFECTS.

B-20.1 Structural Member Load Effects.

The provisions of ASCE 7-22 Chapter 12, as modified by Chapter 3 of this UFC, apply.

B-20.2 Structural Integrity.

The provisions of 2024 IBC Section 1616 apply.

B-20.3 Soils and Foundations.

The provisions of 2024 IBC Chapter 18 apply.

B-21 SEISMIC DESIGN REQUIREMENTS FOR NONSTRUCTURAL COMPONENTS.

B-21.1 Component Design.

The provisions of ASCE 7-22 Chapter 13, as modified by Chapter 3, apply, except as noted in the following paragraphs. Appendix C provides supplementary guidance on design and analysis of some architectural, mechanical, and electrical components.

B-21.2 Performance Objectives.

The design procedure presented in this Appendix includes two overall performance objectives that influence the requirements for architectural, mechanical, and electrical components. First, the design must provide Hazards Reduced (HR) performance for the MCE_R. Second, the design must provide Operational (OP) performance for BSE-1N ground motions.

B-21.2.1 Hazards Reduced Performance Level for Nonstructural Components.

This performance level is defined as the post-earthquake damage state in which nonstructural components are damaged and could potentially create falling hazards. High-hazard nonstructural components identified in Chapter 13, Table 13-1 of ASCE 41-17 are secured to prevent falling into areas of public assembly because falling hazards from those components could pose a risk to life-safety of many people. Preservation of egress, protection of fire suppression systems, and similar life-safety issues are not addressed in this Nonstructural Performance Level.

B-21.2.2 Operational Performance Level for Nonstructural Components.

This performance level is defined as the post-earthquake damage state in which the nonstructural components are able to provide the functions they provided in the building before the earthquake. Nonstructural components in compliance with the acceptance criteria of ASCE 41-17 for Operational Nonstructural Performance and Risk Category IV nonstructural components are expected to achieve this post-earthquake state.

B-21.3 Modification of ASCE 7-22 for Hazards Reduced Design.

B-21.3.1 Ground Motion Parameters for Determination of Hazards Reduced Seismic Forces.

In the application of ASCE 7-22 Section 13.3.1, seismic forces must be determined for the MCE_R ground motion parameters.

B-21.3.2 Nonlinear Static Procedure.

In the application of ASCE 7-22 Section 13.3.1, seismic forces on components, when NSP is used, must be based on ASCE 7-22 Equations 13.3-1 through 13.3-3. The quantity S_{MS} must be substituted for the term S_{DS} found in the equations. In the application of ASCE 7-22 Section 13.3.2, the response of the building to the MCE_R ground motion must be used.

B-21.3.3 Nonlinear Dynamic Procedure.

In the application of ASCE 7-22 Section 13.3.1, seismic forces on components, when NDP is used, must be based on ASCE 7-22 Equation 13.3-7. The term a_i is the maximum acceleration at the level of the component under consideration, as determined from the dynamic analysis. In the application of ASCE 7-22 Section 13.3.2, the response of the building to the MCE_R ground motion must be used.

B-21.4 Modification of ASCE 7-22 for Operational Design.

B-21.4.1 Ground Motion Parameters for Determination of IO Seismic Forces.

In the application of ASCE 7-22 Section 13.3.1, seismic forces must be determined for the BSE-1N ground motion parameters.

B-21.4.2 Nonlinear Static Procedure.

In the application of ASCE 7-22 Section 13.3.1, seismic forces on components, where NSP is used, must be based on ASCE 7-22 Equations 13.3-1 through 13.3-3. In the application of ASCE 7-22 Section 13.3.2, the response of the building to the BSE-1N ground motion must be used.

B-21.4.3 Nonlinear Dynamic Procedure.

In the application of ASCE 7-22 Section 13.3.1, seismic forces on components, where NDP is used, must be based on ASCE 7-22 Equation 13.3-7. The term a_i is the maximum acceleration at the level of the component under consideration, as determined from the dynamic analysis. In the application of ASCE 7-22 Section 13.3.2, the response of the building to the BSE-1N ground motion must be used.

B-21.4.4 Component Importance Factors.

The component importance factor, I_p, is required for force calculations in ASCE 7-22 Section 13.3.1. I_p must be as given in ASCE 7-22 Section 13.1.3.

Table B-1 Permitted Systems for Risk Category IV Buildings Designed Using Alternate Procedure of Chapter 3

Basic Seismic Force-Resisting System[2]	System and Building Height (ft) Limitations[1]				
	Seismic Design Category				
	B	C	D	E	F
Bearing Wall Systems					
Ordinary steel braced frames in light-frame construction	NL	NL	65	65	65
Reinforced concrete ductile coupled walls[7]	NL	NL	160	160	100
Special reinforced concrete shear walls	NL	NL	160	160	100
Ordinary reinforced concrete shear walls	NL	NL	NP	NP	NP
Special reinforced masonry shear walls	NL	NL	160	160	100
Light-framed walls with shear panels - wood structural panels/sheet steel panels	NL	NL	65	65	65
Light-framed walls with shear panels - all other materials	NL	NL	35	NP	NP
Light-framed walls with shear panels - using flat strap bracing	NL	NL	65	65	65
Building Frame Systems					
Steel eccentrically braced frames	NL	NL	160	160	100
Special steel concentrically braced frames	NL	NL	160	160	100
Ordinary steel concentrically braced frames	NL	NL	35[3]	35[3]	NP[3]
Special reinforced concrete shear walls	NL	NL	160	160	160
Reinforced concrete ductile coupled walls[7]	NL	NL	160	160	100
Ordinary reinforced concrete shear walls	NL	NL	NP	NP	NP
Composite eccentrically braced frames	NL	NL	160	160	100
Composite special concentrically braced frames	NL	NL	160	160	100
Ordinary composite braced frames	NL	NL	NP	NP	NP
Composite steel plate shear walls	NL	NL	160	160	100
Special composite reinforced concrete shear walls with steel elements	NL	NL	160	160	100
Special reinforced masonry shear walls	NL	NL	160	160	100
Light-framed walls with shear panels - wood structural panels/sheet steel panels	NL	NL	65	65	65
Light-framed walls with shear panels - all other materials	NL	NL	35	NP	NP
Steel and concrete coupled composite plate shear walls[7]	NL	NL	160	160	100

Table B-1 Permitted Systems for Risk Category IV Buildings Designed Using Alternate Procedure of Chapter 3

Basic Seismic Force-Resisting System[2]	System and Building Height (ft) Limitations[1] Seismic Design Category				
	B	C	D	E	F
Moment-Resisting Frame Systems					
Special steel moment frames	NL	NL	NL	NL	NL
Special steel truss moment frames	NL	NL	160	100	NP
Intermediate steel moment frames	NL	NL	35[5]	NP[5]	NP[5]
Ordinary steel moment frames	NL	NL	NP[6]	NP[6]	NP[6]
Special reinforced concrete moment frames	NL	NL	NL	NL	NL
Intermediate reinforced concrete moment frames	NL	NL	NP	NP	NP
Special composite moment frames	NL	NL	NL	NL	NL
Intermediate composite moment frames	NL	NL	NP	NP	NP
Composite partially restrained moment frames	160	160	100	NP	NP
Dual Systems with Special Moment Frames **capable of resisting at least 25% of prescribed seismic forces**					
Steel eccentrically braced frames	NL	NL	NL	NL	NL
Special steel concentrically braced frames	NL	NL	NL	NL	NL
Special reinforced concrete shear walls	NL	NL	NL	NL	NL
Reinforced concrete ductile coupled walls[7]	NL	NL	NL	NL	NL
Ordinary reinforced concrete shear walls	NL	NL	NP	NP	NP
Composite eccentrically braced frames	NL	NL	NL	NL	NL
Composite special concentrically braced frames	NL	NL	NL	NL	NL
Composite steel plate shear walls	NL	NL	NL	NL	NL
Special composite reinforced concrete shear walls with steel elements	NL	NL	NL	NL	NL
Ordinary composite reinforced concrete shear walls with steel elements	NL	NL	NP	NP	NP
Special reinforced masonry shear walls	NL	NL	NL	NL	NL
Steel and concrete coupled composite plate shear walls[7]	NL	NL	NL	NL	NL

Table B-1 Permitted Systems for Risk Category IV Buildings Designed Using Alternate Procedure of Chapter 3

Basic Seismic Force-Resisting System[2]	System and Building Height (ft) Limitations[1]				
	Seismic Design Category				
	B	C	D	E	F
Dual Systems with Intermediate Moment Frames **capable of resisting at least 25% of prescribed seismic forces**					
Special steel concentrically braced frames[4]	NL	NL	35	NP	NP
Special reinforced concrete shear walls	NL	NL	160	100	100
Ordinary reinforced concrete shear walls	NL	NL	NP	NP	NP
Composite special concentrically braced frames	NL	NL	160	100	NP
Ordinary composite braced frames	NL	NL	NP	NP	NP
Ordinary composite reinforced concrete shear walls with steel elements	NL	NL	NP	NP	NP
Cantilevered Column Systems **detailed to conform to the requirements for:**					
Special steel cantilever column systems	35	35	35	35	35
Special reinforced concrete moment frames	35	35	35	35	35

NP - indicates not permitted, NL – indicates not limited.

[1] Any system that is restricted by this table may be permitted if it is approved by the design review panel (see Section B-1.2).

[2] See Table 3-1 for detailing references for seismic force-resisting systems.

[3] Steel ordinary concentrically braced frames are permitted in single-story buildings, up to a structural height, h_n, of 60 ft, where the dead load of the roof does not exceed 20 psf, and in penthouse structures.

[4] Ordinary moment frames may be used in lieu of intermediate moment frames for Seismic Design Category B or C.

[5] See ASCE 7-22 Section 12.2.5.7 for limitations on structures assigned to Seismic Design Category D, E, or F.

[6] See ASCE 7-22 Section 12.2.5.6 for limitations on structures assigned to Seismic Design Category D, E, or F.

[7] Structural height, h_n, shall not be less than 60 ft (18.3m).

APPENDIX C GUIDANCE FOR SEISMIC DESIGN OF NONSTRUCTURAL COMPONENTS

C-1 INTRODUCTION.

This Appendix defines architectural, mechanical, and electrical components, discusses their participation and importance in relation to the seismic design of the structural system, and provides guidance for their design to resist damage from earthquake-induced forces and displacements. The fundamental principles and underlying requirements of this Appendix are that the design of these components for buildings in Risk Categories (RCs) I, II, and III should be such that they will not collapse and cause personal injury due to the accelerations and displacements caused by severe earthquakes, and that they should withstand more frequent but less severe earthquakes without excessive damage and economic loss. In contrast, designated components in RC IV buildings, are required to remain operational following a design earthquake (BSE-1N).

C-1.1 Design Criteria.

2024 IBC Section 1613, as modified by Chapter 2 of this UFC, governs the seismic design of architectural, mechanical, and electrical components. 2024 IBC Section 1613 references Chapter 13 of ASCE 7-22. Because ASCE 7-22 is the primary source of design requirements for these components, this Appendix cites ASCE 7-22 provisions and expands on them as appropriate.

C-1.2 Walk-down Inspections and Seismic Mitigation for Buildings in Risk Categories IV.

C-1.2.1 General Guidance.

Section 1705.13.6 of UFC 3-301-01 requires that an initial *walk-down* inspection of new RC IV buildings be performed. A walk-down inspection is a visual inspection of a building to identify possible seismic vulnerabilities of its architectural, mechanical, and electrical components. Inspections should include investigating adequacy of component load paths, anchorage and bracing, and components' abilities to accommodate differential motions with respect to supporting building structure. The walk-down inspector should become familiar with the design earthquake motions for the site, structural configuration of the building, building drawings, and documentation of all previous walk-down inspections. Inspectors should document all observations with photographs, schematic drawings, and narrative discussions of apparent vulnerabilities. Inspection reports normally do not include detailed assessments of component vulnerabilities, but they may recommend further detailed assessments. Inspectors should also define mitigation recommendations in inspection reports. Prior to building commissioning, the Authority Having Jurisdiction (AHJ) should ensure seismic mitigation recommendations are fully implemented. An example of a walk-down inspection of Madigan Army Medical Center at Fort Lewis, WA, may be found in

USACERL Technical Report 98/34, *Seismic Mitigation for Equipment at Army Medical Centers*.

C-1.2.2 Periodic Post-commissioning Walk-down Inspections.

In addition to initial walk-down inspections performed at building commissioning, periodic post- construction walk-down inspections should be conducted in RC IV buildings by installation personnel, as part of routine operations and maintenance. For RC IV buildings, such inspections should be conducted at least every second year following building commissioning, or, for affected systems, when any change to architectural, mechanical, or electrical systems occurs.

C-2 ARCHITECTURAL COMPONENTS.

C-2.1 General.

Reference should be made to ASCE 7-22 Section 13.5, Architectural Components.

Architectural components addressed in ASCE 7-22 Chapter 13 are listed in ASCE 7-22 Table 13.5-1. These components are called "architectural" because they are not part of the vertical or lateral load-resisting systems of a building, or part of the mechanical or electrical systems. Although they are usually shown on architectural drawings, they often have a structural aspect and can affect the response of a building to earthquake ground motions. Architects should consult with structural, mechanical, and electrical engineers, as appropriate, when dealing with these elements. The structural engineer must review architectural (as well as mechanical and electrical) component anchorage details, to ensure compliance with anchorage requirements. During this review, the structural engineer must also identify installed architectural (as well as mechanical and electrical) components that may adversely affect the performance of the structural system.

C-2.2 Typical Architectural Components.

Examples of architectural components that have a structural aspect requiring special attention follow.

C-2.2.1 Nonstructural Walls.

A wall is considered architectural or nonstructural when it is not designed to resist transient interior (lateral) air pressure of more than 5psf or superimposed gravity loads beyond the threshold values given in the definition for bearing walls in 2024 IBC Section 202 and ASCE 7-22 Section 11.2. To ensure that nonstructural walls do not resist lateral forces, they should either be disconnected (i.e., isolated) from the building structure at the top and the ends of the wall or be very flexible (in-plane) relative to the structural walls and frames resisting lateral forces. An isolated wall must be capable of acting as a cantilever from the floor or be braced to resist its own out-of-plane motions and loads, without interacting with the lateral force-resisting system. Such interaction may be detrimental to the wall or the lateral force-resisting system or both.

C-2.2.2 Curtain Walls and Filler Walls.

A curtain wall is an exterior wall, often constructed of masonry, that lies outside of and usually conceals the structural frame of a building. A filler wall is an infill, usually constructed of masonry, within the structural members of a frame. These walls are often considered architectural in nature if they are designed and detailed by the architect. However, they can act as shear (structural) walls. If they are connected to the frame, they will be subjected to the deflections of the frame and will participate with the frame in resisting lateral forces. Curtain walls and infill walls in buildings governed by this document should be designed so they do not restrict the deformations of the structural framing under lateral loads (i.e., they are isolated from building lateral deformations). Lateral supports and bracing for these walls should be provided as prescribed in this Appendix.

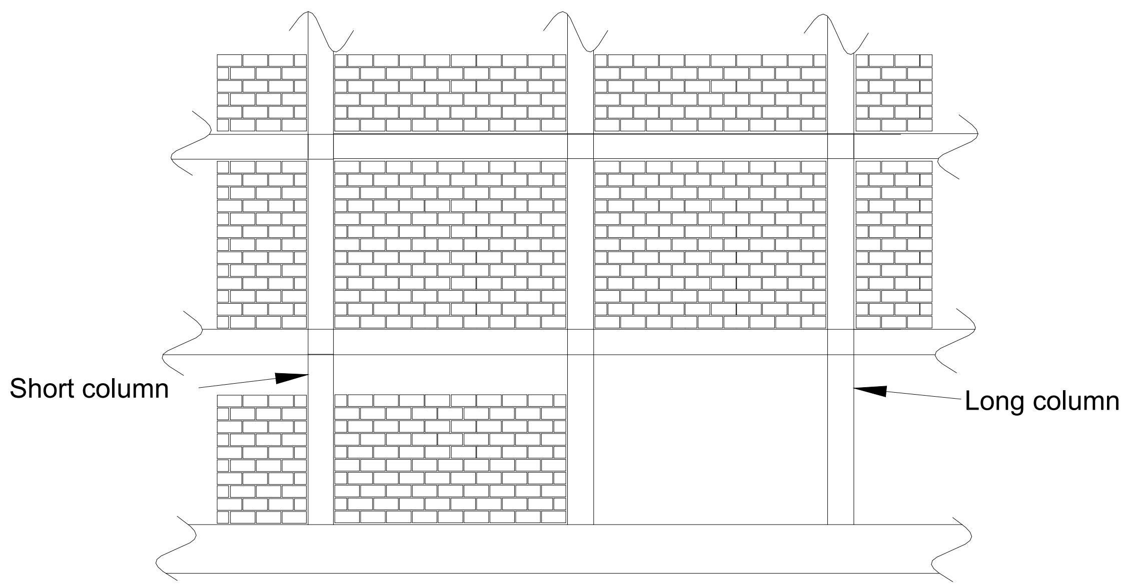
C-2.2.3 Partial Infill Walls.

A partial infill wall is one that has a strip of window between the top of the solid infill and the bottom of the floor above, or has a vertical strip of window between one or both ends of the infill and a column. Such walls require special treatment. If they are not properly isolated from the structural system, they will act as shear walls. The wall with windows along the top is of particular concern because of its potential effect on the adjacent columns. The columns are fully braced where there is an adjacent infill, but are unbraced in the zone between the windows. The upper, unbraced part of the column is a “short column,” and its greater rigidity (compared with the other, longer unbraced columns in the system) must be considered in structural design. Short columns are very susceptible to shear failure in earthquakes. Figure C-1 shows a partial infill wall, with short columns on either side of the infill, which should be avoided. All infills in buildings governed by this document should be considered to be nonstructural components, and should be designed so they do not restrict the deformation of the structural framing under lateral loads. In this instance, the partial infill should be sufficiently isolated from the adjacent frame elements to permit those elements to deform in flexure as designed.

C-2.2.4 Precast Panels.

Exterior walls that consist of precast panels attached to the building frame are addressed in a different way. The general layout and wall section for wall panels is usually shown on architectural drawings, while structural details for the support of the panels are usually shown on structural drawings. It is common for the detailed structural design of the precast panels to be delegated to a specialty engineer engaged by the General Contractor or by the precast concrete panel subcontractor. This is done because the details of design may vary depending on the manufacturing methods and facilities of the panel manufacturer. The specialty engineer is engaged to incorporate those considerations as well as means and methods of construction that the project structural engineer excludes from the scope of work. The structural engineer must review this design as needed to verify that the application of loads and the configuration of the connection details are compatible with the design of the supporting structure. In such cases, structural drawings should include design criteria and representative details in order to show what is expected. The design criteria should include the required design forces and frame deflections that must be accommodated by the panels and their connections. Particular attention should be given to the effects of deflections of the frame members supporting precast panels, to assure that appropriate reaction forces and deflections are considered. Panels with more than two attachment points between their bottom edge and the supporting frame should be avoided. Further guidance can be found in *Architectural Precast Concrete,* 3rd Edition (PCI MNL-122-07), published by the Precast/Prestressed Concrete Institute (PCI).

Figure C-1. Partial Infill Masonry Wall between Two Concrete Columns, Causing Adverse "Short Column" Effect



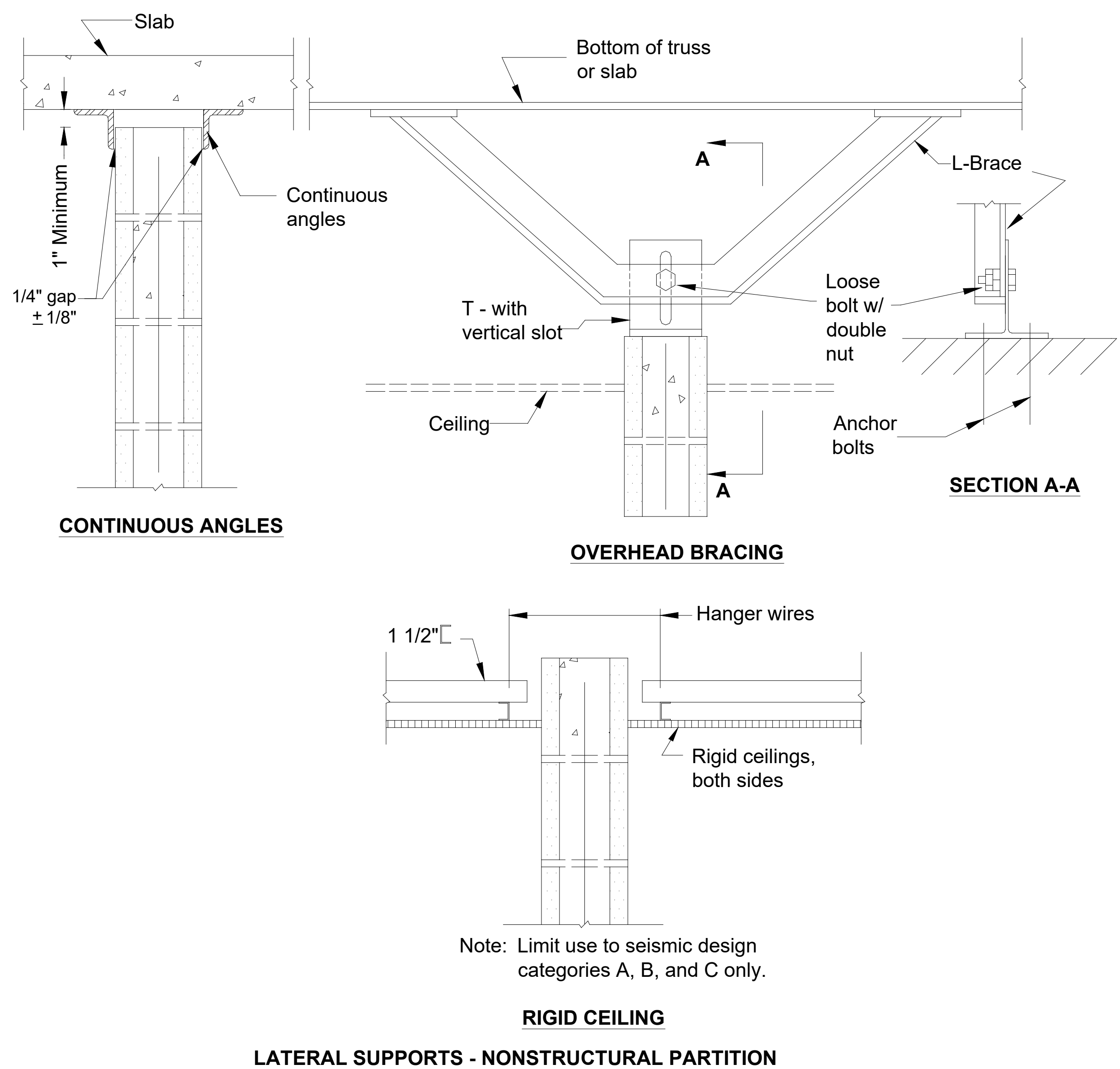
C-2.2.5 Masonry Veneer.

Reference should be made to *Building Code Requirements for Masonry Structures* (TMS 402-22). A masonry veneer is defined as a masonry wythe that provides the exterior finish of a wall system and transfers out-of-plane load directly to a backing, but is not considered to add load-resisting capacity to the wall system. A masonry veneer may be anchored or adhered. An anchored veneer is defined as a masonry veneer secured to and supported laterally by the backing through anchors and supported vertically by the foundation or other structural elements. An adhered veneer is defined as a masonry veneer secured to and supported by the backing through adhesion. Chapter 13 of TMS 402 provides requirements for design and detailing of anchored masonry veneer and adhered masonry veneer. The design of anchored veneer is addressed in Section 13.2 of TMS 402, while the design of adhered veneer is addressed in Section 13.3 of the same document.

C-2.2.6 Rigid Partition Walls.

Rigid partition walls are generally nonstructural masonry walls. Such walls should be isolated, so they are not called upon to resist in-plane lateral forces to which they are subjected, based on relative rigidities. Typical details for isolating these walls are shown in Figure C-2. These walls should be designed for the prescribed forces normal to their plane.

Figure C-2. Typical Details for Isolation of Rigid Partition Walls



C-2.2.7 Nonrigid Partition Walls.

Nonrigid partition walls are generally nonstructural partitions, such as stud and drywall, stud and plaster, and movable partitions. When these partitions are constructed according to standard recommended practice, they are assumed to be able to withstand design in-plane drift of only 0.005 times the story height (1/16 in./ft [5 mm/m] of story height) without damage. This is much less than the most restrictive allowable story drift in ASCE 7-22 Table 12.12-1. Therefore, damage to these partitions should be expected in the design earthquake if they are anchored to the structure in the in-plane direction. For RC IV, these partition walls should be isolated from in-plane building motions at the tops and sides of partitions if drifts exceeding 0.005 times the story height are anticipated in the design earthquake. Partition walls should be designed for the prescribed seismic force acting normal to flat surfaces. However, the wind or the usual 5 pounds per square foot partition load (2024 IBC Section 1607.16) will usually govern.

Economic comparison between potential damage and costs of isolation should be considered. For partitions that are not isolated, a decision has to be made for each project as to the contribution, if any, such partitions will make to damping and response of the structure, and the effect of seismic forces parallel to (in-plane with) the partition resulting from the structural system as a whole. Usually, it may be assumed that this type of a partition is subject to future changes in floor layout location. The structural role of partitions may be controlled by limiting the height of partitions and by varying the method of support.

C-2.2.8 Suspended Ceilings.

Requirements for suspended ceilings are provided in ASCE 7-22 Section 13.5.6, as modified by Chapter 3. Useful guidance is available in ICC-ES AC 368 *Acceptance Criteria for Suspended Ceiling Framing Systems*, issued by the International Code Council Evaluation Service (ICC-ES) in February 2024.

C-3 MECHANICAL AND ELECTRICAL COMPONENTS.

C-3.1 Component Support.

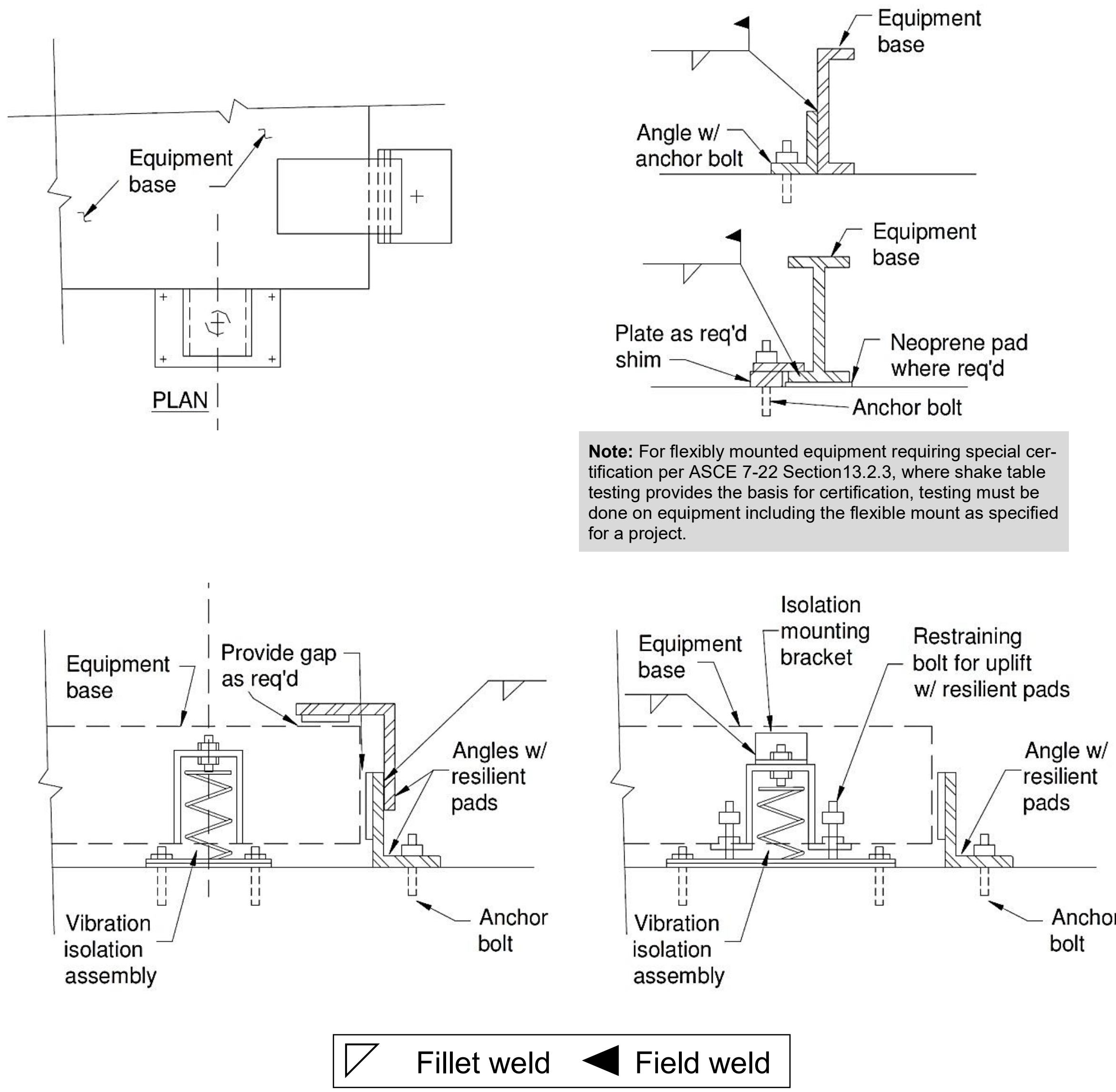
Reference should be made to ASCE 7-22 Section 13.6.4 Component Supports.

C-3.1.1 Base-mounted Equipment in RC IV.

Floor or pad-mounted mission-critical equipment installed in RC IV buildings assigned to SDC D, E, or F should use cast-in-place anchor bolts to anchor them. Alternatively, post-installed anchors are permitted to be used provided they are qualified for earthquake loading in accordance with ACI 355.2, *Qualification of Post-Installed Mechanical Anchors in Concrete*, and ACI 355.4, *Acceptance Criteria for Qualification of Post-Installed Adhesive Anchors in Concrete*, as applicable. For this equipment, two nuts should be provided on each bolt, and anchor bolts should conform to ASTM F1554-20, *Standard Specification for Anchor Bolts, Steel, 36, 55, and 105-ksi Yield*

Strength. Cast-in-place anchor bolts should have an embedded straight length equal to at least 12 times the nominal bolt diameter. Anchor bolts that exceed the depth of equipment foundation piers or pads should either extend into the concrete floor, or the foundation should be increased in depth to accommodate the bolt lengths. Figure C-3 illustrates typical base anchorage and restraint for equipment.

Figure C-3. Typical Seismic Restraints for Floor-mounted Equipment

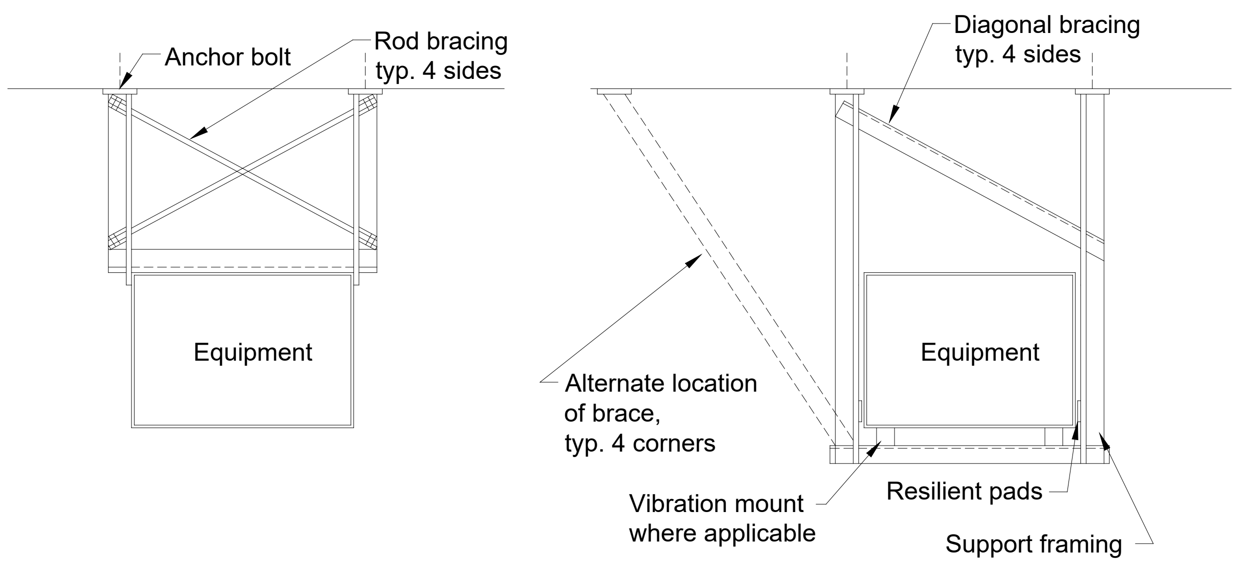


Note: For flexibly mounted equipment requiring special certification per ASCE 7-22 Section13.2.3, where shake table testing provides the basis for certification, testing must be done on equipment including the flexible mount as specified for a project.

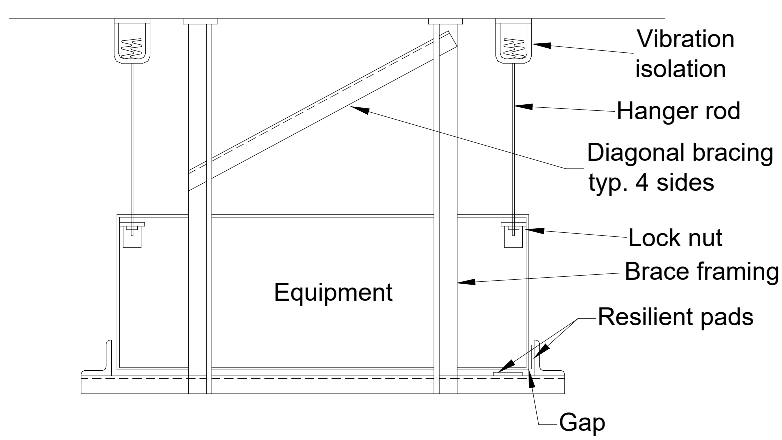
C-3.1.2 Suspended Equipment.

Seismic bracing for suspended equipment may use the bracing recommendations and details in ANSI/SMACNA 001-2008, *Seismic Restraint Manual: Guidelines for Mechanical Systems*, 3rd Edition. Trapeze-type hangers should be secured with not less than two bolts. Figure C-4 shows typical seismic restraints for suspended equipment.

Figure C-4. Typical Seismic Restraints for Suspended Equipment



SUSPENDED EQUIPMENT



SUSPENDED EQUIPMENT WITH VIBRATION MOUNT

C-3.1.3 Supports and Attachments for Piping.

Seismic supports required in accordance with ASCE 7-22-Section 13.6.7, Distribution Systems: Piping and Tubing Systems, should be designed in accordance with the following guidance. This piping is not constructed in accordance with ASME B31 or NFPA 13.

C-3.1.3.1 General.

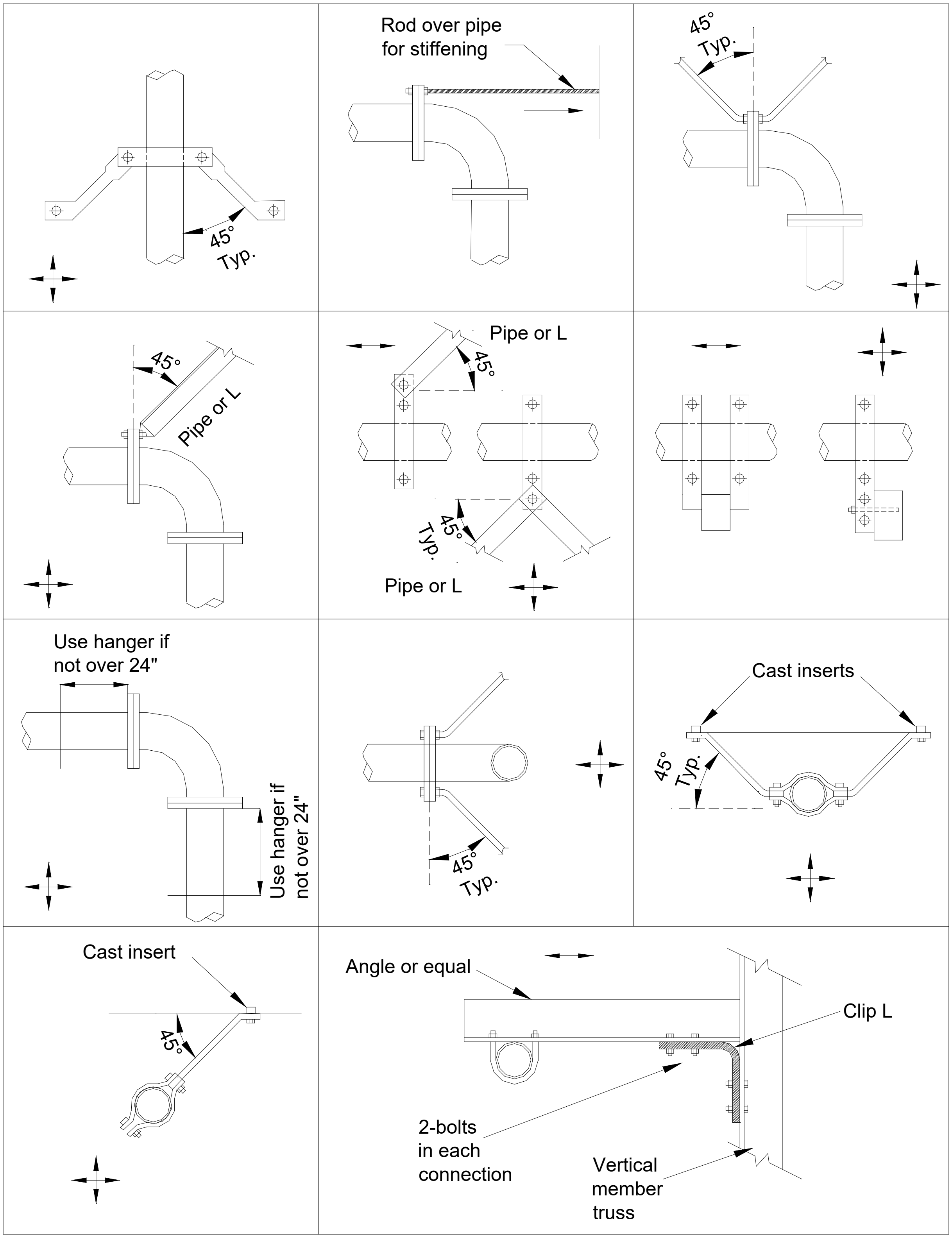
The provisions of this section apply to all risers and riser connections; all horizontal pipes and attached valves; all connections and brackets for pipes; flexible couplings and expansion joints; and spreaders. The following general guidance applies to these elements:

1. For seismic analysis of horizontal pipes, the equivalent static force should be considered to act concurrently with the full dead load of the pipe, including contents.
2. All connections and brackets for pipes should be designed to resist concurrent dead and equivalent static forces. Seismic forces should be determined from ASCE 7-22 Section 13.3.1. Supports should be provided at all pipe joints unless continuity is maintained. Figure C-5 provides acceptable sway bracing details.
3. Flexible couplings should be provided at the bottoms of risers for pipes larger than 3.5 in. (89 mm) in diameter. Flexible couplings and expansion joints should be braced laterally and longitudinally unless such bracing would interfere with the action of the couplings or joints. When pipes enter buildings, flexible couplings should be provided to allow for relative movement between the soil and the building.
4. Spreaders should be provided at appropriate intervals to separate adjacent pipelines unless pipe spans and clear distances between pipes are sufficient to prevent contact between the pipes during an earthquake.

C-3.1.3.2 Rigid versus Flexible Piping Systems.

Piping systems should be considered either rigid or flexible. The dynamic response of rigid piping systems is assumed to be decoupled from the building's amplified response, so that the component resonance ductility factor factor, C_{AR}, is set to 1.0. It is assumed that flexible pipes may couple with and further amplify building motion. Designers are encouraged to use high-deformability pipe systems that may permit longer pipe support spacing. It should be noted that when high-deformability pipe systems, which have the larger R_{po} values, are used (e.g., welded steel pipe systems), F_p, may be limited by the minimum value set forth by ASCE 7-22 Equation 13.3-3. Forces based on ASCE 7-22 Equation 13.3-3 may also govern for pipes installed in lower levels of a building.

Figure C-5. Acceptable Seismic Details for Pipe Sway Bracing



C-3.1.3.2.1 Rigid Piping System.

A piping system is assumed rigid if its maximum period of vibration is no more than 0.06 second (ASCE 7-22-Section 11.2 definition for Component, rigid). ASCE 7-16 Table 13.6-1 Footnote 1 used to indicate that a_p equals 1.0 for rigid pipes, where the support motions are not amplified. Rigid and rigidly attached pipes should be designed in accordance with ASCE 7-22 Equation 13.3-1, where W_p is the weight of the pipes, their contents, and attachments. Forces should be distributed in proportion to the total weight of pipes, contents, and attachments.

Tables C-1, C-2, and C-3 may be used to determine allowable span-diameter relationships for rigid pipes; standard (40S) pipe; extra strong (80S) pipe; types K, L, and M copper tubing; and 85 red brass or SPS copper pipe in RC IV buildings. These tables are based on water-filled pipes with periods equal to 0.06 second. Figures C-6, C-7, and C-8 display support conditions for Tables C-1, C-2, and C-3, respectively. The relationship used to determine maximum pipe lengths, L, shown in the tables, that will result in rigid pipes having a maximum period of vibration of 0.06 seconds, is given in Equation C-1 (which is excerpted from the *Shock and Vibration Handbook*, 6th Edition, 2009):

$$L = \sqrt{C \pi T_a \sqrt{\frac{EI_g}{w}}} \text{, in. or mm} \qquad \textbf{(Equation C-1)}$$

where

C = period constant, equal to 0.50 for pinned-pinned pipes; 0.78 for fixed- pinned pipes; and 1.125 for fixed-fixed pipes

T_a = natural period of pipe in its fundamental mode, set equal to 0.06 second

E = modulus of elasticity of pipe, psi or MPa

I = moment of inertia of pipe, in^4 or mm^4

w = weight of pipe and contents per unit length, lb/in. or N/mm

Table C-1
Maximum Span for Rigid Pipe with Pinned-Pinned Conditions, *L*

Diameter Inches	Std. Wt. Steel Pipe 40S	Ex. Strong Steel Pipe 80S	Copper Tube Type K	Copper Tube Type L	Copper Tube Type M	85 Red Brass & SPS Copper Pipe
1	7'- 0"	7'- 0"	5'- 5"	5'- 4"	4'- 11"	5'- 11"
1 1/2	8'- 5"	8'- 6"	6'- 5"	6'- 3"	5'- 12"	7'- 1"
2	9'- 4"	9'- 5"	7'- 3"	7'- 1"	6'- 10"	7'- 10"
2 1/2	10'- 3"	10'- 5"	7'- 11"	7'- 10"	7'- 5"	8'- 8"
3	11'- 3"	11'- 5"	8'- 8"	8'- 6"	8'- 1"	9'- 6"
3 1/2	11'- 12"	12'- 2"	9'- 3"	9'- 1"	8'- 8"	10'- 2"
4	12'- 8"	12'- 11"	9'- 10"	9'- 9"	9'- 5"	10'- 9"
5	13'- 11"	14'- 3"	10'- 11"	10'- 8"	10'- 4"	11'- 8"
6	15'- 1"	15'- 7"	11'- 12"	11'- 6"	11'- 2"	12'- 7"
8	16'- 12"	17'- 8"				
10	18'- 9"	19'- 4"				
12	20'- 1"	20'- 9"				

Figure C-6. Pinned-pinned Support Condition for Table C-1

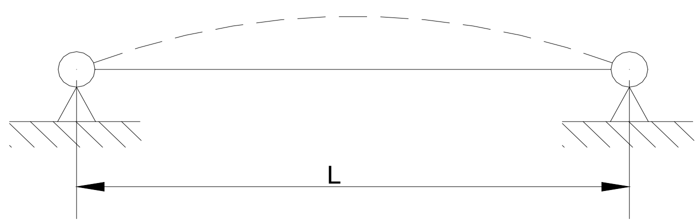


Table C-2
Maximum Span for Rigid Pipe with Fixed-Pinned Condition, *L*

Diameter Inches	Std. Wt. Steel Pipe 40S	Ex. Strong Steel Pipe 80S	Copper Tube Type K	Copper Tube Type L	Copper Tube Type M	85 Red Brass & SPS Copper Pipe
1	8'- 9"	8'- 10"	6'- 9"	6'- 8"	6'- 1"	7'- 5"
1 1/2	10'- 6"	10'- 7"	7'- 12"	7'- 10"	7'- 6"	8'- 10"
2	11'- 7"	11'- 9"	9'- "	8'- 10"	8'- 6"	9'- 9"
2 1/2	12'- 10"	12'- 12"	9'- 11"	9'- 9"	9'- 4"	10'- 9"
3	14'- 1"	14'- 3"	10'- 10"	10'- 7"	10'- 1"	11'- 10"
3 1/2	14'- 11"	15'- 3"	11'- 7"	11'- 4"	10'- 10"	12'- 8"
4	15'- 9"	16'- 1"	12'- 4"	12'- 2"	11'- 9"	13'- 5"
5	17'- 5"	17'- 10"	13'- 8"	13'- 3"	12'- 10"	14'- 7"
6	18'- 10"	19'- 5"	14'- 11"	14'- 5"	13'- 11"	15'- 8"
8	21'- 2"	22'- 0"				
10	23'- 5"	24'- 2"				
12	25'- 1"	25'- 11"				

Figure C-7. Fixed-pinned Support Condition for Table C-2

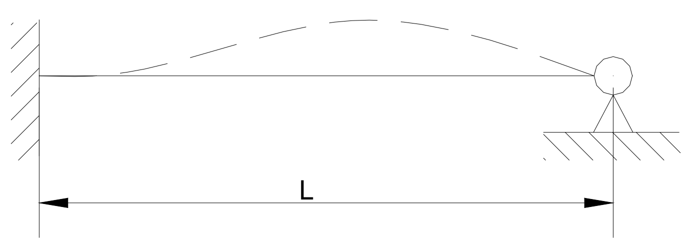
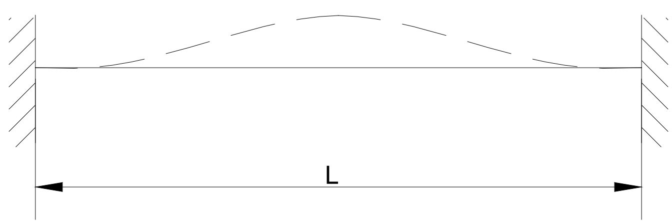


Table C-3
Maximum Span for Rigid Pipe with Fixed-Fixed Condition, *L*

Diameter Inches	Std. Wt. Steel Pipe 40S	Ex. Strong Steel Pipe 80S	Copper Tube Type K	Copper Tube Type L	Copper Tube Type M	85 Red Brass & SPS Copper Pipe
1	10'- 7"	10'- 7"	8'- 1"	7'- 12"	7'- 4"	8'- 11"
1 1/2	12'- 7"	12'- 8"	9'- 7"	9'- 5"	8'- 12"	10'- 8"
2	13'- 11"	14'- 2"	10'- 10"	10'- 8"	10'- 2"	11'- 9"
2 1/2	15'- 5"	15'- 7"	11'- 11"	11'- 9"	11'- 2"	12'- 11"
3	16'- 11"	17'- 2"	12'- 12"	12'- 9"	12'- 1"	14'- 3"
3 1/2	17'- 12"	18'- 4"	13'- 11"	13'- 8"	13'- 1"	15'- 3"
4	18'- 11"	19'- 4"	14'- 9"	14'- 8"	14'- 2"	16'- 1"
5	20'- 11"	21'- 5"	16'- 5"	15'- 11"	15'- 5"	17'- 7"
6	22'- 7"	23'- 4"	17'- 12"	17'- 4"	16'- 9"	18'- 10"
8	25'- 6"	26'- 5"				
10	28'- 2"	29'- 0"				
12	30'- 2"	31'- 1"				

Figure C-8. Fixed-fixed Support Condition for Table C-3



C-3.1.3.2.2 Flexible Piping Systems.

Piping systems that do not comply with the rigidity requirements of Section C-3.1.3.2.1 (i.e., period less than or equal to 0.06 second) should be considered flexible (i.e., period greater than 0.06 second). Flexible piping systems should be designed for seismic forces with consideration given to both the dynamic properties of the piping system and the building or structure in which it is placed. In lieu of a more detailed analysis, equivalent static lateral force may be computed using ASCE 7-22 Equation 13.3-1, with $\left[\frac{C_{AR}}{R_{po}}\right]$ = 2.5. The forces should be distributed in proportion to the total weight of pipes, contents, and attachments. If the weight of attachments is greater than 10% of pipe weight, attachments should be separately braced, or substantiating calculations should be required. If temperature stresses are appreciable, substantiating calculations should be required. The following guidance should also be followed for flexible pipe systems:

1. Separation between pipes should be a minimum of four times the calculated maximum displacement due to F_p, but not less than 4 in. (102 mm) clearance between parallel pipes, unless spreaders are provided.

2. Clearance from walls or rigid elements should be a minimum of three times the calculated displacement due to F_p, but not less than 3 in. (76 mm) clearance from rigid elements.

3. If the provisions of the above paragraphs appear to be too severe for an economical design, alternative methods based on rational and substantial analysis may be applied to flexible piping systems.

4. Acceptable seismic details for sway bracing are shown in Figure C-5.

C-3.2 Stacks (Exhaust) Associated with Buildings.

Reference should me made to ASCE 7-22 Section 13.6, as modified by Section 13.6.1 of Chapter 3 of this UFC, and ASCE 7-22 Chapter 15.

C-3.2.1 General.

Stacks are actually vertical beams with distributed mass and, as such, cannot be modeled accurately by single-mass systems. This design guidance applies to either cantilever or singly-guyed stacks attached to buildings. When a stack foundation is in contact with the ground and the adjacent building does not support the stack, it should be considered to be a nonbuilding structure (see ASCE 7-22 Chapter 15). This guidance is intended for stacks with a constant moment of inertia. Stacks having a slightly varying moment of inertia should be treated as having a uniform moment of inertia with a value equal to the average moment of inertia.

Stacks that extend more than 15 ft (4.6 m) above a rigid attachment to the supporting building should be designed according to the guidance for cantilever stacks presented in Section C-3.2.2 of this UFC. Stacks that extend less than 15 ft (4.6 m) should be designed for the equivalent static lateral force defined in ASCE 7-22 Section 13.3.1 using the C_{AR} and R_{po} values in ASCE 7-22 Table 13.6-1.

Stacks should be anchored to supporting buildings using long anchor bolts (where bolt length is at least 12 bolt diameters). Much more strain energy can be absorbed with long anchor bolts than with short ones. The use of long anchor bolts has been demonstrated to give stacks better seismic performance. A bond-breaker material should be used on the upper portion of the anchor bolt to ensure a length of unbonded bolt for strain energy absorption. Two nuts should be used on anchor bolts to provide an additional factor of safety.

C-3.2.2 Cantilever Stacks.

The fundamental period of a cantilever stack should be determined from the period coefficient (e.g., C = 0.0909) provided in Figure C-9, unless actually computed. The equation and the period coefficients, C, shown in Figure C-9 were derived from the *Shock and Vibration Handbook* (6th Edition, 2009). Dynamic response of ground-supported stacks may be calculated from the appropriate base shear equations for the Equivalent Lateral Force Procedure defined in ASCE 7-22 Section 12.8.

C-3.2.3 Guyed Stacks.

Analysis of guyed stacks depends on the relative rigidities of the cantilever component and the guy cable support system. If a cable is relatively rigid compared to the cantilever component, the stack should respond in a manner similar to the higher modes of vibration of a cantilever, with periods and mode shapes similar to those shown in Figure C-9. The fundamental period of vibration of the guyed system should be somewhere between the values for the fundamental and the appropriate higher mode of a similar cantilever stack. An illustration for a single guyed stack is shown in Figure C-10. Guyed stacks should be designed with rigid cables so that the true deflected shape is closer to that shown on the right side of Figure C-10. This requires pretensioning of guy cables to a minimum of 10 percent of stack seismic forces, F_p. Design for guyed stacks is beyond the scope of this document. However, some guidance may be found in TIA-222-I, *Structural Standard for Antenna Supporting Structures, Antennas and Small Wind Turbine Support Structures,* September 2023.

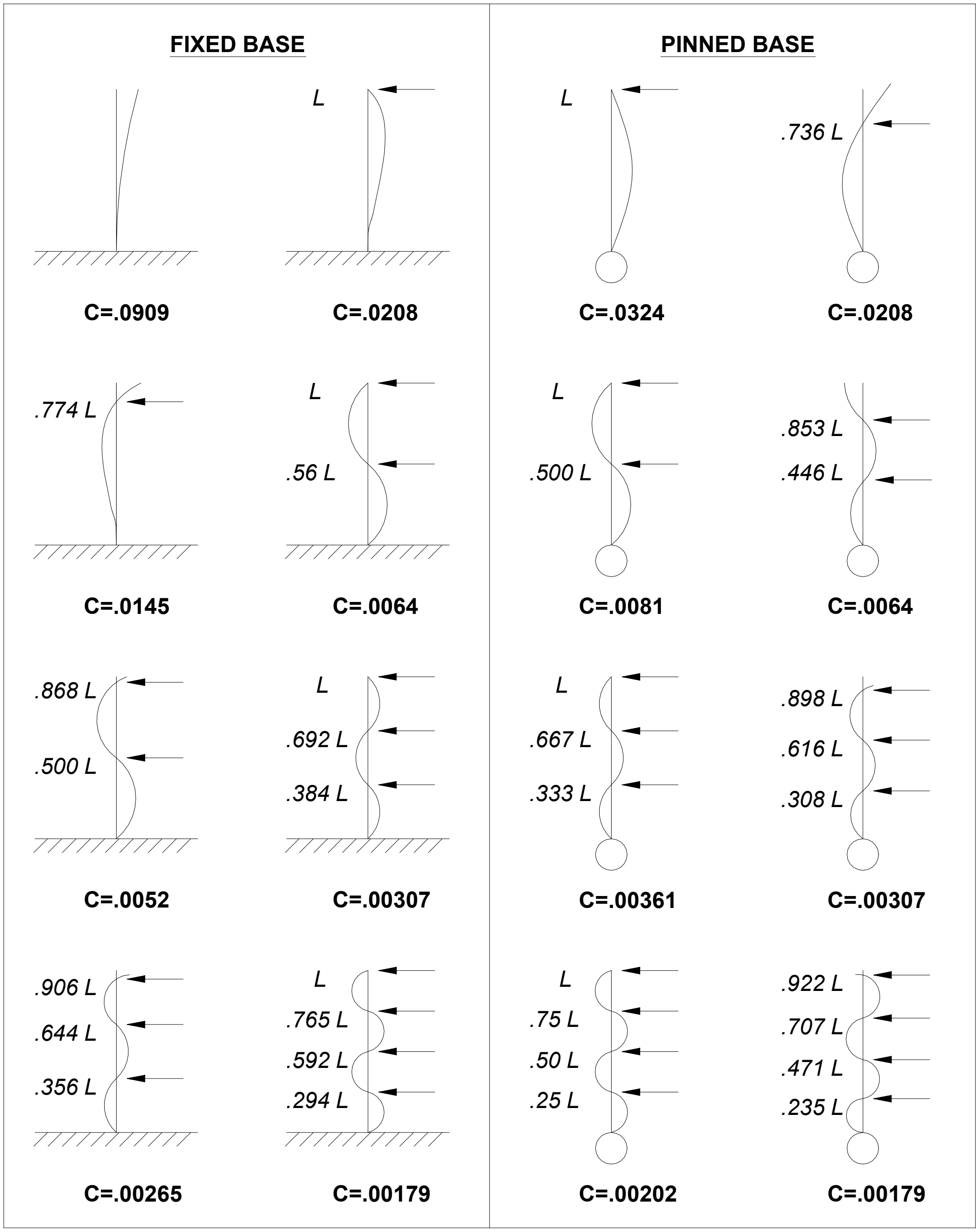
C-3.3 Elevators.

Reference should be made to ASCE 7-22 Section 13.6.11, Elevator and Escalator Design Requirements, as modified by Section 13.6.11.3 of Chapter 3 of this UFC.

C-3.3.1 General.

Elevator car and counterweight frames, roller guide assemblies, retainer plates, guide rails, and supporting brackets and framing (Figure C-11) should be designed in accordance with ASCE 7-22 Section 13.6.11. Lateral forces acting on guide rails should be assumed to be distributed one-third to top guide rollers and two- thirds to bottom guide rollers of elevator cars and counterweights. An elevator car and/or counterweight should be assumed to be located at its most adverse position in relation to its guide rails and support brackets. Horizontal deflections of guide rails should not exceed 1/2 in. (12.7 mm) between supports, and horizontal deflections of the brackets should not exceed 1/4 in. (6.4 mm).

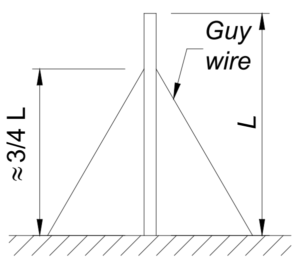
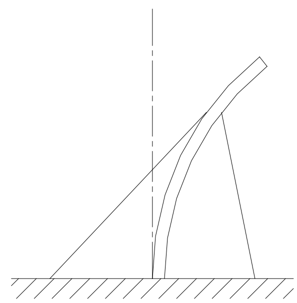
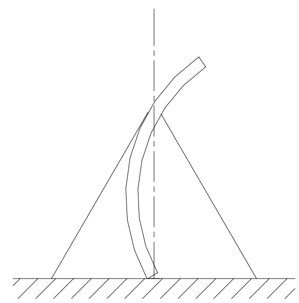
Figure C-9. Period Coefficients for Uniform Beams



$$T_a = C\sqrt{\frac{wL^4}{EI}}$$

T_a = Fundamental period (sec)
w = Weight per unit length of beam (lb/in) (N/mm)
L= Total beam length (in) (mm)
I = Moment of inertia (in^4) (mm^4)
E = Modulus of elasticity (psi) (MPa)
C = Period constant

Figure C-10. Single Guyed Stacks

DESCRIPTION	DEFLECTED SHAPE	
	FLEXIBLE WIRE	RIGID WIRE
		

C-3.3.2 Retainer Plates.

In structures assigned to SDC D, E, and F, clearances between the machined faces of rail and retainer plates should not be more than 3/16 in. (4.8 mm), and the engagement of a rail should not be less than the dimension of its machined side face. When a car safety device attached to lower members of a car frame complies with lateral restraint requirements, a retainer plate is not required for the bottom of the car.

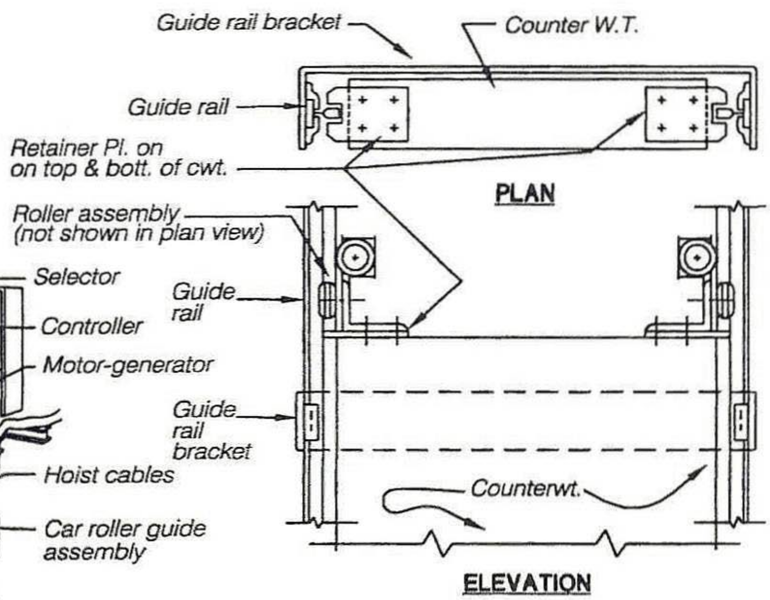
C-3.3.3 Counterweight Tie Brackets.

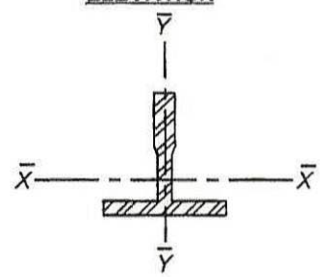
In structures assigned to SDC D, E, and F, the maximum spacing of counterweight rail tie brackets tied to a building structure should not exceed 16 ft (4.9 m). An intermediate spreader bracket, which is not required to be tied to a building structure, should be provided for tie brackets spaced greater than 10 ft (3.0 m), and two intermediate spreader brackets are required for tie brackets spaced greater than 14 ft (4.3 m).

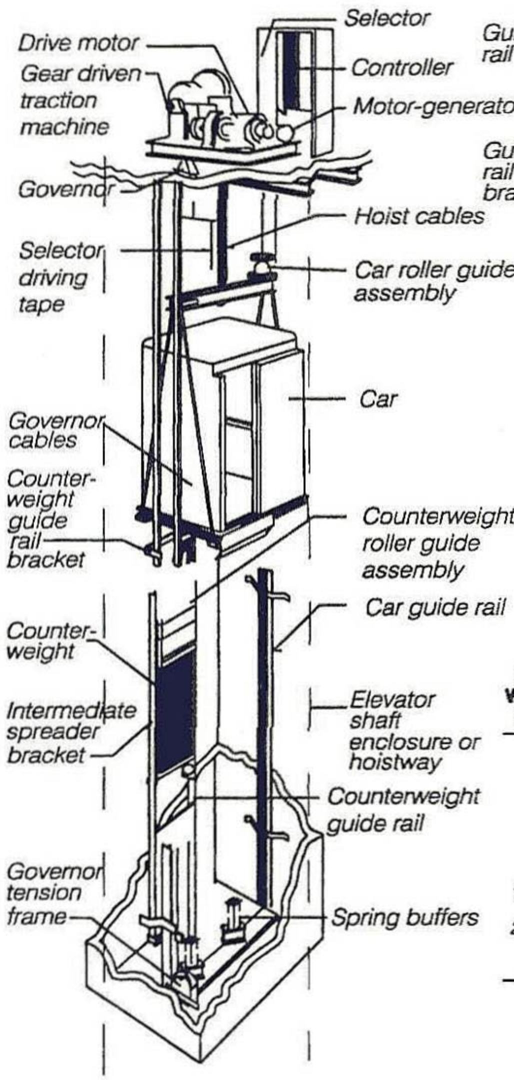
C-3.3.4 Force Calculation.

Elevator machinery and equipment should be designed for $\left[\frac{C_{AR}}{R_{po}}\right]$ = 1.0 in ASCE 7-22 Equation 13.3-1, when rigid and rigidly attached. Non-rigid or flexibly mounted equipment (which has a period greater than 0.06 second) should be designed with $\left[\frac{C_{AR}}{R_{po}}\right]$ = 2.5.

Figure C-11. Elevator Details







TRACTION TYPE ELEVATOR

Section Properties of Elevator Guide Rails

Nom. Wt. per Foot	A	$\bar{y}$	I_x	S_x	r_x	I_y	S_y	r_y
8	2.40	0.81	1.40	0.86	0.78	1.28	0.73	0.74
11	3.24	1.12	4.29	1.80	1.15	2.67	1.19	0.90
12	3.51	1.08	4.49	1.85	1.13	3.61	1.45	1.01
15	4.41	0.97	4.78	1.89	1.04	5.51	2.21	1.12
18.5	5.44	1.26	9.67	3.23	1.33	7.45	2.71	1.17
22.5	6.73	1.38	11.17	4.20	1.28	8.64	3.10	1.13
30	8.93	1.74	24.00	7.37	1.64	11.08	4.03	1.11

A = Area (in.^{2})
$\bar{y}$ = Distance from back of rail to axis x-x (in.)
I_x = Moment of inertia about axis x-x (in.^{4})
S_x = Section modulus about axis x-x (in.^{3})
r_x = Radius of gyration about axis x-x (in.)
I_y = Moment of inertia about axis y-y (in.^{4})
S_y = Section modulus about axis y-y (in.^{3})
r_y = Radius of gyration about axis y-y (in.)

C-3.4 Lighting Fixtures in Buildings

Reference should be made to ASCE 7-22 Sections 13.2.5 Testing Alternative for Seismic Capacity Determination, 13.5.6 Suspended Ceilings, 13.6.1 General, 13.6.2 Mechanical Components, 13.6.3 Electrical Components, and 13.6.4 Component Supports as modified by Chapter 3 of this UFC in the Sections 13.5.6, 13.6.1, 13.6.2, 13.6.3, and 13.6.4.

C-3.4.1 General.

Lighting fixtures, including their attachments and supports, in SDC C, D, E, and F buildings should conform to the following materials and construction requirements:

1. Fixture supports should use materials that are suitable for that purpose. Cast metal parts, other than those of malleable iron, and cast or rolled threads, should be subject to special investigation to ensure structural adequacy.
2. Loop and hook or swivel hanger assemblies for pendant fixtures should be fitted with restraining devices to hold their stems in the support position during earthquake motions. Pendant-supported fluorescent fixtures should also be provided with flexible hanger devices at their attachments to the fixture channel to preclude breaking of the support. Motions of swivels or hinged joints should not cause sharp bends in conductors or damage to insulation.
3. A supporting assembly that is intended to be mounted on an outlet box should be designed to accommodate mounting features on 4 in. (102 mm) boxes, 3 in. (76 mm) plaster rings, and fixture studs.
4. Each surface-mounted individual or continuous row of fluorescent fixtures should be attached to an earthquake-resisting ceiling support system. Support devices for attaching fixtures to suspended ceilings should be locking-type scissor clamps or full loop bands that will securely attach to the ceiling support. Fixtures attached to the underside of a structural slab should be properly anchored to the slab at each of their corners.
5. Each wall-mounted emergency light unit should be secured in a manner that will hold the unit in place during a seismic disturbance.

C-3.5 Bridges, Cranes, and Monorails.

Reference should be made to ASCE 7-22 Section 13.6 Mechanical and Electrical Component, as modified by Chapter 3 of this UFC in the Sections 13.6.14 Bridges, Cranes, and Monorails and 13.6.14.1 Bridges, Cranes, and Monorails for RC IV Buildings and 2024 IBC Section 1607.15.

C-3.5.1 General.

2024 IBC Section 1607.15 provides live load design guidance for cranes. Vertical restraints should be provided to resist crane uplift. Experience has shown that vertical ground motions can be amplified significantly in either crane bridges or crane rail support brackets that are cantilevered from columns. Analysis of cranes should consider their amplified response in the vertical direction, in addition to horizontal response. The criteria in Section 13.6.14 in Chapter 3 of this UFC specify C_{AR} of 1.5 and R_{po} of 1.5, resulting in $c\left[\frac{C_{AR}}{R_{po}}\right]$=1.0 in the direction parallel to crane rails, because a crane bridge would almost certainly be flexible enough along its weak axis to have a natural period greater than 0.06 seconds. The C_{AR} factor is greater than 1.0 because, at large natural periods, a crane bridge can be expected to amplify ground and building motions. This factor has a value of 1.0 perpendicular to crane rails because the bridge would be loaded axially in this direction, resulting in a natural period that is less than 0.06 second. The crane bridge is considered to be rigid when loaded axially, so that it will not amplify ground or building motions. When a crane is not in the locked position, it is reasonable to assume that upper bound forces in the direction parallel to crane rails, between the wheels and the rails, cannot exceed a conservative estimate of the force that could be transmitted by friction between the brake wheels and rails.

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APPENDIX D MECHANICAL AND ELECTRICAL COMPONENT CERTIFICATION

D-1 COMPONENT CERTIFICATION.

D-1.1 General.

The background to mechanical and electrical component certification is explained in *Special Seismic Certification of Nonstructural Components* (Tobolski, M., Structural Engineering and Design, 2011).

ASCE 7-22 Section 13.2 states that certification must be by analysis, testing or experience data. Mechanical and electrical equipment that must remain operable following the design earthquake ground motion must be certified based on shake table testing or experience data unless it can be shown that the component is inherently rugged by comparison with similar seismically qualified components (Section 13.2.3). ASCE 7-22 Section 13.2.3 Item 2 states that "Components with hazardous substances and assigned a component Importance Factor, I_p, of 1.5 in accordance with Section 13.1.3 shall be certified by the manufacturer as maintaining containment following the design earthquake ground motion by (a) analysis, (b) approved shake table testing in accordance with Section 13.2.6, or (c) experience data in accordance with Section 13.2.7."

HCAI has issued a Policy Intent Notice (PIN) 55 on its Special Seismic Certification Preapproval (OSP) program. This program offers a means to obtain prequalification of product lines for special seismic certification. The details of this program can be found at https://hcai.ca.gov/wp-content/uploads/2022/08/PIN-55_Special-Seismic-Certification-Preapproval-OSP_080322_A-1.pdf. Lists of equipment that is pre-approved by HCAI can be found at https://hcai.ca.gov/construction-finance/preapproval-programs/hcai-special-seismic-certification-preapproval-osp-by-category/. The basis of HCAI preapproval always is shake table testing in compliance with ICC-ES AC156 and satisfaction of ICC-ES AC156 post-test acceptance criteria.

References in this appendix are made to ASCE 7-22 Section 13.2, General Design Requirements, and Chapter 3 of this UFC Section 13.2.3.

D-1.1.1 Analytical Certification.

Certification based on analysis, as noted in ASCE 7-22 Section 13.2.3 Item 3, requires a reliable and conservative understanding of the equipment configuration, including the mass distribution, strength, and stiffness of the various subcomponents. From this information, an analytical model may be developed that reliably and conservatively predicts the equipment dynamic response and potential controlling modes of failure. If such detailed information on the equipment or a basis for conservative estimates of these properties is not available, then methods other than analysis must be used. The use of analysis for active or energized components is not permitted (see ASCE 7-22 Section 13.2.3 Item 1). Examples of active designated seismic equipment include mechanical (components of HVACR systems and piping systems) or electrical (power supply distribution) equipment, medical equipment, fire pump equipment, and uninterruptible power supplies for hospitals. Any analytical qualification of equipment should be peer-reviewed independently by qualified, Registered Design Professionals.

D-1.1.2 Certification Based on Testing.

Shake table tests conducted in accordance with either ICC-ES AC156, *Acceptance Criteria for Seismic Qualification by Shake-Table Testing of Nonstructural Components,* or a site-specific study, should first use uniaxial motions along each of the three principal axes of the equipment that is being tested. The measured response recorded with vibration response monitoring instrumentation should be reviewed to determine if out-of-plane response (in terms of peak amplitude) at a given location of instrumentation exceeds 20% of the in-plane response. The in-plane direction is the direction of horizontal test motions, while the out-of-plane direction is at a horizontal angle of 90 degrees with respect to the in-plane axis. An out-of-plane response (equipment relative acceleration or equipment deformation) that exceeds 20% of the in-plane response, for either horizontal test, indicates that significant cross-coupling is occurring. In that case, the final qualification test should be triaxial, with simultaneous phase-incoherent motions along all three principal axes. If out-of-plane response is less than 20% of the in-plane response for both horizontal tests, at each critical location instrumented, then the final qualification tests can be biaxial with motions in one horizontal and the vertical directions. After post-test inspection and functional compliance verification, the Unit Under Test (UUT) may be rotated 90 degrees about the vertical axis and biaxial testing for the other horizontal direction and vertical direction can be conducted. Normally, two biaxial tests, rather than a single triaxial test, would be conducted when a triaxial shake table is not available or the displacement capacity of a triaxial shake table in one direction is small.

The development of ICC-ES AC156 is documented in *ASCE Structures Congress Proceedings: Background on the Development of the NEHRP Seismic Provisions for Non-Structural Components and their Application to Performance Based Seismic Engineering* (Gillengerten, J.D., and Bachman, R.E., ASCE Structures Congress, 2003). For RC V facilities, the site-specific seismic site response analysis will result in a set of site-specific ground motions that define the seismic hazard. The building model could be analyzed with these motions to define predicted time-history motions at each location where critical equipment must be installed. From these building response motions, response spectra could be developed, using 5% of critical damping. If the equipment will be placed at several locations in the same building or in multiple buildings, a required response spectrum (RRS) could be developed that envelopes all the spectra generated from each building response record. As an alternative to the ICC-ES AC156 procedure, the equipment could be qualified with triaxial motions fit to the RRS, but generated according to ICC-ES AC156. A second alternative approach would be to test with the predicted time history motions that have the greatest response spectra amplitude at the measured natural frequency of the equipment in each of the principal directions. Using worst-case records would require that resonance search shake table tests be conducted in each of the three principal directions as defined in ICC-ES AC156. All alternatives to ICC-ES AC156 equipment qualification testing require peer review of the development of test records and test plans by qualified, Registered Design Professionals. Post-test inspection and functional compliance verification would still be required in accordance with ICC-ES AC156.

D-1.1.3 Additional Certification Methods.

Three additional methods are permitted for defining equipment capacity: earthquake experience data, seismic qualification testing data, and the CERL Equipment Fragility and Protection Procedure. The use of these methods requires a peer review by a qualified, Registered Design Professional.

D-1.1.3.1 Earthquake Experience Data.

Earthquake experience data that were obtained by surveying and cataloging the effects of strong ground motion earthquakes on various classes of equipment mounted in conventional power plants and other industrial facilities may be used. Section 4.2.1 of the publication *Generic Implementation Procedure (GIP) for Seismic Verification of Nuclear Plant Equipment* (DOE 1992) provides these data. Based on this work, a Reference Spectrum would be developed to represent the seismic capacity of equipment in the earthquake experience equipment class. DOE/EH-0545, *Seismic Evaluation Procedure for Equipment in U.S. Department of Energy Facilities*, provides guidance on this procedure. A detailed description of the derivation and use of this Reference Spectrum is contained in DoE publication SAND92-0140, *Use of Seismic Experience Data to Show Ruggedness of Equipment in Nuclear Power Plants*. This document should be reviewed before using the Reference Spectrum. The Reference Spectrum and four spectra from which it is derived are shown in Figure 5.3-1 of DOE/EH-0545. The Reference Spectrum and its defining response levels and frequencies are shown in Figure 5.3-2 of the same document. When this approach is used, the Reference Spectrum is used to represent the seismic capacity of equipment, when the equipment is determined to have characteristics similar to the earthquake experience equipment class and meets the intent of the caveats for that class of equipment as defined in Chapter 8 of DOE/EH-0545.

D-1.1.3.2 Seismic Qualification Testing Database.

Data collected from seismic qualification testing of nuclear power plant equipment may be used in the certification of equipment. These data were used to develop generic ruggedness levels for various equipment classes in the form of Generic Equipment Ruggedness Spectra (GERS). The development of the GERS and the limitations on their use are documented in Electric Power Research Institute (EPRI) report NP-5223, *Generic Seismic Ruggedness of Power Plant Equipment in Nuclear Power Plants*. The non-relay GERS and limitations on their use are discussed in Chapter 8 of DOE/EH-0545, while the relay GERS are in Chapter 11 of the same document. The EPRI report should be reviewed by users of the GERS to understand the basis for them. The use of either the Reference Spectrum or the GERS for defining equipment capacity requires careful review of the basis for them to ensure applicability to the equipment being evaluated.

D-1.1.3.3 CERL Equipment Fragility and Protection Procedure.

The CERL Equipment Fragility and Protection Procedure (CEFAPP), defined in USACERL Technical Report 97/58, may be used for defining equipment capacity. Similar to the other methods, CEFAPP defines a response spectrum envelope of the equipment capacity. This method requires a series of shake table tests to develop an actual failure envelope across a frequency range. This experimental approach requires greater effort than the ICC-ES AC156 qualification testing. However, the resulting failure envelope provides a more accurate and complete definition of capacity, rather than simply determining that the equipment survived a defined demand environment. Unlike the AC156 procedure, site-specific testing, or the other two additional methods, CEFAPP defines actual equipment capacity and provides information on modes of failure with respect to response spectra amplitudes and frequency of motion. Definitions of equipment capacity are more accurate with respect to frequency and mode of failure than can be established using the alternative methods. When equipment capacity is compared with the seismic demands at the various locations in which the equipment must be installed, the equipment vulnerability, if any, can be clearly defined in terms of predicted mode of failure and frequency. The procedure provides information on how to protect the equipment, using isolation, strengthening, or stiffening. The use of CEFAPP requires peer review of proposed test motions, the test plan, and use of the data, by qualified Registered Design Professionals.

D-1.1.3.4 Qualification of Power Substation Equipment.

IEEE Recommended Practice for Seismic Design of Substations (IEEE 693-2018) provides detailed guidance for the qualification of equipment used in power substations. This guidance should be used for the qualification of this equipment even if installed at facilities other than substations (e.g., power plants).

APPENDIX E MINIMUM UNIFORMLY DISTRIBUTED LIVE LOADS, L_O, AND MINIMUM CONCENTRATED LIVE LOADS

E-1 REFERENCES.

All section references are to the 2024 International Building Code (2024 IBC). Table E-1 includes 2024 IBC Table 1607.1 with additional Occupancy or Use classification for military facilities that are shown in bold italics.

Table E-1 Minimum Uniformly Distributed Live Loads and Minimum Concentrated Live Loads[a]

OCCUPANCY OR USE	UNIFORM		CONCENTRATED	
	(kPa)	(psf)	(kN)	(lbs.)
1. Apartments (see residential)	---	---	---	---
2. Access floor systems				
Office use	2.4	50	8.9	2,000
Computer use	4.8	100	8.9	2,000
3. Ammunition Storage				
High explosives (one story)	***23.9***	***500***	---	---
Inert explosives (one story)	***23.9***	***500***	---	---
Pyrotechnics (one story)	***23.9***	***500***	---	---
Small arms (one story)	***23.9***	***500***	---	---
Torpedo (one story)	***16.8***	***350***	---	---
4. Armories and drill rooms	7.2[d]	150[d]	---	---
5. Assembly areas				---
Fixed seats (fastened to floor)	2.9[d]	60[d]	---	---
Lobbies				
Movable seats	4.8[d]	100[d]	---	---
Stage floors	4.8[d]	100[d]	---	---
Platforms (assembly)	7.2[d]	150[d]	---	---
Other assembly areas	4.8[d]	100[d]	---	---
	4.8[d]	100[d]	---	---
6. Balconies and decks[b] ***(Balconies serving as primary means of egress for multiple rooms must be considered as corridors.)***	4.8	1.5 times the live load for the area served, not required to exceed 100	---	---
7. Battery charging room	***9.6***	***200***	***---***	***---***
8. Boiler houses	***9.6***	***200***	***---***	***---***
9. Catwalks for maintenance and service access	1.9	40	1.33	300
10. Cleaning gear / trash room compactor	***3.6***	***75***	***---***	***---***

OCCUPANCY OR USE	UNIFORM		CONCENTRATED	
	(kPa)	(psf)	(kN)	(lbs.)
11. Cold Storage (Food or provision freezer) ***First floor*** ***Upper floors***	 ***19.2*** ***14.4***	 ***400*** ***300***	 ***---*** ***---***	 ***---*** ***---***
12. Command Duty Officer Day room	***2.9***	***60***	***---***	***---***
13. Cornices	2.9	60	---	---
14. Corridors First floor Other floors	 4.8 Same as occupancy served except as indicated	 100 Same as occupancy served except as indicated	---	---
15. Court rooms	***3.8***	***80***	***---***	***---***
16. Dining rooms and restaurants	4.8[d]	100[d]	---	---
17. Dwellings (see residential)	---	---	---	---
18. Elevator machine room and control room grating (on area of 50.8 mm x 50.8 mm (2 in. x 2 in.))	---	---	1.33	300
19. Finish light floor plate construction (on area of 25.4 mm x 25.4 mm (1 in. x 1 in.))	---	---	0.89	200
20. Fire escapes On single-family dwellings only	4.8 1.9	100 40	---	---
22. Fixed Ladders	See IBC Section 1607.10	See IBC Section 1607.10	See IBC Section 1607.10	See IBC Section 1607.10
22. Galleys ***Dishwashing rooms*** ***General kitchen area*** ***Provision storage (not refrigerated)*** ***Preparation room*** ***Meat*** ***Vegetable***	 ***14.4*** ***12.0*** ***9.6*** ***12.0*** ***4.8***	 ***300*** ***250*** ***200*** ***250*** ***100***	***---***	***---***
23. Garages and Vehicle floors Passenger vehicle garages Trucks & buses Fire trucks and emergency vehicles Forklifts and movable equipment	 1.9[f] See IBC Section 1607.8	 40[f] See IBC Section 1607.8	 See IBC Section 1607.8	 See IBC Section 1607.8
24. Generator rooms	***9.6***	***200***	***---***	***---***
25. Guard House	***3.6***	***75***	***---***	***---***

OCCUPANCY OR USE	UNIFORM		CONCENTRATED	
	(kPa)	(psf)	(kN)	(lbs.)
26. Handrails, guards and grab bars	See IBC Section 1607.9	See IBC Section 1607.9	See IBC Section 1607.9	See IBC Section 1607.9
27. Helipads[g] Helicopter takeoff weight 3,000 lb (13.35 kN) or less Helicopter takeoff weight more than 3,000 lb (13.35 kN)	 1.9 2.9	 40[d] 60[d]	See IBC Section 1607.6.1	See IBC Section 1607.6.1
28. Hospitals Corridors above first floor Operating rooms, laboratories Patient rooms	 3.8 2.9 1.9	 80 60 40	 4.45 4.45 4.45	 1,000 1,000 1,000
29. Hotels (see residential)	---	---	---	---
30. Incinerators; charging room	***7.2***	***150***	***---***	***---***
31. Laboratories, normal scientific equipment	***6.0***	***125***	***---***	***---***
32. Latrines / Heads / Toilets / Washroom	***3.6***	***75***	***---***	***---***
33. Libraries Reading rooms Stack rooms Corridors above first floor	 2.9 7.2[e] 3.8	 60 150[e](See Section 1607.17) 80	 4.45 4.45 4.45	 1,000 1,000 1,000
34. Manufacturing Light Heavy	 6.0[d] 12.0[d]	 125[d] 250[d]	 8.90 13.34	 2,000 3,000
35. Marquees, except one- and two-family dwellings	3.6	75	---	---
36. Mechanical equipment room (general) [h]	***4.8***	***100***	***---***	***---***
37. Mechanical room (HVAC, elevator machine rooms and floors over elevator hoistways)	***6.0***	***125***	***---***	***---***
38. Mechanical telephone and radio equipment room	***7.2***	***150***	***---***	***---***
39. Morgue	***4.8***	***100***	***---***	***---***

OCCUPANCY OR USE	UNIFORM		CONCENTRATED	
	(kPa)	(psf)	(kN)	(lbs.)
40. Office buildings File and computer rooms shall be designed for heavier loads based on anticipated occupancy Lobbies and first-floor corridors Offices Corridors above first floor	 --- 4.8 2.4 3.8	 --- 100 50 80	 --- 8.9 8.9 8.9	 --- 2,000 2,000 2,000
41. Penal Institutions Cell blocks Corridors	 1.9 4.8	 40 100	---	---
42. Post offices ***General area*** ***Work rooms***	 ***4.8*** ***6.0***	 ***100*** ***125***	***---***	***---***
43. Power plants	***9.6***	***200***	***---***	***---***
44. Projection booths	***4.8***	***100***	***---***	***---***
45. Pump houses	***4.8***	***100***	***---***	***---***
46. Recreation room	***4.8***	***100***	***---***	***---***
47. Recreational uses: Bowling alleys, poolrooms and similar uses Dance halls and ballrooms Gymnasiums Theater projection, control, and follow spot rooms Ice skating rink Reviewing stands, grandstands and bleachers Roller skating rink Stadiums and arenas with fixed seats (fastened to floor)	 3.6[d] 4.8[d] 4.8[d] 2.4 12[e] 4.8[d] (See IBC Section 1607.18) 4.8[d] 2.9[d] (See IBC Section 1607.18)	 75[d] 100[d] 100[d] 50 250[e] 100[d] (See IBC Section 1607.18) 100[d] 60[d] (See IBC Section 1607.18)	---	---
48. Receiving rooms (radio) including roof areas supporting antennas and electronic equipment	***7.2***	***150***	***---***	***---***
49. Refrigeration storage rooms ***Dairy*** ***Meat*** ***Vegetable***	 ***9.6*** ***12.0*** ***13.2***	 ***200*** ***250*** ***275***	 ***---*** ***---*** ***---***	 ***---*** ***---*** ***---***

OCCUPANCY OR USE	UNIFORM		CONCENTRATED	
	(kPa)	(psf)	(kN)	(lbs.)
50. Residential (See IBC Section 1607.21) One- and two-family dwellings				
Uninhabitable attics without storage	0.5	10	---	---
Uninhabitable attics with storage	1.0	20	---	---
Habitable attics and sleeping areas	1.4	30	---	---
Canopies, including marquees	1.0	20	---	---
All other areas except stairs	1.9	40	---	---
Hotels and multifamily dwellings Private rooms and corridors serving them	1.9	40	---	---
Corridors serving as primary means of egress to multiple private rooms	***3.8***	***80***	---	---
Public rooms	4.8[d]	100[d]	---	---
Corridors serving public rooms	4.8	100	---	---
51. Roofs (See IBC Section 1607.15)				
All roof surfaces subject to maintenance workers	---	---	1.33	300
Awnings and canopies:				
Fabric construction supported by a skeleton structure	0.23[d]	5[d]	---	---
All other construction, except one and two-family dwellings	1.0	20	---	---
Ordinary flat, pitched, and curved roofs (that are not occupiable)	1.0	20	---	---
Primary roof members exposed to a work floor:				
Single panel point of lower chord of roof trusses or any point along primary structural members supporting roofs over manufacturing, storage warehouses, and repair garages	---	---	8.9	2000
All other primary roof members	---	---	1.33	300
Vegetative and landscaped roofs:				
Roof gardens	4.8	100	---	---
Roof areas not intended for occupancy	1.0	20	---	---
Roof areas used for assembly purposes	4.8[d]	100[d]	---	---
	Note c	Note c	---	---

OCCUPANCY OR USE	UNIFORM (kPa)	UNIFORM (psf)	CONCENTRATED (kN)	CONCENTRATED (lbs.)
Roof areas used for occupancies other than assembly ***Roof of PV shade structures***	***1.0***	***20***	---	---
52. Schools				
Classrooms	1.9	40	4.45	1,000
Corridors above first floor	3.8	80	4.45	1,000
First floor corridors	4.8	100	4.45	1,000
53. Scuttles, skylight ribs, and accessible ceilings	---	---	0.89	200
54. Shops: Manufacturing and Industrial				
Aircraft utility	***9.6***	***200***	***---***	***---***
Assembly and repair	***12.0***	***250***	***---***	***---***
Bombsight (w/o shielding)	***6.0***	***125***	***---***	***---***
Carpenter	***6.0***	***125***	***---***	***---***
Electrical	***14.4***	***300***	***---***	***---***
Engine overhaul	***14.4***	***300***	***---***	***---***
55. Sidewalks, vehicular driveways and yards, subject to trucking (See IBC Section 1607.19)	12.0[e]	250[e]	35.6	8,000
56. Stairs and exits (See IBC Section 1607.20)				
One- and two-family dwellings	1.9	40	1.3	300
All other	4.8	100	1.3	300
57. Storage warehouses (shall be designed for heavier loads if required for anticipated storage)				
General				
Light	6.0[e]	125[e]		
Heavy	12[e]	250[e]		
Aircraft	***9.6***	***200***		
Building Materials	***12***	***250***	---	---
Drugs, paint, oil	***9.6***	***200***		
Dry Provisions	***14.4***	***300***		
Groceries, wine, Liquor	***14.4***	***300***		
Light Tools	***7.2***	***150***		
Pipe & metal	***48***	***1000***		
Paint and oil (one story)	***24***	***500***		
Hardware	***14.4***	***300***		
58. Stores				
Retail:				
First floor	4.8	100	4.45	1,000
Upper floors	3.6	75	4.45	1,000
Wholesale, all floors	6.0[e]	125[e]	4.45	1,000
59. Tailor shop	***3.6***	***75***	***---***	***---***
60. Telephone exchange rooms \4\ /4/	***7.2***	***150***	***8.9***	***2000***

OCCUPANCY OR USE	UNIFORM		CONCENTRATED	
	(kPa)	(psf)	(kN)	(lbs.)
\4\ ***61. Computer Server and High Density Data Center Rack Space*** /4/		***300***[j]		***3000***
62. Vehicle barriers	See IBC Section1607.11	See IBC Section 1607.11	See IBC Section 1607.11	See IBC Section 1607.11
63. Walkways and elevated platforms (other than exitways) ***Range Towers, Climbing Towers and other Multi-story Training Towers*** ***Pedestrian Bridges***	2.9 ***4.8*** ***AASHTO***[i]	60 ***100*** ***AASHTO***[i]	---	---
64. Yards and terraces, pedestrian	4.8[d]	100[d]	---	---

Notes to Table E-1, "Minimum Uniformly Distributed Live Loads, L_o, and Minimum Concentrated Live Loads"

For SI: 1 inch = 25.4 mm, 1 square inch = 645.16 mm^2, 1 square foot = 0.0929 m^2, 1 pound per square foot = 0.0479 kN/m^2 = 0.0479 kPa, 1 pound = 0.004448 kN, 1 pound per cubic foot = 16 kg/m^3.

a. Where snow loads occur that are in excess of the design conditions, the structure must be designed to support the increased loads caused by drift buildup or greater snow loads determined by the *AHJ*. (See IBC Section 1608).

b. See IBC Section 1604.8.3 for decks attached to exterior walls.

c. Areas of occupiable roofs, other than roof gardens and assembly areas, be designed for appropriate loads as approved by the *AHJ*. Unoccupied landscaped areas of roof be designed in accordance with IBC Section 1607.13.3.

d. Live load reduction is not permitted.

e. Live load reduction is only permitted in accordance with Section 1607.13.1.2 or Item 1 of Section 1607.13.2.

f. Live load reduction is only permitted in accordance with Section 1607.13.1.3 or Item 2 of Section 1607.13.2.

g. Helipads supporting military aircraft must be designed to support the actual aircraft weight and impact loading due to landing.

h. All attics with mechanical units must be designed for mechanical equipment room loading.

i. For live loads on pedestrian bridges see AASHTO LRFD *Guide Specifications for the Design of Pedestrian Bridges.*

j. **\4** *High density data center rack space should be verified for each project as these systems are rapidly evolving and have been known to exceed 400psf in some circumstances.* **/4/**

APPENDIX F COMPOSITES FOR BRIDGING APPLICATIONS [ADDITION]

F-1 INTRODUCTION.

F-1.1 Purpose and Scope.

This Appendix provides design resources to structural engineers interested in using polymer composite technologies for bridge applications. This Appendix is not intended to provide requirements for design and construction. Fiber reinforced polymer (FRP) composite materials and systems are now available that are not necessarily covered by the current AASHTO LRFD Bridge Design Specifications, but which may have performance and cost benefits in the repair and major rehabilitation and replacement of existing highway bridges within the DoD. This Appendix provides design considerations for polymer composites, references to guide specifications published by AASHTO, ACI, ASCE, FHWA, and case studies published by FHWA and USACE. The fiber reinforced polymer (FRP) technologies covered in this Appendix include glass FRP composite reinforcing bars, carbon FRP composite prestressing systems, FRP composite external strengthening and repair systems, and FRP composite elements including bridge piles and bridge decks. This appendix also includes information on thermoplastic materials for replacement of timber bridges including thermoplastic lumber, thermoplastic piles, and thermoplastic I-beams.

F-1.2 Applicability.

This Appendix applies only to polymer composite technologies for bridge applications. The guide specifications referenced herein are not intended to supplant proper training or the exercise of judgment by the Design Professional and state only the minimum requirements necessary to provide for public safety. The Design Professional may require the sophistication of the design or the quality of materials and construction to be higher than the minimum requirements. The Design Professional should be familiar with the provisions of the *AASHTO LRFD Bridge Design Specifications* and latest interim specifications. The decision to implement polymer composite technologies not currently covered by guide specifications should be made in consultation with the Service's lead Structural Engineering POC. This consultation is to ensure less developed technologies are implemented successfully.

F-1.3 Overview of Appendix.

Brief descriptions of the various sections of this appendix follow:

- F-2 – GENERAL. Provides a brief background on thermoset FRP composites and thermoplastic composites.
- F-3 – THERMOSET FRP COMPOSITE TECHNOLOGIES. Provides general design considerations for the use of thermoset FRP composites and reference to guide specifications and case studies for thermoset FRP composite technologies for bridge applications including non-prestressed

and prestressed concrete reinforcement, external strengthening systems for concrete, and FRP bridge elements including piles and decks.

- F-4 – THERMOPLASTIC TECHNOLOGIES. Provides general considerations for the use of thermoplastic technologies and reference to specification when available and case studies for thermoplastic technologies as replacement for timber bridge elements including dimensional lumber, piles, and beams.
- F-5 – REFERENCES. Lists the references included in this Appendix.
- F-6 – ABBREVIATIONS. Lists the abbreviations used in this Appendix.

F-2 GENERAL.

Composite materials are by definition a combination of two or more materials that differ in form and composition on the macro scale. The individual components maintain their phase and are not merged or melted into a new state. The result is an engineered material with desirable characteristics derived from the mechanical properties of the components. Composite materials have been used as construction materials for decades in the form of reinforced concrete and laminated timber products. Beginning in the 1960s, advances in material processing and the need for more durable materials led to the emergence of FRP composite materials.

The fiber reinforcement in an FRP composite provides the primary strength and stiffness while the polymer matrix transfers loads between fibers, ensures proper fiber alignment, and provides protection from environmental effects. Three types of fiber commonly used include glass, aramid, and carbon. Glass is the least expensive with lower strength and stiffness compared to carbon or aramid. Carbon is typically the most expensive with the highest strength and stiffness. As a general rule of thumb, carbon fiber can be around six to ten times as expensive as glass fiber. The fiber reinforcement can take the form of either continuous strands or woven/stitched fabrics.

The two broad families of polymers used are thermosets and thermoplastics. Thermosets are more commonly used in FRP composites due to their low curing temperature, workability, flowability, and resistance to creep, compared to thermoplastics. Thermosets cure by forming long hydrocarbon chains joined by crosslinking covalent bonds through a chemical reaction. Once formed, they cannot be melted or reformed by heat. Thermoplastics are composed of long hydrocarbon chains that are not chemically bonded through crosslinking and can move with respect to each other. Thermoplastic materials typically have high ductility and lower strength than thermoset composites and can be melted and reshaped by temperature. Due to these fundamental differences in chemical structure and mechanical behavior, this Appendix is divided into thermoset FRP composites (Section F-3) and thermoplastic materials (Section F-4).

F-3 THERMOSET FRP COMPOSITE TECHNOLOGIES.

F-3.1 Thermoset FRP Composite Design Considerations.

The following design considerations for thermoset FRP composites are not intended to be comprehensive but are to alert the reader that thermosetting FRP composite materials require different considerations than traditional construction materials. More information on design considerations can be found in the publications referenced throughout F-3.2.

F-3.1.1 Anisotropic behavior.

Thermoset FRP composite materials are anisotropic with strength properties highly dependent on fiber architecture. Composites have higher strengths in the primary direction of the fibers with lower strengths in the transverse direction. Composites with fibers oriented primarily in one direction are called unidirectional composites. Unidirectional composites are used primarily in tension as they have a lower compressive strength compared to tensile strength. As a result of this lower compressive strength, design philosophies for FRP reinforcement and external strengthening systems for concrete do not rely on the contribution of unidirectional composites in compression. FRP composites can also be designed with fiber architectures that orient fibers in multiple directions. This allows composites to be optimized for loading conditions. Multidirectional composite shapes will generally have higher strengths in tension than in compression.

F-3.1.2 Stiffness and ductility.

Glass FRP composites have a stiffness of around 5,000 ksi to 7,000 ksi and a much lower ductility than steel. This lower stiffness results in the majority of glass FRP composite designs being controlled by serviceability criteria rather than strength. Carbon FRP composites can have strength and stiffness that exceed certain grades of steel but have low ductility. Both glass and carbon FRP composites display a linear elastic behavior up until failure. This linear elastic behavior coupled with low ductility has led to conservative design criteria for FRP composite reinforcement for concrete, which reinforces the tensile zone to force failure to occur in concrete compression and limits the strain in the tensile bars (limited to around .008). As a result, FRP reinforced concrete will typically be controlled by a failure mode with low ductility. Retrofits and external strengthening systems for concrete are limited to applications where failure of a bonded repair would not result in the catastrophic failure of the structure. The publications cited in F-3.2 provide further discussions on the design guidance developed in light of these behaviors.

F-3.1.3 Creep and fatigue.

Thermoset FRP composites under sustained tensile load can suddenly rupture after a time period called the endurance time. This phenomenon is known as creep rupture or static fatigue rupture. Fatigue loading can also provide similar failure modes. Creep and fatigue rupture are designed for by limiting the sustained and fatigue stresses in FRP composite elements to a percentage of their ultimate strength. The sustained and fatigue stresses in most design criteria are conservatively limited to around 20% of ultimate strength for glass composites, 30% of ultimate strength for aramid composites, and 50% of ultimate strength for carbon composites. Additional information on this topic is provided in the publications in F-3.2. Note that there are gaps in knowledge about the number of load cycles required to cause fatigue due to the effects of load reversals and about the creep response of FRP composite materials for certain applications. Research into these topics is still ongoing.

F-3.1.4 Durability.

Thermoset FRP composites are resistant to rot, insects, and corrosion. They have displayed good durability in highly corrosive environments leading to their applications in chemical storage tanks and as reinforcement in concrete. Ultra-violet (UV) radiation can degrade the polymer matrix, leading to reduced performance. UV degradation is designed for by adding UV-inhibitors to the resin during fabrication and by applying UV-resistant coatings to FRP composites exposed to direct sunlight. Durability considerations are designed for by applying material resistance factors based upon the type of FRP composite, its application, and its exposure conditions. For additional information on the general durability of FRP composites, refer to *ACI 440R Report on Fiber-Reinforced Polymer (FRP) Reinforcement for Concrete Structures*. The durability considerations found in *ACI 440R* apply directly to FRP composite reinforcement for concrete but the concepts discussed are generally applicable to other FRP composite technologies. Note that though thermoset FRP composites in many applications have demonstrated good durability, research into their long term performance is still on-going.

F-3.2 Thermoset FRP Composite Guidance and Case Studies.

The following section describes the most developed thermoset FRP composite technologies including recommended applications, current guide specifications, and case studies.

F-3.2.1 Glass Fiber Reinforced Polymer (GFRP) Reinforcing Bars.

The following applications may be suitable for deformed or sand-coated GFRP reinforcing bars, but the Design Professional should be aware of the design considerations for GFRP reinforcing bars as well as the limitations and applicability of current guidance before selecting GFRP reinforcing bars for any application:

- Reinforcement for normal weight concrete deck slabs, cast-in-place solid slab (longitudinally reinforced), and pre-cast deck bridges

- Reinforcement for normal-weight concrete beams, girders, and diaphragms.

- Reinforcement for normal-weight concrete piles, piers, and footings.

- Reinforcement for normal-weight concrete bridge railing.

F-3.2.1.1 Guidance.

The following guide specifications are available for GFRP concrete reinforcing bars:

- For guidance on the design of concrete bridge members reinforced with GFRP reinforcing bars, refer to *AASHTO LRFD Bridge Design Guide Specifications for GFRP Reinforced Concrete*. The guide specification should be reviewed carefully for its limitations and applicability as GFRP reinforcing bars may not be suitable for certain applications.

- For information on the characteristics and durability of non-prestressed FRP reinforcing bars in concrete, refer to *ACI 440.1R Guide for the Design and Construction of Structural Concrete Reinforced with Fiber-Reinforced (FRP) Bars*.

- For information on test methods to characterize FRP reinforcing bars, refer to *ACI 440.3R Guide Test Methods for Fiber-Reinforced Polymer (FRP) Composites for Reinforcing or Strengthening Concrete and Masonry Structures*.

- For information on construction specification for FRP reinforcing bars, refer to *ACI 440.5 Specification for Construction with Fiber-Reinforced Polymer Reinforcing Bars.*

F-3.2.1.2 Case Studies.

The following resources can be referred to for demonstrations and case studies related to the implementation of GFRP reinforcing bars for concrete bridge elements:

- For a case study on the use of GFRP reinforcing bars in a bridge replacement project completed by Maine DOT, refer to *Maine Demonstration Project: Hotel Road (Littlefields Bridge) Replacement Using Superstructure Slide-In Technology.* The report can be accessed via the following link: https://www.fhwa.dot.gov/bridge/composite/cpdi.cfm

- For a list of projects reports related to GFRP reinforcement, completed through the FHWA Innovative Bridge Research and Construction/Deployment (IBRC/IBRD) Program, refer to the FHWA website accessed through the following link: https://www.fhwa.dot.gov/bridge/composite/str.cfm.

- For a review of the state of the art for GFRP reinforcing bars, refer to *ACI 440R Report on Fiber-Reinforced Polymer (FRP) Reinforcement for Concrete Structures* and ACI CODE-440.11-22: *Building Code Requirements for Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer* (GFRP) *Bars – Code and Commentary*.

F-3.2.2 Carbon Fiber Reinforced Polymer (CFRP) Prestressing Systems.

The following applications may be suitable for CFRP prestressing systems, but the Design Professional should be aware of the design considerations for CFRP prestressing systems as well as the limitations and applicability of current guidance before selecting CFRP prestressing systems for any application:

- Pretensioned reinforcement for normal weight concrete beams.

- Bonded and unbonded internally post-tensioned reinforcement for normal-weight concrete beams.

F-3.2.2.1 Guidance.

The following guide specifications are available for CFRP prestressing systems for concrete beams:

- For guidance on the design of concrete bridge beams prestressed with CFRP systems, refer to *AASHTO Guide Specification for the Design of Concrete Bridge Beams Prestressed with CFRP Systems*. The guide specification should be reviewed carefully for its limitations and applicability as CFRP prestressing systems may not be suitable for certain applications.

- For requirements not specifically addressed in the previously listed publication, refer to *ACI 440.4R Prestressing Concrete Structures with FRP Tendons* for additional information. For additional information on the design philosophy and research needs for CFRP pretensioned systems, also refer to *ACI 440.4R*.

- For additional recommendations for the design of CFRP prestressing systems, refer to the Florida Department of Transportation (FDOT) *Structures Manual Volume 4: Fiber Reinforced Polymer Guidelines (FRPG)*.

F-3.2.2.2 Case Studies.

The following resources can be referred to for demonstrations and case studies related to the implementation of CFRP prestressing systems for concrete bridge beams:

- For a case study on the use of CFRP reinforcement in concrete bridge beams conducted by Virginia Transportation Research Council, refer to *Concrete Beams Prestressed Using Carbon Fiber Reinforced Polymers, Final Report VTCR 19-R29.* The report can be accessed through the following link: https://www.fhwa.dot.gov/bridge/composite/resources.cfm

- For a list of project reports related to CFRP prestressing systems completed through the FHWA Innovative Bridge Research and Construction/Deployment (IBRC/IBRD) Program, refer to the FHWA website accessed through the following link: https://www.fhwa.dot.gov/bridge/composite/str.cfm.

- For a review of the state of the art for CFRP prestressing systems, refer to *ACI 440R Report on Fiber-Reinforced Polymer (FRP) Reinforcement for Concrete Structures* and *ACI 440.4R Prestressing Concrete Structures with FRP Tendons.*

F-3.2.3 FRP External Strengthening Systems.

The following applications may be suitable for FRP repair and strengthening systems but the Design Professional should be aware of the design considerations for FRP repair and strengthening systems as well as the limitations and applicability of current guidance before selecting FRP repair and strengthening systems for any application:

- External reinforcement of concrete flexural members on the tension face to improve flexural strength.
- Wrapping of existing concrete beams and columns to improve shear strength.
- Confinement of reinforced concrete columns to enhance strength and ductility.
- Strengthening of earthquake damaged and seismically deficient structures.

F-3.2.3.1 Guidance.

The following guide specifications are available for FRP external strengthening and repair systems for concrete bridge elements:

- For guidance on the design of FRP systems for repair and strengthening of concrete bridge members, refer to *AASHTO Guide Specifications for Design of Bonded FRP Systems for Repair and Strengthening of Concrete Bridge Elements.* The guide specification should be reviewed carefully for its limitations and applicability as FRP strengthening systems may not be suitable for certain applications.
- For requirements not specifically addressed in the listed publication and for design examples, refer to *ACI 440.2R Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures*.
- Note that FDOT *Structures Manual Volume 4*: *FRPG* recommends that carbon be the primary reinforcement for FRP composite systems used in repair or strengthening of concrete. It also recommends that if either a pre-cured laminate or wet layup system is used, the resin and adhesive should be a thermoset epoxy formulation specifically designed to be compatible with the fibers or pre-cured shapes. In wet layup systems, the manual recommends limiting shear and flexural reinforcement to no more than three layers except as required for anchorages.

F-3.2.3.2 Case Studies.

The following resources can be referred to for demonstrations and case studies related to the implementation of FRP external strengthening systems for concrete bridge elements:

- For a state of the art of FRP strengthening systems compiled by FHWA, refer to *Report on Techniques for Bridge Strengthening, FHWA-HIF-18-041.* This report can be accessed through the following link: https://www.fhwa.dot.gov/bridge/composite/cpdi.cfm

- For a list of project reports related to strengthening and damage repair of bridges with FRP strengthening systems completed through the FHWA Innovative Bridge Research and Construction/Deployment (IBRC/IBRD) Program, refer to the FHWA website accessed through the following link: https://www.fhwa.dot.gov/bridge/composite/str.cfm.

F-3.2.4 FRP Structural Bridge Elements.

The following applications may be suitable for FRP bridge elements but the Design Professional should be aware of the design considerations for FRP bridge elements as well as the limitations and applicability of current guidance before selecting FRP bridge elements for any application:

- FRP composite bridge fender systems.

- FRP composite stay-in place formwork for concrete bridge decks.

- Concrete-filled FRP composite tubes for bridge culverts and bearing piles.

- FRP composite bridge decking as replacement for concrete bridge decks.

F-3.2.4.1 Guidance.

The following guide specifications and pre-standards are available for FRP composite bridge elements:

- For guidance on the design of concrete-filled FRP tubes as structural members in bridges, refer to *AASHTO LRFD Guide Specifications for Design of Concrete-Filled FRP Tubes for Flexural and Axial Members*. The guide specifications apply to concrete-FRP composite members only. The limitations of this guide specification should be reviewed before use.

- For information on the design of FRP composite members for pedestrian bridges, refer to *AASHTO Guide Specification for Design of FRP Pedestrian Bridges*. Note that this guide specification is from 2008, refers to the outdated *AASHTO 17th edition*, and is only applicable to pedestrian bridges.

- For information on the design of pultruded structural members, refer to *ASCE Pre-standard for Load & Resistance Factor Design (LRFD) of Pultruded FRP Structures.* Note that this document provides design equations for pultruded structural shapes but is not specifically for bridge applications.

- For information on the design of connections for pultruded structural shapes, refer to *ASCE Manuals and Reports on Engineering Practice No. 102, Design Guide for FRP Composite Connections*. Note that this guide contains general design considerations and equations for bolted, adhesive, and mixed connections, but it is not specifically for bridge applications.

F-3.2.4.2 Case Studies.

The following resources can be referred to for demonstrations and case studies related to the implementation of FRP structural bridge elements:

- For a case study on the design and implementation of a composite bridge decking system conducted by FHWA, refer to *Composite Bridge Decking, Publication No. FHWA-HIF-13-029*. The report can be accessed through the following link: https://www.fhwa.dot.gov/bridge/composite/cpdi.cfm

- For information on a demonstration of an FRP composite bridge deck to replace a reinforced concrete bridge deck completed by USACE-ERDC, refer to *ERDC/CERL TR-16-16 Demonstration and Validation of a Lightweight Composite Bridge Deck Technology as an Alternative to Reinforced Concrete*.

- For information on a demonstration of a hybrid composite beam (HCB) system in a bridge replacement project at Fort Knox, Kentucky completed by USACE-ERDC, refer to *ERDC/CERL TR-16-22 Demonstration of Corrosion-Resistant Hybrid Composite Bridge Beams for Structural Applications*. The HCB system consisted of a glass fiber reinforced plastic (GFRP) shell, tension reinforcement using stainless steel cables, low-density foam core, and a concrete arch that provided compression reinforcement.

- For a case study on the implementation of composite piles conducted by FHWA, refer to *A Laboratory and Field Study of Composite Piles for Bridge Substructures, FHWA-HRT-04-043.* The report can be accessed through the following link: https://www.fhwa.dot.gov/bridge/composite/cpdi.cfm

- For a list of project reports related FRP pultruded structural members and composite bridge decking completed through the FHWA Innovative Bridge Research and Construction/Deployment (IBRC/IBRD) Program, refer to the FHWA website accessed through the following link: https://www.fhwa.dot.gov/bridge/composite/str.cfm.

F-4 THERMOPLASTIC TECHNOLOGIES.

Thermoplastics materials have recently emerged as a durable and cost-effective alternative to timber for short span bridges. Thermoplastic materials require no chemical preservatives, are low-maintenance and corrosion-resistant, and have reduced life cycle costs. While this technology is still under development and guidance is limited, this technology has been included to allow readers full exposure to all polymer composites.

F-4.1 Thermoplastic Material Considerations.

The following considerations for thermoplastic materials are not intended to be comprehensive but are to alert the reader that these materials require different considerations than traditional construction materials and thermoset FRP composite materials. More considerations can be found in the publications referenced throughout F-4.2.

F-4.1.1 Procurement.

Guidance on the design and use of thermoplastic materials for structural applications is limited. To implement thermoplastic materials, a performance-based procurement methodology is recommended. The following is one possible approach to this method:

To begin, the Owner would specify the performance requirements of the structure to be procured including the anticipated loads, site conditions, geometric requirements, and serviceability limits. The contractors completing the design-build process would be required to provide the ASTM testing reports of any products used in their design for review by the Owner or his consultant. Possible ASTM specifications to be used for this testing are referenced in section F-4.2.3.1. The design would then be developed based upon values from this testing, which would be reduced to provide factors of safety agreed upon by the Design Professional. Any elements or components identified as critical by the Design Professional or Owner would then be fabricated and tested to the satisfaction of all parties. As elements are fabricated, proof testing would be conducted at predefined check points to ensure that a representative batch of the material has the required mechanical properties. After the construction of the structure, the structure would be field-tested with the operating loads to check that the serviceability requirements are met.

F-4.1.2 Non-Homogenous and Anisotropic Behavior.

Thermoplastic materials are produced through an extrusion process. The thermoplastic materials are melted, pushed through a die or into a mold to form structural shapes, and cooled until hardened. The process cools the outer surface of the material faster than the interior. This results in the outer layers forming a dense, thick skin while the interior can develop voids and air bubbles. The thick outer skins provide the majority of the structural capacity to the member. Thermoplastic profiles should never be notched or split longitudinally to limit warping and to retain the capacity of the components. The extrusion process also produces a distinctive “grain” along the length of the component, parallel to the direction of extrusion. The differences in tensile and compressive strength parallel and perpendicular to this grain can be significant and should be taken into account. This directionality consideration is similar to that in timber design.

F-4.1.3 Viscoelasticity.

Since the hydrocarbon chains making up thermoplastic materials are not chemically cross-linked and can slide past each other, thermoplastic materials display viscoelastic behavior. This viscoelasticity results in a non-linear response to applied loading that is dependent upon the rate of loading, the duration of the loading, and the ambient temperature. This viscoelastic response is unique to thermoplastic materials and research into this behavior is still needed.

- Thermoplastic materials will display changes in ductility and stiffness, dependent upon the rate at which a load is applied. For example, if the same load is applied to a thermoplastic flexural member at two different load rates, the higher load rate will result in a stiffer, less ductile response in the member, compared to the same load applied to the member at the lower load rate.

- Thermoplastic materials will undergo creep if exposed to sustained loads. This tendency for creep is designed for by 1) reducing the modulus of elasticity in calculations involving long-term loads, to provide conservative design values, 2) limiting flexural members to short span lengths, and 3) incorporating chopped fiber or FRP reinforcement within the thermoplastic member to improve creep resistance.

- Thermoplastic materials are affected by ambient temperature. If exposed to extreme heat, thermoplastic materials will display an increase in ductility and a reduction in stiffness. If exposed to extreme cold, thermoplastic materials will display reduced ductility and an increase in stiffness which can lead to brittle failures. These responses to ambient temperature can be avoided by limiting the application of thermoplastics to regions with moderate temperatures.

F-4.1.4 Thermal Expansion.

Thermoplastic materials have high coefficients of thermal expansion compared to traditional construction materials, expanding and contracting noticeably in the direction of the “grain” as temperatures fluctuate. As a result, connections should be designed to accommodate this thermal movement, especially if joining materials with different coefficients of thermal expansion. Note that additional research is needed to more fully quantify this behavior and guidance for thermoplastic connection design and testing is limited.

F-4.1.5 Design Methodology.

Thermoplastic materials are designed using timber design methodologies with adjustment factors for thermoplastics. Allowable Stress Design (ASD) methods are used instead of LRFD as thermoplastic materials have not been calibrated due to their viscoelastic properties and limited empirical data. Thermoplastic materials are less stiff than timber and the majority of thermoplastic material designs are controlled by serviceability criteria and not strength.

F-4.2 Thermoplastic Material Guidance and Case Studies.

The following section describes the emerging thermoplastic technologies suitable for replacements of timber, including recommended applications, current guidance when available, and case studies.

F-4.2.1 Structural Grade Thermoplastic Lumber.

The following applications may be suitable for structural grade thermoplastic lumber, but the Design Professional should be aware of the design considerations for thermoplastic lumber as well as the limitation and applicability of current specifications:

- Decking as a replacement for timber decking.

- Pedestrian railing as a replacement for timber railing.

F-4.2.1.1 Guidance.

There is no AASHTO guidance for structural grade thermoplastic lumber. The following specifications can be reviewed for design and procurement information:

- For procedures to establish design strengths, flame spread index, and knock-down factors relative to load duration, creep rupture, temperature, and stress over time for polyethylene-based structural grade plastic lumber (SPGL), refer to *ASTM D7568 Standard Specification for Polyethylene-Based Structural-Grade Plastic Lumber for Outdoor Applications.* The limitations and applicability of this specification should be reviewed before use.

- For procedures to establish suitable span lengths, flame spread index, slip resistance, and knock-down factors relative to load duration, temperature, and creep adjustment for polyolefin-based decking boards, refer to *ASTM D6662 Standard Specification for Polyolefin-Based Plastic Lumber Decking Boards.* The limitations and applicability of this specification should be reviewed before use.

- For guidance on the procurement and construction of thermoplastic dimensional lumber, refer to *UFGS 06 10 00 Rough Carpentry*. The limitations and applicability of this specification should be reviewed before use.

F-4.2.1.2 Case Study.

For Information on construction recommendations, mechanical connection detailing, and inspection techniques for thermoplastic lumber, refer to *ERDC/CERL TR-17-45 Demonstration of Thermoplastic Composite I-Beam Design Bridge at Camp Mackall, NC*.

F-4.2.2 Thermoplastic Piles.

The following applications may be suitable for thermoplastic pile, but the Design Professional should be aware of the design considerations for thermoplastic piles as well as the limitation and applicability of current specifications:

- Piles as a direct replacement for timber piles.
- Fenders as a direct replacement for timber fenders.

F-4.2.2.1 Guidance.

There is no AASHTO guidance for thermoplastic piles. The following specifications can be reviewed for design and procurement information:

- For design criteria for round and rectangular cross-section polymer piles in axial and lateral load-bearing applications, refer to *ASTM D7258 Standard Specification Polymeric Piles.* The limitations and applicability of this specification should be reviewed carefully before use.
- For guidance on the procurement of thermoplastic piles, refer to *UFGS 35.59.13.14 20 Polymeric Piles.* The limitations and applicability of this specification should be reviewed carefully before use.

F-4.2.2.2 Case Study.

For information on the construction and inspection of thermoplastic piles for a thermoplastic bridge, refer to *ERDC/CERL TR-17-45 Demonstration of Thermoplastic Composite I-Beam Design Bridge at Camp Mackall, NC*.

F-4.2.3 Thermoplastic Structural I-beams.

The following applications may be suitable for thermoplastic structural I-beams, but the Design Professional should be aware of the design considerations for thermoplastic I-beams as well as the lack of guidance and limitations of this technology:

- Thermoplastic I-beams to replace timber beams in vehicular bridges
- Thermoplastic I-beams to replace timber beams in railroad bridges

F-4.2.3.1 Discussion.

In 2009, advances in thermoplastic material processing resulted in the development of prefabricated thermoplastic I-beams for bridge applications. The efficient shape of the I-beam reduced member weight and fabrication cost while maintaining strength and flexural rigidity. The beams were flow-molded from comingled recycled polyolefins (primarily high-density polyethylene (HDPE)) with a combination of thermoplastic coated fiber material or/and polystyrene, poly methyl methacrylate (PMMA), or a combination of the three).

This thermoplastic I-beam technology was used to replace three timber vehicular bridges and two timber railroad bridges on U.S. Army installations as part of initial demonstration of thermoplastic bridges. After these demonstrations, five full scale beams similar to the beams in the bridges were evaluated through full-scale flexural testing. The results of these tests are documented in *ERDC/CERL TR-17-18 Full Scale Testing of Thermoplastic Composite I-Beams for Bridges.* It is strongly recommended that this report be reviewed before considering the use of these beams. During the testing, two of the beams displayed brittle failures (less than 0.2% outer fiber strain as recorded during testing). The brittle failures occurred after the two beams had been cyclically loaded and the failure loads were lower than the ultimate loads applied to the beam during this cyclic loading. This behavior indicates that the flexural strength of the beams was reduced due in some part to the cyclical loading. While the beams displayed significant deflections before failure, more research and testing is needed to fully identify the possible failure modes of these thermoplastic I-beams.

No guidance is currently available for the design of thermoplastic I-beams, but it is possible to procure them with a performance-based procurement process using lessons learned from previous case studies and testing the beams using the following ASTM specifications:

- For flexural strength testing, refer to *ASTM D6109 Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastic Lumber and Related Products*. This standard is for “as manufactured” components. As such, it is not a material property test method.

- For compression strength testing, refer to *ASTM D6108 Standard Test Method for Compressive Properties of Plastic Lumber and Shapes.* This standard is for “as manufactured” components. As such, it is not a material property test method.

- For mechanical connection strength testing, including screws, nails, and staples, refer to *ASTM D6117, Standard Test Methods for Mechanical Fasteners in Plastic Lumber and Shapes*. This standard does not cover the testing of bolted connections.

- For testing to evaluate thermal movement, refer to *ASTM D6341 Standard Test Method for Determination of the Linear Coefficient of Thermal Expansion of Plastic Lumber and Plastic Lumber Shapes Between -30 and 140°F (-34.4 and 60°C).*

F-4.2.3.2 Case Studies.

The following resources can be referenced for information on the implementation and testing of thermoplastic I-beams:

Three vehicular thermoplastic bridges using thermoplastic I-beams replaced deteriorated timber bridges at Camp Mackall, NC. The bridges were designed for HS25 loading and can support an M1 Abrams Tank. These demonstrations are documented in the following reports:

- Refer to *ERDC/CERL TR-17-45 Demonstration of Thermoplastic Composite I-Beam Design Bridge at Camp Mackall, NC* for details on the development, design, construction, and inspection for these bridges.

- Refer to *ERDC/GSL TR-10-19 Field Testing and Load Rating of the World's First Thermoplastic Bridge* for results from load rating conducted on one of these bridges.

- Refer to *ERDC/CERL TR-11-43 Remote Monitoring of a Thermoplastic Composite Bridge at Camp Mackall, NC* for information on a remote monitoring system installed on one of these bridges. This system recorded the deflection of the bridge each time a vehicle passed over the bridge.

- Refer to *ERDC/CERL TR-17-18 Full Scale Testing of Thermoplastic Composite I-Beams for Bridges* for results of material characterization and flexural tests conducted on five of these thermoplastic I-beams.

Two thermoplastic railroad bridges were built at Ft. Eustace, Virginia with thermoplastic I-beams. The railroad bridges were designed to carry the Cooper E60 load and the 260 kip alternate live load on four axles.

- Refer to *World's First Thermoplastic Railroad Bridges* for information on the development, design, construction, and load testing of these thermoplastic railroad bridges.

Summary

Composite materials in bridge design have the advantages of light weight, high strength and strong corrosion resistance, which contribute to low maintenance and long service life for structures. This contributes to life cycle cost savings and provides a long-term economic advantage over traditional materials such as steel and concrete. Because of these special properties, composite materials can have a better application in bridge engineering.

Bridge strengthening techniques using FRP composites can be used to restore capacity or add capacity for a bridge to remain open to legal and unrestricted loads. Composite materials can provide solutions to address emergency situations in a timely manner.

Some of the disadvantages involve higher short-term and uncertain long-term costs, uncertain durability and lack of ductility.

Steel, concrete, and timber bridge design involves utilization of appropriate material according to design standards, codes, and best practices predicated on the use of well-documented and standardized material types. Although there have been considerable advances made in developing design codes and procedures for composite strengthening, there is little standardization of material specifications and construction guidelines. This is due to the fact that many composite materials are producer specific. Because of this, designing with bridge composite materials may sometimes require more specialized knowledge in material behavior and manufacturing process compared to other materials.

Despite the difficulties mentioned above, ACI Committee 440 has been able to develop and publish ACI CODE-440.11-22: *Building Code Requirements for Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (*GFRP*) Bars—Code and Commentary*. The 2024 IBC adopted a proposed change submitted by ACI as follows.

> *1901.2.1 Structural Concrete with GFRP reinforcement.*
>
> *Cast-in-place structural concrete internally reinforced with glass fiber reinforced polymer (GFRP) reinforcement conforming to ASTM D7957 and designed in accordance with ACI CODE 440.11 shall be permitted where fire resistance ratings are not required and only for structures assigned to seismic design category A.*

ACI CODE-440.11-22 is also expected to be adopted by ACI CODE-318-25.

F-5 REFERENCES FOR APPENDIX F.

F-5.1 Government.

UNIFIED FACILITIES GUIDE SPECIFICATIONS (UFGS)

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

UFGS 06 01 00, *Rough Carpentry*

UFGS 35 59 13.14 20, *Polymeric Piles*

U.S. ARMY CORPS OF ENGINEERS

https://www.erdc.usace.army.mil/

ERDC/GSL TR-10-19, *Field Testing and Load Rating of the World's First Thermoplastic Bridge: T-8518, Camp MacKall, Fort Bragg, North Carolina*, Commander, B.C., and Diaz-Alvarez, H., June 2010.

ERDC/CERL TR-11-43, *Remote Monitoring of a Thermoplastic Composite Bridge at Camp Mackall, NC*, Lampo, R.G, Myers, B.K, Palutke, K., and Butler, D.M., November 2011.

ERDC/CERL TR-16-16, *Demonstration and Validation of a Lightweight Composite Bridge Deck Technology as an Alternative to Reinforced Concrete,* Palutke, K., Lampo, R.G., Clark, L., Miles, J., Wilcoski, J., and Skinner, D., August 2016.

ERDC/CERL TR-16-22, *Demonstration of Corrosion-Resistant Hybrid Composite Bridge Beams for Structural Applications*, Sweeney, S.C., Lampo, R.G., Wilcoski, J., Olaes, C., and Clark, L, September 2016.

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Behavior of Fiber-Reinforced Polymer Composite Piles Under Vertical Loads, Publication No. FHWA-HRT-04-107, Juran, I and Komornik, U., August 2006.

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Composite Bridge Decking: Final Project Report, Publication No. FHWA-HIF-13-029, O’Connor, J.S., March 2013.

Laminate Specification and Characterization - Composite Bridge Decking, FHWA-HIF-12-020.

Maine Demonstration Project – Hotel Road (Littlefields Bridge) Replacement Using Superstructure Slide-In Technology, Bhajanda, A., April 2015.

Report on Techniques for Bridge Strengthening: Main Report, Publication No. FHWA-HIF-18-041, Chajes, M., Rollins, T., Dai, H., Murphy, T., April 2019.Composite Bridge Decking - Final Project Report, FHWA-HIF-13-029.

“Steel Versus GFRP Rebars?”, Roger H. L. Chen et al., Public Roads, Vol. 72 No. 2, FHWA-HRT-08-006, Sept/Oct 2008.

“The Ongoing Evolution of FRP Bridges”, Jim Williams, Public Roads, Vol. 72 No. 2, FHWA-HRT-08-006, Sept/Oct 2008.

FLORIDA DEPARTMENT OF TRANSPORTATION

Structures Manual Volume 4: *Fiber Reinforced Polymer Guidelines (FRPG)*, Topic No. 625-020-018, January 2019

Structures Design - Fiber Reinforced Polymer Reinforcing https://www.fdot.gov/structures/innovation/FRP.shtm

VIRGINIA DEPARTMENT OF TRANSPORTATION

Concrete Beams Prestressed Using Carbon Fiber Reinforced Polymer, Publication No. FHWA/VTRC 19-R29, Ozyildirim, H.C. and Sharp, S.R., June 2019.

F-5.2 Non-Government.

AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS (AASHTO)

https://www.transportation.org/

Guide Specification for the Design of Concrete Bridge Beams Prestressed with Carbon Fiber-Reinforced Polymer (CFRP) Systems

Guide Specifications for Design of Bonded FRP Systems for Repair and Strengthening of Concrete Bridge Elements

Guide Specifications for Design of FRP Pedestrian Bridges

LRFD Bridge Design Guide Specifications for GFRP Reinforced Concrete

LRFD Guide Specifications for the Design of Concrete-Filled FRP Tubes for Flexural and Axial Members

AMERICAN CONCRETE INSTITUTE (ACI)

https://www.concrete.org/

ACI 440R, *Report on Fiber-Reinforced Polymer (FRP) Reinforcement for Concrete Structures*

ACI 440.1R*, Guide for the Design and Construction of Structural Concrete Reinforced with Fiber-Reinforced (FRP) Bars*

ACI 440.2R, *Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures*

ACI 440.3R, *Guide Test Methods for Fiber-Reinforced Polymer (FRP) Composites for Reinforcing or Strengthening Concrete and Masonry Structures*

ACI 440.4R, *Prestressing Concrete Structures with FRP Tendons*

ACI 440.5, *Specification for Construction with Fiber-Reinforcing Polymer Reinforcing Bars*

AMERICAN RAILWAY ENGINEERING AND MAINTENANCE-OF-WAY ASSOCIATION (AREMA)

Proceedings of AREMA Annual Conference 2011, *World's First Thermoplastic Railroad Bridges*, Kim, J.S., Chandra, V., and Nosker, T.J.

AMERICAN SOCIETY OF CIVIL ENGINEERS (ASCE)

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ASTM D6109, *Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastic Lumber and Related Products*

ASTM D6117, *Standard Test Methods for Mechanical Fasteners in Plastic Lumber and Shapes*

ASTM D6341, *Standard Test Method for Determination of the Linear Coefficient of Thermal Expansion of Plastic Lumber and Plastic Lumber Shapes Between -30 and 140°F (-34.4 and 60°C)*

ASTM D6662, *Standard Specification for Polyolefin-Based Plastic Lumber Decking Boards*

ASTM D7258, *Standard Specification for Polymeric Piles*

ASTM D7290, *Standard Practice for Evaluating Material Property Characteristic Values for Polymeric Composites for Civil Engineering Structural Applications*

ASTM D7568, *Standard Specification for Polyethylene-Based Structural-Grade Plastic Lumber for Outdoor Applications*

F-6 ABBREVIATIONS FOR APPENDIX F.

AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
AREMA	American Railway Engineering and Maintenance-of-way Association
ASCE	American Society of Civil Engineers
ASD	Allowable Stress Design
ASTM	American Society for Testing and Materials
CERL	Construction Engineering Research Laboratory
CFRP	Carbon Fiber Reinforced Polymer
DoD	Department of Defense
ERDC	Engineering Research and Development Center
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
FRP	Fiber Reinforced Polymer
FRPG	Fiber Reinforced Polymer Guidelines
GFRP	Glass Fiber Reinforced Polymer
GSL	Geotechnical and Structures Laboratory
HCB	Hybrid Composite Bridge
HDPE	High Density Polyethylene
LRFD	Load and Resistance Factor Design
NAVFAC	Naval Facilities Engineering Command
PMMA	Poly (methyl methacrylate)
SGPL	Structural Grade Plastic Lumber
UFC	Unified Facilities Criteria
UFGS	Unified Facilities Guide Specification

APPENDIX G GLASS FIBER-REINFORCED POLYMER (GFRP) BARS FOR CONCRETE STRUCTURES [ADDITION]

G-1 INTRODUCTION.

G-1.1 Purpose and Scope.

This Appendix provides design resources to structural engineers interested in using glass fiber-reinforced polymer (GFRP) reinforcement in concrete structures. It is written for structural engineers proficient in the design of concrete structures using ACI 318, *Building Code Requirements for Structural Concrete*. New standards developed by ASTM and ACI for GFRP bars are discussed along with other supporting guides and reports. Other types of FRP bars, such as carbon, basalt, or aramid are not addressed, since comprehensive standards for these fibers are not yet developed. This Appendix identifies the limits on the use of GFRP reinforcement in concrete structures and key design considerations. For a more general overview on FRP material, reference Appendix F, Composites for Bridging Applications.

G-1.2 Applicability.

This Appendix applies to concrete structures that are designed in accordance with ACI CODE 440.11-22, *Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars--Code and Commentary*. ACI CODE 440.11-22 contains the requirements for design, durability, and construction using GFRP reinforcement. ACI CODE 440.11-22 is written similarly to ACI 318, *Building Code Requirements for Structural Concrete*, and references ACI 318 for requirements that apply independently of the type of reinforcement used.

Historically, the most common application of GFRP bars is to reinforce highway bridge decks in areas where deicing salts are used on the roads and cause severe corrosion to conventional steel reinforcement. Other applications include marine structures such as seawalls or piers, flood mitigation channels, parking garages, water tanks, structures supporting MRI machines, and rail plinths for electric trains. Design reasons to use GFRP bars for other types of structures are:

- They do not corrode in the presence of chloride ions
- They do not interfere with electromagnetic fields
- They are thermally nonconductive

G-1.3 Limitations to Use.

The greatest limitation to the use of GFRP bars is related to fire. The fire ratings are very low to zero and not standardized at this time. Suggested ratings are given in the commentary to ACI CODE 440.11-22. For this reason, DoD does not allow the use of GFRP reinforcement in:

- Structures that have a fire rating above zero. Also, similar structures that may not have a fire rating but could collapse due to fire and threaten life safety (for example, GFRP reinforcing not allowed for upper deck of double-deck piers, and comparable structures similarly affected by heat zones).

- Architectural cast-in-place concrete

- In architectural precast concrete, unless all connections use steel

Other limitations on GFRP use discussed later in this Appendix are:

- Do not use in seismic force-resisting systems for Seismic Design Categories B, C, D, E, and F.

- GFRP reinforcement is permitted in structural members not part of the seismic force-resisting system for Seismic Design Categories A, B, and C.

- GFRP reinforcement is not recommended for lightweight concrete due to insufficient research data.

- GFRP use in prestressed concrete systems is not currently covered.

G-1.4 Overview of Appendix.

Brief descriptions of the various sections of this appendix follow:

- G-2 – GENERAL. Provides an explanation on the use of ASTM D7957/D7957D with ACI CODE 440.11-22.
- G-3 – GFRP REINFORCING BARS. The GFRP reinforcing bar as defined in ASTM D7957/D7957M is described. A comparison with steel reinforcement is provided.
- G-4 – DESIGN. Provides an overview of the design philosophy. Identifies design limitations that are different from those for steel reinforced structures.
- G-5 – DURABILITY. Provides an overview of the environmental and design aspects to be considered when using GFRP.
- G-6 – CONSTRUCTION. Provides a brief discussion on the use of GFRP bars in construction. Construction specification requirements are given in UFGS 03 30 00, Cast-in-Place Concrete.
- G-7 – REFERENCES. Lists the references included in this Appendix.
- G-8 – ABBREVIATIONS. Lists the abbreviations used in this Appendix.

G-2 GENERAL.

Concrete structures with GFRP bars are designed using two standards, ACI CODE 440.11-22, *Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars--Code and Commentary*, and ASTM D7957/D7957M, *Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars*. ASTM D7957/D7957M contains the material properties need for design. ACI CODE 440.11-22 contains the requirements for design. Additional design guidance can be found in ACI 440.1 and Nanni et. al (2014). The process of design has been generally agreed on since the early 2000s. In the United States, guidance was provided in ACI 440.1, *Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars*, in 2001. Other international standard organizations developed similar design methodologies: CSA S806, *Design and construction of building structures with fiber-reinforced polymers*, in 2002; and *fib* Bulletin 40, *FRP Reinforcement in RC Structures*, in 2007. ACI 440.1 was the basis for the ACI CODE 440.11-22 code. ACI CODE 440.11-22 is dependent on ACI 318 for common structural concrete design requirements and is compatible with ASCE 7 for easy integration into practice in the United States.

One of the difficulties in bringing FRP bars to common use is the wide variety of fibers and resins along with varying manufacturing processes that can greatly change the properties of the material. Designers had to contact the manufacturer to find the properties of the material they planned to use. However, the test methods used to measure the properties were not standard. The last several years have been spent standardizing test methods and finding agreement from manufacturers on minimum performance levels, material properties, and sizes. Glass fiber is the most used fiber and is the first fiber to have a full standard for use in concrete reinforcement. ASTM D7957/D7957M has minimum guaranteed values for GFRP properties such as ultimate tensile force, transverse shear strength, modulus of elasticity, and bond strength. Manufacturers can exceed these minimum values and designers are permitted to use the higher actual values. The designer, however, would need to know the manufacturer before design and the manufacturer would need to submit certified material tests for confirmation.

G-3 GFRP REINFORCING BARS.

GFRP bars are made of continuous strands of glass fiber encapsulated in a protective resin. The bars have strength comparable to steel reinforcement in tension, but lower strength in the transverse direction. This behavior is called anisotropic, whereas steel is isotropic. The material behavior of GFRP is explained in more detail in Appendix F. The surface of the bar is modified to create a mechanical interlock with the concrete for bond. The modifications may be a sand coating or fibers wound around the bar, creating deformations.

G-3.1 Material Specification.

The material specification for GFRP reinforcing bars is ASTM D7957/D7957M. The specification establishes property limits and test methods for qualification and certification. Minimum guaranteed values for design are established. These limits must be met but the manufacturer may exceed these limits. The specification does not have grades like steel. It provides a baseline strength and durability that a designer may use without having to have a greater understanding of the fiber material and encapsulating resin.

G-3.2 Tensile Strength.

The specification establishes bar sizes similar to steel reinforcement. The bar sizes range from No. 2 to No. 10. Although there are many shapes for GFRP bars, round bars are used because of designers' and contractors' familiarity with steel reinforcement. The stress in the GFRP bar at its breaking strength decreases as bar size increases. The rate of stress reduction can vary; thus, the specification requires a minimum guaranteed ultimate tensile force rather than a stress. Consequently, the designer will have to calculate the ultimate tensile stress for each bar size. For instance, the tensile strength of a No. 2 bar is 124 ksi (855 MPa) compared to a No. 10 bar, for which it is 77 ksi (531 MPa).

GFRP bar bends are formed during the manufacturing process rather than bending a straight bar after production, which would rupture the bar. The specification establishes a minimum ultimate tensile force of a bent portion of the bar. Due to the anisotropic behavior of GFRP bars, the tensile strength at bends is lower than that of the straight portion of the bar. The specification sets this lower strength at 60 percent of ultimate tensile force of a bar. ACI CODE 440.11-22 limits the shear reinforcement stress to be compatible with this limit.

G-3.3 Material Properties.

GFRP reinforcing bars are similar in strength to steel reinforcing bars in tension. Table G-1 provides a comparison of GFRP and steel material properties. Some key observations:

- The GFRP bars are different from steel bars in that they do not yield. They demonstrate elastic behavior until they fracture.

- GFRP is about one-fourth the stiffness of steel, thus controlling deflection at service loads is essential to mitigate excessive cracking.

- Shear strength of the GFRP bar depends mostly on the resin. The bar is not as strong as steel when used as a dowel.

- GFRP bars are about one-fourth of the weight of steel. This makes the material easier to handle in the field, which can reduce construction time.

Table G-1 Comparison of GFRP and steel material properties

Property	ASTM D7957/D7957M GFRP	ASTM A615/A615M Steel
Minimum yield strength	None, elastic until failure	40, 60, 80, 100 ksi
Ultimate tensile strength	77 ksi to 124 ksi	60, 90, 105, 115 ksi
Modulus of Elasticity	6500 ksi	29,000 ksi
Transverse shear strength	19 ksi	Same as yield strength
Density	Approx. 135 lb/ft^3 at 70% fiber mass content	493 lb/ft^3

G-4 DESIGN.

The design methodology used in ACI CODE 440.11-22 is strength design, similar to the methodology in ACI 318. The main difference is that GFRP reinforcement is linear elastic until failure, unlike steel reinforcement. Steel reinforced members are designed to yield before failure. This provides some warning that an overloading of the structure is occurring before collapse. GFRP reinforced members do not have a yield plateau, so extra capacity is needed to prevent sudden failures due to overloading. This is done by reducing the Φ factors. A full explanation of the rationale is given in the Commentary to Chapter 21 of ACI CODE 440.11-22. The result is that, in flexure, either GFRP rupture or concrete crushing is an acceptable failure mode. The design requirements and discussion are provided in Chapter 22 of ACI CODE 440.11-22.

G-4.1 Shear Design.

Shear design philosophy in ACI CODE 440.11-22 is similar to that of ACI 318. The main difference is that GFRP reinforcement has lower axial stiffness than steel. This shifts the neutral axis in design, creating a smaller compression region in the cross section. The result is larger cracks. The equation for V_c has been modified to account for the lower stiffness in the longitudinal reinforcement. The GFRP shear reinforcement calculations are similar to those per ACI 318. A stress limit is placed on the shear reinforcement due to the reduced tensile strength of the reinforcement at the bend of a bar. The design requirements and discussion are provided in Chapter 22 of ACI CODE 440.11-22.

G-4.2 Serviceability.

Serviceability requirements in ACI CODE 440.11-22 often control the design of concrete slabs, joists, or beams with GFRP reinforcement. Service level effects to be considered are deflection, distribution of flexural reinforcement to reduce cracking, shrinkage and temperature reinforcement, and permissible tensile stresses. Deflections must be calculated in ACI CODE 440.11-22; one cannot choose a minimum depth for a span as permitted in ACI 318. The ACI CODE 440.11-22 calculations have been modified to use the Bischoff equations as was done in ACI 318-19. Requirements for the distribution of flexural reinforcement and shrinkage and temperature reinforcement were slightly modified to account for the less stiff material. Most importantly, a limit on service stress has been added to address creep rupture and fatigue, two important limit states that need to be addressed in GFRP reinforcement. A maximum sustained stress limit of 0.3 times the ultimate tensile stress is given. A method to calculate the sustained stress is based on the unfactored moment due to the sustained load on the member. This equation can also be used to address fatigue loading. The design requirements and discussion are provided in Chapter 24 of ACI CODE 440.11-22.

G-4.3 Development and Lap Splices.

Development of GFRP reinforcement is accomplished with a straight bar end or hook. GFRP reinforcement cannot yield so the design philosophy takes a shift. The development length of the bar need only be such that the stress of the controlling limit state rather than the ultimate strength of the bar is developed. Also, only 90-degree hooks are effective in developing the bars, due to a lack of ductility. Use lap splices for reinforcement continuity. The code provides the design requirements for a mechanical device, however, there are no commercially available devices that currently can meet these requirements for GFRP reinforcement. The commercially available mechanical splices developed for steel reinforcement damage GFRP bars and reduce strength; therefore, they are prohibited from being used with GFRP bars. The tie, stirrup, hook, and spiral provisions are modified to reflect the practice of manufacturing GFRP shapes. The design requirements and discussion are provided in Chapter 25 of ACI CODE 440.11-22.

G-4.4 Other Design Considerations.

In I-1.2, Applicability, DoD does not allow the use of GFRP reinforcement in structures that have a fire rating. Other key observations about designing with GFRP reinforcement according to ACI CODE 440.11-22:

- Do not count on moment redistribution. Since GFRP does not yield, plastic hinges cannot develop, nor can it yield in areas of greater restraint to allow for moment redistribution.
- Strength of GFRP reinforcement in compression is ignored.
- GFRP reinforcement is not recommended for lightweight concrete due to insufficient research data.
- Use of GFRP reinforcement in prestressed concrete systems is currently not covered.
- Use of GFRP reinforcement in diaphragms are not covered.
- Do not use GFRP reinforcement in seismic force-resisting systems for Seismic Design Categories B, C, D, E, and F.

- GFRP reinforcement is permitted in structural members not part of the seismic-force-resisting system for Seismic Design Categories A, B, and C.

G-5 DURABILITY

Because it is a relatively new construction material, there is some concern regarding the long-term durability of GFRP reinforcement. FRP reinforcement has been in service in North America since 1993. Since that time, there have been a couple hundred bridge decks and other structures that have been built with FRP bars.

G-5.1 Strength and Stiffness.

Depending on the materials and manufacturing process used, GFRP bars can be susceptible to reduced strength and stiffness when exposed to moisture or high-alkaline environments. Much of the testing to gage this sensitivity, however, has been done with short-term experiments using environments that are much more aggressive than the field conditions. Extrapolation of these results to field conditions and expected lifetimes is not possible in the absence of real-time data. To account for these detrimental effects, the GFRP reinforcement needs to be manufactured to a minimum quality that mitigates these effects. ASTM 7957/7957M establishes the quality assurance for long-term performance; in general, the bars have proven to be durable.

Although GFRP reinforcement has shown to be durable to date, only predictive models based on accelerated tests can estimate how long the reinforcement will remain at design level strengths. To account for the uncertainty of predictive models, ACI CODE 440.11-22 has placed an environmental reduction factor, C_E, of 0.85 to the guaranteed ultimate tensile strength. Over time, the actual performance of GFRP reinforcement will be compared to the predictive models and whether an environmental factor is necessary will be evaluated. The design requirements and discussion are provided in Chapter 20 of ACI CODE 440.11-22.

G-5.2 Creep and fatigue.

Time-dependent effects that can degrade the strength of GFRP over time are creep rupture and static fatigue. The design aspects of these effects are discussed in Section G-4.2, as part of the serviceability requirements. Creep rupture is the sudden failure of FRP material due to sustained loads over time. Static fatigue is similar in that a sudden failure will occur under sustained cyclical loading. Both can be mitigated if the stress in the reinforcement due to the sustained load or cyclical loading is restricted to a lower limit.

G-5.3 Exposure to Temperatures and Sunlight.

The potential for exposure to high temperatures needs to be considered when using GFRP reinforcement. The resin in the reinforcement will soften as the temperature approaches the glass transition temperature. ASTM D7957/D7957M requires the mean glass transition temperature to be at least 212 deg F (100 deg C). ACI CODE 440.11-22 suggests that GFRP bars should not be used in environments with a service temperature higher than 27 deg F (15 deg C) below the glass transition temperature. This calculates to an in-service limit of 185 deg F (85 deg C).

Ultra-violet radiation can be detrimental to GFRP reinforcement if exposed for long period of times to the sun before being placed in concrete. ACI 440.5 recommends if GFRP bars are stored outside for more than 4 months, they should be covered with opaque plastic. The requirement in UFGS 03 30 00, Cast-in-Place Concrete, places this limit at 2 months.

G-6 CONSTRUCTION

Construction specifications for GFRP reinforcement has been added to UFGS 03 30 00, Cast-in-Place Concrete. The information was developed from the requirements of ACI 440.5. The development of ASTM D7957/D7957M simplified the specification of GFRP reinforcement. Prior to its development, specifiers had to identify all the test methods and limits necessary for quality assurance. Manufacturers were providing different reinforcement shapes and sizes of reinforcement. ASTM D7957/D7957M established a standard bar size chart similar to steel reinforcement.

Key observations on construction with GFRP reinforcement.

- If the surface of the bar is damaged, it will need to be replaced. Visible damage is defined in the specification.
- On-site storage: cover the bars from the sun if exposed more than 2 months; and prevent exposing bars to greater than 120 °F.
- Concrete cover is different than it is for steel reinforcement.
- Support reinforcement with dielectric material or steel coated with dielectric material.
- Field cutting is permitted but bars cannot be field bent.

G-7 REFERENCES FOR APPENDIX G.

G-7.1 Government.

UNIFIED FACILITIES GUIDE SPECIFICATIONS (UFGS)

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

UFGS 03 30 00, *Cast-In-Place Concrete*

G-7.2 Non-Government.

AMERICAN CONCRETE INSTITUTE (ACI)

https://www.concrete.org/

ACI 318, *Building Code Requirements for Structural Concrete*

ACI 440.1R*, Guide for the Design and Construction of Structural Concrete Reinforced with Fiber-Reinforced (FRP) Bars*

ACI 440.5, *Specification for Construction with Fiber-Reinforcing Polymer Reinforcing Bars*

ACI CODE 440.11, *Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars--Code and Commentary*

AMERICAN SOCIETY OF CIVIL ENGINEERS (ASCE)

https://www.asce.org/

ASCE 7, *Minimum Design Loads for Buildings and Other Structures*

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ASTM D7957/D7957M, *Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement*

CANADIAN STANDARDS ASSOCIATION

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THE INTERNATIONAL FEDERATION FOR STRUCTURAL CONCRETE

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G-7.3 Other Publications.

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G-8 ABBREVIATIONS FOR APPENDIX G.

ACI	American Concrete Institute
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
deg	degrees
DoD	Department of Defense
FRP	Fiber Reinforced Polymer
GFRP	Glass Fiber Reinforced Polymer
LRFD	Load and Resistance Factor Design
UFC	Unified Facilities Criteria
UFGS	Unified Facilities Guide Specification

APPENDIX H GLOSSARY

H-1 ABBREVIATIONS.

g	Gravitational Acceleration
µm	Micrometer (micron)
3-D	Three Dimensional
AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
AEC	Architecture/Engineering/Construction
AFCEC	Air Force Civil Engineer Center
AHJ	Authority Having Jurisdiction (See MIL-STD 3007G, Nov 2019)
AISC	American Institute of Steel Construction
AISI	American Iron and Steel Institute
ANSI	American National Standards Institute
AREMA	American Railway Engineering and Maintenance-of-Way Association
ASCE	American Society of Civil Engineers
ASM	American Society for Metals
ASME	American Society of Mechanical Engineers
ASSE	American Society of Safety Engineers
ASTM	American Society for Testing and Materials, now ASTM International
ATFP	Anti-Terrorism Force Protection
ATCT	Air Traffic Control Tower
AWWA	American Water Works Association
BIA	Brick Industry Association (formerly Brick Institute of America)
BPON	Basic Performance Objective Equivalent to New Building Standards
BSE	Basic Safety Earthquake

CEFAPP	CERL Equipment Fragility and Protection Procedure
CERL	Construction Engineering Research Laboratory (formerly USACERL)
CP	Collapse Prevention
CRREL	Cold Regions Research and Engineering Laboratory
DC	Damage Control
DoD	Department of Defense
DoE	Department of Energy
EGL	Energy Grade Line
ELF	Equivalent Lateral Force
EPRI	Electric Power Research Institute
ERDC	U.S. Army Engineer Research and Development Center
FEMA	Federal Emergency Management Agency
GERS	Generic Equipment Ruggedness Spectra
GIP	Generic Implementation Procedure
GSREB	Guidelines for Seismic Retrofit of Existing Buildings
HCAI	California Department of Health Care Access and Information (formerly California Office of Statewide Health Planning and Development or OSHPD)
HVAC	Heating, Ventilating, and Air Conditioning
IBC	International Building Code
ICC-ES	International Code Council – Evaluation Service
ICSSC	Interagency Committee on Seismic Safety in Construction
IEBC	International Existing Building Code
IEEE	Institute of Electrical and Electronics Engineers
IMF	Intermediate Moment Frame

in.	Inch
in./ft	Inches per Foot
ICBO	International Conference of Building Officials
IO	Immediate Occupancy (Performance Objective/Level)
ISAT	International Seismic Application Technologies
kg	Kilogram
kg/m^3	Kilograms per Cubic Meter
km/h	Kilometers per Hour
kN	Kilonewton
kN/m	Kilonewton per Meter
kN/m^2	Kilonewton per Square Meter
kPa	Kilopascal
lb/ft	Pounds per Foot
lb	Pound
LmS	Limited Safety
LRFD	Load and Resistance Factor Design
LS	Life Safety (Performance Objective/Level)
m	Meter
m/s	Meters per Second
m^2	Square Meter
MC-1	Mission-Critical Level 1
MC-2	Mission-Critical Level 2
MCE_R	Risk-Targeted Maximum Considered Earthquake
mil	0.001 Inch
mm	Millimeter

mm^2	Square Millimeter
MPa	Megapascal
MPa/m	Megapascal per Meter
mph	Miles per Hour
MRI	Mean Recurrence Interval
NACE	National Association of Corrosion Engineers
NAS	National Academy of Sciences
NAVFAC	Naval Facilities Engineering Command
NCMA	National Concrete Masonry Association
NDP	Nonlinear Dynamic Procedure
NEHRP	National Earthquake Hazards Reduction Program
NFPA	National Fire Protection Association
NFS	Non-Frost Susceptible
NIST	National Institute of Standards and Technology
NL	Not Limited
NMC	Non-Mission-Critical
NSP	Nonlinear Static Procedure
O&M	Operation and Maintenance
OCBF	Ordinary Concentrically Braced Frame
OMF	Ordinary Moment Frame
OP	Operational (Performance Objective/Level)
OSP	HCAI Special Seismic Certification Preapproval Program
PCI	Precast/Prestressed Concrete Institute
pci	Pounds per Cubic Inch
psf	Pounds per Square Foot

psi	Pounds per Square Inch
PSSQ	Project Specific Seismic Qualification
PTHA	Probabilistic Tsunami Hazard Analysis
PTI	Post-Tensioning Institute
RACF	Radar Approach Control Facility
RC	Risk Category
RCSC	Research Council on Structural Connections
RFP	Request for Proposal
RP	Recommended Practice (also Resource Paper)
RRS	Required Response Spectrum
SBC	Standard Building Code
SDC	Seismic Design Category
SDI	Steel Deck Institute
SDPWS	Special Design Provisions for Wind and Seismic
SEAOC	Structural Engineers Association of California
SEI	Structural Engineering Institute
SER	Structural Engineer of Record
SIOR	Special Inspector of Record
SMF	Special Moment Frame
TI	Technical Instruction
TIA	Tentative Interim Agreement; Telecommunications Industry Association
TMS	The Masonry Society
TRS	Test Response Spectrum
UBC	Uniform Building Code
UFC	Unified Facilities Criteria

UFGS Unified Facilities Guide Specifications

URM Unreinforced Masonry

USACE U.S. Army Corps of Engineers

USACERL United States Army Construction Engineering Research Laboratory (now ERDC-CERL)

UUT Unit Under Test

$\mathbf{V_{asd}}$ Allowable Stress Design Wind Speed

$\mathbf{V_{fm}}$ Fastest Mile Wind Speed

V Basic Wind Speed

WEF Water Environment Federation

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11 April 2023
Change 1, 25 February 2025

UNIFIED FACILITIES CRITERIA (UFC)

DESIGN OF RISK CATEGORY V STRUCTURES, NATIONAL STRATEGIC MILITARY ASSETS

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UNIFIED FACILITIES CRITERIA (UFC)

DESIGN OF RISK CATEGORY V STRUCTURES, NATIONAL STRATEGIC MILITARY ASSETS

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING SYSTEMS COMMAND (Preparing Activity)

AIR FORCE CIVIL ENGINEER CENTER

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

Change No.	**Date**	**Location**
1	Feb 25, 2025	See Change Summary

This UFC supersedes UFC 3-301-02, dated 3 March 2020.

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FOREWORD

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

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

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

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

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

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UNIFIED FACILITIES CRITERIA (UFC)
REVISION SUMMARY SHEET

Document: UFC 3-301-02, Change 1, Dated February 25, 2025
Superseding: UFC 3-301-02, Dated April 11, 2023

\1
Description of changes
-Adoption of the 2024 I-codes
-Adoption of ASCE 7-22, Minimum Design Loads and Associated Criteria for Buildings and Other Structures

Reason for changes:
Maintain concurrence with model building codes and alignment with DoD building code (1 200 01).

Impact:
Typical of the code update cycle.
/1/

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CHAPTER 1 INTRODUCTION

1-1 BACKGROUND.

UFC 1-200-01 uses and supplements 2024 IBC as the building code for DoD. UFC 3-301-01 contains all structural requirements for structures assigned to Risk Category I, II, III, or IV. Only the enhanced structural requirements for RC V structures are contained in this UFC. These enhanced requirements are revised to be consistent with the 2024 IBC and ASCE 7-22.

1-2 REISSUE AND CANCELS.

This edition of UFC 3-301-02 cancels UFC 3-301-02 dated 3 March 2020.

1-3 PURPOSE AND SCOPE.

This Unified Facility Criteria (UFC) provides enhanced design requirements for Risk Category V (RC V) structures, national strategic military assets designed and constructed for the Department of Defense (DoD). These technical requirements are based on the 2024 *International Building Code* (2024 IBC) and the structural standard referenced by the 2024 IBC: ASCE/SEI 7-22 *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* (hereafter referred to simply as ASCE 7-22).

This UFC must be used for the design and analysis of buildings and other structures assigned to Risk Category V.

RC V - is assigned to facilities that are considered to be national strategic military assets (see UFC 3-301-01 Table 2-2). Special design and analysis procedures apply to RC V buildings and other structures. Design RC V structures to ensure that their foundations, superstructures and installed mission-essential nonstructural elements remain elastic, and their installed equipment remains operational when subjected to severe environmental loading.

This UFC modifies provisions of the 2024 IBC and ASCE 7-22 for use in analyzing RC V buildings and structures. In cases where a provision in the 2024 IBC or ASCE 7-22 is not modified by this UFC, first apply UFC 3-301-01 and then apply UFC 1-200-01. If neither of these UFC documents modifies the relevant provision, then apply the 2024 IBC and ASCE7-22 directly.

1-4 APPLICABILITY.

This UFC follows the same applicability as UFC 1-200-01, paragraph 1-3, with no exceptions.

1-5 CONFLICTS AND MODIFICATIONS.

The 2024 IBC provisions are directed toward public health, safety, and general welfare, presenting minimum standards that must be met by the private sector construction industry. The use of industry standards for DoD projects promotes communication in the marketplace, improves competition, and results in cost savings. However, the military sometimes requires higher standards to achieve unique building performance, or to construct types of facilities that are not used in the private sector, especially when the structures are national strategic military assets. In addition, the construction of military facilities outside the United States can introduce requirements that are not addressed in national model building codes. The provisions contained in this UFC are intended to fulfill the unique military requirements for RC V structures that are not found in the model building codes. When conflicts between the 2024 IBC or ASCE 7-22 and this UFC arise, this UFC prevails.

In addition, for construction outside the United States, conflicts between host nation building codes and the UFC may arise. In those instances, the more stringent design provisions apply. Notify the SER of where conflicts are discovered.

1-6 COMMENTARY.

Limited commentary has been added in the chapters. Section designations for such commentary are preceded by a “[C]”, and the commentary narrative is shaded.

1-7 OTHER CRITERIA.

Military criteria other than those listed in this document may be applicable to specific types of structures. Such structures must meet the additional requirements of the applicable military criteria.

1-7.1 General Building Requirements.

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

1-7.2 Structural Requirements.

Comply with UFC 3-301-01, *Structural Engineering*. UFC 3-301-01 modifies certain structural provisions of the model building codes for the purpose of DoD structures. Use this UFC in addition to UFC 3-301-01 and the UFCs and government criteria referenced therein.

1-7.3 Progressive Collapse Analysis and Design.

Apply UFC 4-023-03, *Design of Buildings to Resist Progressive Collapse*.

1-7.4 Cybersecurity.

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

1-8 REFERENCES.

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

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CHAPTER 2 DESIGN FOR ENHANCED RC V PERFORMANCE OBJECTIVES

2-1 DESIGN REVIEW.

2-1.1 Independent Structural Design Review.

A design review of the proposed seismic force-resisting system and associated structural analysis (calculations) must be conducted by an independent licensed professional engineer with at least 15 years of experience in the theory and application of nonlinear seismic analysis and structural behavior under extreme cyclic loads. The Independent Reviewer shall not be an employee of, or affiliated with, the design entity. The independent design reviewer must have previous real world design experience commensurate in complexity to the project being reviewed. Selection of the independent design reviewer is subject to the review and approval of the AHJ and the reviewer must be retained by the A/E design firm (DBB) or the General Contractor (DB). The design review must include, but is not necessarily limited to, the following:

1. Any site-specific seismic criteria used in the analysis, including the development of site-specific spectra and ground motion time-histories.

2. Any acceptance criteria used to demonstrate the adequacy of structural elements and systems to withstand the calculated force and deformation demands, together with any laboratory or other data used to substantiate the criteria.

3. The preliminary design, including the selection of the structural system; the configuration of structural elements; and supports for all architectural, mechanical, and electrical components.

4. The final design of the entire structural system and supports for all architectural, mechanical, and electrical components, and all supporting analyses.

5. All procurement documents (statements of work, specifications, and so forth.) that are developed for seismic qualification of equipment that must remain operable following the design earthquake; verification of post-earthquake operability by shake table testing, experience data, or analysis.

6. All documentation that is developed for seismic qualification of equipment that must remain operable following the design earthquake.

[C] 2-1.1 Independent Structural Design Review.

An independent Structural Design Review is to be conducted at the contractor's expense. The structural design review should be started early in the design process to ensure that the seismic design of the RC V facility is performed to the satisfaction of the Independent Structural Reviewer. The Independent Structural Reviewer should create a full report documenting the findings for each of the tasks listed in this section. A detailed list of all documents that were evaluated should be included in the report. Each evaluation should discuss how each topic was assessed, the criteria that were used for evaluation, a quantitative comparison of calculated response to allowable limits, and discussion on whether the criteria were satisfied. Additionally, the report should include discussion of critical element utilization ratios, the extent to which seismic effects govern the design of structural elements and how calculations and finite element (FE) models were evaluated, with a focus on modeling assumptions and boundary conditions.

The comprehensive report is to be signed and stamped by the independent structural reviewer and at a minimum must include:

1. Evaluation of Site Specific Seismic Hazard Analysis
    a. Evaluation of development of site specific spectra
    b. Evaluation of development of ground motion response histories
2. Evaluation of Seismic Force-Resisting System Response
    a. Evaluation of seismic force-resisting system narrative
    b. Evaluation of acceptance criteria for structural elements, including contributing and non-contributing structural elements
    c. Evaluation of seismic calculations and analyses demonstrating that structure can withstand seismic force and deformation demands
3. Evaluation of development of in-structure response spectra
4. Evaluation of nonstructural component designation as MC-1, MC-2, and NMC.
    a. Evaluation of the basis for determination of equipment designations to ensure owner/user intent has been considered and satisfied.
    b. Concurrence with the list and designations
    c. Review of draft Screening Evaluation Work Sheets (SEWS) for each MC-1 component.
    d. Evaluation of procurement documents (statements of work, specifications, qualification criteria, and so forth) for MC-1 and MC-2 architectural, mechanical, and electrical equipment and systems to ensure proper seismic qualification and labeling of equipment that must remain operable following the design earthquake.

2-1.2 Nonstructural Component Design Review.

A review of the nonstructural component design (including anchorage) must be performed by an independent licensed professional engineer with at least 15 years of experience in the theory and application of nonlinear seismic analysis and structural behavior under extreme cyclic loads. Previous design experience must be commensurate in complexity to the project being reviewed. Selection of the independent nonstructural component design reviewer is subject to the review and approval of the AHJ and the reviewer must be retained by the A/E design firm (DBB) or the General Contractor (DB). The structural and nonstructural component design review may be conducted by the same independent reviewer subject to the already noted qualifications. The nonstructural component design review should occur prior to commissioning and should include, but not necessarily be limited to, the following:

1. Review of in-structure response data and confirmation that any recommendations made by the Structural Design Reviewer have been incorporated into the in-structure response.

2. Review of component qualifications to confirm proper in-structure response was utilized.

3. Upon completion of design review of all documentation, the reviewer must perform a walk-down inspection of the project and confirm the following:

    a. Component installations are in their submitted and approved location.

    b. Identification nameplates are installed as specified in Section 2-17.8

    c. Component qualification documentation has been incorporated into the Operations & Maintenance Manual as specified in Section 2-17.7.

[C] 2-1.2 Nonstructural Component Design Review.

An independent Nonstructural Component Design Review is to be conducted at the contractor's expense. The nonstructural component design review should be started early in the construction phase of the RC V project to ensure the contractor meets the requirements of the UFC to the satisfaction of the Nonstructural Reviewer. The Nonstructural Reviewer should create a comprehensive report documenting completion of each of the tasks listed in this section. The report should contain all required data, including but not limited to, photos, field notes, equipment tags, and measurements. The report should also identify any variance to the Structural Design Review report and ultimately state whether criteria for Risk Category V have been satisfied.

The comprehensive report is to be signed and wet stamped by the Nonstructural Component Design Reviewer and at a minimum must include:

1. Review of anchorage design for all nonstructural components
2. Review of in-structure response data confirming that comments from the Structural Reviewer have been incorporated
3. Review of component qualification documents to ensure that the proper in-structure seismic demand was used
4. After completion of the design review activities listed above and before commissioning, a walk-down inspection of the facility to confirm the following:

a. Location of installed Mission Critical components

b. Installation of identification nameplates as specified in Section 2-17.8 of this UFC

c. Incorporation of component qualification documents into the O&M Manual as specified in Section 2-17.7 of this UFC

2-2 DEFINITIONS AND NOTATIONS.

2-2.1 General.

2024 IBC Section 202, as modified by UFC 3-301-01 and this section applies.

ACTIVE FAULT

An active fault is defined in ASCE 7-22 as follows: A fault determined to be active by the Authority Having Jurisdiction from properly substantiated data (e.g., most recent mapping of active faults by the US Geological Survey).

[C] ACTIVE FAULT

In UFC 3-301-02, 11 April 2023 (the previous version of this UFC), an active fault was defined as a fault for which there is an average historic slip rate of 1 mm or more per year and for which there is geographic evidence of seismic activity in Holocene times (the most recent 11,000 years). This definition dates back to the 2000 IBC.

WIND-BORNE DEBRIS REGION

For locations within the United States and its territories and possessions, areas within hurricane-prone regions located:

1. Within 1 mile (1.61 km) of the mean high water line where an Exposure D condition exists upwind of the waterline and the basic wind speed, *V*, is 130 mph (58 m/s) or greater; or

2. In areas where the basic wind speed is 140 mph (63.6 m/s) or greater.

For locations outside of the United States and its territories and possessions, any region where either of the above two conditions apply.

The wind speeds referenced above are Risk Category V wind speeds (See Section 2-9.1).

DESIGNATED SEISMIC SYSTEMS

Those nonstructural components that require design in accordance with ASCE 7-22 Chapter 13. This designation applies to systems that are required to be operational following the MCE_R for RC V structures. All systems in RC V facilities designated as MC-1 (see Section 2-17.2) must be considered part of the Designated Seismic System.

2-3 CONSTRUCTION DOCUMENTS.

2-3.1 General.

2024 IBC Section 1603, as modified by UFC 3-301-01, applies.

Exceptions**:**

1. The Seismic Importance Factor, I_e, the seismic response coefficient, C_S, the Response Modification Factor, R, and the Seismic Design Category do not apply and must not be listed in construction documents.

2. The classification of the building in RC V, that it is designed in accordance with the provisions of this UFC, and the date of this UFC, must be listed in construction documents.

3. Construction documents for architectural, mechanical, and electrical components must be prepared by a Registered Design Professional for all buildings assigned to RC V.

2-4 GENERAL DESIGN REQUIREMENTS.

2-4.1 General.

2024 IBC Section 1604, as modified by UFC 3-301-01, applies. UFC 3-301-01 Table 2-2 is to replace 2024 IBC Table 1604.5.

2-4.2 Wind and Seismic Detailing.

2024 IBC Section 1604.9 does not apply to RC V facilities.

2-5 LOAD COMBINATIONS.

2-5.1 General.

2024 IBC Section 1605 applies.

Exceptions**:**

1. For all load combinations, structural elements must be designed to remain linear (elastic).

2. Only Strength Design load combinations are permitted.

3. In load combinations involving seismic load effects, the combined effect of earthquake forces, *E*, needs to be computed using the procedures outlined in this UFC.

2-6 DEAD LOADS.

2-6.1 General.

2024 IBC Section 1606 applies.

2-7 LIVE LOADS.

2-7.1 General.

2024 IBC Section 1607, as modified by UFC 3-301-01, applies. Wherever Table 1607.1 is referenced in the IBC, it is to be replaced by Table E-1 of UFC 3-301-01.

2-8 SNOW AND ICE LOADS.

2-8.1 General.

Design snow loads are to be determined in accordance with 2024 IBC Section 1608, as modified by UFC 3-301-01. Design atmospheric ice loads on ice-sensitive structures are to be determined in accordance with ASCE 7-22 Chapter 10.

Exceptions**:**

1. Ground snow loads and winter wind parameter W2 for RC V structures must be determined using a spreadsheet found under related materials on the WBDG Risk Category V Structures UFC.

2. In the determination of atmospheric ice loads for RC V structures, the nominal values of ice thickness, and concurrent wind speed and temperature must be determined using a spreadsheet found under related materials on the WBDG Risk Category V Structures UFC.

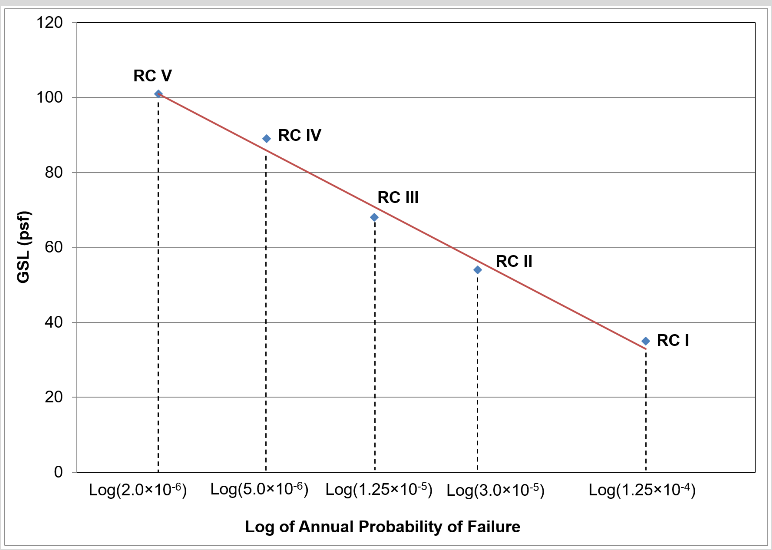
3. At locations where Risk Category V snow or ice loads are not provided, contact the AHJ for further guidance. For OCONUS locations reference the following commentary

[C] 2-8 SNOW AND ICE LOADS

Ground snow load (GSL) for an RC V structure at a given location was determined based on the GSL values at the same location corresponding to RC I, II, III and IV structures obtained from the ASCE Hazard Tool. As explained in ASCE 7-22 Commentary Section C7.2:

The ground snow load, p_g, values contained in the ASCE Design Ground Snow Load Geodatabase, mapped in Figures 7.2-1A through 7.2-1D and provided in the ASCE Hazard Tool are based on a reliability analysis consistent with the targets in Table 1.3-1 for a "failure that is not sudden and does not lead to widespread progression of damage."

In other words, the GSL values for RC I, II, III and IV structures correspond to target annual probabilities of failure (P_F) of 1.25×10^{-4}, 3.0×10^{-5}, 1.25×10^{-5}, and 5.0×10^{-6}, respectively. Plotting these GSL values against the Log of their corresponding P_F, it was observed that the points lie on an approximate straight line, as seen in the figure below. The exercise was repeated for more than 300 locations and the same linear relationship was observed. Consequently, it was decided to determine the GSL value for RC V structures based on extrapolation using the best-fitting straight line drawn through the four points described above. From ASCE 7-22 Table 1.3-1, a P_F value of 2.0×10^{-6} was deemed appropriate for RC V structures, as can be seen in the figure below.



It can be noted that, in high snow locations, the procedure described above provides lower GSL values when compared to the old method of multiplying an importance factor of 1.5 to the GSL value of RC II structures. This is expected because using a single importance factor for all locations was meant to be conservative.

The same procedure was followed to determine the nominal ice thickness for RC structures. Nominal ice thickness values for RCs I, II, III and IV structures correspond to mean recurrence interval (MRI) of 250, 500, 1000 and 1400 years, respectively. An MRI of 2500 years was assigned to RC V structures for ice loading.

2-8.2 Snow Load Case Studies.

Snow load case studies may be done to clarify and refine snow loadings at site-specific locations with the approval of the AHJ. A site-specific study must be conducted if the ground snow load is greater than 100 psf (4.78 KPa). The methodology used to conduct snow load case studies at site-specific locations is presented in the Cold Regions Research and Engineering Laboratory (CRREL) report “Database and Methodology for Conducting Site Specific Snow Load Case Studies for the United States.” by Tobiasson and Greatorex and “Site-Specific Case Studies for Determining Ground Snow Loads in the United States” by Buska, Greatorex, and Tobiasson.

[C] 2-8.2 Snow Load Case Studies.

The provisions of this section are similar to those in Section 1608.2.3 in UFC 3-301-01, except that there is a threshold GSL value of 100 psf. In UFC 3-301-01, 11 April 2023, Change 1, 2 October 2023, there was a threshold GSL value of 30 psf for having to do site-specific snow load case studies. The 30 psf service-level GSL was converted to 45 psf strength-level GSL. Since this value was for RC I through IV structures, it was brought up to 70 psf for RC V structures by multiplying with an importance factor 1.5 and then rounding up. The snow load importance factor for RC V structures was scaled up from an importance factor of 1.2 for RC IV structures. The 70 psf was increased to 100 psf based on discussions with the Designated Working Group (DWG).

2-9 WIND LOADS.

2-9.1 Design Wind Speeds Inside and Outside of the United States.

Risk Category V OCONUS wind speed can be found using a spreadsheet that is located on the Whole Building Design Guide Structural Engineering UFC Page as a related item for download

For Risk Category V CONUS wind speeds use ASCE’s hazard tool and select the wind speed for a 100,000-year return period.

At locations where the basic wind speed is not provided, use the best locally available information.

At locations where the basic wind speed is not provided, contact the AHJ for further guidance.

2-10 SOIL LATERAL LOADS.

2-10.1 General.

2024 IBC Section 1610 applies except as follows: The exception in section 1610.1 to allow the use of active soil pressure under certain conditions is disallowed for RC V structures.

2-11 RAIN LOADS.

2-11.1 General.

2024 IBC Section 1611 applies.

Exception:

1. The design rainfall intensity for RC V structures must be must be determined using a spreadsheet found under related materials on the WBDG Risk Category V Structures UFC.
2. At locations where the design rainfall intensity is not provided, contact the AHJ for further guidance and see the following commentary.

[C] 2-11 RAIN LOADS

The design rainfall intensity (in./h or mm/h) for RC V structures is based on 15-min storm of 1000-yr return period. These values can also be obtained from the following webpage on the website of National Oceanic and Atmospheric Administration (NOAA).

https://hdsc.nws.noaa.gov/pfds/pfds_map_cont.html

2-12 FLOOD LOADS.

2-12.1 General.

2024 IBC Section 1612 applies.

Exceptions**:**

1. The **DESIGN FLOOD** is to be defined as a flood with a 2 percent chance of exceedance in 50 years (2500-year mean recurrence interval).
2. The **FLOOD HAZARD AREA** is to be defined as the area within a flood plain subject to a 2 percent chance of flood exceedance in 50 years (2500-year mean recurrence interval). A probabilistic flood hazard analysis must be performed where a facility does not clearly fall outside of said area by inspection.

2-13 TSUNAMI LOADS.

2-13.1 General.

Section 2-4.8 of UFC 3-301-01 applies.

2-14 EXISTING BUILDINGS.

2-14.1 Seismic Evaluation and Retrofit.

RC V structures must be designed to ensure that during the $MCE_{R'}$ their superstructures and installed mission-essential non-structural components remain elastic and, following the $MCE_{R'}$ their installed equipment remains operational. ASCE 41 is not to be used for evaluating existing buildings that are classified as RC V facilities. For any evaluations of existing RC V buildings, the analysis procedures of this UFC apply. All strengthening of existing buildings and additions to existing buildings that must satisfy RC V performance requirements need to satisfy the requirements of this UFC.

2-15 EARTHQUAKE LOADS.

2-15.1 Structural Design Criteria.

Each RC V structure is to be designed in accordance with the provisions of this Chapter. Permissible structural systems are listed in Table 2-1. The components of a structure that must be designed for seismic resistance and the types of lateral force analysis that must be performed are prescribed in this Chapter. Each structure is to be provided with complete seismic and vertical force-resisting systems capable of providing adequate strength and stiffness to withstand the design earthquake ground motions determined in accordance with Section 2-15.2, within the prescribed deformation limits of Section 2-16.9. The design ground motions are to be assumed to occur along any horizontal direction of a structure, as well as in the vertical direction. A continuous load path, or paths, with adequate strength and stiffness to transfer forces induced by the design earthquake ground motions from the points of application to the final point of resistance must be provided.

2-15.2 Seismic Ground Motion Values.

2-15.2.1 Development of MCE_R Spectral Response Accelerations and Response History Criteria.

The Site-Specific Ground Motion Procedures outlined in ASCE 7-22 Chapter 21 are to be used to develop MCE_R ground motion acceleration time histories for RC V structures. The MCE_R can generally be characterized by a 5-percent-damped acceleration response spectrum. A lower value of damping may be more appropriate and the value should be as approved by the Structural Design Reviewer (see Section 2-1.1). In the application of seismic provisions of the 2024 IBC and ASCE 7-22, the terms S_{DS} and S_{D1} are to be replaced by S_{MS} and S_{M1}, respectively, obtained from this response spectrum.

A linear response history analysis in accordance with ASCE 7-22 Section 12.9.2 is also to be conducted to determine the in-structure demand for the design and qualification of nonstructural equipment and distributed systems. The ASCE/SEI 43-19, Section 2.4 Criteria for Developing Synthetic or Modified Recorded Acceleration Time Series must be used to develop the seismic response histories for RC V facilities.

Table 2-1 Systems Permitted for Risk Category V Buildings

Basic Seismic Force-Resisting System	Detailing Requirements
Bearing Wall Systems	
Ordinary reinforced concrete shear walls	ACI 318, excluding Ch. 18
Ordinary reinforced masonry shear walls	TMS 402
Building Frame Systems	
Steel eccentrically braced frames, moment-resisting connections at columns away from links	AISC 360
Steel eccentrically braced frames, non-moment-resisting connections at columns away from links	
Ordinary steel concentrically braced frames	
Ordinary reinforced concrete shear walls	ACI 318, excluding Ch. 18
Composite steel and concrete eccentrically braced frames	AISC 360 (LRFD) and ACI 318, excluding Ch. 18
Composite steel and concrete concentrically braced frames	
Ordinary composite steel and concrete braced frames	
Composite steel plate shear walls	
Ordinary composite reinforced concrete shear walls with steel elements	
Ordinary reinforced masonry shear walls	TMS 402
Moment-Resisting Frame Systems	
Ordinary steel moment frames	AISC 360
Ordinary reinforced concrete moment frames	ACI 318, excluding Ch. 18
Ordinary composite moment frames	AISC 360 (LRFD) and ACI 318, excluding Ch. 18
Composite partially restrained moment frames	
Cantilevered Column Systems Detailed to Conform to the Requirements for:	
Ordinary steel moment frames	AISC 360
Ordinary reinforced concrete moment frames	ACI 318, excluding Ch. 18

Note: Any system prohibited here may be permitted if approved by the Independent Structural Design Reviewer (Section 2-1.1).

At least seven 3-component ground motions must be selected and scaled from individual recorded events for in-structure response analysis. The histories must be selected from events having magnitudes, fault distances, and source mechanisms that are consistent with those that control the MCE_R for the RC V structure. Ground motion records are to be sourced from stations with similar soil profiles, defined in terms of Site Class, to that at the site of the RC V structure. The shape of the spectra of the recorded motions must be similar to that of the target spectra.

2-15.2.2 Design Response Spectrum.

[redacted] Design Horizontal Response Spectrum.

The unreduced MCE_R ground motions determined from the Site Specific Ground Motion Procedure are to be used.

[redacted] Design Vertical Response Spectrum.

The unreduced MCE_R ground motions determined from the Site Specific Ground Motion Procedure are to be used. The vertical spectrum values, S_{aMv}, cannot be lower than the minimum ordinates determined from ASCE 7-22 Section 11.9.2. Ground motions for calculating the minimum ordinates are to be the site-specific MCE_R ground motions determined in 2-15.2.2.1. The 'Gulerce Abrahamson Method' may also be used for deriving vertical acceleration if conditions for the method are met.

2-15.3 Importance Factor and Risk Category.

2-15.3.1 Importance Factor.

A seismic importance factor is not required for RC V buildings and other structures (see UFC 3-301-01 Table 2-2). However, some referenced sections of ASCE 7-22 require the use of I_e. In these cases, I_e is to be taken as 1.0.

[C] 2-15.3.1 Importance Factor

The provisions of this UFC are for designing RC V structures only. The seismic forces required in this UFC already take into account the critical nature of these structures, and as a result, are set to a very high level, which is reflected in the fact that these structures are designed to remain elastic during an MCE_R-level event. For this reason, application of an importance factor is not required.

2-15.4 Seismic Design Category.

The requirements of ASCE 7-22 Section 11.6 do not apply to RC V structures.

2-15.4.1 Design Requirements for Seismic Design Category A.

The requirements of ASCE 7-22 Section 11.7 do not apply to RC V structures.

2-15.5 Geological Hazards and Geotechnical Investigation.

2-15.5.1 Site Limitations for Risk Category V Structures.

A structure assigned to RC V must not be sited where there is a known potential for an active fault to cause rupture of the ground surface at the structure. The term *active fault* is defined in Section 2-2.1 of this UFC.

2-16 SEISMIC DESIGN REQUIREMENTS FOR BUILDING STRUCTURES.

2-16.1 Structural System Selection.

2-16.1.1 Selections and Limitations.

Table 2-1, *Systems Permitted for Risk Category V Buildings*, is to be used to determine whether a seismic force-resisting system is permitted for use in an RC V structure. Exceptions may be authorized when permission is granted by the Structural Design Reviewer (see Section 2-1.1).

Once a permitted structural system has been selected, no specific building height limitations apply. The requirement to ensure elastic behavior at the MCE_R-level earthquake mitigates the need for height limitations.

2-16.1.2 Combinations of Framing Systems.

Combinations of permitted structural systems (see Table 2-1) may be used to resist seismic forces, both along the same axis of a building and along the orthogonal axes of the building. For systems combined along the same axis of a building, total seismic force resistance is to be provided by the combination of the different systems, with each contributing resistance in proportion to its stiffness. Displacements of parallel framing systems must be shown by analysis to be compatible.

2-16.1.3 R, C_d, and Ω_0 Values for Vertical and Horizontal Combinations.

The design of RC V structures must use a linear elastic Modal Response Spectrum Analysis (MRSA) procedure. Structural response is to be restricted to elastic behavior. No yielding is to be permitted for the MCE_R ground motions. The factors R, C_d, and Ω_0 are to be set to 1.0.

[C] 2-16.1.3 R, C_d, and Ω_0 Values for Vertical and Horizontal Combinations

The factors R, C_d, and Ω_0 are meant to quantify the inelastic properties of a structure that is designed to undergo inelastic deformations in the course of resisting an MCE-level seismic event. In contrast, structures assigned to RC V are designed to remain elastic during an MCE-level event. As a result, these three seismic factors are irrelevant in the design of RC V structures.

ASCE 7-22 has removed virtually all restrictions on the use of the Equivalent Lateral Force (ELF) procedure. However, the mandatory use of the Modal Response

Spectrum Analysis (MRSA) procedure is retained here because it provides a more accurate assessment of seismic structural response.

2-16.2 Diaphragm Flexibility, Configuration Irregularities, and Redundancy.

2-16.2.1 Irregular or Regular Classification and Limitations and Additional Requirements for Systems with Structural Irregularities.

ASCE 7-22 Sections 12.3.2 and 12.3.3 do not apply.

[C] 2-17.2.1 Irregular or Regular Classification and Limitations and Additional Requirements for Systems with Structural Irregularities.

Because buildings assigned to RC V are designed to respond to MCE_R ground shaking in an elastic manner, and they are required to be analyzed by procedures that adequately account for any structural irregularity, it is not necessary to classify RC V buildings as regular or irregular. In addition, any design provisions intended to account for structural irregularities need not apply.

2-16.2.2 Redundancy.

ASCE 7-22 Section 12.3.4 applies. For the purpose of determining the redundancy factor ρ, assume the seismic design category to be D. Structural systems with a redundancy factor, ρ, equal to 1.3 are not permitted (see Section 2-16.4.1).

2-16.2.3 Upward Force for Horizontal Cantilevers.

Vertical seismic forces are to be computed from the vertical spectral accelerations specified in this Chapter. The minimum vertical force in ASCE 7-22 Section 12.4.4 applies, except that the net upward force must be 0.8D.

[C] 2-16.2.3 Upward Force for Horizontal Cantilevers.

In ASCE 7-22 Section 12.4.4, a net upward force of 0.2D for horizontal cantilever members is specified for the Design Earthquake with an implicit assumption that an upward seismic force of 1.2D is acting in conjunction with the weight (1.0D) of the cantilever member. For design using MCE_R, the vertical seismic force needs to be scaled up by a factor of 1.5, which produces an upward seismic force of 1.8D. As a result, the net upward force on the member becomes 1.8D – 1.0D = 0.8D.

2-16.3 Direction of Loading.

2-16.3.1 Direction of Loading Criteria.

When effects from the three earthquake ground motion components with respect to the principal axes of the building are calculated separately, the combined earthquake-induced response for each principal axis of the building must consist of the sum of

100% of the maximum value resulting from loading applied parallel to that axis and 40% of both maximum values that result from loading components orthogonal to that axis. Absolute values from all loading components must be used, so that all values are additive. If the three quantities are designated E_x, E_y, and E_z, they are to be combined in accordance with Equations 2-1, 2-2, and 2-3, and the maximum response, $E_{T\text{-}max}$, is to be the most severe effects of Equations 2-1, 2-2, or 2-3, for each individual structural element:

$$E_T = \pm\,[1.0\,E_x + 0.4\,E_y + 0.4\,E_z] \qquad \textbf{(Equation 2-1)}$$

$$E_T = \pm\,[0.4\,E_x + 1.0\,E_y + 0.4\,E_z] \qquad \textbf{(Equation 2-2)}$$

$$E_T = \pm\,[0.4\,E_x + 0.4\,E_y + 1.0\,E_z] \qquad \textbf{(Equation 2-3)}$$

Where:

E_x, E_y = *Maximum horizontal components of response*
E_z = *Maximum vertical component of response*
E_T = *Maximum combined response from three orthogonal components*

2-16.4 Analysis Procedure Selection.

2-16.4.1 General Requirements.

Structures assigned to RC V must be designed to ensure that their superstructures and installed mission-critical nonstructural elements remain elastic, when subjected to MCE_R ground motions, and that mission-essential equipment remains operable immediately following the MCE_R ground motions. MCE_R spectral acceleration parameters must be based on the procedures outlined in Section 2-15.2. In all analyses performed using the provisions of this Chapter, the variables R, C_d, ρ (see Section 2-16.2.2) and Ω_0 are all to be set to 1.0, as indicated in Section 2-16.1.3 of this UFC.

2-16.4.2 Horizontal and Vertical Force Determination.

Except for seismically isolated structures and structures using supplemental damping, structural analysis for horizontal and vertical force determination must be accomplished using a combined three-dimensional linear elastic Modal Response Spectrum Analysis (MRSA) in accordance with the provisions of ASCE 7-22 Sections 12.7.3 and 12.9.1. Refer to Section 2-15.3.1 for application of the Importance Factor, I_e, in ASCE 7-22 Section 12.9.1. Modal values are to be combined in accordance with the provisions of ASCE 7-22 Section 12.9.1.3. Further information on the use of the MRSA can be found in ASCE 4-16, *Seismic Analysis of Safety-Related Nuclear Structures*. For the ground motion component associated with each horizontal plan dimension of the structure, applied forces are to be determined using linear horizontal response spectra that are developed in accordance with the provisions of Sections 2-15.2.1 and 2-15.2.2.1.

For the ground motion component associated with the vertical axis of the structure, applied forces are to be determined using linear vertical response spectra that are developed in accordance with the provisions of Sections 2-15.2.1 and 2-15.2.2.2.

Exception: For structures using seismic isolation or supplemental damping, horizontal and vertical seismic forces must be determined using nonlinear dynamic analysis, in which the seismic isolators or dampers are modeled with nonlinear properties consistent with test results, and the remaining structural system is modeled as linearly elastic. The nonlinear response history analysis procedures of ASCE 7-22 Section 17.6 are to be used for the nonlinear analyses, except that vertical ground motions need to be included in the analyses.

2-16.4.3 Member Forces.

Response in structural elements and nonstructural elements that directly support critical functions must remain linear for the MCE_R ground motions, at anticipated drift demands. The requirement for linear response may be met through any combination of elastic member design, added damping or energy dissipation, or base isolation. The designer should consider the economics of these options, as well as the performance of critical installed equipment, in the structural design process.

[redacted] Low Seismicity Applications.

In areas of low seismic activity (S_{MS} < 0.25 and S_{M1} < 0.10), it is anticipated that linear response may be achieved through proper design of all structural elements in both the lateral load and gravity load systems, using one or more of the seismic force-resisting systems listed in Table 2-1. Alternatives may be used, if they are verified adequately through analysis and are approved by the Structural Design Reviewer (see Section 2-1.1).

[redacted] Moderate Seismicity Applications.

In areas of moderate seismic activity (0.25 ≤ S_{MS} ≤ 0.75, 0.10 ≤ S_{M1} ≤ 0.30), it is anticipated that linear response in the gravity load system and critical nonstructural elements may be achieved using supplemental energy dissipation (added damping) systems, in conjunction with one or more of the seismic force-resisting systems listed in Table 2-1. Where supplemental damping systems are used, they must be designed, tested, and constructed in accordance with the requirements of ASCE 7-22 Chapter 18. Analysis must conform to the requirements of ASCE 7-22 Section 18.7.1, Response Spectrum Procedure. It is recognized that damping systems generally have inherent nonlinear behavior. It is not the intent of these provisions to require linear behavior in damping or isolation systems. Alternatives may be used, if they are verified adequately through analysis and are approved by the Structural Design Reviewer (see Section 2-1.1).

[redacted] High to Very High Seismicity Applications.

In areas of high to very high seismic activity (S_{MS} > 0.75 or S_{M1} > 0.30), it is anticipated that linear response in the gravity load system and critical nonstructural elements may be achieved using seismic isolation systems, in conjunction with one or more of the seismic force-resisting systems listed in Table 2-1. In such situations, ASCE 7-22 Chapter 17 must be applied. It is recognized that isolation systems generally have inherent nonlinear behavior. It is not the intent of these provisions to require linear behavior in damping or isolation systems. Alternatives may be used, if they are verified adequately through analysis and are approved by the Structural Design Reviewer (see Section 2-1.1).

Exception: ASCE 7-22 Chapter 17 requires the use of the factor R_I for scaling the forces for structural elements above the isolation system. For RC V structures, the R_I factor is to be taken as 1.0. Table 2-1 must be used for selecting the structural system.

2-16.5 Equivalent Lateral Force Procedure.

The application of ASCE 7-22 Section 12.8 is not permitted for RC V structures.

[C] 2-16.5 Equivalent Lateral Force Procedure.

ASCE 7-22 has removed virtually all restrictions on the use of the Equivalent Lateral Force (ELF) procedure. However, the prohibition on the use of the procedure for RC V structures is retained here because Modal Response Spectrum Analysis (MRSA) provides a more accurate assessment of seismic structural response.

2-16.6 Modal Response Spectrum Analysis.

2-16.6.1 Modal Response Parameters.

Story drifts must be computed using a linear elastic MRSA procedure (see Section 2-16.4.2). Story drifts and P-Delta effects are to be determined using the procedures outlined in ASCE 7-22 Section 12.9.1. Refer to Section 2-15.3.1 for application of Importance Factor, I_e, in this section.

2-16.7 Diaphragms, Chords, and Collectors.

Diaphragm, chords, and collectors must be designed in accordance with ASCE 7-22 Section 12.10.

2-16.7.1 Design by ASCE 7-22 Sections 12.10.1 and 12.10.2.

When diaphragm forces are determined from ASCE 7-22 Section 12.10.1, apply a multiplier of 2 to the force at the uppermost level and design the diaphragm at each floor level for that force. In the application of ASCE 7-22 Section 12.10.1, the terms S_{DS} and S_{D1} are to be replaced by S_{MS} and S_{M1}, respectively (see Section 2-15.2.1 of this UFC).

The same adjustment applies to the design of collector elements by ASCE 7-22 Section 12.10.2.

ASCE 7-22 Section 12.10.1.1, is to be modified to delete the maximum force limit ($0.4S_{DS}I_e w_{px}$) that is placed on Equation 12.10-1.

[C] 2-17.7.1 Diaphragms, Chords, and Collectors

The above adjustments are intended to ensure that diaphragm behavior will remain elastic all the way up to the MCE_R. There are ample indications that the diaphragm design force levels of ASCE 7-22 Section 12.10.1 do not result in elastic diaphragm behavior even in the Design Earthquake (DE). The suggested modifications are adapted from the manual: Seismic Design of Precast/Prestressed Concrete Structures (PCI MNL-140, 2nd Edition) and the PCI Design Handbook (PCI MNL-120,8th Edition) published by the Precast/Prestressed Concrete Institute (PCI). The multiplier assumes that shear walls or braced frames form part of the seismic force-resisting system, which is typical of RC V structures.

A multiplier of 3 is appropriate when the diaphragm forces are determined based on the DE using S_{DS} and S_{D1}. However, in this UFC, all seismic forces are determined based on the MCE_R using S_{MS} and S_{M1}. As a result, the multiplier was scaled down to 2 in order to avoid an overly conservative design.

ASCE 7-22 Section 12.10.3 was introduced to address the above problem, which led to the addition of Section 2-16.7.2 of this UFC.

2-16.7.2 Design by ASCE 7-22 Sections 12.10.3.

When the alternative design provisions of ASCE 7-22 Section 12.10.3 are used, the ground motion parameters S_{DS} and S_{D1} are to be replaced by S_{MS} and S_{M1}, respectively. Diaphragm design force reduction factor, R_s, is to be taken as 1.0. The collector elements must be designed using ASCE 7-22 Section 12.10.3.4.

2-16.8 Structural Walls and Their Anchorage.

2-16.8.1 Design for Out-of-Plane Forces and Anchorage of Structural Walls and Transfer of Design Forces into Diaphragms.

Unless otherwise specified in this Chapter, transmitted seismic force, F_p, must be the maximum of F_p calculated in accordance with the provisions of ASCE 7-22 Section 12.11.2 and the actual forces computed using the procedures of this Chapter. The value of S_{MS} is to be used in lieu of S_{DS} in the equation for F_p in ASCE 7-22 Section 12.11.2. ASCE 7-22 lower-bound value for wall anchorage forces must be revised to the larger of $0.3k_aI_eW_p$ and 7.5 lb/ft^2. Refer to Section 2-15.3.1 for application of Importance Factor, I_e, in this section.

2-16.9 Drift and Deformation.

2-16.9.1 Story Drift Limit.

The design story drift (Δ) must not exceed the allowable story drift (Δ_a) for RC IV structures in ASCE 7-22 Table 12.12-1.

Exception: Where performance requirements for installed equipment or other nonstructural features require smaller allowable drifts than those permitted by this Section, the smaller drifts govern.

2-16.9.2 Deformational Compatibility.

ASCE 7-22 Section 12.12.4 does not apply.

2-17 SEISMIC DESIGN REQUIREMENTS FOR NONSTRUCTURAL COMPONENTS.

2-17.1 General.

2-17.1.1 Scope.

The provisions of ASCE 7-22 Chapter 13, as modified by UFC 3-301-01, apply, except as noted in the following paragraphs. Appendix C of UFC 3-301-01 provides supplementary guidance on design and analysis of architectural, mechanical, and electrical components. Appendix D of UFC 3-301-01 provides supplementary guidance on certification of mechanical and electrical components.

2-17.2 General Design Requirements.

2-17.2.1 General Requirements.

All architectural, mechanical, and electrical components must be designed for the in-structure horizontal and vertical response spectra developed in Section 2-17.4.4. Designs must include bracing, anchorage, isolators, and energy dissipation devices, as appropriate, for all components, in addition to the components themselves. Motion amplification through component supports must be determined and accommodated in design. Installed architectural, mechanical, and electrical components are to be classified as Mission-Critical Level 1 (MC-1), Mission-Critical Level 2 (MC-2), or Non-mission-critical (NMC). The structural engineer must classify all architectural, mechanical, and electrical components, in consultation with functional risk representatives designated by the AHJ.

Unless specifically noted otherwise in this UFC, any ASCE 7-22 Chapter 13 provision that is specific to RC IV structures must also be applied to RC V structures. Where ASCE 7-22 Chapter 13 requirements are based on the SDC of a structure, determine SDC assuming RC to be IV.

2-17.2.2 Mission-Critical Level 1 Components.

MC-1 components are those architectural, mechanical, and electrical components that are critical to the mission of the facility and must be operational immediately following the MCE_R ground shaking. MC-1 components are part of the Designated Seismic

System and as such must be certified as operable immediately following the MCE_R ground shaking in accordance with the provisions of ASCE 7-22 Section 13.2.3 as modified by UFC 3-301-01.

Exception: When shake table testing is performed, the Required Response Spectra (RRS) are not permitted to be derived using ICC-ES AC156.

2-17.2.3 Mission-Critical Level 2 Components.

MC-2 components are those architectural, mechanical, and electrical components that may incur minor damage that would be reparable with parts stocked at or near the facility within a 3-day period, by on-site personnel, following the MCE_R ground shaking. If the failure of an MC-2 component can cause the failure of an MC-1 component, then the MC-2 component must be considered as an MC-1 component. Typical MC-2 components may be suspended ceiling system components, lights, overhead cranes, and so forth. MC-2 components must be attached, anchored, and supported to resist the MCE_R-induced building motions. All supporting structures for MC-2 components must remain elastic during the MCE_R-induced building motions.

2-17.2.4 Non-Mission-Critical Components.

NMC components are those architectural, mechanical, and electrical components that may incur damage in the MCE_R ground shaking. If the failure of an NMC component can cause the failure of an MC-1 or MC-2 component, then the NMC component must be classified the same as the corresponding MC-1 or MC-2 component. NMC components must be designed so they will not cause falling hazards or impede facility egress. Typical NMC components may include bathroom vent fans, space heaters, and so forth.

2-17.2.5 Component Qualification Documentation.

The seismic qualification documentation for each piece of equipment must contain the following as a minimum:

1. The engineering submittal containing the following:

    a. Design calculations and complete description of the equipment or component with cut sheets or photographs containing all germane data including fastening requirements, welds, post-installed anchors, and so forth.

    b. Development of the in-structure response demand for vertical and horizontal shaking.

    c. For MC-1 components, development of the response capacity (fragility curve) for vertical and horizontal shaking.

    d. Design of the anchorage including anchor qualifications, calculations indicating forces predicated on the seismic loads, and capacity of the anchors.

e. A drawing indicating the equipment/component and location in the facility sufficient to be used for the installation.

All of the above elements must be checked and signed by the designer and nonstructural component design reviewer (UFC 3-301-02 Section 2-1.2). The designer must affix his/her Professional Engineer seal on the cover page. The cover page must identify the equipment/component and the performance category (MC-1 or MC-2).

2. Documentation of an independent design review of Item 1.

3. The Department of Energy (DOE) Screening Evaluation Worksheet (SEWS) of the installed MC-1 equipment/component. Documentation of the accompanying Special Inspection of any post-installed anchorages or Special Inspection of components identifying the Special Inspector. Consideration must be given to the installed condition and proximity to adjacent structures and components to avoid pounding effect.

   The appropriate DOE SEWS can be obtained from the DOE web site at: https://ehss.energy.gov/au/seismic/. Other evaluation worksheets can be used upon approval by the Authority Having Jurisdiction.

4. For MC-1 components, documentation of the independent “walk-down” inspection of the equipment in the final installed condition.

2-17.3 Seismic Demands on Nonstructural Components.

In the application of ASCE 7-22 Section 13.3.1, seismic forces are to be determined using the MCE_R ground motion parameters. The force calculations found in ASCE 7-22 Equations 13.3-1 through 13.3-3 do not apply. The following procedures must be used.

[redacted] MC-1 Components.

Forces for MC-1 components are to be determined by response spectrum analysis or equivalent static analysis, using as input the in-structure response spectra determined in accordance with Section 2-17.4.4. MC-1 components and their supports must remain elastic. MC-1 component forces are to be determined using Equation 2-4, with R_p for both components and supports set to 1.0.

$$F_p = \frac{a_{ip} W_p}{R_p} \qquad \textbf{(Equation 2-4)}$$

Where:
F_p = seismic design force centered at the component’s center of gravity and distributed according to the component’s mass distribution
a_{ip} = component spectral acceleration in a given direction, at the fundamental period of the component

W_p = component operating weight
R_p = component response modification factor

[redacted] MC-2 Components.

Forces for MC-2 components are to be determined by response spectrum analysis or equivalent static analysis, using as input the in-structure response spectra developed in accordance with Section 2-17.4.4. MC-2 component supports must remain elastic, while limited inelasticity in component response is permitted. MC-2 component forces are to be determined using Equation 2-4, with R_p for supports set to 1.0, and R_p for components as specified in Tables 2-2 and 2-3.

[C] 2-17.3.1.1 and 2-17.3.1.2 MC-1 and MC-2 Components

Major changes are made in ASCE 7-22 in the provisions for determining seismic forces in nonstructural components. One item in this revision is that the Component Response Modification Factor, R_p, is no longer there; a Component Strength Factor, R_{po} appears in its place. The primary difference between these two factors is, while R_p accounted for component ductility and overstrength, R_{po} accounts for only the component overstrength. Component ductility is now incorporated into another new parameter C_{AR} (Component Resonance Ductility Factor), which takes the place of the old a_p parameter.

In other words, in Equation 2-4, R_p cannot simply be replaced by R_{po} because then the effect of component ductility would be lost. At the same time, the new parameter C_{AR} cannot be included in Equation 2-4 either, because it also incorporates dynamic amplification of the component, which is already captured by a_{ip} in the equation.

In view of the above, it was decided to preserve the old R_p parameter in Equation 2-4 and to reproduce its values from ASCE 7-16 Tables 13.5-1 and 13.6-1 in this UFC in Tables 2-2 and 2-3, respectively. These R_p values have been a part of ASCE 7 for a long time, and should be satisfactory for the purpose of this UFC.

Note that while reproducing ASCE 7-16 Table 13.5-1 as Table 2-2, any reference to component connections or attachments have been deleted. This is because this section requires R_p for supports to be set to 1.0.

[redacted] NMC Components.

ASCE 7-22 Equation 13.3-7 must be used for NMC component force calculations. The peak in-structure floor acceleration determined in accordance with Section 2-17.4.4 is to be substituted for the term a_i, the acceleration at level i. Inelastic deformations are permitted in both component and support response. In applying ASCE 7-22 Equation 13.3-7, the values of C_{AR} and R_{po} specified in ASCE 7-22 Tables 13.5-1 and 13.6-1 are to be used. The component importance factor, I_p, is required for force calculations in ASCE 7-22 Equation 13.3-7. I_p is to be taken as 1.0, in lieu of the importance factors listed in ASCE 7-22 Sections 13.1.3.

Table 2-2 R_p Values for MC-2 Architectural Components

Architectural Component	R_p
Interior nonstructural walls and partitions	2½
Cantilever elements (unbraced or braced to structural frame below its center of mass)	
Parapets and cantilever interior nonstructural walls	2½
Chimneys where laterally braced or supported by the structural frame	2½
Cantilever elements (braced to structural frame above its center of mass)	
Parapets	2½
Chimneys	2½
Exterior nonstructural walls	2½
Exterior nonstructural wall elements	
Wall element	2½
Veneer	
Limited deformability elements	2½
Low-deformability elements	1½
Penthouses (except where framed by an extension of the building frame)	3½
Ceilings	
All	2½
Cabinets	
Permanent floor-supported storage cabinets more than 6 ft (1,829 mm) tall, including contents	2½
Permanent floor-supported library shelving, book stacks, and bookshelves more than 6 ft (1,829 mm) tall, including contents	2½
Laboratory equipment	2½
Access floors	
Special access floors (designed in accordance with Section 13.5.7.2)	2½
All other	1½
Appendages and ornamentations	2½
Signs and Billboards	3
Other rigid components	
High-deformability elements	3½
Limited-deformability elements	2½
Low-deformability materials	1½
Other flexible components	
High-deformability elements	3½
Limited-deformability elements	2½
Low-deformability materials	1½
Egress stairs and ramp fasteners	2½

Table 2-3 R_p Values for MC-2 Mechanical and Electrical Components

Components	R_p
MECHANICAL AND ELECTRICAL COMPONENTS	
Air-side HVACR, fans, air handlers, air conditioning units, cabinet heaters, air distribution boxes, and other mechanical components constructed of sheet metal framing	6
Wet-side HVACR, boilers, furnaces, atmospheric tanks and bins, chillers, water heaters, heat exchangers, evaporators, air separators, manufacturing or process equipment, and other mechanical components constructed of high-deformability materials	2½
Air coolers (fin fans), air-cooled heat exchangers, condensing units, dry coolers, remote radiators and other mechanical components elevated on integral structural steel or sheet metal supports	3
Engines, turbines, pumps, compressors, and pressure vessels not supported on skirts and not within the scope of Chapter 15	2½
Skirt-supported pressure vessels not within the scope of Chapter 15	2½
Elevator and escalator components	2½
Generators, batteries, inverters, motors, transformers, and other electrical components constructed of high-deformability materials	2½
Motor control centers, panel boards, switch gear, instrumentation cabinets, and other components constructed of sheet metal framing	6
Communication equipment, computers, instrumentation, and controls	2½
Roof-mounted stacks, cooling and electrical towers laterally braced below their center of mass	3
Roof-mounted stacks, cooling and electrical towers laterally braced above their center of mass	2½
Lighting fixtures	1½
Other mechanical or electrical components	1½
VIBRATION-ISOLATED COMPONENTS AND SYSTEMS	
Components and systems isolated using neoprene elements and neoprene isolated floors with built-in or separate elastomeric snubbing devices or resilient perimeter stops	2½
Spring-isolated components and systems and vibration-isolated floors closely restrained using built-in or separate elastomeric snubbing devices or resilient perimeter stops	2
Internally isolated components and systems	2
Suspended vibration-isolated equipment including in-line duct devices and suspended internally isolated components	2½
DISTRIBUTION SYSTEMS	
Piping in accordance with ASME B31 (2001, 2002, 2008, and 2010), including in-line components with joints made by welding or brazing	12
Piping in accordance with ASME B31, including in-line components, constructed of high- or limited-deformability materials, with joints made by threading, bonding, compression couplings, or grooved couplings	6
Piping and tubing not in accordance with ASME B31, including in-line components, constructed of high-deformability materials, with joints made by welding or brazing	9

Components	R_p
Piping and tubing not in accordance with ASME B31, including in-line components, constructed of high- or limited-deformability materials, with joints made by threading, bonding, compression couplings, or grooved couplings	4½
Piping and tubing constructed of low-deformability materials, such as cast iron, glass, and nonductile plastics	3
Ductwork, including in-line components, constructed of high-deformability materials, with joints made by welding or brazing	9
Ductwork, including in-line components, constructed of high- or limited-deformability materials with joints made by means other than welding or brazing	6
Ductwork, including in-line components, constructed of low-deformability materials, such as cast iron, glass, and nonductile plastics	3
Electrical conduit and cable trays	6
Bus ducts	2½
Plumbing	2½
Pneumatic tube transport systems	6

2-17.4 Response Analysis Procedures for Architectural, Mechanical, and Electrical Components.

2-17.4.1 General.

ASCE 4-16, *Seismic Analysis of Safety-Related Nuclear Structures*, is to serve as a reference in response analysis.

2-17.4.2 Dynamic Coupling Effects.

It is anticipated that installed mechanical and electrical systems may require significant secondary structural systems in RC V buildings. The provisions of ASCE 4-16 Section 3.7, *Dynamic Coupling Criteria*, apply.

2-17.4.3 Modeling Flooring Systems.

Structures with rigid flooring systems are to be modeled in accordance with the provisions of ASCE 4-16 Section 3.8.1.1, *Structures with Rigid Floor Diaphragms*. Structures with flexible flooring systems are to be modeled in accordance with the provisions of ASCE 4-16 Section 3.8.1.2, *Structures with Flexible Floor Diaphragms*.

2-17.4.4 In-structure Response Spectra.

Provisions of ASCE 4-16 Section 6, *Input for Subsystem Analysis*, apply for the construction of in-structure response spectra needed for the determination of accelerations and displacements for installed architectural, mechanical, and electrical components. In-structure response spectra must be developed from models of primary structures subjected to MCE_R ground motions. Frequency interval of the response spectra is to be set based on ASCE 4-16 Section 6.2.2. However, the lower-bound frequency is to be set at 0.1 Hz. Increments above 34 Hz are to be at 3 Hz and increments below 0.5 Hz are to be at 0.10 Hz.

Exception: In the application of ASCE 4-16 Section 6, those provisions that relate to spectra-to-spectra analysis in Section 6.2.1.2 do not apply.

2-17.5 Design of Architectural Components.

2-17.5.1 Suspended Ceilings.

In addition to the provisions of ASCE 7-22, as modified by UFC 3-301-01, suspended ceilings are to be designed to resist seismic effects using a rigid bracing system, where the braces are capable of resisting tension and compression forces, or diagonal splay wires, where the wires are installed taut. Particular attention should be given in walk-down inspections (see Section 2-18.4) to ensure splay wires are taut. Positive attachment is required to be provided to prevent vertical movement of ceiling elements. Vertical support elements need to be capable of resisting both compressive and tensile forces. Vertical supports and braces designed for compression must have a slenderness ratio, Kl/r, of less than 200. Additional guidance on suspended ceiling design is provided in Section C-2.2.8 of UFC 3-301-01.

2-17.6 Design of Mechanical and Electrical Components.

2-17.6.1 Seismic Controls for Elevators.

For buildings that are assigned to RC V, seismic switches are not permitted to be used. Elevator system design for RC V buildings must ensure elevator operability at accelerations computed from building response analysis. Additional guidance on the design of elevator systems is found in Section C-3.3 of UFC 3-301-01.

2-17.7 Component Qualification Documentation and Operations & Maintenance (O&M) Manual.

All MC-1 and MC-2 equipment qualification documentation as outlined in Section 2-17.2.5 must be maintained in a file identified as “Mission Critical Components and Equipment Qualifications Manual” that is to be a part of the Operations & Maintenance Manual that is turned over to the Authority Having Jurisdiction. The project specifications should require the Operations & Maintenance Manual to state that replaced or modified components need to be qualified per the original qualification criteria.

2-17.8 Component Identification Nameplate.

All MC-1 and MC-2 equipment must bear permanent marking or nameplates constructed of a durable heat and water resistant material. Nameplates must be mechanically attached to all nonstructural components and placed on the component for clear identification. The nameplate must not be less than 5" x 7" with red letters 1" in height on a white background stating MC-1 or MC-2 as appropriate. The following statement must be on the nameplate: “This equipment/component is Mission Critical. No modifications are allowed unless authorized in advance and documented in the Mission Critical Equipment Qualifications Manual.” The nameplate must also contain the component identification number in accordance with the drawings/specifications and the O&M manuals. Continuous piping, and conduits must be similarly marked as specified in the contract documents.

2-18 SPECIAL INSPECTIONS AND TESTS.

2-18.1 General.

2024 IBC Chapter 17, as modified by UFC 1-200-01 and UFC 3-301-01, applies to RC V structures.

2-18.2 Structural Observations for Structures.

Replace the text of IBC Section 1704.6.1 with the following:

Structural observations must be provided for RC V structures.

2-18.3 Special Inspections for Seismic Resistance.

Replace the existing text in 2024 IBC Section 1705.13 with the following:

Special Inspections itemized in Sections 1705.13.1 through 1705.13.9 apply to structures assigned to Risk Category V.

2-18.4 Plumbing, Mechanical and Electrical Components.

Add the following before the existing text in 2024 IBC Section 1705.13.6:

Special inspection and verification are required for Designated Seismic Systems and must be performed as required by the Statement of Special Inspections, and the Schedule of Special Inspections, which must be prepared for each project. Templates for these documents may be downloaded from the following link, under “Related Materials”:

https://www.wbdg.org/dod/ufgs/ufgs-01-45-35

The SER must prepare a Statement of Special Inspections in accordance with 2024 IBC Section 1704 for the Designated Seismic Systems.

The Statement of Special Inspections is required to define the periodic walk-down inspections that must be performed to ensure that the nonstructural elements satisfy life safety mounting requirements. The walk-down inspections must be performed by design professionals who are familiar with the construction and installation of mechanical and electrical components, and their vulnerabilities to earthquakes. The selection of the design professional is subject to the approval of the SER.

Designated Seismic Systems require a final walk-down inspection by the SER and by the Nonstructural Component Design Reviewer (see Section 2-1.2). The final review must be documented in a report. The final report prepared by the SER needs to include the following:

1. Record/observations of final site visit
2. Documentation that all required inspections were performed in accordance with the Statement of Special Inspections.
3. Documentation that the Designated Seismic Systems were installed in accordance with the construction documents and inspected in accordance with the requirements of 2024 IBC Chapter 17, as modified by this UFC.

2-18.5 Testing for Seismic Resistance.

Add the following before the first paragraph in 2024 IBC Section 1705.14:

Any requirements for structural testing for structures assigned to Seismic Design Category C or higher also apply to structures assigned to Risk Category V.

2-19 SOILS AND FOUNDATIONS.

Such provisions of 2024 IBC Chapter 18 as are consistent with the foundation remaining elastic apply to RC V structures, [except that the minimum Chapter 18 provisions applied are to be those required for SDC D structures]. In addition, the requirement in the following paragraph applies.

2-19.1 Foundation Uplift and Rocking.

The requirement for elastic response of these RC V structures may lead to the existence of significant overturning forces in the structural system, and accompanying foundation element uplift forces or rocking. The SER is to be responsible for evaluating foundation overturning and rocking in the analysis and design, and this evaluation must be reviewed by the Structural Design Reviewer (see Section 2-1.1).

APPENDIX A REFERENCES

UNIFIED FACILITIES CRITERIA

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

UFC 1-200-01, *DoD Building Code*

UFC 3-301-01, *Structural Engineering*

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

UFC 4-023-03, *Design of Buildings to Resist Progressive Collapse*

AMERICAN CONCRETE INSTITUTE

https://www.concrete.org/

ACI CODE-318, *Building Code Requirements for Structural Concrete and Commentary*

AMERICAN INSTITUTE OF STEEL CONSTRUCTION

https://www.aisc.org/

AISC 360, *Specification for Structural Steel Buildings*

AMERICAN SOCIETY OF CIVIL ENGINEERS

https://www.asce.org/

ASCE/SEI 7, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*

ASCE/SEI 43, *Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities*

ASCE/SEI 4, *Seismic Analysis of Safety-Related Nuclear Structures*

COLD REGIONS RESEARCH AND ENGINEERING LABORATORY

https://www.erdc.usace.army.mil/Locations/CRREL/

Database and Methodology for Conducting Site Specific Snow Load Case Studies for the United States, Tobiasson, W., Greatorex, A., Snow Engineering: Recent Advances, Izumi, Nakamura & Sack (eds), Balkema, Rotterdam, 1997.

ERDC/CRREL SR-20-1*, Site-Specific Case Studies for Determining Ground Snow Loads in the United States*, Buska, J., Greatorex, A., and Tobiasson, W., The U.S.

Army Engineer Research and Development Center (ERDC), Cold Regions Research and Engineering Laboratory (CRREL), Hanover, NH, 2020.

EARTHQUAKE ENGINEERING RESEARCH INSTITUTE

https://www.eeri.org/

Gulerce, Z. and Abrahamson, N. A., *Site-Specific Design Spectra for Vertical Ground Motion*, Earthquake Spectra, V. 27, No. 4, 2011

INTERNATIONAL CODE COUNCIL

https://www.iccsafe.org/

International Building Code

PRECAST/PRESTRESSED CONCRETE INSTITUTE

https://www.pci.org/

PCI MNL-120, *PCI Design Handbook*

PCI MNL-140, *Seismic Design of Precast/Prestressed Concrete Structures*

THE MASONRY SOCIETY

https://masonrysociety.org/

The Masonry Society (TMS), TMS 402-22/ACI 530-22/ASCE 5-22, TMS 602-22/ACI 530.1-22/ASCE 6-22, *Building Code Requirements and Specification for Masonry Structures*

UFC 3-310-08
17 July 2018

UNIFIED FACILITIES CRITERIA (UFC)

NON-EXPEDITIONARY BRIDGE INSPECTION, MAINTENANCE, AND REPAIR

UNIFIED FACILITIES CRITERIA (UFC)

NON-EXPEDITIONARY BRIDGE INSPECTION, MAINTENANCE, AND REPAIR

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER CENTER (Preparing Activity)

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

Change No.	Date	Location

This UFC supersedes UFC 3-310-08, *Non-Expeditionary Bridge Inspection, Maintenance, and Repair*, dated 16 August 2010.

FOREWORD

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

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and the Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Military Departments, the Defense Agencies, and DOD Field Activities should contact the preparing Service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DOD working group. Recommended changes with supporting rationale should be sent to the respective Service proponent office by the following electronic form: Criteria Change Request. The form is also accessible from the Internet site listed below.

- UFC are effective upon issuance and are distributed only in electronic media from the following source: Whole Building Design Guide web site http://dod.wbdg.org/.

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

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UNIFIED FACILITIES CRITERIA (UFC)
REVISION SUMMARY SHEET

Document: UFC 3-310-08, *Non-Expeditionary Bridge Inspection, Maintenance, and Repair*

Superseding: UFC 3-310-08, *Non-Expeditionary Bridge Inspection, Maintenance, and Repair,* dated 16 August 2010

Description: This document provides guidance to ensure military garrison/base bridges remain safely in operation and behave reliably for civilian and military traffic.

Reasons for Document:

- Purpose: To ensure that military installation bridges remain safely in operation and perform reliably for civilian and military traffic. The bridges inspected, operated, and maintained by military agencies should meet or exceed the same standards to which bridges under U.S. civilian jurisdiction are subject.

- Application: This UFC provides direction so all military installation bridges are appropriately inspected and the results reported in accordance with current federal standards, Federal Highway Administration (FHWA) criteria, and Federal Railway Administration (FRA) criteria. This UFC also provides direction to ensure all military installation bridges are maintained and repaired in a consistent manner and in accordance with industry standards.

Impact:

The publication of UFC 3-310-08 will not result in any increased cost to the Services. Each Service is already in compliance with the National Bridge Inspection Standards (NBIS) and the reporting requirements directed by the Code of Federal Regulations, Title 23, Part 650, Subpart C, and Title 49, Subtitle B, Chapter II, Part 237. The provisions in this UFC are already being accomplished by each Service as directed by separate Service documents (Army ER 1110-2111, Air Force ETL 07-5 [superseded by this UFC], and Navy UG-60020-OCN).

Unification Issues:

Not applicable; all agencies affected by this UFC are subject to the same requirements.

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CHAPTER 1 INTRODUCTION

1-1 BACKGROUND.

In an effort to develop a coherent and consistent Department of Defense (DOD) policy for the inspection, evaluation, maintenance, and repair of installation bridges, this UFC was created to consolidate evolving federal bridge inspection and industry standards. As federal and state regulations, standards, guidelines, and procedures continually change, it is critical to remain current with the industry and update this UFC to ensure compliance with all bridge inspection, evaluation, load rating, maintenance, and repair requirements.

1-2 PURPOSE.

This UFC defines requirements for inspection, maintenance, and repair of bridges on military installations in accordance with current federal and industry standards. In particular, highway bridges must conform to Federal Highway Administration (FHWA) criteria (23 CFR 650 Subpart C) while railroad bridges must conform to Federal Railroad Administration (FRA) criteria (49 CFR 237). The purpose of these requirements is to ensure military installation bridges can safely and reliably carry civilian and military traffic. All bridges inspected, operated, and maintained by military agencies should meet or exceed the same standards to which bridges under U.S. civilian jurisdiction are subject.

1-3 SCOPE.

This UFC applies to all military installation bridges, whether located in the contiguous United States (CONUS) or outside the contiguous United States (OCONUS), including Alaska, Hawaii, U.S. territories and possessions, and foreign territories. Installation bridges can be classified according to the type of traffic “over” the bridge as 1) highway bridges, 2) railroad bridges, 3) pedestrian bridges, 4) golf cart bridges, or 5) taxiway bridges. This UFC does not apply to expeditionary bridges located in military theaters of operation. This UFC does not apply to Army Corps of Engineers civil works bridges located outside of an installation.

1-4 REFERENCES.

Appendix A contains a list of references used in this UFC.

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CHAPTER 2 DOD BRIDGE INSPECTION AND MANAGEMENT PROGRAM

This chapter provides technical requirements for a bridge inspection and management program. Refer to the appropriate sections in this UFC for inspection, load rating, reporting, maintenance, and repair requirements for each type of bridge.

2-1 ORGANIZATIONAL STRUCTURE – RESPONSIBILITIES AND QUALIFICATIONS.

The U.S. Code of Federal Regulations (23 CFR 650.305 and 49 CFR 237) requires each Military Department to establish and maintain a bridge inspection and management program. At the head of each program is a National Bridge Program Manager who enforces the bridge program in accordance with the Military Department's policies.

Point of contact information for each Military Department's bridge program is found in Appendix B, paragraph B-3.

The credentials, qualifications, and responsibilities of the key bridge program positions are described below. The fulfillment of these duties can be accomplished using in-house personnel, contracted personnel, or personnel from another government agency.

2-1.1 National Bridge Program Manager.

The National Bridge Program Manager for each Military Department provides overall leadership and inspection guidance for every bridge in the Department's bridge inventory (CONUS and OCONUS). The National Bridge Program Manager must successfully complete an FHWA-approved comprehensive bridge inspection training course followed by an FHWA-approved refresher training course every subsequent five years. Also, the National Bridge Program Manager must either be a licensed professional engineer (P.E.) or have 10 years of bridge inspection experience. The National Bridge Program Manager should have a general understanding of all aspects of bridge engineering, including design, load rating, new construction, rehabilitation, inspection or condition evaluation, and maintenance.

Refer to Appendix B, paragraph B-10, Table B-4, for delineation of responsibilities between the National Bridge Program Manager and Installation Bridge Managers for each Military Department.

2-1.2 Installation Bridge Manager.

An Installation Bridge Manager typically carries out responsibilities delegated from the National Bridge Program Manager at a specific military installation as delineated in Appendix B, paragraph B-10, Table B-4. The Installation Bridge Manager must have completed an FHWA-approved comprehensive bridge inspection training course and must complete an FHWA-approved refresher training course every five years after completing the FHWA-approved comprehensive training course.

2-1.3 Load Rating Engineer.

As required by 23 CFR 650.309(c), each Military Department must designate a Load Rating Engineer who will be responsible for ensuring load ratings are performed as specified in this UFC. The individual responsible for load rating calculations or determining a load rating by engineering judgment must be a P.E.

For railroad bridges falling under the jurisdiction of the FRA bridge safety standards, 49 CFR 237, the Load Rating Engineer must also meet the requirements of 49 CFR 237.51 and be designated as a Railroad Bridge Engineer.

2-1.4 Railroad Bridge Engineer.

Railroad bridge inspection, maintenance, and load rating functions must be performed under the direction of a Railroad Bridge Engineer. A Railroad Bridge Engineer is a person determined by the track owner to be competent to perform the functions identified in 49 CFR 237.51(a). These functions include determining forces and stresses in railroad bridges and bridge components, prescribing safe loading conditions for railroad bridges, prescribing inspection and maintenance procedures for railroad bridges, and designing repairs and modifications to railroad bridges.

A Railroad Bridge Engineer must meet the educational qualifications as specified in 49 CFR 237.51(b), including either an engineering degree from an accredited program or current registration as a P.E.

2-1.5 Railroad Bridge Inspector.

A Railroad Bridge Inspector must meet the requirements specified in 49 CFR 237.53.

2-1.6 Inspection Team Leader (Highway Bridges).

The Inspection Team Leader must meet the requirements specified in 23 CFR 650.305. Inspection Team Leaders must complete an FHWA-approved refresher training course every five years after completing the FHWA-approved comprehensive training course.

2-1.7 Underwater Bridge Inspector.

The underwater bridge inspection diver must have a commercial diver certification. Diver training certification must conform to Section 30.A.06 of Army Engineering Manual (EM) 385-1-1, *Safety and Health Requirements*. An underwater bridge inspection diver who does not meet the qualifications of paragraph 2-1.6 must have completed an FHWA-approved comprehensive bridge inspection training course or other FHWA-approved underwater bridge inspection training course. Underwater Bridge Inspection Team Leader requirements are the same as those listed in paragraph 2-1.6. All underwater inspections will be under the direct supervision of a qualified Inspection Team Leader with underwater inspection experience.

Underwater inspector qualifications must meet host country underwater diver qualifications in addition to the requirements of the National Bridge Inspection Standards (NBIS) and with the approval of the National Bridge Program Manager.

2-1.8 Hydraulic Bridge Engineer.

Hydraulic Bridge Engineers performing scour calculations must be licensed P.E.s and have relevant work experience in bridge hydraulic modeling and scour evaluations.

2-2 BRIDGE INVENTORY DATA REQUIREMENTS.

2-2.1 Components of Bridge File.

Complete, accurate, and current bridge records must be maintained in a bridge file for each National Bridge Inventory (NBI) highway bridge in accordance with AASHTO MBE-2-M, *The Manual for Bridge Evaluation*, Section 2. It is recommended that bridge files for all other bridges follow this format. The bridge file provides a full history of the structure, including construction drawings, as-built drawings, photographs, damage, repairs, and capacity calculations. At a minimum, significant bridge file components that must be maintained include:

- Inspection reports
- Waterway information (channel cross-sections, soundings, stream profiles)
- Significant correspondence
- Special inspection procedures or requirements
- Load rating documentation, including load testing results
- Posting documentation
- Critical findings and actions taken
- Scour assessment
- Scour plan of action (POA) for scour critical bridges and those with unknown foundations and documentation of post-event inspection or follow-up
- Inventory and evaluation data and collection/verification forms.

Refer to Section 2 of AASHTO MBE-2-M, *The Manual for Bridge Evaluation*; 49 CFR 237.33; and FHWA-PD-96-001, *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges*, for additional information regarding bridge files.

2-2.2 File Retention/Data Storage.

File retention and organization policies will be determined by the National Bridge Program Manager. Each Military Department's National Bridge Program Manager will determine the storage location in accordance with Section 2 of AASHTO MBE-2-M.

Bridge files must be readily accessible to the Installation Bridge Manager. It is highly recommended that hard copies of inspection reports and load ratings be maintained for two full inspection cycles (typically 48 months). Electronic copies of components of the bridge file, inspection reports, and load ratings will be maintained in perpetuity, along with bridge inventory database information. If components of the bridge file are found to be deficient or incomplete, a plan of corrective action will be developed to remedy future recordkeeping procedures.

2-3 QUALITY CONTROL/QUALITY ASSURANCE REQUIREMENTS.

The National Bridge Program Manager will determine the specific procedures for quality control (QC) and quality assurance (QA) reviews. At a minimum, 5 percent of bridge inspection teams and 5 percent of the inspected bridges will be audited annually in some manner (e.g., through field reviews of inspection teams or office reviews of inspection reports). FHWA *Bridge Inspector's Reference Manual* (BIRM), Topic 1.3.4, discusses the FHWA-recommended QC/QA framework.

As part of the QC/QA framework, the bridge management program will identify QC and QA responsibilities.

Once established, QC/QA procedures for each agency must be compiled in a manual that is readily available to all personnel involved with bridge inspection; this manual will be updated to reflect any procedural changes.

CHAPTER 3 HIGHWAY BRIDGES

3-1 DEFINITIONS.

3-1.1 Highway.

A “highway” is defined by 23 U.S.C. 101(a)(11) as follows:

> *(11) Highway. - The term "highway" includes –*
>
> *(A) a road, street, and parkway;*
>
> *(B) a right-of-way, bridge, railroad-highway crossing, tunnel, drainage structure including public roads on dams, sign, guardrail, and protective structure, in connection with a highway.*

Therefore, all roads on military installations are considered to be “highways.”

3-1.2 Public Road.

A “public road**”** is defined by 23 U.S.C. 101(a)(21) as follows:

> *(21) Public road. - The term "public road" means any road or street under the jurisdiction of and maintained by a public authority and open to public travel.*

Since roads on military installations are typically accessible to military personnel, government civilians, contractor personnel, and retired personnel, all road bridges on military installations are deemed to be public highway bridges regardless of the bridge’s access restrictions unless the Installation Commander designates otherwise (with the Military Department’s National Bridge Program Manager’s approval). Non-public designations will be avoided unless warranted by special circumstances.

3-1.3 Bridge.

A “bridge” is defined in 23 CFR 650.305 as follows:

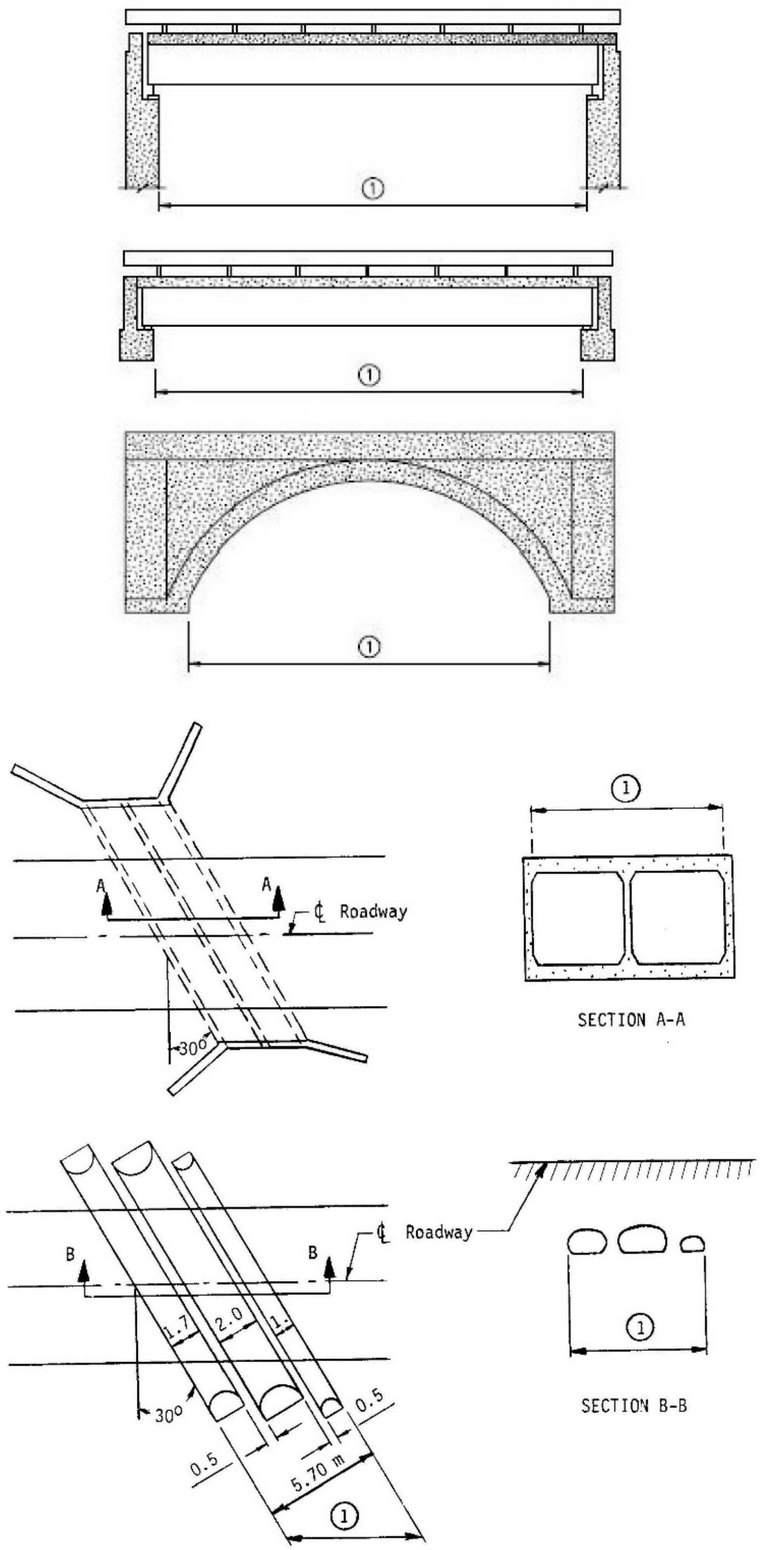
> *“A structure including supports erected over a depression or an obstruction, such as water, highway, or railway, and having a track or passageway for carrying traffic or other moving loads, and having an opening measured along the center of the roadway of more than 20 feet (6.1 meters) between undercopings of abutments or spring lines of arches, or extreme ends of openings for multiple boxes; it may also include multiple pipes, where the clear distance between openings is less than half of the smaller contiguous opening.”*

The method to measure bridge length is depicted in Figure 3-1 as taken from FHWA-PD-96-001.

The NBIS apply to installation highway bridges (in U.S. states and territories) that meet the length requirement above. Highway bridges that meet the length requirements specified in the NBIS are required to be included in the NBI. Requirements for installation bridges in foreign territories have similar requirements, as described in paragraph 3-3.2.

Culverts also qualify as bridges if the preceding definition applies. Culverts that do not meet the preceding definition may be managed similarly to other installation drainage structures.

Figure 3-1 NBIS Bridge Length



① Item 112 ~ NBIS Bridge Length

3-1.4 Strategic Highway Corridor Network (STRAHNET)

FHWA-PD-96-001 defines the Strategic Highway Corridor Network (STRAHNET) and connectors as a system of highways that are strategically important to the defense of the United States. There are no STRAHNET highways or connectors carried by bridges on military installations. For situations where an installation owns a bridge over a STRAHNET highway or connector, refer to the description of item 5A in FHWA-PD-96-001 for coding instructions.

3-2 NATIONAL BRIDGE INVENTORY (NBI) HIGHWAY BRIDGES.

All NBI highway bridges must be inspected in accordance with the NBIS. These standards establish minimum federal requirements for inspection procedures, inspection intervals, personnel qualifications, inspection reports, and bridge inventory records. Although not reproduced verbatim in this UFC, the standards are listed in Appendix A as a reference. The NBIS should be consulted whenever a question arises regarding federal inspection requirements.

The FHWA has developed 23 metrics for the oversight of the National Bridge Inspection Program. Agencies and installations must take the necessary steps to remain compliant with the NBIS as determined by FHWA and the 23 metrics. Refer to FHWA *Metrics for the Oversight of the National Bridge Inspection Program* for additional information.

3-2.1 History of the NBIS Program.

Several catastrophic bridge failures since 1967 have led to the creation of and modifications to federal laws that constitute the FHWA-managed NBIS. The NBIS provides requirements for inspecting highway bridges and reporting bridge conditions annually in the NBI database. The procedures to implement the NBIS requirements are explained in the BIRM. For a more comprehensive history of the National Bridge Inspection Program, refer to the BIRM, Chapter 1.

3-2.2 Bridge Inspection Requirements.

3-2.2.1 Inspection Types and Interval.

Bridge inspections are conducted to determine the physical condition of the structure, to develop the basis for load rating analyses, to assess the need for maintenance, and to track the functional condition and rate of deterioration over time. There are seven inspection types requiring unique levels of effort: initial/inventory, routine, damage, in-depth, fracture critical, underwater, and special.

Descriptions of and the required inspection intervals for each type of inspection are specified below. The inspection intervals may be altered but must meet all applicable NBIS criteria. See Appendix B, paragraph B-2, for inspection interval alteration procedures. Late inspections require a justification of unusual circumstances (e.g., natural disaster, ongoing bridge construction activity) and will be included in the bridge file.

3-2.2.1.1 Initial/Inventory Inspection.

The initial/inventory inspection is the first inspection after a bridge is built or added to the installation real property and becomes a part of the bridge file. Elements of the initial/inventory inspection will also apply when there has been a change in configuration of the structure (e.g., widening, lengthening, and supplemental bents). It is important for the inspectors to identify any existing problems or locations in the structure where potential problems may arise. An initial inspection must provide all Structure Inventory and Appraisal (SI&A) data. A thorough review of as-built plans will be conducted prior to the initial inspection and the inspector will note any fracture critical members (FCM) or details during this inspection. A Level 1 scour screening is required if the bridge crosses over a waterway. A revised or new load rating may be required with the initial inspection if the rating was not part of the construction submittal or if repairs affected the structural capacity. The initial/inventory inspection documents the baseline condition assessment of the bridge.

Initial/inventory inspections must be performed **within 90 days** of the bridge opening to traffic. New bridges must be added to the installation real property and become a part of the bridge file prior to opening to traffic.

3-2.2.1.2 Routine Inspection.

Routine inspections are regularly scheduled inspections serving to collect observations and measurements of any changes from the initial inspection or any previously conducted inspection. The routine inspection must be performed and reported in accordance with NBIS requirements.

All routine inspections will be conducted at regular intervals **not to exceed 24 months**. The National Bridge Program Manager may increase routine inspection intervals for bridges that meet the criteria for increased inspection intervals discussed in Appendix B, paragraph B-2.

3-2.2.1.3 Damage Inspection.

Damage inspections are one-time unscheduled inspections performed after environmental events or human actions such as collisions, floods, or earthquakes. Damage inspections are performed to 1) determine if structural damage has occurred, 2) evaluate the extent of any structural damage, and 3) determine the level of effort for required repairs.

Damage inspections must be performed within a reasonable time after a natural disaster or human-caused action. The inspectors must document all damaged members, measuring, at a minimum, any section loss, member misalignment, and any loss of foundation support. The inspection must provide all of the information necessary to determine if bridge closure is required or to perform an emergency load restriction.

Local installation personnel may make an initial assessment of the bridge if personnel meeting required inspector qualifications are not immediately available. The results of the initial damage assessment will be forwarded to the Installation Bridge Manager for review. Based on the information in the initial damage assessment, the Installation Bridge Manager will determine if additional resources (e.g., additional inspection, testing, load rating, design) are required to fully evaluate or correct the damaged condition. The Installation Bridge Manager or National Bridge Program Manager may recommend a follow-up in-depth inspection of the bridge to monitor the structure.

3-2.2.1.4 In-Depth Inspection.

In-depth inspections are hands-on, close-up inspections of one or more members above or below the waterline. In-depth inspections are more detailed and may require special access techniques to inspect areas not easily detectable in a routine inspection.

In-depth inspections are required every 24 months for fracture critical bridges. For other bridge types, in-depth inspections may be performed after damage or other special inspections are performed, at the direction of the Installation Bridge Manager or National Bridge Program Manager. For small bridges, the in-depth inspection includes inspection of all critical members of the structure. For large and complex structures, these inspections may be scheduled separately for defined segments of the bridge or bridge elements, connections, or details.

3-2.2.1.5 Fracture Critical Inspection.

Fracture critical inspections are detailed, hands-on inspections of steel bridges with FCMs that may include visual or other nondestructive evaluations. Prior to inspection, a thorough review of the design or as-built plans, fracture-critical inspection plan, previous inspection reports, load rating, and fatigue-prone details must be made. In the absence of plans or identification of fatigue-prone details, the inspector should be able to determine the fatigue-prone details based on the information provided in Table 6.6.1.2.3-1 of AASHTO LRFDUS-7, *LRFD Bridge Design Specifications*. FCMs require a “hands-on” inspection, where the inspector is capable of touching the area being inspected (arm’s length). Physical inspection methods may be necessary to more accurately assess the condition of an FCM. Advanced inspection methods may need to be employed, including nondestructive testing (NDT) methods. The hands-on inspection should identify and note the condition of problematic details prone to crack development.

For more information regarding inspection techniques for fracture critical bridges, refer to the BIRM or FHWA-NHI-11-015, *Fracture Critical Inspection Techniques for Steel Bridges Participant Workbook.* For additional information and case studies on fatigue damage in welded, bolted, and riveted structures, refer to FHWA *Manual for Inspecting Bridges for Fatigue Damage Conditions* and John W. Fisher’s *Fatigue and Fracture in Steel Bridges – Case Studies*.

Fracture critical inspections will be conducted at regular intervals not to exceed 24 months. In order to establish the criteria for fracture critical inspection intervals and level of effort, factors such as bridge age, fatigue-prone details, and known deficiencies will be considered.

3-2.2.1.6 Underwater Inspection.

3-2.2.1.6.1 Underwater inspections include diving to visually inspect and measure bridge components, probing for scour or undermining, and sounding to locate the bottom of the channel. The inspection must include such methods as necessary to adequately perform a condition assessment of the structure. If a bridge can be adequately inspected by wading, shallow probing, or with the use of cameras at low water conditions, a formal underwater inspection (divers) is not required. For bridges that do not require a formal underwater inspection, Item 93B on the SI&A form will not be coded. The Installation Bridge Manager will ensure inspections occur at low water conditions while maintaining compliance with the required bridge inspection schedule.

3-2.2.1.6.2 According to the BIRM, there are three levels of underwater inspection intensity:

- Level 1 – Visual, tactile inspection
- Level 2 – Detailed inspection with partial cleaning
- Level 3 – Highly detailed inspection with NDT or partially destructive testing (PDT)

3-2.2.1.6.3 Bridge inspectors must examine previous inspection reports or gather sufficient bridge and channel information to determine which level of underwater inspection is required when contracted or tasked to perform underwater inspections for specific bridges.

3-2.2.1.6.4 Level 1 inspections are required for all routine underwater inspections and will be performed within arm’s reach of the areas being inspected. Visual inspections are performed across the entire submerged structure, but, in areas of poor water clarity, a tactile sweeping motion of the hands and arms may be used to inspect the entire substructure.

3-2.2.1.6.5 Level 2 inspections include cleaning off marine or aquatic growth at critical inspection areas and inspecting high-stress, damaged, and deteriorated areas that may be shielded by the growth. Critical areas near the low waterline, mudline, and midway between will be inspected. Piers and abutments will have at least 1 square foot (0.09 square meter) cleaned at three or more levels on each face. For structures greater than 50 feet (15.2 meters) in length, an additional three levels will be cleaned at each exposed face. For piles, horizontal bands a minimum of 10 inches (254 millimeters) long will be cleaned along the following locations:

- Rectangular – At least three sides
- Octagonal – At least six sides
- Round – At least 75 percent of circumference
- H-pile – At least the outside faces of flanges and one side of web

3-2.2.1.6.6 Level 2 inspection is recommended for 10 percent of all underwater elements.

3-2.2.1.6.7 Level 3 inspections include the complete cleaning of a structural element and NDT or PDT. Detailed measurements will be made along with testing techniques such as ultrasonic, physical material sampling, or boring. These inspections are generally performed when a structural repair or possible replacement is being considered.

3-2.2.1.6.8 Level 3 inspections are recommended for members that require repair or rehabilitation.

3-2.2.1.6.9 For additional information, it may be helpful to review FHWA-NHI-10-027, *Underwater Bridge Inspection*. This report contains valuable information on underwater inspection techniques, underwater repair techniques, and scour issues.

3-2.2.1.6.10 Underwater inspections must be completed at regular intervals not to exceed 60 months. The Installation Bridge Manager may decrease the interval of underwater inspections based on Level 1 or Level 2 scour evaluations, evidence of substructure movement, stream migration, bank sloughing, or debris buildup. Any deviation in the underwater inspection interval must be documented in the bridge file. FHWA-NHI-10-027 provides guidance for alterations to underwater inspection intervals.

3-2.2.1.7 Special Inspection.

Special inspections monitor a known member deficiency or other conditions that warrant special attention, such as foundation settlement or scour, fatigue damage, severe section loss, critical findings, or the public's use of a load posted bridge. These inspections are not usually comprehensive enough to meet NBIS requirements for routine inspections.

Based on the recommendations in the inspection reports, the Installation Bridge Manager will determine when special inspections are required. Special inspections are scheduled based on the severity of the deficiency/condition being monitored and the anticipated rate of continued deterioration (i.e., special inspections for scour should be performed after high-water events; special inspections for section loss should be at three-, six-, or twelve-month intervals, based on the severity of deterioration and its effect on the bridge's safe load capacity).

For bridges that do not require a formal special inspection, Items 92C and 93C on the SI&A form will not be coded. For bridges where items 92C and 93C are coded, a separate report for this inspection is required. If the inspection is conducted in conjunction with other inspections, the scope, procedures, findings, and recommendations must be recorded in a separate paragraph in the bridge inspection report.

3-2.2.2 Inspection Procedures.

Each bridge must be inspected in accordance with 23 CFR 650. Guidance on various bridge inspection procedures is provided in the BIRM and AASHTO MBE-2-M. A minimum of one qualified team leader must be present at all times during initial, routine, in-depth, FCM, and underwater inspections.

3-2.3 Load Rating and Posting Requirements.

For new bridge design, load rating calculations must be a contract deliverable. Load ratings will be performed during all initial inspections or when no previous load rating exists. During routine, in-depth, fracture critical, underwater, or special inspections, any changed conditions identified that may alter the load rating will be forwarded to the Load Rating Engineer for review. If damage, deterioration, or structure alterations noted during the inspection are determined by the Load Rating Engineer to be significant, an updated load rating will be performed and load restriction may be required.

The load rating report must clearly state basic information about the bridge (e.g., configuration, material type, age), method of analysis, references, and all assumptions used to establish a valid load rating.

3-2.3.1 AASHTO Load Ratings.

Load rating must be performed for all roadway bridges that meet the NBIS definition of a bridge (over 20 feet [6.1 meters] measured along the centerline of the roadway). The load rating must be calculated in accordance with AASHTO MBE-2-M. For highway bridges on an installation in foreign territory, if the foreign country's bridge code is more stringent than AASHTO, the foreign bridge code will govern the load rating. Posting of bridges (including the specific sign) for civilian vehicles, when determined to be necessary from the load rating, will be in accordance with local requirements (typically, state legal load limits or the foreign code legal load limits); see Appendix B, paragraph B-4, for state posting loads. Highway bridges must have load ratings for special hauling vehicles (SHV) per FHWA's *Load Rating of Specialized Hauling Vehicles* Memorandum. All NBI bridges must have valid load rating calculations in the bridge file.

3-2.3.2 Military Load Classification (MLC) Load Ratings.

All installation highways that have or will have military tactical vehicles traveling on them must have military load classification (MLC) load ratings on file for the bridges. The MLC is determined using the procedures in AASHTO MBE-2-M, with the live loads shown in Appendix B, paragraph B-1. MLC methods in Army Field Manuals and Training Aids are not permitted. Appropriate MLC signs must be placed at both ends of the bridge; this must be done for all vehicular bridges requiring a load rating (i.e., all roadway bridges over 20 feet [6.1 meters] long). If an installation or roadway is deemed as "administrative" only, with no military vehicle usage, the Installation Bridge Manager may waive, at the approval of the National Bridge Program Manager, the MLC load rating requirement for the bridge. Posting of "No Tactical Vehicles on Bridge" may be required. Additionally, MLC is determined for military tactical vehicle use of the bridge only; it is not considered part of the load rating information submitted to FHWA.

3-2.3.3 Limited Information Bridges.

Bridges with limited as-built information (i.e., no design drawings or calculations) must be rated based on as-inspected field measurements and/or the procedures in Section 6.1.4 of AASHTO MBE-2-M. When material sampling from the structure is not possible, refer to the current version of AASHTO MBE-2-M for material specifications based on the approximate year of construction. The load rating report must clearly state basic information about the bridge (e.g., configuration, material type, age), method of analysis, references, and all assumptions used to establish a valid load rating. In the absence of previous design, as-built, or shop drawings, it is recommended to field-measure all member dimensions necessary to establish as-built properties for the load rating analysis.

Inventory and operating level ratings may be assigned based on design loading, given the bridge meets the requirements of the FHWA memorandum, *Action: Assigned Load Ratings*, dated September 29, 2011.

3-2.3.4 Load Posting of Bridges.

Bridges where the load rating determines that the safe load-carrying capacity is below statutory (most often the state or host nation) levels will be posted for a load restriction. The maximum safe load, as determined by the load rating, must be posted using signage in accordance with the FHWA *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) R12 series signs or local requirements.

Installations will install load posting signs as soon as possible—no later than 90 days after notification that posting is required. In cases where known existing loads significantly exceed the recommended posting limit or the route is of significant importance (e.g., bus routes, emergency vehicle routes), posting more quickly is important to ensure safety.

Load posting signs must be placed at the bridge for each direction of travel, as well as a minimum of 0.25 mile (0.4 kilometer) in advance of the bridge, or at the location of the nearest intersection prior to the bridge, for each direction of travel.

3-2.4 Bridge Inventory Data Requirements.

All bridge records must be maintained by the installation, including the inspection reports, plans, and follow-up actions taken to address deficiencies identified during inspections. Findings will be recorded on standardized agency forms. Complex bridges and bridges with FCMs, underwater elements, or scour critical status must be identified and given special attention according to the appropriate procedures.

An inventory of all bridges must be maintained by the Military Department with jurisdiction over those bridges. Reporting of inspection data will be per each individual agency’s policy and FHWA-PD-96-001 (and FHWA-PD-96-001’s most current Errata Sheet). Inspection data, including inventory and appraisal data (SI&A data), will be collected and maintained for all bridges that are inspected. Refer to Appendix B, paragraph B-5, for a bridge inspection reporting flowchart.

SI&A data will be entered into the agency's inventory within 90 days of the date of updating, change, or editing.

3-2.5 Deficiencies and Critical Findings.

The Installation Bridge Manager is responsible for ensuring all deficiencies identified in bridge inspection reports are addressed as soon as possible. Maintenance issues and minor repairs can be addressed immediately using in-house resources. Other deficiencies require projects to be programmed following Military Department-specific procedures. The Installation Bridge Manager is responsible for programming and providing advocacy for projects addressing identified bridge deficiencies. The Installation Bridge Manager must ensure that critical findings are addressed in accordance with the procedures described in paragraph 7-1. The Installation Bridge Manager will maintain supporting documents showing the actions taken to address all deficiencies identified in the bridge inspection reports.

3-3 NON-NBI HIGHWAY BRIDGES.

Highway bridges in foreign territories and all other highway bridges that do not meet the span length or public road requirements of the NBIS are not included in the NBI and are referred to as "Non-NBI Highway Bridges." The requirements for these bridges are described in the following paragraphs.

3-3.1 Short Span and Non-Public Highway Bridges.

3-3.1.1 Inspection Requirements.

Highway bridges that do not meet the NBIS span length and/or public road requirements must be inspected at a frequency interval of not greater than 48 months.

The National Bridge Program Manager can approve the exemption of short span bridges from the inspection requirement if engineering judgement indicates that failure of the bridge will not significantly endanger the safety of people or property.

3-3.1.2 Load Rating Requirements.

Highway bridges less than 20 feet (6.1 meters) and bridges deemed non-public will be load rated at the discretion of the National Bridge Program Manager.

3-3.2 Highway Bridges in Foreign Territories.

3-3.2.1 Inspection Requirements.

Highway bridges in foreign territories meeting the NBIS span length and public road requirements must conform to the bridge inspection requirements of paragraph 3-2.2. The inspection interval may be extended without approval of the FHWA and at the discretion of the National Bridge Program Manager.

3-3.2.2 Load Rating Requirements.

Highway bridges in foreign territories meeting the NBIS span length and public road requirements must conform to the load rating requirements of paragraph 3-2.3.

3-3.3 Bridge Inventory Data Requirements.

An inventory of non-NBI bridges must be maintained by the Military Department with jurisdiction over those bridges. It is not necessary to transmit SI&A data to the FHWA for bridges on any installation in foreign territory or for “non-NBI” bridges owned by DOD. There is one exception to this: the FHWA needs to be advised about “non-NBI” bridges that go over a Federal-Aid highway, STRAHNET route or connector, or other important structure. Inventory data (not appraisal information) on bridges that fall into this category should be reported if no record of the bridge has been previously reported or if the bridge is modified. Refer to Appendix B, paragraph B-5, for a bridge inspection reporting flowchart.

For the purposes of internal recordkeeping, each agency’s standard SI&A form may be further modified, as desired, to better reflect bridge data in a foreign territory.

CHAPTER 4 RAILROAD BRIDGES

4-1 INTRODUCTION.

Railroad bridges differ from other types of bridges in the types of live loads they undergo, in their modes of failure and distress, and in their construction details. The FRA requires that all track owners have an implemented railroad bridge safety management program including, but not limited to, clear definitions of the roles and responsibilities of all designated qualified personnel; an inventory of all railroad bridges; bridge capacities through load ratings; and detailed bridge inspection policies. Refer to 49 CFR 237 for additional information.

4-1.1 History of FRA Railroad Bridge Inspection Regulations.

Regular inspection of railroad bridges has been an industry practice for over 100 years. Railroad operators learned early in their development through bridge failures, often resulting in fatalities, the importance of comprehensive bridge inspections to ensure that developing flaws did not lead to catastrophe. In 1968, as a result of the Silver Bridge collapse at Point Pleasant, West Virginia, the President established a White House Task Force on Bridge Safety. In support of this task force, the Association of American Railroads (AAR) organized the AAR Railroad Bridge Safety Committee. This committee solicited information from all the railroads in the United States on their bridge inspection, rating, and maintenance practices. Responses from all of the Class I railroads, which made up 94 percent of the nation’s railroad mileage, indicated that all of their bridges received a comprehensive inspection by qualified personnel at least once per year. The survey also revealed that every Class I railroad followed bridge inspection and rating practices equal to or greater than the instructions set forth in the Manual of Recommended Practice for Railway Engineering issued jointly by the AAR Engineering Division and the American Railway Engineering Association, a predecessor to the American Railway Engineering and Maintenance-of-Way Association (AREMA) *Manual for Railway Engineering*.

In 1995, the FRA issued an Interim Statement of Policy on the Safety of Railroad Bridges. This was followed in 2000 by a Final Statement of Agency Policy on the Safety of Railroad Bridges. These statements, while non-regulatory, established criteria for railroads to use to ensure the structural integrity of railroad bridges.

With the signing into law of the Railroad Safety Improvement Act of 2008, the FRA was directed to issue regulations requiring track owners to adopt and follow specific procedures to protect the safety of their bridges. As a result, the FRA issued its Bridge Safety Standards, Final Rule, on July 15, 2010. The rule became effective on September 13, 2010, with a staggered implementation schedule whereby the largest freight and passenger railroads were required to comply first, followed by the mid-size and then the smallest railroads.

4-1.2 Applicability.

FRA bridge safety standards apply to all railroad bridges located within CONUS, Alaska, or Hawaii supporting a track with a gage of 2 feet (0.6 meter) or more used to transport freight in railcars moved by railroads that are part of the general railroad system of transportation. Railroad bridges on military installations that meet these criteria fall under the jurisdiction of FRA and must comply with regulations in 49 CFR 237.

The following railroads (and bridges) on military installations do not fall under the jurisdiction of the FRA. However, non-FRA railroad bridges must also be inspected and managed in accordance with UFC paragraphs 4-2, 4-3, and 4-4.

- Bridge structures in foreign territories
- Bridge structures supporting track used exclusively for rapid transit operations
- Bridge structures located within an installation that are not part of the general railroad system and over which the movement of rail equipment is performed only by military or installation employees

4-1.3 Railroad Bridges Reportable to FHWA.

Railroad bridges that go over a Federal-Aid highway, STRAHNET route or connector, or other important structure, must be reported to the FHWA. Inventory data (not appraisal information) on bridges that fall into this category must be reported if no record of the bridge has been previously reported or if the bridge is modified.

4-2 BRIDGE INSPECTION REQUIREMENTS.

4-2.1 Inspection Types.

Bridge inspections are conducted to determine the physical condition of the structure, to develop the basis for load rating analyses, to assess the need for maintenance, and to track the functional condition and rate of deterioration over time. There are seven inspection types requiring unique levels of effort. These inspection types are initial/inventory, routine, damage, in-depth, fracture critical, underwater, and special, as described below.

Any railroad bridge that has been out of service and has not received an inspection within the scheduled time specified in the Railroad Bridge Management Program will be inspected by a Railroad Bridge Inspector and the report reviewed and approved by a Railroad Bridge Engineer prior to reopening to service. Where deemed necessary by the Railroad Bridge Engineer, an updated load rating will be performed for the bridge and filed in the bridge file prior to reopening to service. Late inspections require an explanation to be included in the bridge file.

4-2.1.1 Initial/Inventory Inspection.

The initial/inventory inspection is the first inspection after a bridge is built or added to the installation real property and becomes a part of the bridge file. Elements of the initial/inventory inspection may also apply when there has been a change in configuration of the structure (e.g., widening, lengthening, supplemental bents). It is important for the inspectors to identify any existing problems or locations in the structure where potential problems may arise. A thorough review of as-built plans should be conducted prior to the initial inspection and the inspector should note any FCMs or details during this inspection. A Level 1 scour screening is required if the bridge crosses over a waterway.

Initial inspections must be performed within 90 days of opening to rail traffic. A new railroad bridge must be added to the installation real property and becomes a part of the bridge file prior to opening.

4-2.1.2 Routine Inspection.

A routine inspection is a regularly scheduled inspection to collect observations and measurements of any changes from the initial inspection or any previously conducted inspection.

All routine inspections must be conducted at least once each calendar year, with no more than 540 days between any successive inspections. The Railroad Bridge Engineer may increase routine inspection intervals based on the physical or functional condition of the bridge. It is the responsibility of the Railroad Bridge Engineer to establish criteria for decreased inspection intervals.

4-2.1.3 Damage Inspection.

A damage inspection is a one-time unscheduled inspection to evaluate structural damage resulting from environmental or human actions such as collisions, floods, derailments, fires, or earthquakes, and is performed to establish the repair level of effort. Damage inspections must be performed within a reasonable time after a natural disaster or human-caused action. The inspectors will document all damaged members, measuring, at a minimum, any section loss, member misalignment, and any loss of foundation support. The inspection must provide all information necessary to potentially close the bridge or perform an emergency load restriction. Local installation personnel may make an initial assessment of the bridge if personnel meeting required inspector qualifications are not immediately available. The National Bridge Program Manager may recommend a follow-up in-depth inspection of the bridge to monitor the structure. The National Bridge Program Manager will maintain bridge damage inspection procedures within the railroad bridge management program specific to each event type. Examples of bridge damage inspection instructions are provided in AREMA *Manual for Railway Engineering*, Volume 2, Chapter 10.

4-2.1.4 In-Depth Inspection.

An in-depth inspection is a hands-on, close-up inspection of one or more members above or below the waterline. In-depth inspections are more detailed and may require special access techniques to inspect areas not easily detectable from a routine inspection. The Railroad Bridge Engineer is responsible, in conjunction with the Installation Bridge Manager, for establishing the need for and required interval of an in-depth inspection.

4-2.1.5 Fracture Critical Inspection.

Fracture critical inspections are detailed, hands-on inspections of steel bridges with FCMs that may include visual or other nondestructive evaluations. Prior to inspection, a thorough review of the design or as-built plans, previous inspection reports, load rating, and fatigue-prone details must be made. In the absence of plans or fatigue-prone details, the inspector should be able to determine the fatigue-prone details based on the details provided in Table 6.6.1.2.3-1 of AASHTO LRFDUS-7. FCMs require a "hands-on" inspection where the inspector is capable of touching the area being inspected (arm's length). Physical inspection methods may be necessary to more accurately assess the condition of an FCM. Advanced inspection methods may need to be employed, including NDT methods. The hands-on inspection will identify and note the condition of problematic details prone to crack development.

For more information regarding inspection techniques for fracture critical bridges, refer to the BIRM or FHWA-NHI-11-015*.* For additional information and case studies on fatigue damage in welded, bolted, and riveted structures, refer to FHWA's *Manual for Inspecting Bridges for Fatigue Damage Conditions* and John W. Fisher's *Fatigue and Fracture in Steel Bridges – Case Studies*.

Fracture critical inspections must be conducted at regular intervals not to exceed 24 months. When a routine inspection interval is decreased due to a FCM finding, it is recommended that the fracture critical inspection interval be decreased to match the routine inspection interval. In order to establish the criteria for fracture critical inspection intervals and level of effort, factors such as bridge age, fatigue-prone details, and known deficiencies must be considered.

4-2.1.6 Underwater Inspection.

4-2.1.6.1. An underwater inspection is diving to visually inspect and measure bridge components, probing for scour or undermining, and sounding to locate the bottom of the channel. The inspection will include such methods as necessary to adequately perform a condition assessment of the structure. If a bridge can be adequately inspected by wading, shallow probing, or with the use of cameras at low water conditions, a formal underwater inspection (divers) is not required. For bridges that do not require a formal underwater inspection, Item 93 on the SI&A form will not be coded. The Installation Bridge Manager will develop a mechanism to ensure inspections occur at low water conditions.

4-2.1.6.2. These inspections must be performed by experienced inspectors determined by the Railroad Program Manager to be competent in underwater inspection procedures. It is recommended that the Underwater Inspection Bridge Inspectors are divers qualified per paragraph 2-1.7 and have completed an approved equivalent to the FHWA-approved underwater bridge inspection diver training course.

4-2.1.6.3. According to the BIRM, there are three levels of underwater inspection intensity:

- Level 1 – Visual, tactile inspection
- Level 2 – Detailed inspection with partial cleaning
- Level 3 – Highly detailed inspection with NDT or PDT

4-2.1.6.4. Level 1 inspections are required for all routine underwater inspections and must be performed within arm's reach of the areas being inspected. Visual inspections are performed across the entire submerged structure, but, in areas of poor water clarity, a tactile sweeping motion of the hands and arms may be utilized to cover the entire substructure.

4-2.1.6.5. Level 2 inspections include cleaning off marine or aquatic growth at critical inspection areas and inspecting high-stress, damaged, and deteriorated areas that may be shielded by the growth. Critical areas near the low waterline, mudline, and midway between will be inspected. Piers and abutments must have at least 1 square foot (0.09 square meter) cleaned at three or more levels on each face. For structures greater than 50 feet (15 meters) in length, an additional three levels must be cleaned at each exposed face. For piles, horizontal bands a minimum of 10 inches (254 millimeters) long will be cleaned along the following locations:

- Rectangular – At least three sides
- Octagonal – At least six sides
- Round – At least 75 percent of circumference
- H-pile – At least the outside faces of flanges and one side of web

4-2.1.6.6. Level 3 inspections include complete cleaning of a structural element and NDT or PDT. Detailed measurements are typically made along with testing techniques such as ultrasonic, physical material sampling, or boring. These inspections are generally performed when a structural repair or possible replacement is being considered.

4-2.1.6.7. Underwater inspections must be completed at regular intervals not to exceed 60 months. The Railroad Bridge Engineer may decrease the interval of underwater inspections based on Level 1 or Level 2 scour evaluations, evidence of substructure movement, stream migration, bank sloughing, or debris buildup. Any deviation in the underwater inspection interval must be documented in the bridge file. Prior to requesting an alteration to underwater inspection intervals, it may be helpful to review FHWA-NHI-10-027. This report not only lists various factors that affect the needed interval of underwater inspection but also contains valuable information on underwater inspection techniques, underwater repair techniques, and scour issues.

4-2.1.7 Special Inspection.

Inspections that monitor a known member deficiency or other conditions that warrant special attention, such as foundation settlement or scour, fatigue damage, severe section loss; or to evaluate damage caused by a natural or accidental event, including, but not limited to, flood, fire, earthquake, derailment, or vehicular or vessel impact. Based on these criteria, the Railroad Bridge Engineer will determine when special inspections are required. A special inspection must be performed based on the criteria in 49 CFR 237, Subpart E, *Bridge Inspection*.

4-2.2 Inspection Procedures.

The Railroad Bridge Engineer must specify the bridge inspection procedures in conformance with the requirements of 49 CFR 237. The bridge inspection procedures will include the following:

- Methods, means of access, and level of detail to be recorded for the various components of that bridge or class of bridges
- Assurance that the level of detail and the inspection procedures are appropriate to the bridge configuration, conditions found during previous inspections, the nature of the railroad traffic, and vulnerability of the bridge to damage
- Be designed to detect, report, and address deterioration and deficiencies before they present a hazard to safe train operation

Bridge inspections must be conducted under the direct supervision of a designated Railroad Bridge Inspector. A bridge or portion of a bridge may be inspected more frequently when a Railroad Bridge Engineer deems necessary, considering the conditions noted during previous inspections, bridge type and configuration, weight and frequency of rail traffic, and the type or nature of rail traffic. In addition, bridge inspection reports will be reviewed by Railroad Bridge Engineers and railroad bridge supervisors to:

- Determine whether inspections have been performed in accordance with the prescribed schedule and specified procedures
- Evaluate whether any items on the report represent a present or potential hazard to safety
- Prescribe any modifications to the inspection procedures or inspection interval for that particular bridge
- Determine the need for further higher-level review

4-3 LOAD RATING AND LOAD RESTRICTION REQUIREMENTS.

All railroad bridges must have a load rating on file within the railroad bridge file performed by a Railroad Bridge Engineer. The load ratings will be expressed in terms of numerical values related to a standard system of train loads (i.e., Cooper E-equivalent configuration).

All railroad bridge load rating methods are recommended to abide by AREMA *Manual for Railway Engineering*, Volume 2, Chapter 7. Timber bridges are addressed in Chapter 7, concrete bridges are addressed in Chapter 8, and steel bridges are addressed in Chapter 15. As an alternative to evaluating the capacity of railroad bridge components within the aforementioned chapters, other methods prescribed by the Railroad Bridge Engineer may be utilized, such as strain gage data, deflection measurements, or non-destructive testing for identifying embedded concrete reinforcement. All methods used to determine the capacity of the bridge must be clearly stated in the bridge file.

In addition, the Railroad Bridge Engineer will issue instructions specifying the maximum equipment weight along with either the minimum equipment length or axle spacing. These instructions are for use by those persons responsible for controlling the movement of rail equipment over railroad bridges to ensure the bridges are not overloaded. For railroad bridges that present horizontal or vertical restrictions, the Railroad Bridge Engineer will issue instructions necessary to prevent damage from over-dimension loads. Refer to 49 CFR 237.73 for further information.

4-4 BRIDGE MANAGEMENT PROGRAM REQUIREMENTS.

The National Bridge Program Manager is responsible for maintaining the railroad bridge management program and ensuring its continued compliance with this UFC and FRA guidelines. At a minimum, the program must include all of the following:

- An accurate inventory of railroad bridges
- A record of the safe load capacity of each bridge
- A provision to obtain and maintain design documents, including repairs, modifications, and inspections of each bridge
- A bridge inspection program covering as a minimum:
    - Inspection personnel safety considerations;
    - Types of inspection, including required detail;
    - Definitions of defect levels and associated condition codes if condition codes are used;
    - The method of documenting inspections, including standard forms or formats;
    - Structure type and component nomenclature; and

  - Numbering or identification protocol for substructure units, spans, and individual components

The railroad bridge management program must include, at a minimum, the following requirements:

- Record of each inspection required to be performed
- Record of an inspection will be prepared from notes taken on the day(s) the inspection was made and will be dated with the date(s) the physical inspection takes place and the date the record is created
- Each bridge inspection report must include, at a minimum, the following information:
  - A precise identification of the bridge inspected;
  - Date on which the physical inspection was completed;
  - Identification and written or electronic signature of the inspector;
  - Type of inspection performed;
  - Identification of inspection findings requiring expedited or critical review by a Railroad Bridge Engineer and any restrictions placed at the time of inspection;
  - Condition of components inspected; and
  - Identification of the portions of the bridge that were inspected
- Initial report of each bridge will be placed in the bridge file within 30 calendar days of the completion of inspection
- Complete report of each bridge inspection within 120 calendar days of the completion of the inspection

Refer to 49 CFR 237.109 for additional information on what FRA requires for bridge inspection records.

CHAPTER 5 PEDESTRIAN BRIDGES AND GOLF CART BRIDGES

5-1 BRIDGE INSPECTION REQUIREMENTS.

Pedestrian bridges and golf cart bridges must be inspected at a minimum interval of 48 months if the bridge crosses a highway, crosses a railroad, or if failure of the bridge could significantly endanger the safety of people or property. The National Bridge Program Manager approves the bridges requiring inspection and the required inspection interval.

5-2 LOAD RATING REQUIREMENTS.

Pedestrian bridges and golf cart bridges must be load rated if the bridge crosses a highway, crosses a railroad, or if failure of the bridge could endanger the safety of people or property. If a pedestrian bridge load rating is less than 60 pounds per square foot (psf) (293 kilograms per square meter), the bridge must be posted for reduced pedestrian traffic. If a pedestrian bridge load rating is performed and found to be less than 40 psf (195 kilograms per square meter), the bridge must be closed to pedestrian traffic until it is repaired. AASHTO GSDPB-2-UL*, LRFD Guide Specifications for Design of Pedestrian Bridges*, is a good reference for this topic.

Pedestrian and golf cart bridges intended to support maintenance or emergency vehicles will meet the load rating and inspection requirements of highway bridges. These bridges must be posted and barricaded or equipped with bollards to prevent non-emergency vehicle use.

5-3 BRIDGE INVENTORY DATA REQUIREMENTS.

An inventory of inspected pedestrian and golf cart bridges must be maintained by the Military Department with jurisdiction over those bridges. Do not include these bridges in the NBI provided to FHWA. However, the FHWA must be advised about bridges that go over a Federal-Aid highway, STRAHNET route or connector, or other important structure. Inventory data (not appraisal information) on bridges that fall into this category will be reported if no record of the bridge has been previously reported or if the bridge is modified. Refer to Appendix B, paragraph B-5, for a bridge inspection reporting flowchart.

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CHAPTER 6 SPECIAL BRIDGE TYPES

6-1 COMPLEX BRIDGES.

Complex bridges must be inspected and reported to the FHWA per the requirements specified in the UFC. Complex bridges include movable, suspension, and cable-stayed bridges, as well as other bridges with unusual characteristics. The National Bridge Program Manager will identify specialized bridge inspection procedures and any additional inspector training and experience necessary to safely and accurately perform the inspections.

6-2 TAXIWAY BRIDGES.

All taxiway bridges must be inspected at least every two years and load rated to ensure the bridge can safely carry airfield traffic. All requirements for NBI bridges apply for taxiway bridges. Since the NBI requires reporting of only highway bridges based on the type of traffic "over" the bridge, taxiway bridges over highways will not be included in the NBI reporting to FHWA.

6-3 MILITARY BRIDGE SET TRUSS PANEL BRIDGES.

Although originally intended for temporary, battlefield applications, prefabricated military bridge sets (i.e., Bailey and Mabey-Johnson or similar truss panel bridges) often remain in use in a permanent capacity. Army Technical Manual (TM) 3-34.23, *M2 Bailey Bridge*, contains useful information on the Bailey system and load capacities.

Because there are many variations of the Bailey and Mabey-Johnson bridge systems, it is recommended that the manufacturer's literature be consulted prior to performing a load rating of these bridge types. In lieu of using the manufacturer's loading data, it is also permissible to load-rate these bridges as a generic truss; however, this procedure will be time-consuming due to the amount of calculations involved.

Military bridge set bridges meeting the criteria for a reportable bridge must abide by the requirements of paragraph 3-2.

6-4 MODEL AND TRAINING BRIDGES.

Model and training bridges are commonly found on installations. They are often referred to as research, development, testing and evaluation (RDT&E) models, simulations, or replicas. These are not real property, are not reportable, and will not be part of the installation bridge inventory database, nor will they be part of the NBI. They must be closed off to all traffic (other than vehicles used for testing or training) and stored in a secure, locked area when not in use. If a load rating or actual regular traffic use on these bridges is desired, an initial inspection will be performed prior to adding the structure to the bridge inventory.

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CHAPTER 7 COMMON REQUIREMENTS OF ALL BRIDGES

7-1 CRITICAL FINDINGS.

Critical findings are defined as structural or safety-related deficiencies that require immediate follow-up inspection or action. It is the responsibility of the National Bridge Program Manager to implement procedures for addressing critical deficiencies, including:

- Immediate critical deficiency reporting steps
- Emergency notification of police and the public
- Rapid evaluation of the deficiencies
- Rapid implementation of corrective or protective actions
- A tracking system to ensure adequate follow-up
- Provisions for identifying other bridges with similar structural details for follow-up inspections

The National Bridge Program Manager must establish a bridge program procedure to ensure that critical findings are addressed in a timely manner and in conformance with Appendix B, paragraph B-8, “Flow Chart for Critical Findings.” General steps must be taken to assure that critical findings are identified and resolved as quickly and efficiently as possible. Viable options include permanent repair, temporary repair, and restriction of load on a bridge. Refer to the BIRM, Topic 4.5, “Critical Findings,” for additional information and guidance on addressing critical findings.

7-1.1 Inspection Procedures and Reporting.

The bridge program procedure must require the immediate verbal notification of a potential critical finding to the National Bridge Program Manager and Load Rating Engineer. In addition to the verbal notification, the procedures should include a written notification following a standardized format in either hardcopy or electronic format. See Appendix B, paragraph B-9, for a sample Critical Inspection Finding Report form. The written notification should include notes, photographs, and sketches and/or drawings to accurately portray the potential critical finding. Temporary actions may also be taken to safeguard the public until proper repairs are completed. These actions may include:

- Load posting
- Traffic restrictions from the damaged area
- Speed restrictions
- Temporary lane closure

- Temporary shoring
- Complete bridge closure

After submittal of the written report, the finding will be assessed and severity established with the proper repair strategy or POA. The procedures will require notification of critical findings for reportable highway bridges to the FHWA.

The BIRM, Chapter 4.5.3, lists numerous examples of critical findings for timber, steel, and concrete bridges, for both reduced load capacity and public safety hazard conditions.

7-1.2 Prioritizing Maintenance Procedures.

The National Bridge Program Manager must establish prioritization criteria to help facilitate maintenance work plan strategies. A list of example priority criteria can be found in the BIRM, Topic 4.5.

7-1.3 Plan of Action (POA).

A POA will be developed and approved within seven calendar days of a critical finding. It may be necessary to begin addressing a critical finding prior to full development and acceptance of a POA. It is the responsibility of the National Bridge Program Manager, in conjunction with the Installation Bridge Manager, to implement procedures for addressing critical deficiencies, including:

- Immediate critical deficiency reporting steps
- Emergency notification of police and the public
- Rapid evaluation of the deficiencies
- Rapid implementation of corrective or protective actions
- A tracking system to ensure adequate follow-up
- Provisions for identifying other bridges with similar structural details for follow-up inspections

7-1.4 Repair.

Critical findings that significantly impact a bridge’s structural integrity and/or create a safety hazard will be addressed immediately through complete or partial bridge closure or repair. A critical finding that impacts a bridge’s structural integrity will be retrofitted through short-term repairs (i.e., temporary shoring or bracing) or permanent repairs that are designed and constructed to restore the affected member(s) to their original load capacity. This may include installation of new structural steel plates or shapes; removal and replacement of deteriorated concrete and steel reinforcing; or installation of other materials (e.g., timber, steel cable, fiber reinforced polymer composites, masonry), depending on the structure type.

Critical findings that create a safety hazard (e.g., broken railings or safety devices that may not provide proper containment or redirection; loose concrete or steel that creates a falling hazard) will be isolated by removing traffic from the area of the hazard until the hazard is removed and/or repaired.

The FHWA will be notified annually of critical finding repairs and post-repair progress which impacts data for NBI highway bridges.

7-2 SCOUR EVALUATION.

7-2.1 Scour Screening.

All existing bridges must be screened to determine their vulnerability to scour. This includes, but is not limited to, a Level 1 stream stability analysis and a review of the existing bridge plans. Critical information from the bridge plans includes, but is not limited to, the foundation types, locations, and depths. If this level of analysis indicates that the bridge is not susceptible to scour then the bridge should be appropriately coded and continue to be monitored during each routine inspection. HEC-18, *Evaluating Scour at Bridges*, Table 10.2, provides a list of items to consider when assessing the susceptibility of a bridge to scour.

7-2.2 Unknown Foundation Coding.

For bridges with an unknown foundation and determined through a Level 1 stream stability analysis to not be susceptible to scour, Code Item 113 will remain “U” and a scour critical POA will be prepared until a higher-level analysis has been performed.

7-2.3 Higher Level Scour Analysis.

If after the initial screening the bridge is susceptible to scour, additional analysis is needed. This includes the evaluation of the flooding history of the bridge and the development of a hydraulic model (typically the Army Hydrologic Engineering Center’s River Analysis System [HEC-RAS]) to determine the scour potential at the bridge site. Higher level scour evaluations must be performed by a Hydraulic Bridge Engineer who is a professional engineer with relevant work experience in bridge hydraulic modeling and scour evaluations. This scour evaluation should also consider the potential for debris collecting on the bridge substructure. Previous inspection reports, along with the current channel stability and observed debris, will provide guidance. Once the theoretical (potential) scour depth is determined from the hydraulic model, this depth should be compared to the existing foundation depths so a determination can be made as to the bridge’s overall susceptibility to scour. This process involves a multi-disciplinary team approach that should include hydraulic, geotechnical, and structural engineers to determine the reasonableness of the results. If, after this analysis, any bridge can be considered unstable should the potential scour depth be reached, it should be considered “scour critical” and a POA, including a detailed plan for potential bridge closure, should be developed. See Appendix B, paragraph B-7, for an example Scour Critical Bridge POA.

7-2.4 2D Hydraulic Model.

Some bridge crossings, such as tidally influenced bridges or a wide floodplain that contains multiple bridges, will require a higher level of hydraulic analysis. A 2D hydraulic model will be conducted to analyze the scour susceptibility.

7-2.5 Unknown Foundation Risk Analysis.

Bridges are classified as having unknown foundations when the type and depth of foundations are unknown. The initial approach is to perform extensive data mining to ensure the foundations are in fact unknown. If the foundations are in fact unknown, HEC-18, Appendix F, provides guidance for performing a risk-based analysis to prioritize bridges for further evaluation. Each Military Department is responsible for implementing a risk-based approach to reclassify bridges with unknown foundations and subsequently evaluate the susceptibility to scour. HEC-18, Appendix F, recommends to first prioritize bridges based on their functional classification. Secondly, collect historical documentation of foundation and design practices based on the date of original construction, consider the subsurface conditions and bridge standards from nearby bridges, and/or perform proven NDT to assess foundation type and length. Once the information has been gathered, perform a scour evaluation based on the data and update Code Item 113 accordingly. If the scour evaluation determines the bridge to be scour critical (items to be coded with a 3, 2, or 1), a POA will be implemented for the bridge. For bridges with unknown foundations even after a risk analysis has been performed, a POA will be implemented that includes a bridge closure plan. FHWA *Attachment "B" – Guidance for Developing and Implementing Plans of Action for Bridges with Unknown Foundations* provides recommended steps for developing POAs for bridges with unknown foundations.

7-2.6 Unknown Foundation Evaluation.

FHWA and the Florida Department of Transportation (FDOT) published a manual titled *Procedural Manual: Reclassify Unknown Foundation Bridges*, that provides detailed procedures and guidelines for evaluating bridges with unknown foundations through a risk-based approach. The manual provides multiple flow charts to assist in evaluating unknown foundations, including steps to reclassify bridges with unknown foundations, reverse engineering for estimating unknown pile embedment, and recommended NDT methods for multiple foundation types.

7-2.7 Scour Critical POA.

Bridges that are considered scour critical must have a detailed POA in the bridge file. See Appendix B, paragraph B-7, for an example Scour Critical Bridge POA.

7-3 FRACTURE CRITICAL PLAN.

A fracture critical member (FCM) is a steel member in tension or with a tension element whose failure could potentially cause a portion of or the entire bridge to collapse. A fracture critical plan identifies all FCMs on a bridge, establishes an inspection interval, and determines inspection methods. Fracture critical plans will be developed and maintained for each fracture critical bridge in the bridge file. The plan must, at a minimum, include:

- Bridge identification
- Bridge location (with map)
- Structure description
- Means of access
- Identification of all FCMs (plan and elevation sketch with FCMs identified)
- List of all relevant AASHTO fatigue-prone details with photo references

Table 6.6.1.2.3-1 in AASHTO LRFDUS-7 presents fatigue-prone details caused by in-plane stresses and categorizes them in Categories A through E. The table provides the inspector categories for classifying fatigue-prone details for fracture critical bridges. The letter designation is a rating assigned to a detail that represents its fatigue strength, with "A" being the highest and "E" being the lowest. Refer to Appendix B, paragraph B-6, for an example fatigue-prone detail form.

Refer to the BIRM, Topic 6.4, "Fatigue and Fracture in Steel," for additional information on FCMs.

7-4 SEISMIC EVALUATION.

All bridges must be evaluated to determine if further analysis is warranted for seismic activity, and, if necessary, further investigation will be recommended. Refer to Part 1 of FHWA-RD-94-052, *Seismic Retrofitting Manual for Highway Structures*. The retrofit philosophy in FHWA-RD-94-052 is performance-based and distinguishes between important new bridges and less-important bridges near the end of their service life. Based on bridge importance and desired service life, categories are assigned for screening, in-depth evaluation, and retrofitting. Numerous retrofit options exist, such as restrainers, bridge seat extensions, column jackets, footing overlays, and soil remediation.

7-5 TRAFFIC SAFETY DEVICES.

All roadsides and bridges/structures must have traffic safety devices (e.g., guardrail, end treatments, delineators) installed according to AASHTO GDHS-6, *A Policy on Geometric Design of Highways and Streets (Green Book)*, AASHTO RSDG-4, *Roadside Design Guide*, and FHWA MUTCD. For facilities that carry low-volume traffic, traffic safety devices may be installed based on the provisions of AASHTO VLVLR-1, *Guidelines for Geometric Design of Very Low-Volume Local Roads (ADT ≤ 400)*.

MUTCD Section 5A.01 defines a “low-volume road” as a facility lying outside of built-up cities, towns, and communities, and having a volume of less than 400 average annual daily traffic (AADT). Low-volume roads will not be freeways, expressways, interchange ramps, freeway service roads, roads on a designated state highway system, or a residential street in a neighborhood. For bridges not on the National Highway System, each Military Department must establish criteria for updating traffic safety devices. Factors to consider when establishing these criteria are roadway volume, posted speed limit, and approach roadway geometry (e.g., low-volume, low-speed roadways with good geometry are less prone to crashes with vehicles leaving the roadway). The AASHTO-AGC-ARTBA Task Force 13 *A Guide to Standardized Highway Barrier Hardware*, as well as local standards for traffic safety, are also recommended resources.

7-6 CLOSED BRIDGES.

Signage must be placed to identify a bridge as being closed to vehicular and/or pedestrian traffic. Physical barriers of a mass not easily moved will be positioned to prevent access to the structure.

CHAPTER 8 BRIDGE MAINTENANCE

8-1 INTRODUCTION.

A goal of this UFC is to ensure that installation bridges are maintained in a safe, usable condition. Preventive maintenance is a planned strategy of cost-effective treatments applied at the proper time to preserve and extend the useful life of a bridge.

8-2 INDUSTRY PRACTICE.

Any deficiencies requiring maintenance identified in an inspection will be expediently addressed. The Installation Bridge Manager will review all inspection reports and provide a report of deficiencies requiring maintenance to the National Bridge Program Manager in a timely manner.

Bridge maintenance must be conducted in accordance with the latest industry practice. Valuable references include American Concrete Institute (ACI) 345.1R-16, *Guide for Maintenance of Concrete Bridge Members*; ACI SP-277, *Recent Advances in Maintenance and Repair of Concrete Bridges*; AASHTO MM-4, *Maintenance Manual for Roadways and Bridges*; and FHWA-NHI-14-050, *Bridge Maintenance Training Reference Manual*.

General maintenance encompasses cleaning activities such as annually water-flushing all decks, drains, bearings, joints, pier caps, abutment seats, rails, and parapets (typically in the spring). Preventive maintenance encompasses routine activities such as painting; minor coating and sealant applications; minor deck membrane and wearing surface patching; and railing repairs. Stream channel maintenance encompasses activities such as debris removal. Consideration should be given to prioritizing any maintenance recommendations from the bridge inspection reports.

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CHAPTER 9 BRIDGE REPAIR

9-1 INTRODUCTION.

A goal of this UFC is to ensure that bridge deficiencies are discovered and repaired in a timely manner so installation bridges remain open and in a safe, usable condition.

9-2 INDUSTRY PRACTICE.

Bridge repairs must be conducted in accordance with the latest industry practice. Valuable references include Part 2 of FHWA-RD-94-052, *Seismic Retrofitting Manual for Highway Structures*, and FHWA HEC-23, *Bridge Scour and Stream Instability Countermeasures*. Additionally, 49 CFR 237.131 and 49 CFR 237.133 include requirements for the design and supervision of railroad bridge repairs.

Repairs encompass activities such as jacking up the structure, epoxy injection of cracks, adjusting bearing systems, sealing expansion joints, major deck patching, major applications of coatings and sealants, and reinforcement of structural members like stringers, beams, piers, pier caps, pile caps, abutments, and footings. Stream channel repairs encompass activities such as stabilizing banks and correcting erosion problems. Consideration should be given to prioritizing any repair recommendations from the bridge inspection reports.

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APPENDIX B BEST PRACTICES

B-1 MILITARY LOAD CLASSIFICATION (MLC) AND MILITARY VEHICLE LIVE LOAD DATA.

Excerpted from FM 3-34.343, *Military Nonstandard Fixed Bridging*, Appendix B, "Vehicle Classification", 12 February 2002, Headquarters, Department of the Army, Washington, DC:

[Note: Minor edits have been made for this appendix to eliminate non-relevant material, typos, and page number references from FM 3-34.343. Ultimately, all data herein is based on NATO STANAG 2021.]

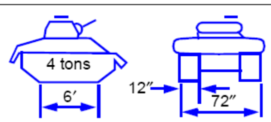
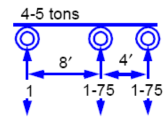
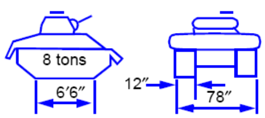
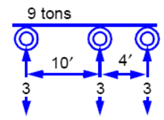
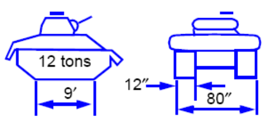
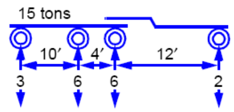
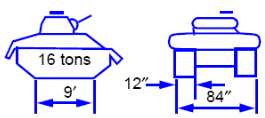
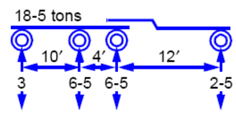
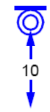
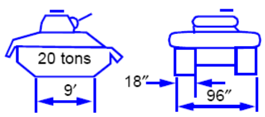
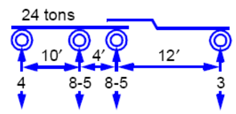
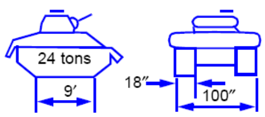
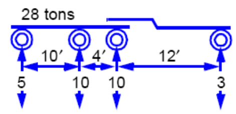
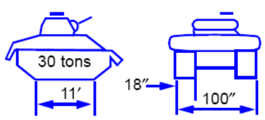
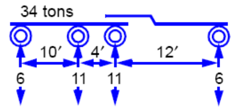
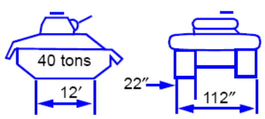
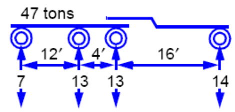
Vehicles are assigned MLC numbers, which represent the loading effects they have on a bridge. The MLC does not represent the actual weight of a vehicle. It represents a combination of factors that include gross weight, axle spacing, weight distribution to the axles, and speed. All standard Army vehicles and special equipment that use bridges of military importance have an MLC. Trailers that are rated with a payload of 1.5 tons or less are exceptions. They have a combined classification with their towing vehicle. Classifying vehicles, trailers, or vehicle combinations with a gross weight of 3 tons or less is optional.

Table B-1 shows 16 standard classes of hypothetical vehicles ranging from 4 to 150. The weight of the tracked vehicle in short tons was chosen as the classification number. A wheeled vehicle has a weight greater than its classification number. Each classification number has a specified maximum single-axle load. Also specified are the maximum tire load, the minimum tire size, and the maximum tire pressure. The classification numbers were originally developed from studies of the hypothetical vehicles having characteristics about the same as the actual military vehicles of NATO nations.

The moment and shear forces produced by the hypothetical vehicles or single-axle loads are provided in Tables B-2 and B-3. These figures are based on the assumption that the nearest ground contact points of two different vehicles (wheeled or tracked) are 100 feet apart. Table B-1 gives critical tire loads and tire sizes.

Standard classification curves were developed for classifying vehicles, for designing nonstandard bridges, and for estimating the capacity of existing bridges. Each standard class has a moment and a shear curve (Figure B-1 and Figures B-2 through B-4). The maximum moment and shear forces were induced against the simple-span lengths by the hypothetical vehicles for each standard class. These forces were plotted to determine the curves. The actual values for the curves are found in Tables B-2 and B-3. Note that in the curves, shear is represented in units of kips; however, in Table B-3, shear is represented in units of tons. No allowance is made for impact, and the assumption is made that all vehicles will maintain the normal convoy spacing of 100 feet between ground contact points.

Table B-1 Standard Classes of Hypothetical Vehicles

Hypothetical Vehicles for Classification of Actual Vehicles and Bridges			
1	2	3	4
Class	Tracked Vehicles	Wheeled Vehicles: Axle Loads and Spacing	Wheeled Vehicles: Maximum Single-Axle Load (in Short Tons)
4			
8			
12			
16			
20			
24			
30			
40			

NOTES:
1. The single-axle tire sizes shown in Columns 5, 6, and 7 refer to the maximum single-axle loads given in Column 4.
2. The bogie-axle tire sizes shown in Columns 5, 6, and 7 refer to the maximum bogie-axle loads shown on the diagrams in Column 3.
3. The maximum tire pressure for all tires shown in Column 8 should be taken as 75 psi. The first dimension of tire size refers to the overall width of the tire and the second dimension is the rim diameter of the tire.

[Note: There is a typo in Column 3, Class 12 above, as the axle loads shown do not add up to 15 tons. The middle two axles should be labeled 5, not 6.]

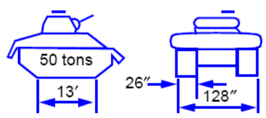
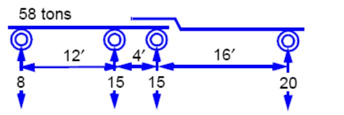
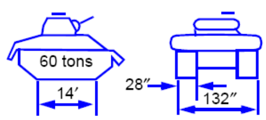
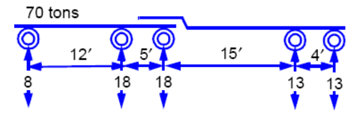
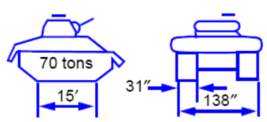
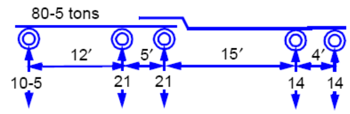
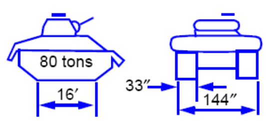
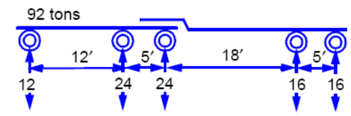
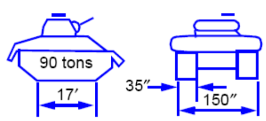
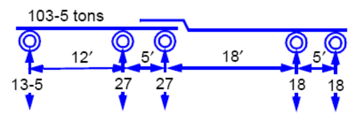
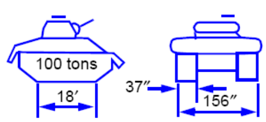
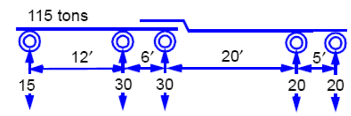
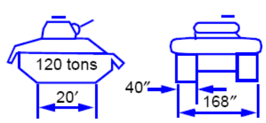
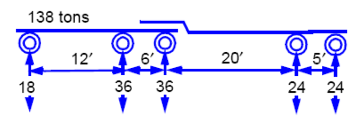
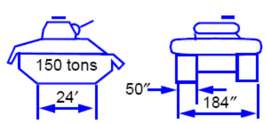
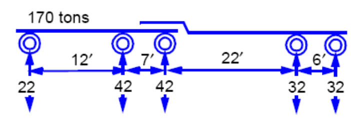
Table B-1 Standard Classes of Hypothetical Vehicles (cont.)

Hypothetical Vehicles for Classification of Actual Vehicles and Bridges				
1	**5**	**6**	**7**	**8**
Class	**Wheeled Vehicles**			
	Minimum Wheel Spacing and Tire Sizes of Critical Axles			**Maximum Tire Load and Minimum Tire Size**
4	Single axle: 7 - 50 x 20 72″ Bogie axle: 7 - 50 x 20	Single axle: 6 - 00 x 20 14″ 72″ Bogie axle: 6 - 00 x 16		2,500 lb on 7 - 50 x 20
8	Single axle: 12 - 00 x 20 82″ Bogie axle: 9 - 00 x 20	Single axle: 8 - 25 x 20 19″ 18″ 82″ Bogie axle: 7 - 50 x 20		5,500 lb on 12 - 00 x 20
12	Single axle: 14 - 00 x 20 84″ Bogie axle: 9 - 00 x 20	Single axle: 10 - 00 x 20 23″ 18″ 84″ Bogie axle: 7 - 50 x 20		8,000 lb on 14 - 00 x 20
16	Single axle: 16 - 00 x 24 90″ Bogie axle: 14 - 00 x 20	Single axle: 12 - 00 x 20 26″ 21″ 90″ Bogie axle: 9 - 00 x 20	Single axle: 21 - 00 x 20 90″ Bogie axle: 9 - 00 x 20	10,000 lb on 16 - 00 x 24
20	Single axle: 18 - 00 x 24 96″ Bogie axle: 14 - 00 x 24	Single axle: 12 - 00 x 20 26″ 96″ Bogie axle: 12 - 00 x 20	Single axle: 12 - 00 x 20 96″ Bogie axle: 12 - 00 x 20	11,000 lb on 18 - 00 x 24
24	Single axle: 18 - 00 x 24 96″ Bogie axle: 16 - 00 x 24	Single axle: 14 - 00 x 20 32″ 26″ 96″ Bogie axle: 12 - 00 x 20	Single axle: 14 - 00 x 20 96″ Bogie axle: 12 - 00 x 20	12,000 lb on 18 - 00 x 24
30	Single axle: 18 - 00 x 24 96″ Bogie axle: 16 - 00 x 24	Single axle: 12 - 00 x 20 26″ 96″ Bogie axle: 12 - 00 x 20	Single axle: 14 - 00 x 20 96″ Bogie axle: 12 - 00 x 20	13,500 lb on 18 - 00 x 24
40	Single axle: 21 - 00 x 24 100″ Bogie axle: 18 - 00 x 24	Single axle: 14 - 00 x 24 32″ 100″ Bogie axle: 14 - 00 x 20	Single axle: 14 - 00 x 24 100″ Bogie axle: 14 - 00 x 20	17,000 lb on 21 - 00 x 24

NOTES:

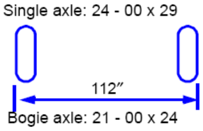
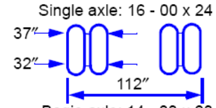
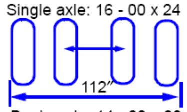
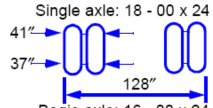
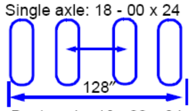
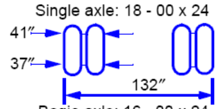
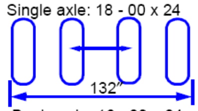
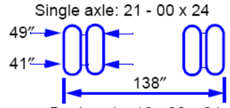
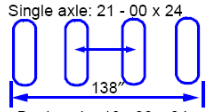
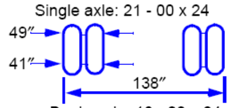
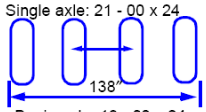
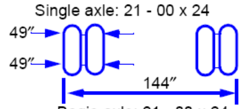
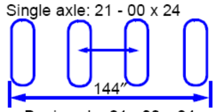
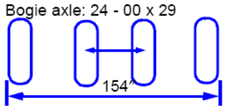
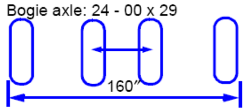
1. The single-axle tire sizes shown in Columns 5, 6, and 7 refer to the maximum single-axle loads given in Column 4.
2. The bogie-axle tire sizes shown in Columns 5, 6, and 7 refer to the maximum bogie-axle loads shown on the diagrams in Column 3.
3. The maximum tire pressure for all tires shown in Column 8 should be taken as 75 psi. The first dimension of tire size refers to the overall width of the tire and the second dimension is the rim diameter of the tire.

Table B-1 Standard Classes of Hypothetical Vehicles (cont.)

Hypothetical Vehicles for Classification of Actual Vehicles and Bridges			
1	2	3	4
Class	Tracked Vehicles	Wheeled Vehicles	
		Axle Loads and Spacing	Maximum Single-Axle Load (in Short Tons)
50			
60			
70			
80			
90			
100			
120			
150			

NOTES:
1. The single-axle tire sizes shown in Columns 5, 6, and 7 refer to the maximum single-axle loads given in Column 4.
2. The bogie-axle tire sizes shown in Columns 5, 6, and 7 refer to the maximum bogie-axle loads shown on the diagrams in Column 3.
3. The maximum tire pressure for all tires shown in Column 8 should be taken as 75 psi. The first dimension of tire size refers to the overall width of the tire and the second dimension is the rim diameter of the tire.

Table B-1 Standard Classes of Hypothetical Vehicles (cont.)

Hypothetical Vehicles for Classification of Actual Vehicles and Bridges				
1	5	6	7	8
Class	Wheeled Vehicles			
	Minimum Wheel Spacing and Tire Sizes of Critical Axles			Maximum Tire Load and Minimum Tire Size
50	Single axle: 24 - 00 x 29  112″ Bogie axle: 21 - 00 x 24	Single axle: 16 - 00 x 24  37″ 32″ 112″ Bogie axle: 14 - 00 x 20	Single axle: 16 - 00 x 24  112″ Bogie axle: 14 - 00 x 20	 20,000 lb on 24 - 00 x 29
60		Single axle: 18 - 00 x 24  41″ 37″ 128″ Bogie axle: 16 - 00 x 24	Single axle: 18 - 00 x 24  128″ Bogie axle: 16 - 00 x 24	 20,000 lb on 24 - 00 x 29
70		Single axle: 18 - 00 x 24  41″ 37″ 132″ Bogie axle: 16 - 00 x 24	Single axle: 18 - 00 x 24  132″ Bogie axle: 16 - 00 x 24	 20,000 lb on 24 - 00 x 29
80		Single axle: 21 - 00 x 24  49″ 41″ 138″ Bogie axle: 18 - 00 x 24	Single axle: 21 - 00 x 24  138″ Bogie axle: 18 - 00 x 24	 20,000 lb on 24 - 00 x 29
90		Single axle: 21 - 00 x 24  49″ 41″ 138″ Bogie axle: 18 - 00 x 24	Single axle: 21 - 00 x 24  138″ Bogie axle: 18 - 00 x 24	 20,000 lb on 24 - 00 x 29
100		Single axle: 21 - 00 x 24  49″ 49″ 144″ Bogie axle: 21 - 00 x 24	Single axle: 21 - 00 x 24  144″ Bogie axle: 21 - 00 x 24	 20,000 lb on 24 - 00 x 29
120			Bogie axle: 24 - 00 x 29  154″	 20,000 lb on 24 - 00 x 29
150			Bogie axle: 24 - 00 x 29  160″	 21,000 lb on 24 - 00 x 29

NOTES:
1. The single-axle tire sizes shown in Columns 5, 6, and 7 refer to the maximum single-axle loads given in Column 4.
2. The bogie-axle tire sizes shown in Columns 5, 6, and 7 refer to the maximum bogie-axle loads shown on the diagrams in Column 3.
3. The maximum tire pressure for all tires shown in Column 8 should be taken as 75 psi. The first dimension of tire size refers to the overall width of the tire and the second dimension is the rim diameter of the tire.

Table B-2 Wheeled- and Tracked-Vehicle Moment (kip-feet)

Class	Wheeled/ Tracked	Span Length (feet)										
		4	6	8	10	12	14	16	18	20	25	30
4	W	4.96	7.44	9.92	12.40	14.88	17.92	21.40	25.60	30.00	41.00	52.20
	T	2.64	6.00	9.92	14.00	18.00	22.10	25.90	29.90	34.00	44.00	54.00
8	W	10.96	16.44	21.90	27.40	32.90	38.30	43.60	49.30	54.80	71.00	93.60
	T	4.88	11.04	19.04	27.00	35.00	43.10	50.90	59.00	66.80	87.00	106.80
12	W	16.00	24.00	32.00	40.00	48.00	56.00	64.00	72.00	80.80	112.50	145.20
	T	5.44	12.00	21.30	33.00	44.90	57.10	69.10	81.00	92.80	123.00	153.00
16	W	20.00	30.00	40.00	50.00	60.00	70.00	80.00	92.50	105.20	144.00	184.20
	T	7.12	15.96	28.50	44.00	60.00	75.90	91.80	108.00	124.00	164.00	204.00
20	W	22.00	33.00	44.00	55.00	70.80	87.40	104.00	121.00	137.60	188.50	241.00
	T	8.88	20.00	35.50	55.00	74.90	94.90	114.90	135.00	154.80	205.00	255.00
24	W	24.00	36.00	48.00	64.00	83.30	102.80	122.60	142.20	162.00	223.00	285.00
	T	10.64	24.00	42.70	66.00	90.00	114.00	137.90	162.00	186.00	246.00	306.00
30	W	26.70	40.40	53.90	70.40	91.70	113.10	134.70	156.60	178.00	246.00	316.00
	T	10.88	24.50	43.70	68.20	97.40	127.40	157.40	187.60	218.00	293.00	367.00
40	W	34.00	51.00	68.00	85.00	108.30	133.80	159.40	185.00	210.00	277.00	359.00
	T	13.36	30.00	53.30	83.40	120.00	158.90	200.00	240.00	280.00	380.00	480.00
50	W	40.00	60.00	80.00	100.00	125.00	154.30	183.70	213.00	243.00	320.00	415.00
	T	15.36	34.60	61.60	96.20	138.50	187.60	237.00	288.00	338.00	463.00	587.00
60	W	46.00	69.00	92.00	115.00	138.00	170.00	205.00	240.00	276.00	365.00	474.00
	T	17.12	38.50	68.60	107.20	154.30	210.00	270.00	330.00	390.00	540.00	690.00
70	W	51.00	76.40	101.90	127.40	157.90	198.20	239.00	280.00	322.00	426.00	557.00
	T	18.64	42.00	74.70	116.60	168.00	229.00	298.00	368.00	438.00	613.00	787.00
80	W	56.00	84.00	112.00	140.00	180.50	227.00	273.00	320.00	368.00	486.00	636.00
	T	20.00	45.00	80.00	125.00	180.00	245.00	320.00	400.00	480.00	680.00	880.00
90	W	60.00	90.00	120.00	151.80	203.00	225.00	308.00	360.00	414.00	547.00	716.00
	T	21.20	47.60	84.60	132.40	190.60	259.00	339.00	427.00	518.00	743.00	967.00
100	W	64.00	96.00	128.00	160.00	203.00	259.00	317.00	375.00	434.00	581.00	765.00
	T	22.20	50.00	89.00	138.80	199.90	272.00	356.00	450.00	550.00	800.00	1,050.00
120	W	72.00	108.00	144.00	180.00	243.00	311.00	380.00	450.00	520.00	697.00	918.00
	T	24.00	54.00	96.00	150.00	216.00	294.00	384.00	486.00	600.00	900.00	1,200.00
150	W	84.00	126.00	168.00	210.00	253.00	331.00	410.00	491.00	572.00	777.00	1,032.00
	T	25.00	56.30	100.00	156.20	225.00	306.00	400.00	506.00	625.00	975.00	1,350.00

Table B-2 Wheeled- and Tracked-Vehicle Moment (kip-feet) (cont.)

Class	Wheeled/ Tracked	Span Length (feet)									
		35	40	45	50	55	60	70	80	90	100
4	W	63.70	75.20	86.40	97.00	108.90	120.00	142.80	164.80	187.20	210.00
	T	63.70	73.80	83.70	94.00	103.40	114.00	134.40	153.60	174.60	194.00
8	W	116.20	138.40	161.10	183.00	206.00	228.00	273.00	318.00	364.00	408.00
	T	126.70	147.20	167.40	187.00	207.00	227.00	267.00	307.00	347.00	386.00
12	W	180.60	218.00	256.00	293.00	331.00	368.00	444.00	518.00	592.00	668.00
	T	182.70	213.00	243.00	273.00	303.00	332.00	393.00	453.00	513.00	572.00
16	W	229.00	275.00	321.00	367.00	414.00	460.00	552.00	645.00	736.00	830.00
	T	244.00	284.00	324.00	364.00	404.00	444.00	524.00	603.00	684.00	764.00
20	W	299.00	359.00	419.00	479.00	539.00	599.00	718.00	838.00	958.00	1,078.00
	T	305.00	355.00	405.00	455.00	505.00	554.00	655.00	755.00	855.00	954.00
24	W	353.00	422.00	492.00	562.00	633.00	702.00	843.00	982.00	1,121.00	1,262.00
	T	366.00	426.00	486.00	546.00	606.00	666.00	785.00	906.00	1,026.00	1,146.00
30	W	398.00	482.00	567.00	652.00	737.00	822.00	991.00	1,162.00	1,130.00	1,500.00
	T	442.00	518.00	592.00	667.00	743.00	817.00	967.00	1,117.00	1,267.00	1,418.00
40	W	442.00	553.00	671.00	788.00	905.00	1,022.00	1,257.00	1,493.00	1,728.00	1,962.00
	T	580.00	680.00	780.00	880.00	980.00	1,080.00	1,280.00	1,480.00	1,679.00	1,880.00
50	W	511.00	656.00	800.00	945.00	1,090.00	1,235.00	1,525.00	1,814.00	2,100.00	2,390.00
	T	713.00	838.00	962.00	1,087.00	1,212.00	1,338.00	1,588.00	1,837.00	2,090.00	2,340.00
60	W	584.00	740.00	914.00	1,089.00	1,263.00	1,438.00	1,786.00	2,140.00	2,490.00	2,840.00
	T	840.00	990.00	1,140.00	1,290.00	1,440.00	1,590.00	1,890.00	2,190.00	2,490.00	2,790.00
70	W	688.00	856.00	1,057.00	1,257.00	1,458.00	1,658.00	2,060.00	2,460.00	2,870.00	3,270.00
	T	963.00	1,138.00	1,312.00	1,478.00	1,662.00	1,837.00	2,190.00	2,540.00	2,890.00	3,240.00
80	W	786.00	936.00	1,103.00	1,332.00	1,561.00	1,790.00	2,250.00	2,710.00	3,170.00	3,630.00
	T	1,080.00	1,280.00	1,480.00	1,680.00	1,880.00	2,080.00	2,480.00	2,880.00	3,280.00	3,680.00
90	W	884.00	1,053.00	1,242.00	1,499.00	1,757.00	2,010.00	2,530.00	3,050.00	3,560.00	4,080.00
	T	1,193.00	1,418.00	1,643.00	1,867.00	2,090.00	2,320.00	2,770.00	3,220.00	3,670.00	4,120.00
100	W	953.00	1,140.00	1,328.00	1,543.00	1,828.00	2,110.00	2,690.00	3,260.00	3,830.00	4,410.00
	T	1,300.00	1,550.00	1,800.00	2,050.00	2,300.00	2,550.00	3,050.00	3,550.00	4,050.00	4,550.00
120	W	1,143.00	1,368.00	1,593.00	1,851.00	2,195.00	2,540.00	3,230.00	3,910.00	4,600.00	5,290.00
	T	1,500.00	1,800.00	2,100.00	2,400.00	2,700.00	3,000.00	3,600.00	4,200.00	4,800.00	5,400.00
150	W	1,297.00	1,562.00	1,827.00	2,092.00	2,405.00	2,830.00	3,670.00	4,520.00	5,560.00	6,210.00
	T	1,725.00	2,100.00	2,478.00	2,850.00	3,230.00	3,600.00	4,350.00	5,100.00	5,850.00	6,600.00

Table B-2 Wheeled- and Tracked-Vehicle Moment (kip-feet) (cont.)

Class	Wheeled/ Tracked	Span Length (feet)									
		110	120	130	140	150	160	170	180	190	200
4	W	233	254	278	270	321	346	367	389	414	448
	T	213	233	255	274	294	314	333	353	391	428
8	W	453	499	543	588	633	678	724	767	813	880
	T	427	468	507	546	588	627	666	706	775	852
12	W	744	818	892	969	1,044	1,117	1,193	1,267	1,341	1,416
	T	634	694	754	812	873	934	993	1,051	1,136	1,248
16	W	922	1,015	1,108	1,198	1,293	1,386	1,476	1,570	1,661	1,752
	T	845	924	1,004	1,084	1,164	1,245	1,323	1,404	1,516	1,664
20	W	1,199	1,318	1,438	1,557	1,677	1,798	1,918	2,040	2,160	2,280
	T	1,054	1,154	1,256	1,355	1,455	1,555	1,656	1,753	1,896	2,080
24	W	1,401	1,543	1,682	1,823	1,962	2,100	2,240	2,380	2,520	2,660
	T	1,265	1,385	1,505	1,627	1,746	1,866	1,986	2,110	2,280	2,500
30	W	1,670	1,841	2,010	2,180	2,350	2,520	2,690	2,860	3,030	3,200
	T	1,566	1,718	1,867	2,020	2,170	2,310	2,470	2,620	2,790	3,070
40	W	2,200	2,430	2,670	2,900	3,140	3,370	3,610	3,840	4,080	4,310
	T	2,080	2,280	2,480	2,680	2,880	3,080	3,280	3,480	3,680	4,050
50	W	2,680	2,970	3,260	3,550	3,840	4,130	4,420	4,710	5,000	5,290
	T	2,590	2,840	3,090	3,340	3,590	3,840	4,090	4,340	4,590	5,020
60	W	3,190	3,540	3,880	4,230	4,580	4,930	5,280	5,630	5,990	6,330
	T	3,090	3,390	3,690	4,000	4,290	4,590	4,890	5,190	5,490	5,970
70	W	3,670	4,070	4,470	4,880	5,280	5,680	6,080	6,490	6,890	7,290
	T	3,590	3,940	4,290	4,640	4,990	5,340	5,690	6,040	6,390	6,900
80	W	4,090	4,550	5,010	5,460	5,930	6,380	6,840	7,300	7,760	8,820
	T	4,080	4,480	4,880	5,280	5,680	6,080	6,480	6,880	7,280	7,810
90	W	4,600	5,110	5,630	6,150	6,670	7,180	7,700	8,220	8,730	9,250
	T	4,570	5,020	5,470	5,920	6,370	6,820	7,270	7,720	8,170	8,700
100	W	4,980	5,560	6,130	6,710	7,280	7,860	8,430	9,000	9,580	10,160
	T	5,050	5,550	6,050	6,550	7,050	7,550	8,050	8,550	9,050	9,570
120	W	5,980	6,670	7,360	8,050	8,740	9,430	10,120	10,810	11,500	12,180
	T	6,000	6,600	7,200	7,800	8,400	9,000	9,600	10,200	10,800	11,400
150	W	7,060	7,910	8,760	9,600	10,450	11,300	12,150	13,000	13,850	14,700
	T	7,350	8,100	8,850	9,600	10,350	11,100	11,850	12,600	13,350	14,100

Table B-2 Wheeled- and Tracked-Vehicle Moment (kip-feet) (cont.)

Class	Wheeled/ Tracked	Span Length (feet)									
		210	220	230	240	250	260	270	280	290	300
4	W	491	532	579	619	665	733	799	868	934	1,002
	T	466	502	538	586	645	707	767	823	887	948
8	W	966	1,052	1,136	1,224	1,310	1,414	1,550	1,686	1,821	1,956
	T	924	1,003	1,076	1,162	1,285	1,404	1,523	1,641	1,763	1,884
12	W	1,491	1,593	1,734	1,877	2,020	2,160	2,310	2,450	2,660	2,890
	T	1,361	1,474	1,587	1,704	1,855	2,040	2,220	2,400	2,580	2,750
16	W	1,848	1,958	2,130	2,390	2,490	2,660	2,840	3,020	3,290	3,570
	T	1,814	1,967	2,120	2,270	2,480	2,710	2,950	3,200	3,430	3,680
20	W	2,400	2,540	2,770	3,000	3,230	3,460	3,690	3,920	4,270	4,630
	T	2,270	2,460	2,650	2,840	3,100	3,400	3,690	3,990	4,290	4,600
24	W	2,800	2,970	3,240	3,500	3,700	4,040	4,310	4,580	4,990	5,410
	T	2,720	2,950	3,170	3,400	3,720	4,070	4,430	4,790	5,160	5,510
30	W	3,370	3,590	3,910	4,240	4,570	4,890	5,220	5,550	6,020	6,530
	T	3,350	3,630	3,910	4,200	4,510	4,960	5,410	5,860	6,310	6,760
40	W	4,550	4,780	5,140	5,590	6,040	6,490	6,940	7,400	7,850	8,310
	T	4,430	4,800	5,180	5,560	5,940	6,520	7,120	7,720	8,320	8,920
50	W	5,580	5,870	6,370	6,930	7,480	8,030	8,590	9,150	9,710	10,270
	T	5,490	5,950	6,430	6,900	7,380	8,040	8,790	9,540	10,290	11,040
60	W	6,680	7,030	7,410	8,070	8,740	9,410	10,050	10,760	11,430	12,110
	T	6,530	7,090	7,650	8,220	8,800	9,510	10,410	11,310	12,210	13,110
70	W	7,690	8,100	8,500	9,260	10,030	10,800	11,570	12,350	13,130	13,910
	T	7,550	8,200	8,860	9,530	10,200	10,940	11,990	13,040	14,090	15,140
80	W	8,680	9,140	9,600	10,180	11,060	11,940	12,830	13,720	14,610	15,500
	T	8,550	9,300	10,060	10,810	11,580	12,340	13,520	14,720	15,920	17,120
90	W	9,770	10,290	10,810	11,450	12,450	13,440	14,430	15,440	16,440	17,440
	T	9,530	10,380	11,220	12,080	12,940	13,800	15,010	16,360	17,710	19,060
100	W	10,730	11,300	11,880	12,450	13,480	14,580	15,690	16,800	17,910	19,030
	T	10,500	11,440	12,380	13,330	14,280	15,230	16,450	17,950	19,450	21,000
120	W	12,870	13,570	14,260	14,940	16,170	17,490	18,820	20,200	21,500	22,800
	T	12,380	13,500	14,630	15,760	16,910	18,050	19,200	21,000	22,800	24,600
150	W	15,550	16,400	17,250	18,100	19,300	20,900	22,500	24,200	25,800	27,500
	T	14,910	16,320	17,720	19,140	20,600	22,000	23,400	24,700	27,200	29,400

Table B-3 Wheeled- and Tracked-Vehicle Shear (tons)

Class	Wheeled/ Tracked	Span Length (feet)									
		4	6	8	10	12	14	16	18	20	25
4	W	2.50	2.50	2.63	2.80	2.92	3.14	3.31	3.44	3.55	3.74
	T	1.33	2.00	2.50	2.80	3.00	3.14	3.25	3.33	3.40	3.52
8	W	5.50	5.50	5.50	5.50	5.50	5.50	5.63	6.00	6.30	6.84
	T	2.46	3.69	4.75	5.40	5.83	6.14	6.38	6.56	6.70	6.96
12	W	8.00	8.00	8.00	8.00	8.33	8.57	9.13	9.56	9.90	10.52
	T	2.67	4.00	5.33	6.60	7.50	8.14	8.62	9.00	9.30	9.84
16	W	10.00	10.00	10.00	10.40	10.83	11.14	11.75	12.22	12.60	13.28
	T	3.56	5.33	7.11	8.80	10.00	10.86	11.50	12.00	12.40	13.12
20	W	11.00	11.33	12.75	13.60	14.17	14.57	15.38	16.00	16.50	17.40
	T	4.44	6.67	8.89	11.00	12.50	13.57	14.38	15.00	15.50	16.40
24	W	12.00	13.33	15.00	16.00	16.67	17.14	18.13	18.89	19.50	20.60
	T	5.53	8.00	10.67	13.20	15.00	16.28	17.25	18.00	18.60	19.68
30	W	13.50	14.67	16.50	17.60	18.33	18.86	20.00	20.89	21.60	22.88
	T	5.46	8.18	10.91	13.64	16.25	18.22	19.69	20.83	21.75	23.40
40	W	17.00	17.33	19.50	20.80	21.67	22.29	22.75	23.89	24.80	26.72
	T	6.67	10.00	13.33	16.67	20.00	22.86	25.00	26.67	28.00	30.40
50	W	20.00	20.00	22.50	24.00	25.00	25.71	26.25	27.56	28.60	31.60
	T	7.69	11.54	15.38	19.23	23.08	26.78	29.69	31.94	33.75	37.00
60	W	23.00	23.00	24.75	27.00	28.50	29.57	30.38	31.44	32.70	35.52
	T	8.57	12.86	17.14	21.43	25.72	30.00	33.75	36.67	39.00	43.20
70	W	25.50	25.50	28.88	31.50	33.25	34.50	35.44	36.75	38.33	41.16
	T	9.33	14.00	18.67	23.33	28.00	32.67	37.19	40.83	43.75	49.00
80	W	28.00	28.00	33.00	36.00	38.00	39.43	40.50	42.00	43.80	47.04
	T	10.00	15.00	20.00	25.00	30.00	35.00	40.00	44.44	48.00	54.40
90	W	30.00	31.50	37.13	40.50	42.75	44.36	45.56	47.25	49.28	52.92
	T	10.59	15.88	21.18	26.47	31.76	37.06	42.35	47.50	51.75	59.40
100	W	32.00	32.00	37.50	42.00	45.00	47.14	48.75	50.00	52.50	57.00
	T	11.11	16.67	22.22	27.78	33.33	38.89	44.44	50.00	55.00	64.00
120	W	36.00	36.00	45.00	50.40	54.00	56.57	38.50	60.00	63.00	68.40
	T	12.00	18.00	24.00	30.00	36.00	42.00	48.00	54.00	60.00	72.00
150	W	42.00	42.00	47.25	54.60	59.50	63.00	65.63	67.67	70.40	77.52
	T	12.50	18.75	25.00	31.25	37.50	43.75	50.00	56.25	62.50	78.00

Table B-3 Wheeled- and Tracked-Vehicle Shear (tons) (cont.)

Class	Wheeled/ Tracked	Span Length (feet)										
		30	35	40	45	50	55	60	70	80	90	100
4	W	3.87	3.96	4.03	4.08	4.12	4.15	4.18	4.23	4.26	4.29	4.31
	T	3.60	3.66	3.70	3.73	3.76	3.78	3.80	3.83	3.85	3.87	3.88
8	W	7.20	7.46	7.65	7.80	7.92	8.02	8.10	8.23	8.33	8.40	8.46
	T	7.13	7.26	7.35	7.42	7.48	7.53	7.57	7.63	7.68	7.71	7.74
12	W	10.93	11.23	11.45	11.62	11.76	11.87	12.13	12.54	12.85	13.09	13.28
	T	10.20	10.46	10.65	10.80	10.92	11.02	11.10	11.23	11.32	11.40	11.46
16	W	13.73	14.06	14.30	14.49	14.64	14.76	14.87	15.34	15.74	16.04	16.29
	T	13.60	13.94	14.20	14.40	14.56	14.69	14.80	14.97	15.10	15.20	15.28
20	W	18.00	18.43	18.75	19.00	19.20	19.36	19.50	19.97	20.48	20.87	21.18
	T	17.00	17.43	17.75	18.00	18.20	18.36	18.50	18.72	18.88	19.00	19.10
24	W	21.33	21.86	22.25	22.56	22.80	23.00	23.17	23.46	24.03	24.47	24.82
	T	20.40	20.92	21.30	21.60	21.84	22.04	22.20	22.46	22.65	22.80	22.92
30	W	23.73	24.34	24.80	25.16	25.60	26.36	27.00	28.00	28.75	29.33	29.80
	T	24.50	25.28	25.88	26.33	26.70	27.00	27.25	27.64	27.94	28.17	28.35
40	W	28.93	30.51	31.70	32.62	33.36	34.42	35.47	37.11	38.35	39.31	40.08
	T	32.00	33.14	34.00	34.67	35.20	35.64	36.00	36.57	37.00	37.33	37.60
50	W	34.67	36.86	38.50	40.31	42.08	43.53	44.73	46.63	48.05	49.16	50.04
	T	39.17	40.72	41.88	42.78	43.50	44.09	44.58	45.36	45.94	46.39	46.75
60	W	39.93	42.09	45.45	47.29	48.76	49.96	51.43	54.09	56.08	57.62	58.86
	T	46.00	48.00	49.50	50.67	51.60	52.36	53.00	54.00	54.75	55.33	55.60
70	W	45.97	49.40	51.98	53.98	55.58	56.89	58.22	61.40	63.79	65.64	67.13
	T	52.50	55.00	56.88	58.33	59.50	60.46	61.25	62.50	63.44	64.17	64.75
80	W	49.20	53.26	56.60	59.20	61.28	62.98	64.40	66.63	69.70	72.18	74.16
	T	58.67	61.72	64.00	65.78	67.20	68.36	69.33	70.86	72.00	72.89	73.60
90	W	55.35	59.91	63.68	66.60	68.94	70.85	72.45	74.96	78.41	81.20	83.43
	T	64.50	68.14	70.88	73.00	74.70	76.09	77.25	79.07	80.44	81.50	82.35
100	W	60.02	64.57	69.00	72.44	75.20	77.45	79.33	82.29	84.69	88.06	90.75
	T	70.00	74.28	77.50	80.00	82.00	83.64	85.00	87.14	88.75	90.00	91.00
120	W	72.02	77.49	82.80	86.93	90.24	92.94	95.20	98.74	101.60	105.70	108.90
	T	80.00	85.71	90.00	93.33	96.00	98.18	100.00	102.90	105.00	106.70	108.00
150	W	82.98	85.66	89.45	95.76	101.20	105.40	109.00	114.70	121.60	127.00	131.30
	T	90.00	98.57	105.00	110.00	114.00	117.30	120.00	124.30	127.50	130.00	132.00

Table B-3 Wheeled- and Tracked-Vehicle Shear (tons) (cont.)

Class	Wheeled/ Tracked	Span Length (feet)									
		110	120	130	140	150	160	170	180	190	200
4	W	4.33	4.52	4.83	5.13	5.39	5.61	5.81	5.99	6.15	6.29
	T	3.94	4.27	4.56	4.80	5.01	5.20	5.36	5.51	5.64	5.76
8	W	8.51	8.75	9.28	9.90	10.44	10.91	11.33	11.70	12.03	12.33
	T	7.83	8.47	9.05	9.54	9.97	10.35	10.68	10.98	11.24	11.48
12	W	13.44	13.57	13.77	14.21	15.13	16.04	16.86	17.59	18.24	18.83
	T	11.52	12.20	13.10	13.89	14.56	15.15	15.67	16.13	16.55	16.92
16	W	16.50	16.65	16.89	17.41	18.55	19.67	20.69	21.59	22.41	23.14
	T	15.35	16.27	17.48	18.51	19.41	20.20	20.89	21.51	22.06	22.56
20	W	21.44	21.65	21.95	22.63	24.12	25.58	26.89	28.07	29.12	30.06
	T	19.19	20.33	21.85	23.14	24.27	25.25	26.12	26.89	27.58	28.20
24	W	25.11	25.35	25.71	26.51	28.28	29.98	31.51	32.87	33.67	35.18
	T	23.03	24.40	26.22	27.77	29.12	30.30	31.34	32.27	33.09	33.84
30	W	30.18	30.50	30.95	31.91	33.92	35.98	37.36	39.53	41.03	42.38
	T	28.50	29.55	31.85	33.86	35.60	37.13	38.47	39.67	40.74	41.70
40	W	40.71	41.23	41.68	42.86	44.24	46.75	49.36	51.84	54.06	56.06
	T	37.82	38.89	41.85	44.57	46.93	49.00	50.82	52.44	53.89	55.20
50	W	50.76	51.37	51.88	53.46	55.29	58.40	61.60	64.62	67.33	69.76
	T	47.04	48.08	51.54	55.00	58.00	60.63	62.94	65.00	66.84	68.50
60	W	59.87	60.71	61.43	62.41	63.57	67.18	70.99	74.74	78.17	81.26
	T	56.18	57.14	60.92	65.14	68.80	72.00	74.82	77.33	79.58	81.60
70	W	68.35	69.36	70.22	71.35	73.88	76.65	80.99	85.31	89.31	92.89
	T	65.23	66.11	70.00	75.00	79.33	83.13	86.47	89.44	92.10	94.50
80	W	75.78	77.13	78.28	79.26	81.71	84.35	87.95	92.62	97.43	101.80
	T	74.18	75.00	78.85	84.57	89.60	93.89	97.77	101.20	104.30	107.10
90	W	85.25	86.77	88.06	89.16	91.92	94.89	98.85	104.20	109.60	114.50
	T	83.04	83.82	87.56	93.86	99.60	104.60	109.10	113.00	116.50	119.70
100	W	92.95	94.79	96.35	97.68	100.00	103.50	106.90	112.20	117.90	123.50
	T	91.82	92.59	96.15	102.90	109.30	115.00	120.00	124.40	128.40	132.00
120	W	111.50	113.80	115.60	117.20	120.00	124.20	128.20	134.60	141.50	148.20
	T	109.10	110.00	113.10	120.00	128.00	135.00	141.20	146.70	151.60	156.00
150	W	134.80	137.70	140.20	142.30	144.80	149.80	154.80	160.30	168.20	176.30
	T	133.60	135.00	137.00	142.90	152.00	161.30	169.40	176.70	183.20	189.00

Table B-3 Wheeled- and Tracked-Vehicle Shear (tons) (cont.)

Class	Wheeled/ Tracked	Span Length (feet)									
		210	220	230	240	250	260	270	280	290	300
4	W	6.42	6.54	6.70	6.96	7.22	7.47	7.69	7.90	8.09	8.27
	T	5.87	6.05	6.31	6.55	6.77	6.97	7.16	7.33	7.49	7.64
8	W	12.60	12.84	13.10	13.53	14.04	14.54	15.00	15.43	15.83	16.20
	T	11.70	12.03	12.55	13.02	13.46	13.87	14.24	14.59	14.92	15.22
12	W	19.36	19.85	20.29	20.69	21.06	21.50	22.15	22.91	23.67	24.38
	T	17.26	17.58	18.23	18.97	19.66	20.28	20.87	21.41	21.91	22.38
16	W	23.80	24.40	24.94	25.45	25.91	26.43	27.22	28.16	29.10	29.98
	T	23.01	23.43	24.31	25.30	26.21	27.05	27.82	28.54	29.21	29.84
20	W	30.91	31.69	32.40	33.05	33.65	34.32	35.36	36.58	37.80	38.94
	T	28.76	29.29	30.39	31.62	32.76	33.81	34.78	35.68	36.52	37.30
24	W	36.17	37.07	37.90	38.65	39.34	40.14	41.36	42.79	44.21	45.54
	T	34.51	35.15	36.47	37.95	39.31	40.57	41.73	42.81	43.82	44.76
30	W	43.60	44.71	45.72	46.65	47.50	48.48	49.91	51.60	53.34	54.96
	T	42.57	43.36	44.47	46.31	48.06	49.67	51.17	52.55	53.84	55.05
40	W	57.87	59.51	61.01	62.38	63.65	64.82	66.21	67.70	69.81	72.04
	T	56.38	57.45	58.70	61.00	63.36	65.54	67.56	69.43	71.17	72.80
50	W	71.96	73.96	75.79	77.47	79.01	80.43	82.19	84.11	86.73	89.48
	T	70.00	71.36	72.74	75.31	78.30	81.06	83.61	85.98	88.19	90.25
60	W	84.06	86.60	88.92	91.05	93.01	94.82	96.49	98.60	100.92	103.87
	T	83.43	85.09	86.65	89.29	92.88	96.23	99.33	102.20	104.90	107.40
70	W	96.13	99.08	101.80	104.20	106.50	108.60	110.60	113.00	115.60	118.90
	T	96.67	98.64	100.40	103.10	107.10	111.10	114.70	118.10	121.30	124.30
80	W	105.70	109.20	112.50	115.50	118.20	120.70	123.10	125.30	128.10	131.00
	T	109.60	112.00	114.10	116.70	121.00	125.50	129.80	133.70	137.40	140.80
90	W	118.90	122.90	126.60	129.90	133.00	135.80	138.50	140.90	144.10	147.40
	T	122.60	125.20	127.60	130.10	134.50	139.70	144.50	149.00	153.20	157.10
100	W	128.60	133.20	137.40	141.30	144.80	148.10	151.10	153.90	156.80	160.60
	T	135.20	138.20	140.90	143.50	147.70	153.50	158.90	163.90	168.60	173.00
120	W	154.30	159.80	164.90	169.50	173.80	177.70	181.40	184.70	188.20	192.70
	T	160.00	163.60	167.00	170.00	174.00	180.00	186.70	192.90	198.60	204.00
150	W	184.10	191.20	197.77	203.60	209.10	214.40	218.80	223.10	227.10	231.50
	T	194.30	199.10	203.50	207.50	211.30	216.30	223.40	231.40	239.00	246.00

Figure B-1 Wheeled Bending Moment

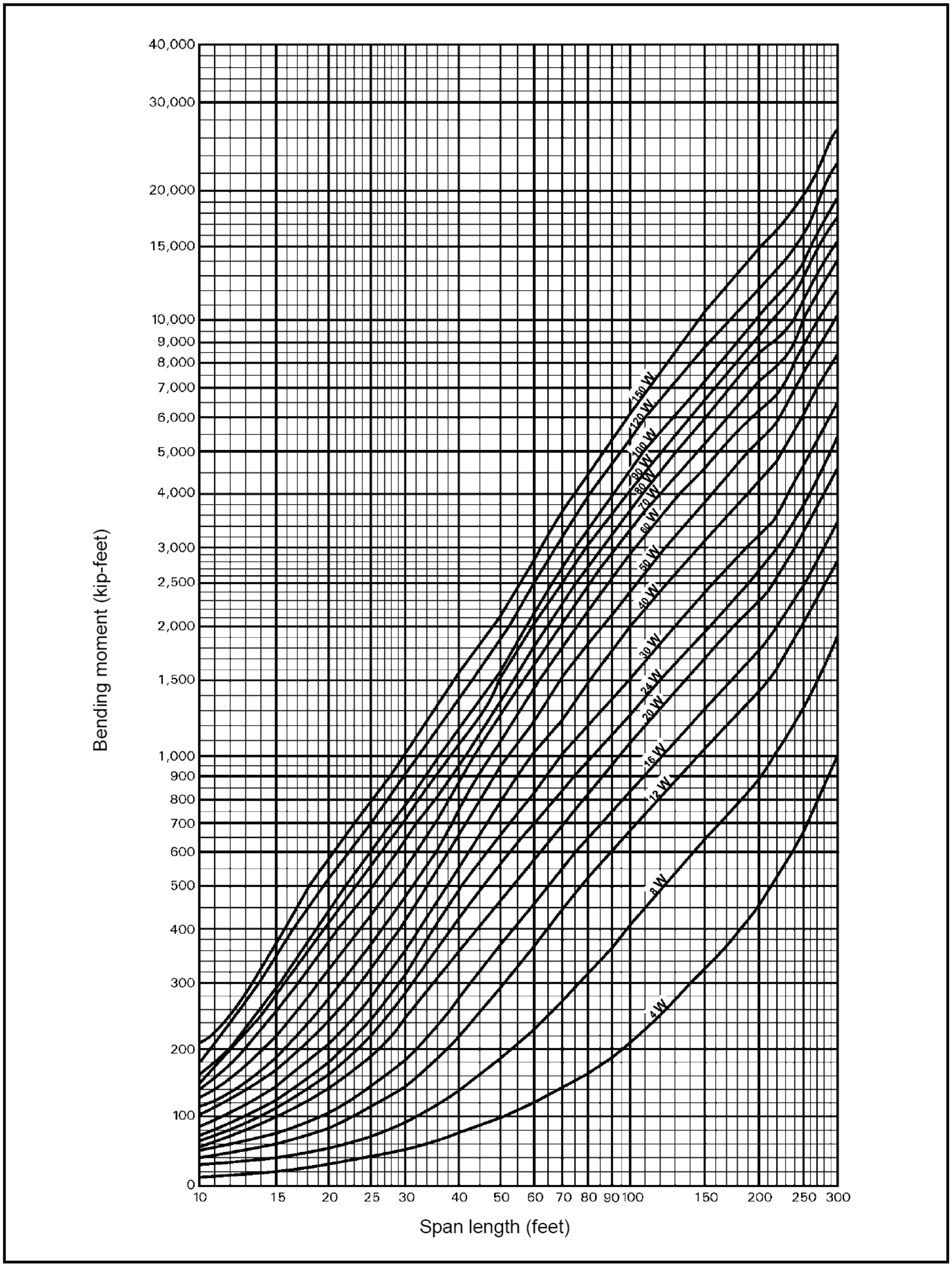


Figure B-2 Tracked Bending Moment

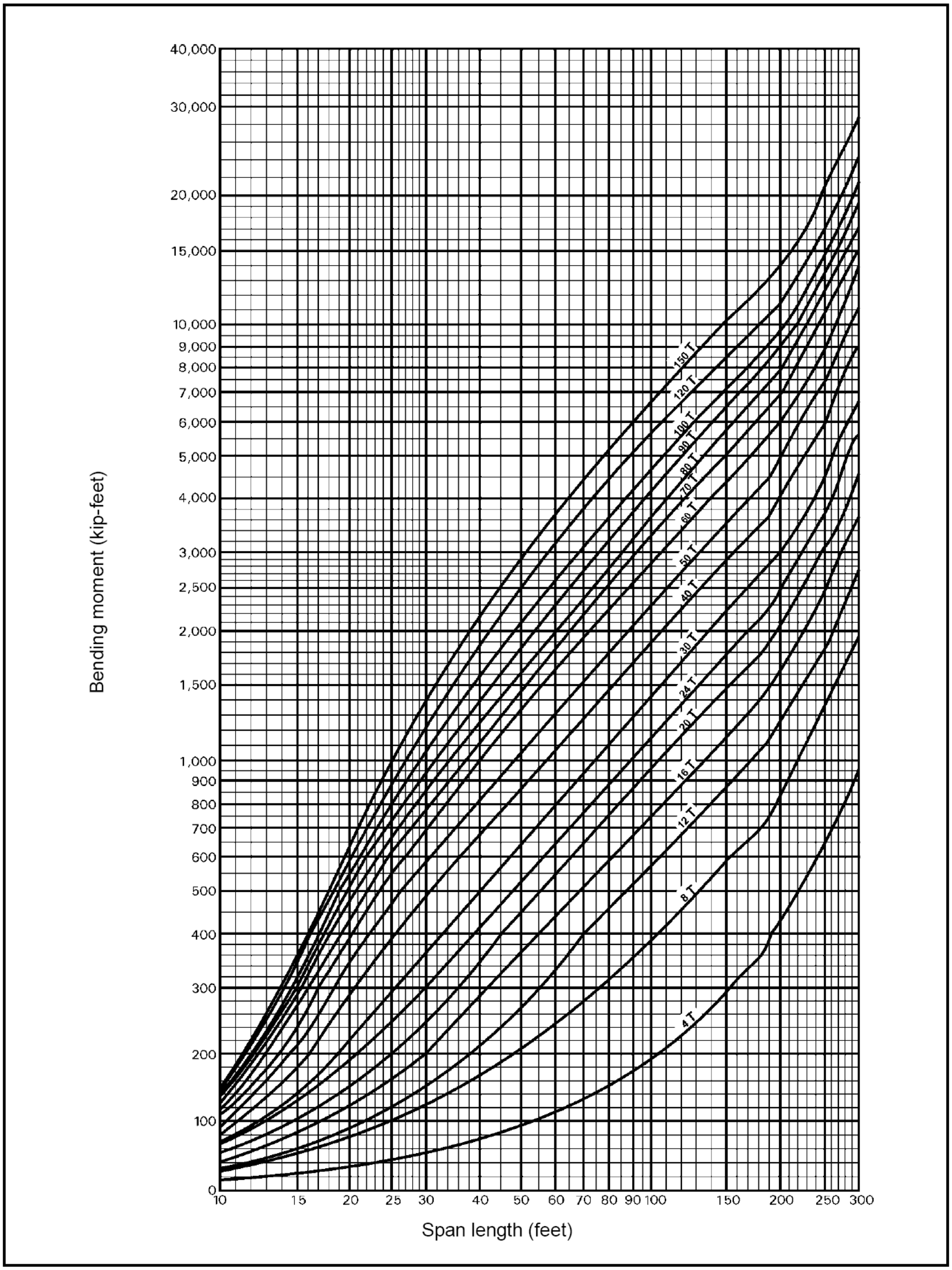


Figure B-3 Wheeled Shear

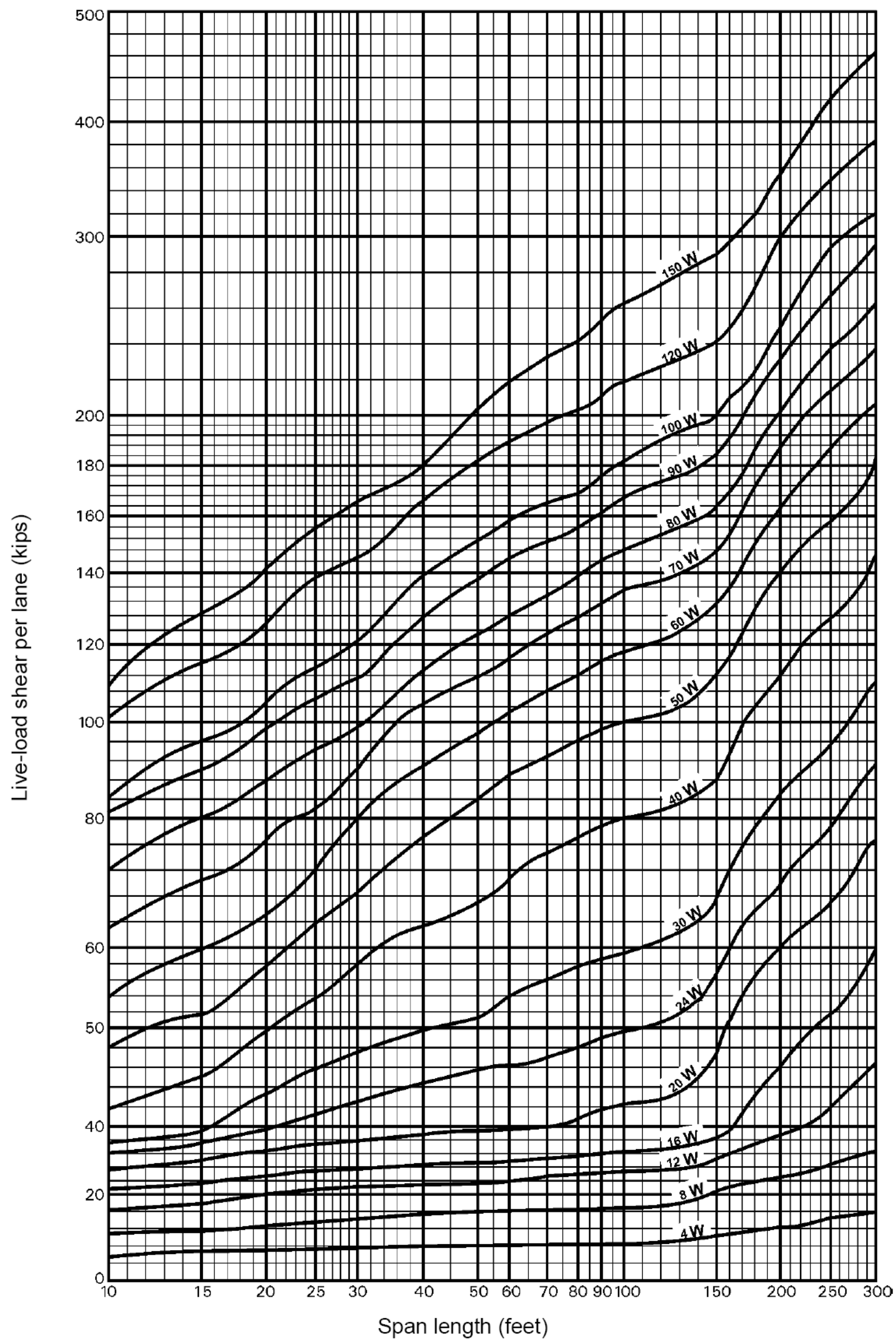
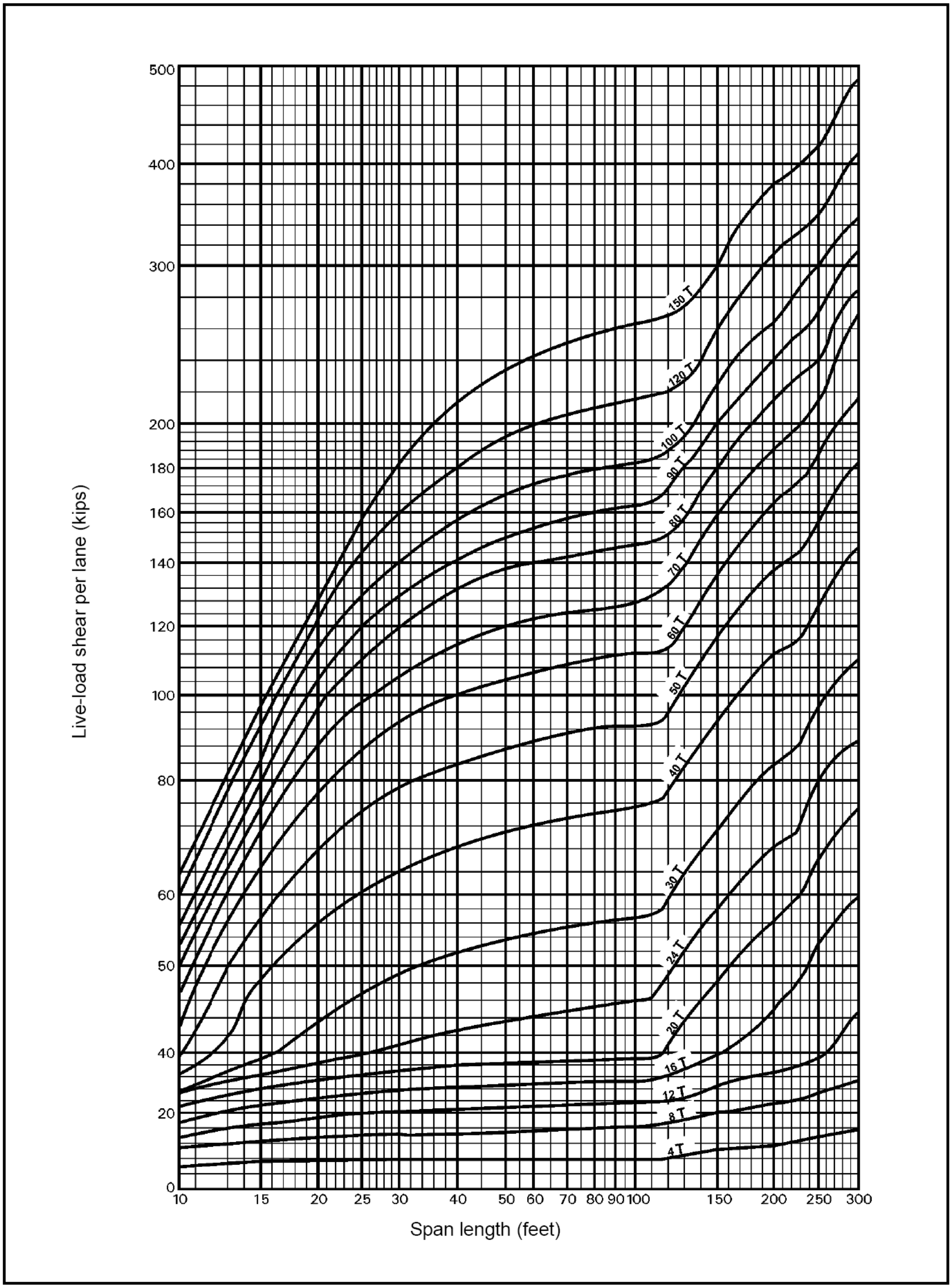


Figure B-4 Tracked Shear



B-2 CRITERIA FOR NATIONAL BRIDGE PROGRAM MANAGER TO ALTER INSPECTION INTERVAL.

The National Bridge Program Manager may alter the routine inspection interval for NBI highway bridges per the following criteria and procedures. It should be noted that the routine inspection interval may be either increased or decreased from the standard 24-month interval, although FHWA approval is only required for a decreased inspection interval.

Inspection intervals must be evaluated and, if necessary, adjusted after each inspection. Regardless of the interval selected for routine inspection, individual bridge members may require differing types and intervals of inspection (e.g., FCMs, distressed members, underwater members).

B-2.1 Procedure for FHWA Approval of Increased Inspection Intervals.

The National Bridge Program Manager will submit a request to increase the routine inspection interval to more than 24 months to the FHWA Eastern Federal Lands Highway Division (EFLHD). The FHWA will send approval of acceptance to the National Bridge Program Manager. Submissions to the FHWA for increased inspection intervals must contain the following information, at a minimum:

- The criteria used in establishing the interval between inspections, outlined above
- A discussion of failure experience, maintenance history, and latest inspection findings for the group of structures identified
- The proposed inspection interval

A template for requesting an extension of the inspection interval to 48 months for Service bridges that meet specific criteria is provided in paragraph B-2.2.

B-2.2 Template for Requesting Increasing Bridge Inspection Interval to Four Years for Qualifying Bridges.

Mr. Hratch Pakhchanian, P.E. (or current EFLHD Bridge Engineer)
Bridge Engineer
Eastern Federal Lands Highway Division
21400 Ridgetop Circle, #341
Sterling, VA 20166
hratch.pakhchanian@dot.gov
(703) 404-6246

Subject: Submittal of Bureau of Reclamation's Criteria for Varying Bridge Inspection Frequency from Two-Year to a Four-Year Inspection Frequency

Dear Mr. Pakhchanian:

In accordance to the National Bridge Inspection Standards, Code of Federal Regulations, 23 Highways - Part 650, Subpart C, and Technical Advisory 5140.2 1 dated September 16, 1988, we hereby submit our application for increasing the two-year inspection interval for some of our structures to four years.

See Attachment A for our criteria for increasing the bridge inspection interval.

Should you have any questions regarding these criteria, please contact ***<insert name>*** at ***<insert phone number>***, or email at ***<insert email address>***.

Sincerely,

<insert signature block>

Attachment A

cc: Yohannes Mesfin (or current EFLHD Federal Agency Bridge Safety Engineer)
Federal Agency Bridge Safety Engineer
Eastern Federal Lands Highway Division
21400 Ridgetop Circle #341
Sterling, VA 20166
Yohannes.Mesfin@dot.gov
(703) 404-6256

ATTACHMENT A:

CRITERIA FOR INCREASING ***<insert Military Department here>*** BRIDGE INSPECTION INTERVAL FROM TWO-YEAR TO A FOUR-YEAR INSPECTION FREQUENCY

The ***<insert Military Department here>*** policy for increasing routine inspections inspection interval from the two-year requirement to four years on selected bridges is based on the general guidelines contained in *Federal Highway Administration (FHWA) Technical Advisory, Revisions to the National Bridge Inspection Standards (NBIS), TA 5140.21*. The ***<insert Military Department here>*** assessment is that the bridges selected for a decrease in routine inspection interval from the typical two-year inspection interval are in good to very good condition, will adhere to FHWA Technical Advisory 5140.21 Guidelines, and in addition meet the following criteria:

All of the following criteria must be met before a bridge will be considered for an inspection interval greater than two years. Bridges eligible for increasing inspection interval from two years to a maximum of four years are:

Bridges with condition ratings of 6 or greater. *NBI 58, 59, 60, 61, and 62 ≥ 6.*

Bridges that have inventory ratings greater than or equal to the state's legal load. *NBI 66 ≥ HS20 (36 tons) or MS18 (32.4 metric tons) or HL-93 with a rating factor ≥ 1.0.*

Structures with length of maximum span (measured from center to center of bearing points) less than or equal to 100 feet. *NBI 48 ≤ 100 feet (30.5 m).*

Structure types with load path redundancy. NBI 43B = 1, 2, 3, 4, 5, 6, 7, 11, 19. This rule applies to structures of all material types. No structure with fracture critical details will go on the extended policy, NBI 92A = N.

Bridge Roadway Width, Curb to Curb is greater than or equal to 12 feet.
NBI 51 ≥ 12.0 feet (3.66 m)

Any vertical over or under clearances are greater than or equal to 14 feet. *NBI 53 & 54 ≥ 14 feet (4.27 m)*.

Structure is not susceptible to scour. *NBI 113 > 4 and 113 ≠ 6.*

New bridge structures or newly rehabilitated structures must have received an inventory inspection and an in-depth inspection one or two years later.

Any bridge considered for inspection intervals longer than two years must have received an in-depth inspection which revealed no major deficiencies.

As a matter of policy, and in accordance with 23 Code of Federal Regulations (CFR) 650, National Bridge Inspection Standards (NBIS), the ***<insert Military Department here>*** inspects their bridges at two-year intervals and will continue to inspect most of our bridges at two-year intervals. Each ***<insert Military Department here>*** installation is responsible for inspecting bridges within their boundary; therefore, each Installation Bridge Manager in conjunction with the National Bridge Program Manager will determine which of the bridges located within their jurisdiction are eligible for an increased inspection interval of up to four years. Those structures that do not meet the criteria listed above are not eligible for increasing the inspection interval.

Note: All references to National Bridge Inventory (NBI) items are those defined by FHWA-PD-96-001, *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges*, dated December 1995.

B-3 POINT OF CONTACT INFORMATION FOR MILITARY DEPARTMENT.

Note: This contact information is valid as of the date of publication for this UFC.

Department of the Army:

Mike Dean
Army Bridge Inspection Program Proponent
OACSIM, ATTN: DAIM-ODF
NC1 Presidential Towers
2511 Jefferson Davis Highway
Arlington, VA 22202
Telephone: 703-601-0703
Email: mike.dean@us.army.mil

Ali A. Achmar
Army Bridge Inspection Program Manager
HQ IMCOM, ATTN: IMPW-E
2509 Dunston Road Building 2007, 3rd Floor
Fort Sam Houston, TX 78234
Telephone: 210-295-0993
BB: 210-426-6872
Email: ali.achmar@us.army.mil

Department of the Navy:

Kevin Haskins, P.E.
Navy Bridge Inspection Program Manager
Naval Facilities and Expeditionary Warfare Center
(NAVFAC EXWC)
720 Kennon St., S.E.
Building 36 Suite 333
Washington Navy Yard, DC 20374-5063
Telephone: 202-433-5083
Email: kevin.l.haskins@navy.mil

Department of the Air Force:

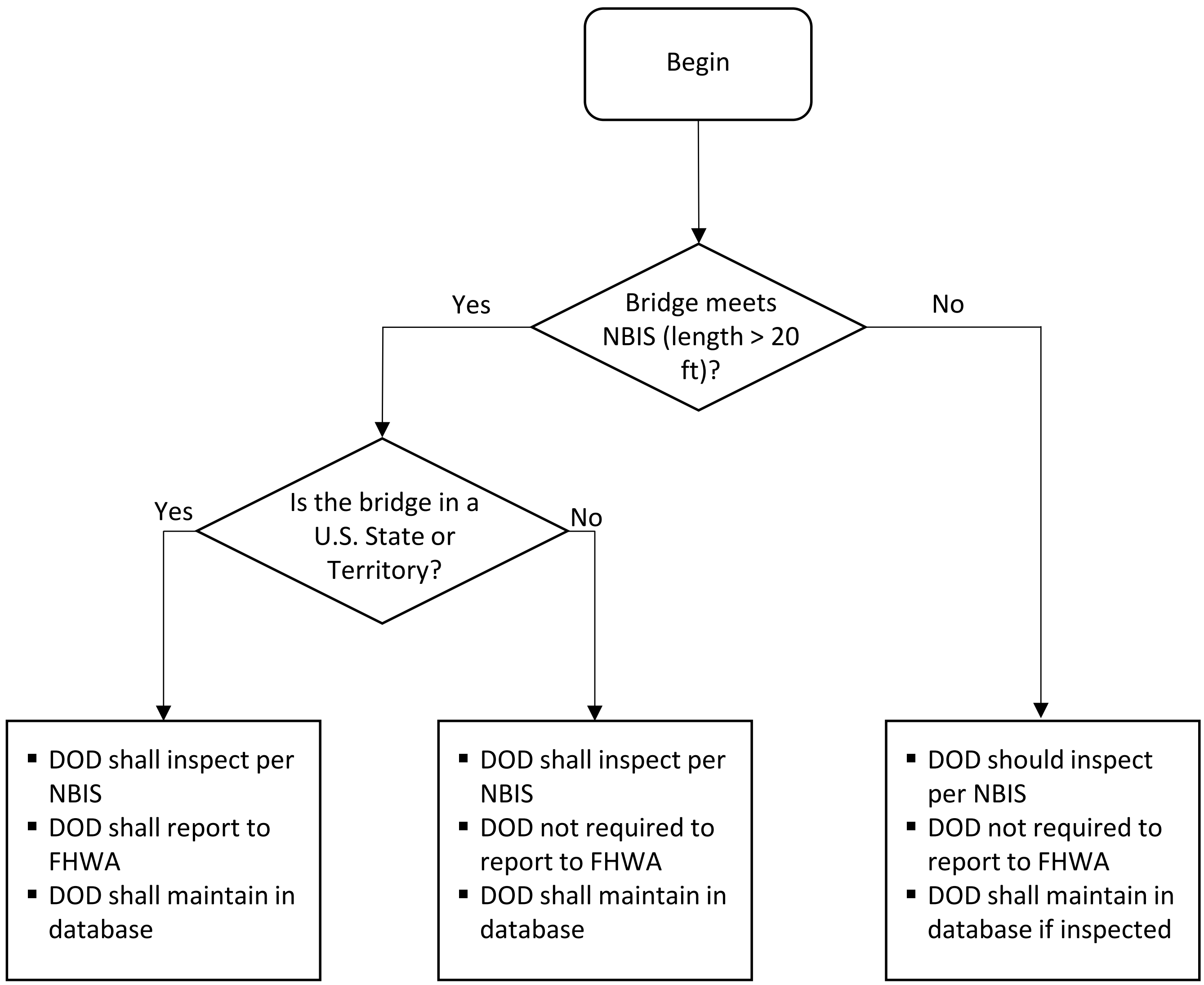
Tracy Coughlin, P.E.
Air Force Civil Engineer Center
139 Barnes Drive, Suite 1
Tyndall AFB, FL 32403
Telephone: 850-283-6801
Email: tracy.coughlin.1@us.af.mil

B-4 STATE LEGAL LOAD LIMITS FOR POSTING.

For the most current information on state legal load posting and load rating requirements, the following department of transportation websites should be consulted.

State/District	Agency Name	Website
Alabama	Alabama Department of Transportation (ALDOT)	http://www.dot.state.al.us
Alaska	Alaska Department of Transportation & Public Facilities (ADOT&PF)	http://www.dot.state.ak.us
Arizona	Arizona Department of Transportation (ADOT)	http://www.azdot.gov
Arkansas	Arkansas State Highway and Transportation Department (AHTD)	http://www.arkansashighways.com
California	California Department of Transportation (Caltrans)	http://www.dot.ca.gov
Colorado	Colorado Department of Transportation (CDOT)	https://www.codot.gov
Connecticut	Connecticut Department of Transportation (ConnDOT)	http://www.ct.gov/dot
Delaware	Delaware Department of Transportation (DelDOT)	http://www.deldot.gov
District of Columbia	District Department of Transportation (DDOT)	http://ddot.dc.gov
Florida	Florida Department of Transportation (FDOT)	http://www.dot.state.fl.us
Georgia	Georgia Department of Transportation (GDOT)	http://www.dot.ga.gov
Hawaii	Hawaii Department of Transportation (HDOT)	http://hidot.hawaii.gov
Idaho	Idaho Transportation Department (ITD)	http://itd.idaho.gov
Illinois	Illinois Department of Transportation (IDOT)	http://www.idot.illinois.gov
Indiana	Indiana Department of Transportation (INDOT)	http://www.in.gov/indot
Iowa	Iowa Department of Transportation (IowaDOT)	http://www.iowadot.gov
Kansas	Kansas Department of Transportation (KDOT)	http://www.ksdot.org
Kentucky	Kentucky Transportation Cabinet (KYTC)	http://transportation.ky.gov
Louisiana	Louisiana Department of Transportation & Development (LaDOTD)	http://wwwsp.dotd.la.gov
Maine	Maine Department of Transportation (MaineDOT)	http://maine.gov/mdot
Maryland	Maryland Department of Transportation (MDOT)	http://www.mdot.maryland.gov
Massachusetts	Massachusetts Department of Transportation (MassDOT)	http://www.massdot.state.ma.us
Michigan	Michigan Department of Transportation (MDOT)	http://www.michigan.gov/mdot
Minnesota	Minnesota Department of Transportation (MnDOT)	http://www.dot.state.mn.us
Mississippi	Mississippi Department of Transportation (MDOT)	http://mdot.ms.gov
Missouri	Missouri Department of Transportation (MoDOT)	http://www.modot.org
Montana	Montana Department of Transportation (MDT)	http://www.mdt.mt.gov
Nebraska	Nebraska Department of Roads (NDOR)	http://roads.nebraska.gov/
Nevada	Nevada Department of Transportation (NDOT)	http://www.nevadadot.com
New Hampshire	New Hampshire Department of Transportation (NHDOT)	http://www.nh.gov/dot
New Jersey	New Jersey Department of Transportation (NJDOT)	http://www.state.nj.us/transportation
New Mexico	New Mexico Department of Transportation (NMDOT)	http://dot.state.nm.us
New York	New York State Department of Transportation (NYSDOT)	http://www.dot.ny.gov
North Carolina	North Carolina Department of Transportation (NCDOT)	http://www.ncdot.gov
North Dakota	North Dakota Department of Transportation (NDDOT)	http://www.dot.nd.gov
Ohio	Ohio Department of Transportation (ODOT)	http://www.dot.state.oh.us
Oklahoma	Oklahoma Department of Transportation (ODOT)	http://ok.gov/odot
Oregon	Oregon Department of Transportation (ODOT)	http://www.oregon.gov/ODOT
Pennsylvania	Pennsylvania Department of Transportation (PennDOT)	http://www.penndot.gov
Rhode Island	Rhode Island Department of Transportation (RIDOT)	http://www.dot.ri.gov
South Carolina	South Carolina Department of Transportation (SCDOT)	http://www.dot.state.sc.us
South Dakota	South Dakota Department of Transportation (SDDOT)	http://www.sddot.com
Tennessee	Tennessee Department of Transportation (TDOT)	http://www.tn.gov/tdot
Texas	Texas Department of Transportation (TxDOT)	http://www.txdot.gov
Utah	Utah Department of Transportation (UDOT)	http://www.udot.utah.gov
Vermont	Vermont Agency of Transportation (VTrans)	http://vtrans.vermont.gov
Virginia	Virginia Department of Transportation (VDOT)	http://virginiadot.org
Washington	Washington Department of Transportation (WSDOT)	http://www.wsdot.wa.gov
West Virginia	West Virginia Department of Transportation (WVDOT)	http://www.transportation.wv.gov
Wisconsin	Wisconsin Department of Transportation (WisDOT)	http://wisconsindot.gov
Wyoming	Wyoming Department of Transportation (WYDOT)	http://www.dot.state.wy.us

B-5 SIMPLIFIED HIGHWAY BRIDGE INSPECTION FLOWCHART.



B-6 EXAMPLE FATIGUE-PRONE DETAIL FORM FOR FCM PLAN.

Fatigue Detail Sheet

BRIDGE # : 01-139-AA05-77-001
LOCATION: CR 577 over Morrison Creek
INSPECTION DATE(S): December 10, 2014
FRACTURE CRITICAL MEMBER(S): 3 bent caps at Bents 1 through 3

CRITICAL AREA: Bottom flange and bottom half of the web plates in positive moment regions.
Top flange and top half of the web plates in negative moment regions,
and the web plates in primary shear regions.

DETAIL DESCRIPTION	FATIGUE CATEGORY	COMMENTS	PHOTO NUMBER(S)
Base metal of steel away from all welds or structural connections	A	Isolated locations with paint failure	7
Web and flange splice weld with weld reinforcement not removed	C	OK	8
Base metal at the toe of transverse connection plate welds	C'	Isolated locations of poor fusion	9, 13
Net section at open holes in member	D	OK	10
Base metal of bent cap flange at errant transverse weld	E	OK	11

(The fatigue-prone details listed above are provided as examples only. The specific fatigue-prone details for the fracture critical bridge to be inspected must be determined and listed as part of the bridge's fracture critical plan.)

B-7 EXAMPLE SCOUR CRITICAL BRIDGE PLAN OF ACTION.

SCOUR CRITICAL BRIDGE - PLAN OF ACTION

1. GENERAL INFORMATION

Structure number: ______	City, County, State: ______	Waterway: ______
Structure name: ______	State highway or facility carried: ______	Owner: ______

Year built: ____	Year rebuilt: ____	Bridge replacement plans (if scheduled): _____ Anticipated opening date: _____

Structure type: ☐ Bridge ☐ Culvert
Structure size and description: _____

Foundations: ☐ Known, type: _____ Depth: _____ ☐ Unknown

Subsurface soil information (*check all that apply*): ☐ Non-cohesive ☐ Cohesive ☐ Rock

Bridge ADT: _____	Year/ADT: _____	% Trucks: _____

Does the bridge provide service to emergency facilities and/or an evacuation route (Y/N)? ____
If so, describe: _____

2. RESPONSIBILITY FOR POA

Author(s) of POA (name, title, agency/organization, telephone, pager, email):

Date: _____

Concurrences on POA (name, title, agency/organization, telephone, pager, email):

POA updated by (name, title, agency, organization): _____ Date of update: ___
Items update: _____

POA to be updated every _____ months by (name, title, agency/organization):_____
Date of next update:_____

3. SCOUR VULNERABILITY

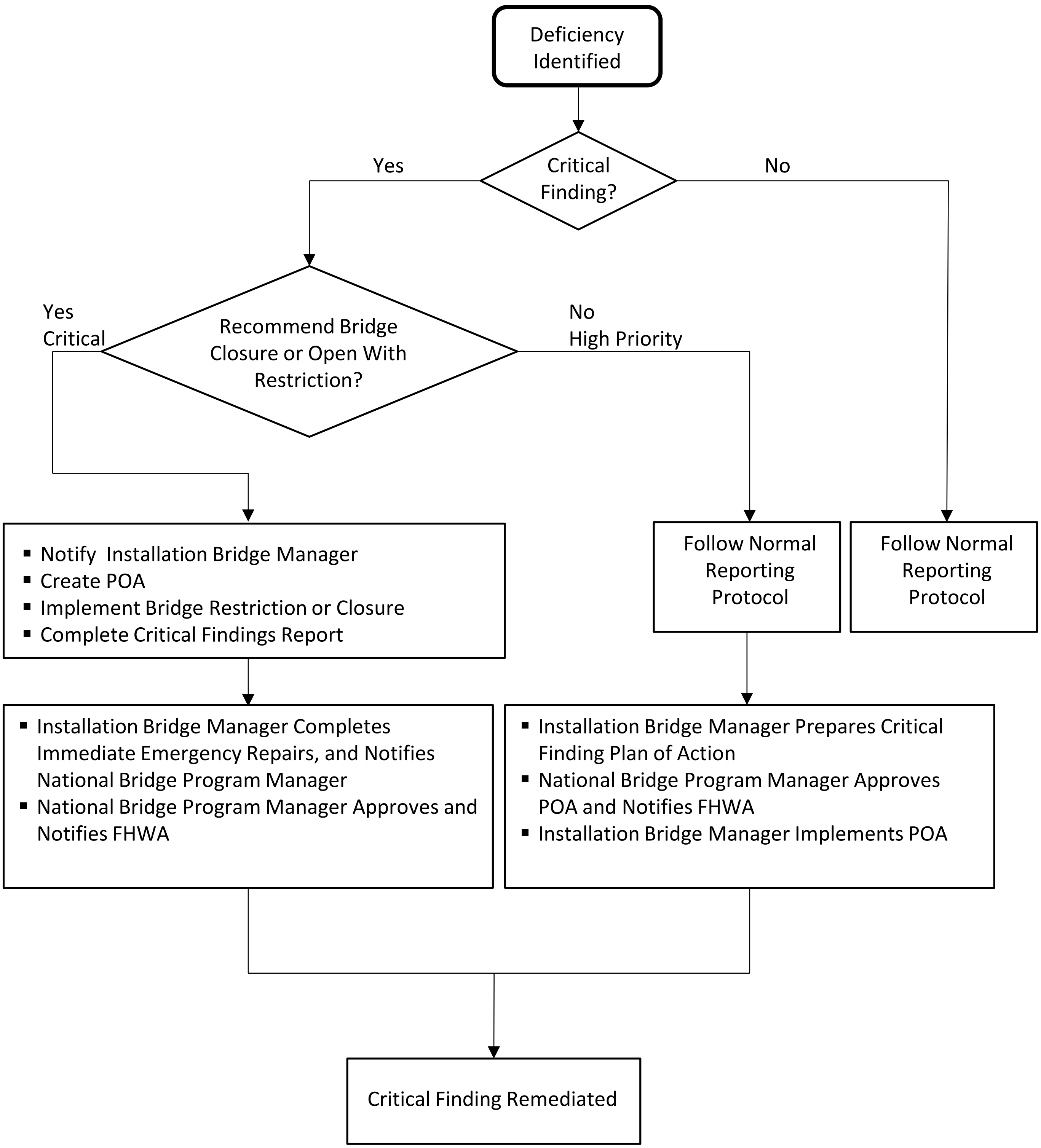
a. Current Item 113 Code: ☐ 3 ☐ 2 ☐ 1 Other: _____

b. Source of Scour Critical Code: ☐ Observed ☐ Assessment ☐ Calculated Other: _____

c. Scour Evaluation Summary: _____

d. Scour History: _____

B-8 FLOW CHART FOR CRITICAL FINDINGS.



B-9 EXAMPLE CRITICAL INSPECTION FINDING REPORT.

CRITICAL INSPECTION FINDING REPORT

Bridge: ____________ **Route:** ________ **Installation:** ______________ **Country:** ______________

Inspector: ______________________ **Inspection Date:** ______________ **AADT:** ______________

Reason for Critical Inspection Finding Report (Be specific about deficiencies, attach photographs):

____

____

____

Inspector's Immediate Recommendations:

____Immediate Closure Required ____Immediate Blocking/Shoring Required

____Reduce Travelway Width (provide details): ______________________________

____

____Other: ______________________________________

____

____Immediate Notification:

Installation Bridge Manager: ______________________

National Bridge Program Manager: ______________________

Plan of Action: Date: ______________

____

____

____

____

Follow-up Actions: Completion Date: ______________

____

____

____

____

B-10 ORGANIZATIONAL RESPONSIBILITIES.

Table B-4 National Bridge Program Manager (NBPM) and Installation Bridge Manager (IBM) Responsibilities by Military Department

BRIDGE INSPECTION RESPONSIBILITIES				Navy		Air Force		Army	
ID No.	Category	Task	Para. Ref.	NBPM	IBM	NBPM	IBM	NBPM	IBM
B11.1	Qualifications	Responsible for approving all bridge inspector qualifications prior to inspection per 23 CFR Subpart C, 49 CFR 237, and UFC 3-310-08.	2-1.5, 2-1.6, 2-1.7	X			X	X	
B11.2	Inventory	Responsible for establishing and maintaining program bridge inventory per UFC guidelines.	2-1.1	X		X		X	
B11.3	Inventory	Responsible for notifying NBPM of changes to the existing bridge inventory.	3-1, 3-2		X		X		X
B11.4	Inventory	Responsible for compiling and maintaining bridge inspection inventory.	2-1.1, 2-1.2	GLOBAL	LOCAL	GLOBAL	LOCAL	GLOBAL	LOCAL
B11.5	Inventory	Recommends bridges to be removed and/or placed onto the bridge inspection inventory.	Ch. 3, 4, 5, 6	X			X		X
B11.6	Inventory	Responsible for implementing the NBPM recommendations for bridge inspection inventory.	2-1.2		X		X		X
B11.7	Records	Responsible for establishing a standard bridge records system.	2-2, 2-2.1, 2-2.2	X		X		X	
B11.8	Records	Responsible for maintaining bridge records per the UFC, including inspection reports and follow-up actions taken.	2-2.1, 2-2.2, 3-2.4, 3-3.3, 4-4, 5.3	GLOBAL	LOCAL		X		X
B11.9	Planning	Responsible for coordination with the NBPM and granting access to facilitate bridge inspection operations.	2-1.2		X		X		X
B11.10	Planning	Responsible for coordination with the NBPM and granting access to allow adequate QC/QA.	2-1.2, 2-3		X		X		X
B11.11	Execution	Responsible for implementing and executing NBIS and FRA reportable inspections, including development of inspection reports and recommendations.	2-1.1, 2-1.2, 3-2, 4-1	X		N/A	X	N/A	X

BRIDGE INSPECTION RESPONSIBILITIES				Navy		Air Force		Army	
ID No.	Category	Task	Para. Ref.	NBPM	IBM	NBPM	IBM	NBPM	IBM
B11.12	Execution	Responsible for funding, implementing, and executing pedestrian and golf cart bridge inspections that require a load rating under paragraph 5-2, including developing inspection reports and recommendations.	5-1, 5-2	X		N/A	X	N/A	X
B11.13	Execution	Responsible for funding, implementing, and executing inspection of all other NBIS and FRA non-reportable bridge inspections and pedestrian and golf cart bridge inspections not inspected under the requirements of B11.12, including developing inspection reports and recommendations.	3-3, 4-2, 5-1		X	N/A	X	N/A	X
B11.14	Execution	Responsible for developing inspection report content and compliance with current CFR requirements.	3-2.2 4-1.3	X			X	X	
B11.15	QA	Responsible for implementing and performing QC/QA, including review of inspection reports, recommendations, plans of action, and periodic field reviews.	2-3	X			X	X	
B11.16	QA	Recommends corrective action to Installation Commander based upon QC/QA findings.	2-3	X		X	X	X	
B11.17	QA	Responsible for taking corrective action on QC/QA issues.	2-3		X		X		X
B11.18	Interval	Recommends decreasing inspection interval.	3-2.2.1, 4-2.1	X		X	X	X	
B11.19	Interval	Responsible to implement the NBPM interval recommendation.	3-2.2.1	X			X		X
B11.20	Interval	May request variance from UFC guidance with regards to inspection interval.	3-2.2.1, 4-2.1	X		X	X	X	X
B11.21	Repair	Responsible for executing and completing repair recommendations.	7-1.4, 9-2		X		X		X
B11.22	Repair	Reviews that appropriate actions are taken on recommended repairs.	7-1.4, 9-2	X	X	X	X	X	X
B11.23	Scour	Responsible for assessing scour and providing recommendations and a scour POA	7-2	X			X		X
B11.24	Scour	Responsible for implementing scour recommendations and adhering to a scour POA	7-2		X		X		X

BRIDGE INSPECTION RESPONSIBILITIES				Navy		Air Force		Army	
ID No.	Category	Task	Para. Ref.	NBPM	IBM	NBPM	IBM	NBPM	IBM
B11.25	Load Rating	Ensure bridges are load rated and files are maintained. Responsible for reviewing load ratings and load rating records.	3-2.3, 3-3.1, 3-3.2, 4-3, 5-2	GLOBAL	LOCAL		X		X
B11.26	Load Rating	Responsible to determine and communicate live load cases required, including tactical vehicles and special rail car usage to the NBPM.	3-2.3, 3-3.1, 3-3.2, 4-3, 5-2		X		X		X
B11.27	Load Rating	Responsible for performing and updating load ratings in accordance with current standards and mobilization requirements, as well as maintaining records.	3-1.3, 3-2.2, 4-3, 5-2	X			X		X
B11.28	Posting	Responsible for recommending load posting.	3-2.3.4, 4-3, 5-2	X			X		X
B11.29	Posting	Responsible for posting bridges.	3-2.3.4, 4-3, 5-2		X		X		X
B11.30	New Projects	Responsible for advising the NBPM of new bridge construction projects and providing the PM with the DD-1391 as well as design documentation and schedules so that appropriate resources can be allocated for initial and subsequent routine bridge inspections.	N/A		X	N/A	N/A	N/A	N/A
B11.31	Repair Projects	Responsible for advising the NBPM of bridge repair projects and providing design documentation and schedules so appropriate planning can be performed to accommodate additional bridge inspection funding and requirements such as a revised load rating.	7-1.4, 9-2		X	N/A	N/A	N/A	N/A

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APPENDIX C GLOSSARY

AAR—Association of American Railroads

AASHTO— American Association of State Highway and Transportation Officials

ACI—American Concrete Institute

AREMA—American Railway Engineering and Maintenance-of-Way Association

BIRM—FHWA *Bridge Inspector's Reference Manual*

CFR—Code of Federal Regulations

CONUS—Continental United States

DD 1391—FY ___ Military Construction Project Data

DOD—Department of Defense

EM—Army Engineering Manual

FCM—fracture critical member

FHWA EFLHD—Federal Highway Administration, Eastern Federal Lands Highway Division

FHWA—Federal Highway Administration

FM—Army Field Manual

FRA—Federal Railway Administration

IBM—Installation Bridge Manager

LRFD—Load and resistance factor design

MLC—military load classification

MUTCD—AASHTO *Manual on Uniform Traffic Control Devices for Streets and Highways*

NBI—National Bridge Inventory

NBIS—*National Bridge Inspection Standards*

NBPM—National Bridge Program Manager

NDT—nondestructive techniques

OCONUS—Outside Continental United States

PDT—partially destructive techniques

P.E.—Professional Engineer

POA—Plan of Action

psf—pound per square foot

QA—quality assurance

QC—quality control

SI&A—Structure Inventory and Appraisal

STANAG—Standardization Agreement

STRAHNET—Strategic Highway Corridor Network

TM—Army Technical Manual

UFC—Unified Facilities Criteria

USC—United States Code

UFC 3-340-01

UNIFIED FACILITIES CRITERIA (UFC)

DESIGN AND ANALYSIS
OF
HARDENED STRUCTURES
TO
CONVENTIONAL WEAPONS EFFECTS

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Telephone No: 402-995-2366	**Telephone No: 757-322-4229**

UFC 3-340-02
5 December 2008
Change 2, 1 September 2014

UNIFIED FACILITIES CRITERIA (UFC)

STRUCTURES TO RESIST THE EFFECTS OF ACCIDENTAL EXPLOSIONS

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

UNIFIED FACILITIES CRITERIA (UFC)

STRUCTURES TO RESIST THE EFFECTS OF ACCIDENTAL EXPLOSIONS

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING COMMAND (Preparing Activity)

AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

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

Change No.	**Date**	**Location**
1	TBD	See Change Summary sheet for details. Editorial changes throughout.

This UFC supersedes ARMY TM 5-1300, dated November 1990.

FOREWORD

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

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale should be sent to the respective service proponent office by the following electronic form: Criteria Change Request. The form is also accessible from the Internet sites listed below.

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

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

Refer to UFC 1-200-01, General Building Requirements, for implementation of new issuances on projects.

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UNIFIED FACILITIES CRITERIA (UFC)

UFC 3-340-02 SUMMARY SHEET

Document: UFC 3-340-02 with Change 2
Superseding: UFC 3-340-02 with Change 1 dated 1 July 2014

Description of Changes:

- Rescinding changes to section 4-55 and figure 4-65a. The equations and figure updated in Change 1 were mistakenly based on SI units. This section now matches the 5 December 2008 version, which is based on U.S. customary units. Other Change 1 revisions are still valid.

Reason for Changes:

- To correct errors

Impact: There are no anticipated cost impacts.

UNIFIED FACILITIES CRITERIA (UFC)

UFC 3-340-02 SUMMARY SHEET

Document: UFC 3-340-02 with Change 1
Superseding: UFC 3-340-02 dated 8 December 2008

Description of Changes:

- Revised section 4-55 and figure 4-65a to incorporate updated spall and breach thresholds for reinforced concrete walls
- Implemented major revision to the masonry analysis and design guidance in sections 6-7, 6-8 and 6-9 and incorporated new example problems 6A-1a and 6A-1b, illustrating the new procedures
- Revised performance requirements for mechanical splices of reinforcing bars and added mandatory validation testing protocol to section 4-21.8
- Added guidance to the Scope sections (fourth section in each chapter) clarifying the intended applications and limitations of this document in satisfying DoD 6055.09-M requirements
- Corrected constants in equations 2-60, 2-62 and 2-63
- Expanded figure 2-152 to show peak quasistatic pressure for lower charge weight to volume ratios
- Modified figures 3-29 through 3-32 and figure 3-38 to correct errors that occurred during conversion of tri-service document Army TM 5-1300, Navy NAVFAC P-397, and Air Force AFR 88-22, Revision 1 (TM 5-1300) to UFC 3-340-02. These figures are now consistent with previous tri-service manual.
- Added supplementary minimum lap splice requirements, previously provided in TM 5-1300, and introduced guidance on acceptable applications of non-contract lap splices to section 4-21.7
- Revised variables in equation 2-47 to align equation with other DoD fragment velocity models; calculated values for the velocity change coefficient, k_v, will not be affected by this change.
- Revised Chapter 4 to exclude use of steel wire reinforcement and steel welded wire reinforcement for reinforced concrete
- Reduced support rotation limit for continuously supported reinforced concrete slabs and reinforced concrete beams designed for Protection Category 2 to 6-degrees. Per section 1-9, Protection Category 2 is used to protect equipment, supplies and stored explosives from fragment impact, blast pressures and structural response. This change should prevent any significant concrete scabbing of these elements, enhancing protection to these items.

Reasons for Changes:

- To correct errors and inconsistencies and to add clarifications
- To clarify applications and limitations of this document in satisfying DoD 6055.09-M requirements
- To update sections based on current state-of-the-knowledge and recent testing
- To improve document usability and change the document format to simplify implementation of future changes

Impact: There are no anticipated cost impacts. However, the following benefits should be realized.

- The document has a more user-friendly format including the ability to simultaneously view figures and tables with the discussion in the text
- The new masonry design procedures are based on current construction practice and allow the more cost effective use of blast resistant masonry walls
- The new mechanical splice requirements will, for the first time, allow mechanical couplers to be used in blast resistant construction, significantly reducing reinforcing bar congestion and simplifying concrete placement
- The changes to the document's format will simplify implementation of future changes

UNIFIED FACILITIES CRITERIA (UFC)
UFC 3-340-02 SUMMARY SHEET
(Provided for Archiving Purposes)

Document: UFC 3-340-02 (dated 8 December 2008)
Superseding: ARMY TM 5-1300, Navy NAVFAC P-397, and Air Force AFR 88-22 (dated November 1990)

Description of Changes:

- All substantive changes were made to Chapter 4, Reinforced Concrete Design as detailed in table below.

Description	References
Increases maximum design support rotation for nonlaced reinforced concrete elements under flexural action to 6-degrees	Section 4-9.2, Section 4-9.3, Section 4-16, Section 4-23.3, Section 4-24, Section 4-25.1, Section 4-25.3, Section 4-26.1 and Section 4-34
Increases maximum design support rotation for nonlaced reinforced concrete elements under tension membrane action to 12-degrees.	Section 4-9.3 and Section 4-25.4
Allows use of ASTM A 706 reinforcing bars in lieu of ASTM A 615 reinforcing bars.	Section 4-12.2
Updates and expands dynamic increase factor data for concrete and reinforcing bars.	Section 4-13.2, Figure 4-9a, Figure 4-9b and Figure 4-10
Revises dynamic design stresses for elements with a maximum design support rotation, θm, 5o < θm ≤ 6o.	Section 4-13.3 (Table 4-2)
Provides new equations for calculating minimum reinforcement ratios for slabs. Equations now explicitly consider the concrete's compressive strength and the reinforcing bar's yield strength.	Section 4-17.3, Table 4-3, Section 4-33.4.2 and Appendix 4A (Example 4A-1, step 6 and Example 4A-4, step 6)
Adds alternate ACI equation for calculating the allowable shear stress on the unreinforced web of an element subjected to flexure only.	Section 4-18.2

Description	**References**
Revises diagonal tension design requirements for slabs that are based upon the scaled charge distance.	Section 4-18.3
Updates minimum design shear stresses. In addition, instead of basing requirements upon close-in and far design ranges, requirements are now based upon the scaled charge distance from an element.	Section 4-18.4 and Table 4-4
Revises the equation for allowable ultimate direct shear force, Vd, that may be resisted by the concrete in a slab.	Section 4-19.2 and Section 4-19.3
Adds new sections on tension design requirements in non-laced slabs, laced slabs and beams (previously provided in section 4-68).	Section 4-20A, Section 4-26.3 and Section 4-35A
Significantly revises reinforcing bar development and lap splice requirements. In general, reinforcing bar development and lap splice lengths now calculated in accordance with the provisions of the latest ACI 318 Building Code. Supplementary requirements are noted.	Section 4-21 and subsections, Section 4-64, Section 4-65.3 and Section 4-66 subsections
Significantly expands allowable uses of single leg stirrups for diagonal tension reinforcement in slabs. Provides limits on the use of 3 different single leg stirrup types (designated as Type A, Type B and Type C).	Section 4-22 and Section 4-32
Updates figures summarizing design parameters for unlaced and laced elements to incorporate new criteria.	Figure 4-17 and Figure 4-29
Replaces minimum reinforcement ratio guidance with new equations that explicitly consider the concrete's compressive strength and the reinforcing bar's yield strength.	Section 4-38.3 and Appendix 4A (Example 4A-6, step 4d)
Provides new equations for calculating the minimum area of closed ties in columns.	Section 4-48.4
Provides new equations for calculating the minimum area of spiral reinforcement in columns.	Section 4-49.4
Section completely revised to incorporate UFC 3- 340-01's procedures for predicting concrete spall and breach. Since UFC 3-340-01 is a limited distribution document, these open distribution procedures were not previously available to the public.	Section 4-55 (including Figure 4-65, Figure 4-65a and Table 4-15a)
Defines Type A, Type B and Type C single leg stirrups and their allowable uses.	Section 4-66.3.1

Description	**References**
Section revised to eliminate now duplicate guidance for non-laced slabs, laced slabs and beams (now provided in Section 4-20A, Section 4-26.3 and Section 4-35A, respectively).	Section 4-68
Figures updated to incorporate changes to design criteria.	Figure 4-1, Figure 4-2, Figure 4-18, Figure 4-21, Figure 4-59, Figure 4-83, Figure 4-85, Figure 4-101, Figure 4-102 and Figure 4-103
Updates and expands bibliography.	Appendix 4C

UFC 3-340-02, “Structures to Resist the Effects of Accidental Explosions.”

This document is Change 2 for UFC 3-340-02. This UFC was an update of Army TM5-1300, Navy NAVFAC P-397, and Air Force AFR 88-22, dated November 1990.

Change 2 of UFC 3-340-02 has been converted into an Acrobat PDF Portfolio file. This file is essentially a folder that contains separate pdf files for each chapter, chapter appendix, and the cover pages. All of the pdf files can be accessed by using Acrobat to open the portfolio file and clicking on the appropriate file.

Two downloadable files are provided.

1. “ufc_3_340_02_dplot_v1.zip”: This zip file has an Acrobat PDF Portfolio with pdf files that will allow the plots contained within the document to be opened with Dplot pre-version 2.1, to enhance their functionality. You must have Dplot installed on your computer to use this capability. If you have a Dplot version 2.1 or later installed, you should download the file “ufc_3_340_02_dplot_v2.zip” instead of this one.
2. “ufc_3_340_02_dplot_v2.zip”: This zip file has an Acrobat PDF Portfolio with pdf files that will allow the plots contained within the document to be opened with Dplot version 2.1 or later, to enhance their functionality. You must have Dplot installed on your computer to use this capability. If you have a Dplot pre-version 2.1 installed, you should download the file “ufc_3_340_02_dplot_v1.zip” instead of this one.

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1. “ufc_3_340_02_dplot_v1.zip”: For use with Dplot (pre version 2.1) (63mb)
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Notes regarding the zipped files:

The UFC has been developed so that the plot files contained in the document can be opened in DPlot to enhance their functionality. Figures and tables can also be opened in a separate window by either by clicking directly on the figures and tables or by clicking on a (+) sign that is shown in the text of the pdf files next to each callout of a figure or table.

DPlot is a plotting program developed by HydeSoft Computing LLC (www.dplot.com) that allows viewing and editing of a variety of data plots.

After installing the appropriate zipped file, the source DPlot files can be opened when the plot images or the (+) sign in the text after a callout for a figure in the PDF version of UFC are clicked.

The two zipped files, representing two versions of the document differ only with regard to DPlot file compatibility.

If the user has an older version of DPlot (pre-2.1), version 1 of this document, “ufc_3_340_02_dplot_v1.zip”, should be used for compatibility. If the user has a current version of DPlot (v2.1 or later), version 2 of this document, “ufc_3_340_02_dplot_v2.zip”, should be used.

Notes regarding installation:

1. The compressed ZIP file for the document can be uncompressed to any location that the user desires.
2. The "Plots," “Figures,” and “Tables” folders must remain located adjacent to the PDF portfolio document for the hyperlinked images to run correctly. That is, the document and the folders should be co-located; the document should never be placed within any of those three folders. Extracting the zip file to a specified location on your computer should set up the appropriate file structure.

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1. Navigate in windows explorer to a DPlot file
2. Right click on the file, and select "open with" from the drop-down menu
3. Use the "Browse" button to navigate to the Program directory, selecting the "DPLOT.exe" program from the DPlot folder. Select "open" or "OK".
4. After selecting the program, the computer will return to the prior "Open With" dialogue. MAKE sure to check the box for the option to always open files of this type with the DPlot program that you selected.

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Second, the tables of contents, figures, and tables located in the text pages of the document are hyperlinked. Clicking on the text will allow the user to jump immediately to particular sections, images, or tables. After jumping to a figure or table, the user can go back to their prior location by clicking Alt+BackArrow.